
# INTRODUCTION TO INDUSTRY 4.0 AND INDUSTRIAL INTERNET OF THINGS

**prof. Sudip Misra**
**Computer Science and Engineering**
**IIT Kharagpur**

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## *Week 12*

# Introduction to Industry 4.0 and Industrial Internet of Things

**Prof. Sudip Misra**
**Department of Computer Science and Engineering**
**Indian Institute of Technology, Kharagpur**

## Lecture – 01
## Introduction: Sensing & Actuation

In this course, you are going to learn about Industry 4.0 and Industrial IoT (IIoT). So, we will get into the depth of each of these in detail throughout the course. However, let us first try to understand, what is central to each of these technologies. So, IIoT is Industrial IoT, which is about the applications of IoT in the industries. There are some industry specific requirements, for which the existing IoT technology, which have applications in different domains, will have specific requirements of industries. We will have to be tailored to get to cater to those industrial requirements. So, that is where industrial IoT comes into picture, and is so much popular, particularly in the industry.

Nowadays, most of the industries are transforming globally. They have been mandated to transform to be Industry 4.0 compliant. And they are transforming towards the adoption of IIoT technologies. So, we will be learning about the different aspects of each of these Industry 4.0 and IIoT. But first, let us try to understand, what is IoT.

Precisely, IoT is about internet of things. IoT is a technology, which tries to build up an inter-network of different things, different physical objects that we use and see around us. These physical objects could be anything and everything that we can think of starting from things like, the toothbrushes which we use very early in the morning, to the air conditioner of the room, the heating system, and the projection system in front of us. And this also includes the traditional computational devices such as computers and PDAs.

The computational as well as the traditional computational devices, the present different physical objects, mentioned earlier like the toothbrush, projection system, heating system and this refrigeration system. All of these things would be inter-networked and interconnected. Then this inter-network is going to send huge amount of data, which will have to be processed, in order to make use of the data retrieved.

There are different uses of it. IoT finds applications in building smart homes for instance, smart cities and so on. So, there are even different components of smart cities like smart transportation, smart parking, and smart healthcare. IoT finds applications in making cities and homes smart. In the industrial context, we are trying to think about an extension of all of these to serve making the industrial processes, much more efficient and autonomous. So, we will look into each of these.

Sensors and actuators are central to the IoT or IIoT. And there are few other associated peripheral technologies also, but sensing and actuation is the key to IoT and IIoT. So, let us try to understand, what is this sensor, and what is this actuator.

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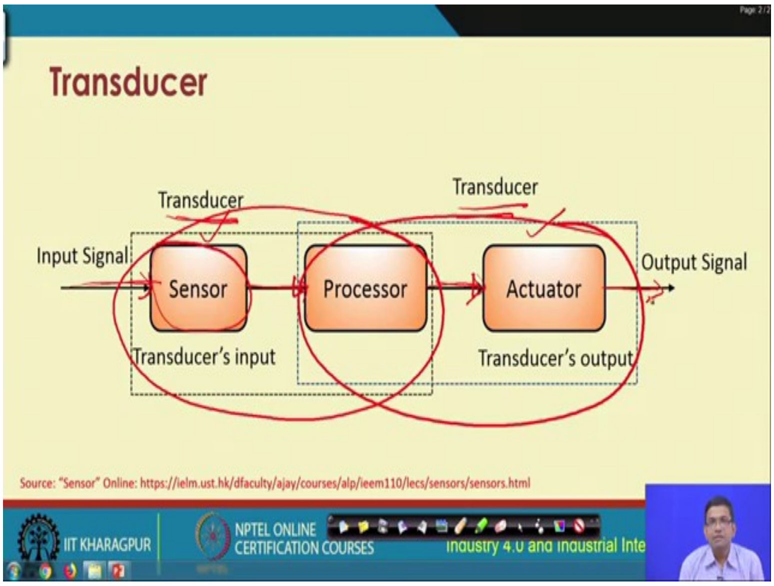


Both the sensors and actuators can be classified as transducers. Transducer converts the signal in one form into a signal in another form. The sensor plus the processor, which will process the input coming from these sensors, is a transducer. Similarly, actuator plus processor is also a transducer.

The transducer and the sensor takes some input signal and produce a certain output, send certain output, which will be processed further. And based on the processed data, the transducer will be actuated. Therefore, energy transformation is happening. The actuator then produces certain output. This is how transducers work.

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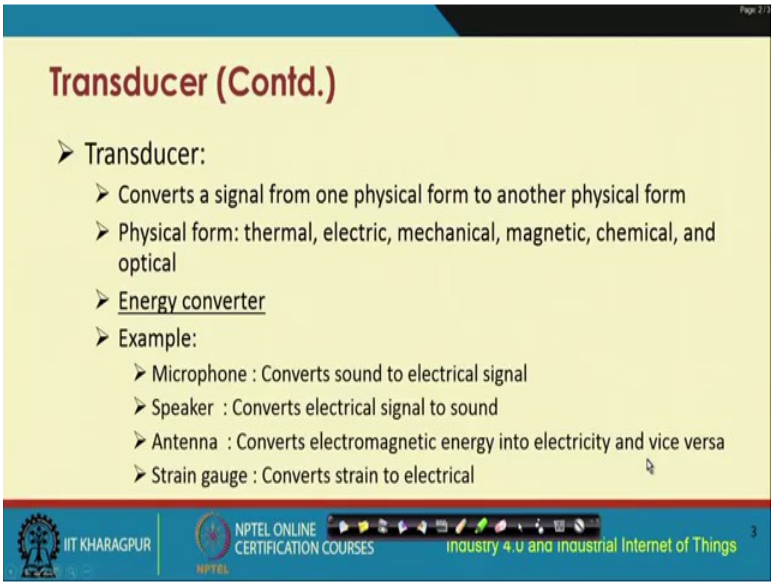


The transducer converts a signal from one physical form to another physical form. These physical forms could be like electrical form, mechanical form, magnetic form, thermal, chemical, and optical. Therefore, a transducer is nothing but an energy converter. It converts the energy from one form to the energy in another form.

For instance, things like traditional microphone, basically converts sound signals to electrical signals, which basically are amplified and the speakers basically through the speakers we are able to hear. This is the basic working concept of a microphone. A speaker is also likewise a converter of energy from electrical form to sound. So, a speaker is also another example of the transducer.

Similarly, we have antennas which converts electromagnetic energy into electrical energy and vice versa. Therefore, antenna is also a transducer. There are many other examples of transducer such as a strain gauge.

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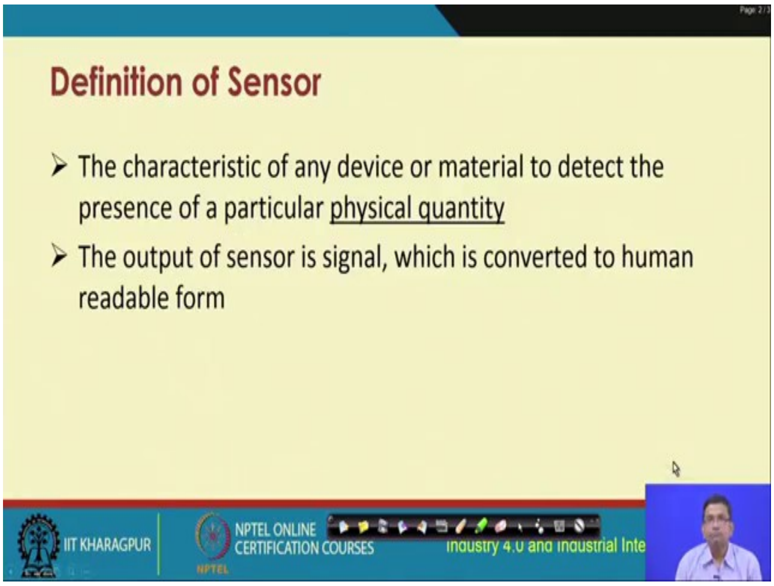


Sensor as this name suggests senses some physical quantity, which changes with the characteristic of the environment, in which it is operating. For example, a temperature sensor, will sense the changes in the temperature of the environment in which the sensor, has been deployed and operating.

The output of the sensor is a signal which is converted to some human readable form, which can be different forms. For example, changes in the current characteristics, changes in the voltage characteristics, changes in the resistance, changes in the capacitance, and changes in the impedance, are understandable by humans.

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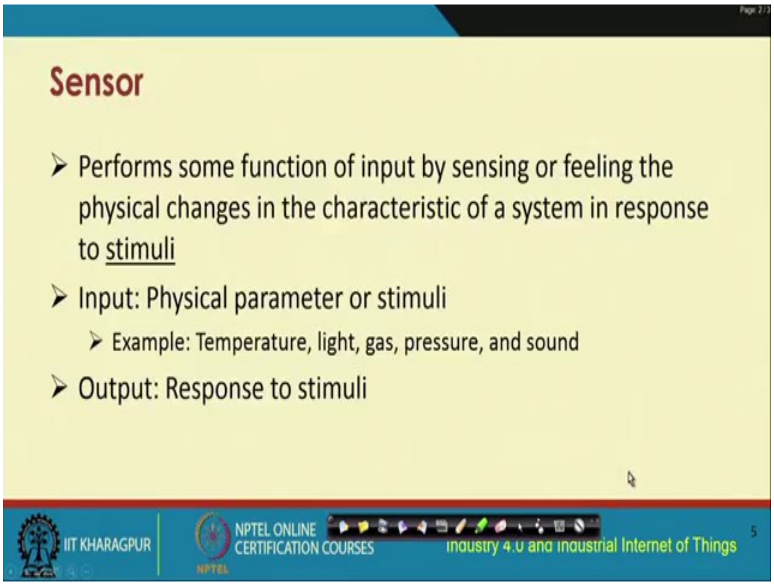


A sensor basically performs some function of input by sensing or feeling the physical changes in the characteristic of a system, in response to some stimulus. These stimuli are the physical parameters. This stimulus could be changes in the temperature, changes in the lighting condition, or changes in the gas. For example, a gas sensor senses the changes in different gases. Gas sensors such as methane gas sensor, a carbon dioxide sensor, carbon monoxide sensor, oxygen sensor have been devised to sense the changes in the amounts of these gases in the environment. So, gas sensors are incidentally useful to monitor presence of different gases particularly in context of environment. They are also very useful for mining environments. Methane sensors are used in the mines to detect the increase in methane gas in coal mines. As you know, these gases are very dangerous. The physical quantity sensed and the response is in the form of some changes in the resistive capacities, changes in the capacitive capacities or changes in current voltage characteristics in the form of the output.

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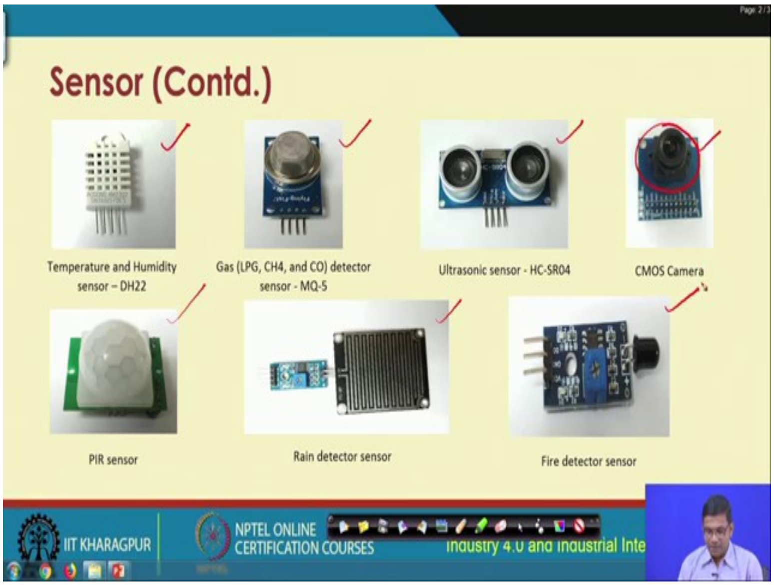


So, here are some pictures of certain sensors. These are the sensors that I have in my lab, and there are many other sensors also. I picked up these ones in order to show you how different sensors look like. Actually, the sensors basically they come in different shapes and sizes. Some of these are macro-sized sensors, but you could also have micro-sized sensors which are like MEMs based sensors. There could be nano-sensors also available for different purposes.

This is a temperature and humidity sensor. This is a type of gas sensor which detects LPG gas, methane, and carbon monoxide. This is an ultrasonic sensor. This is a camera sensor you can see the camera over here, Camera sensor. This is PIR sensor, this is rain detector sensor, and this is fire detector sensor. Now, let me see if I can show you some of these different sensors.

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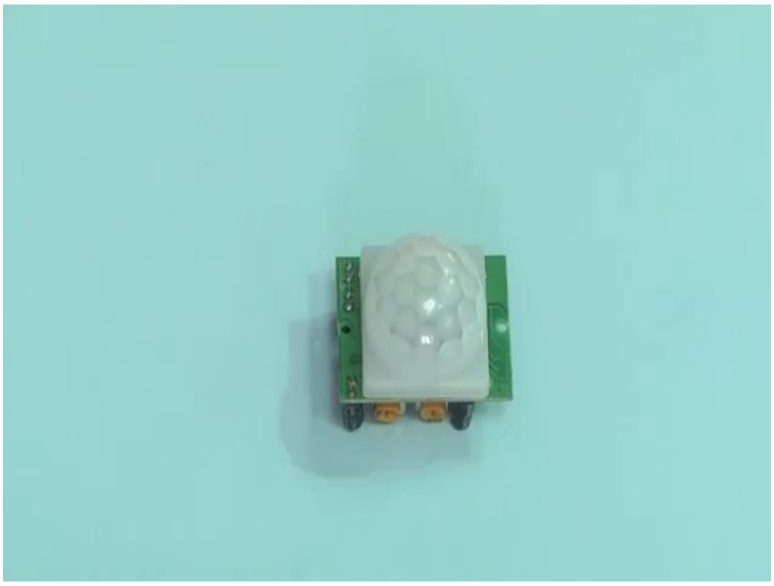

So, this is a PIR sensor.

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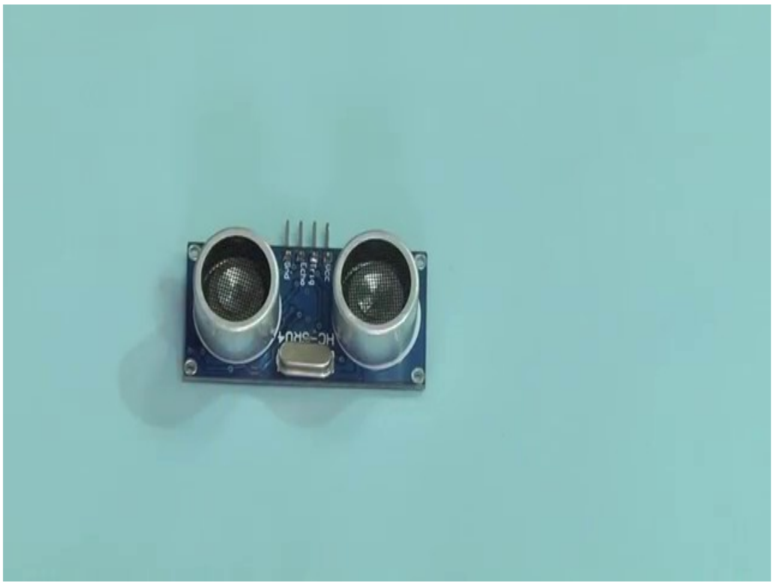

This is an ultrasonic sensor which helps you to detect how far a particular object is. Therefore, obstacles can be detected with the help of this sensor. When ultrasound, a sound wave that is sent from any one of these two cylinders, one cylinder sends sound signal, it gets reflected by that obstacle, and is detected by the other. Based on this how far a particular obstacle is, or whether there is an obstacle in its range.

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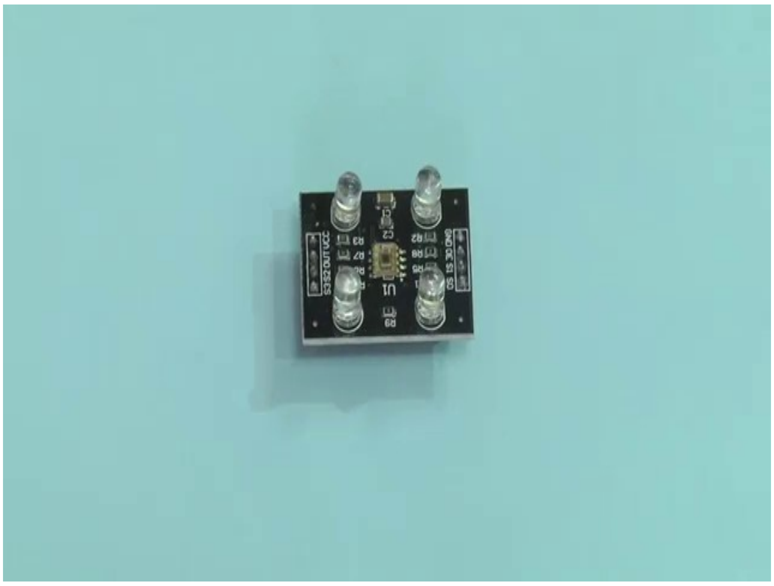

Let me show you another sensor of different type, the color sensor, which can detect different types of colors.

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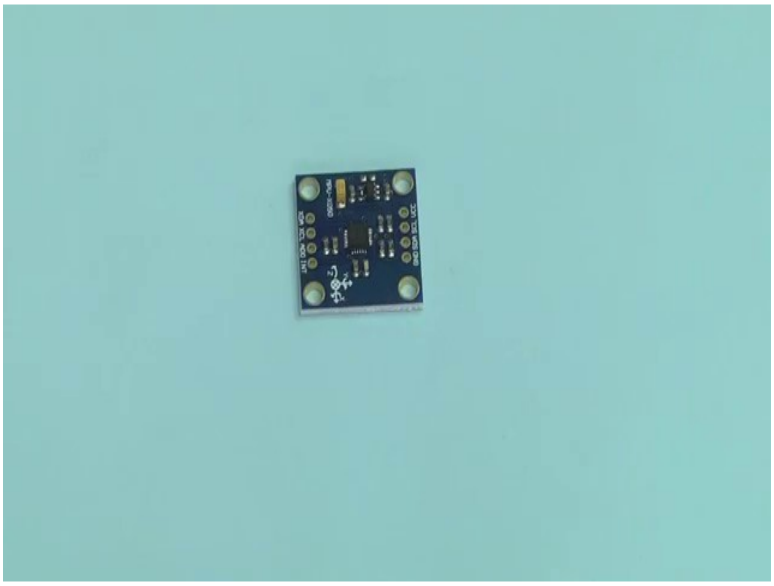

This is an accelerometer sensor.

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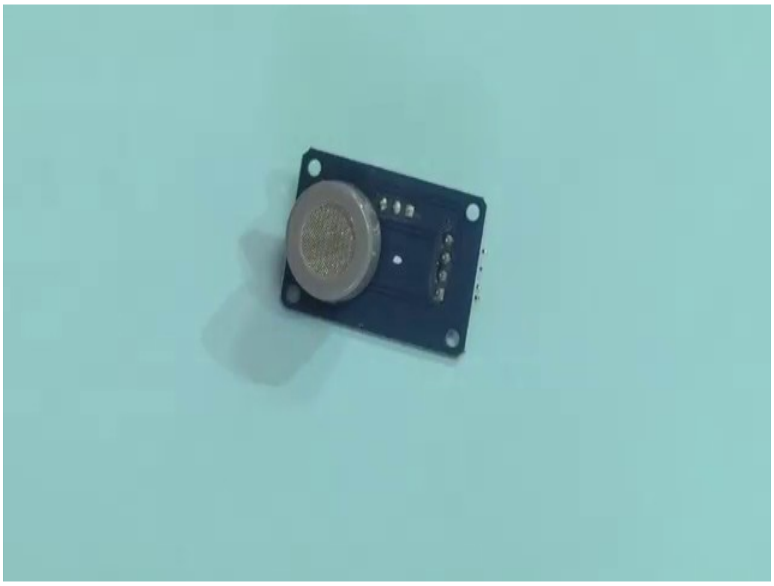

Then we have the gas sensor, carbon monoxide, which detect carbon monoxide gas. Then, we I have also brought for you another sensor which is the rain gauge. Rainfall sensors detects the rainfall.

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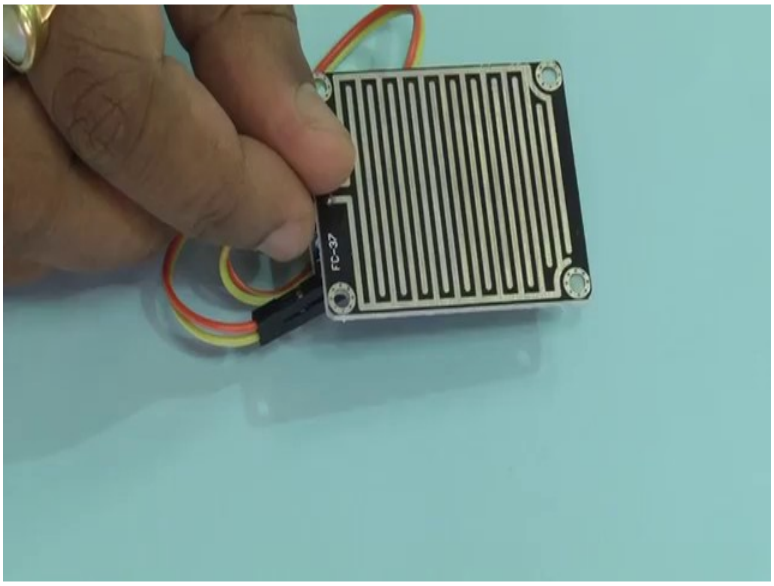

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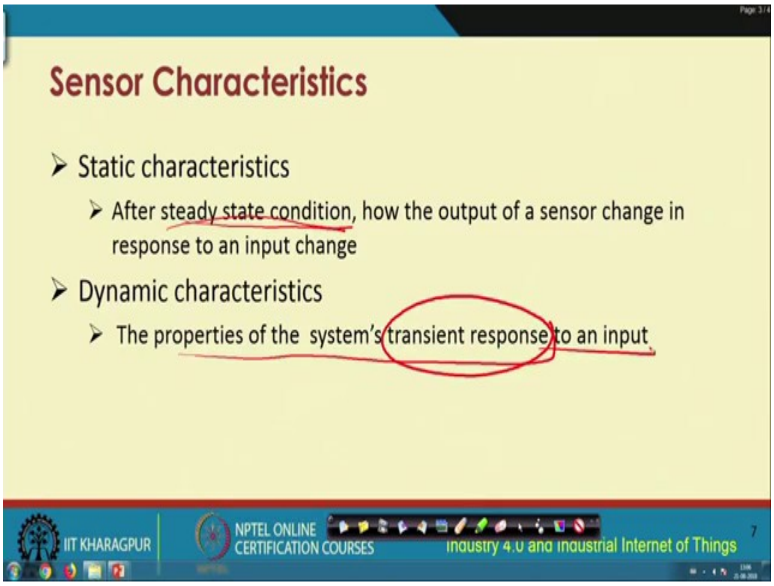


The characteristics of sensors can be classified into two types, the static characteristics and the dynamic characteristics. Different sensors have different operating mechanisms. In general, when a sensor starts its operation, it takes a while, in general, not necessarily in many cases, to come to the steady state. Static characteristics are the characteristics of a particular sensor in the steady state condition. Once the sensor has attained its steady state, the output of a sensor does not change significantly in response to the change in input. Dynamic characteristics are about the properties of the systems transient response to an input, before the sensor achieves the steady state.

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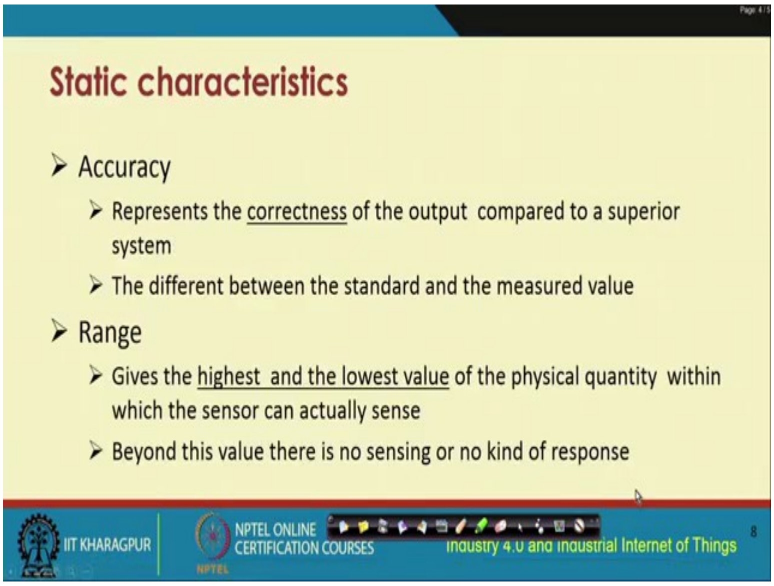

The static characteristics could be characteristics such as accuracy. As this name suggests, it is about the correctness of the output compared to a superior system. In other words, how accurately the sensor measures. Range means the range of operation lowest value to highest value. The range of operation of a particular sensor, lowest temperature to highest temperature of a particular temperature sensor is the range of that particular sensor.

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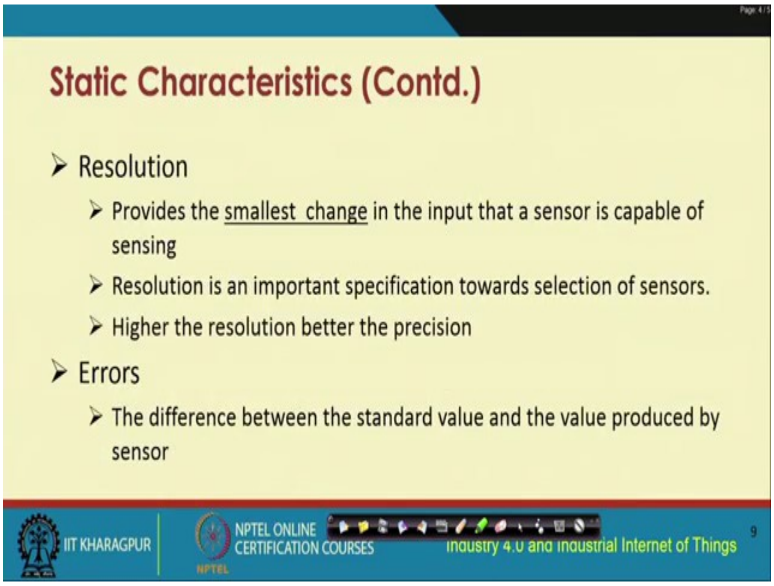


Resolution is the smallest change in the input that a sensor is capable of sensing. Similarly, you have the resolution of a sensor like a temperature sensor. The smallest change in temperature that a particular temperature sensor is able to sense or detect is basically the resolution of a particular sensor. Error is the difference between the standard value and the value produced by the sensor.

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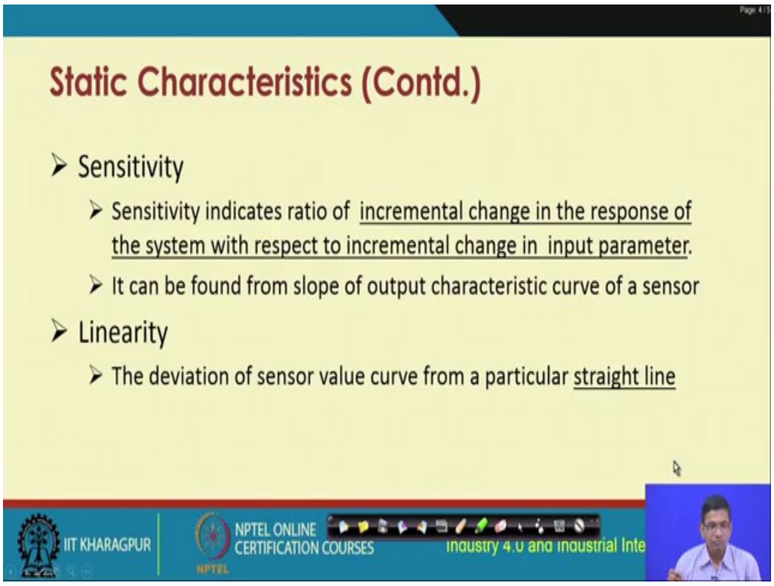


Sensitivity indicates the ratio of incremental change in the response of the system with respect to the incremental change in the input parameter. The linearity characteristic is the deviation of the value of a sensor from the straight line curve.

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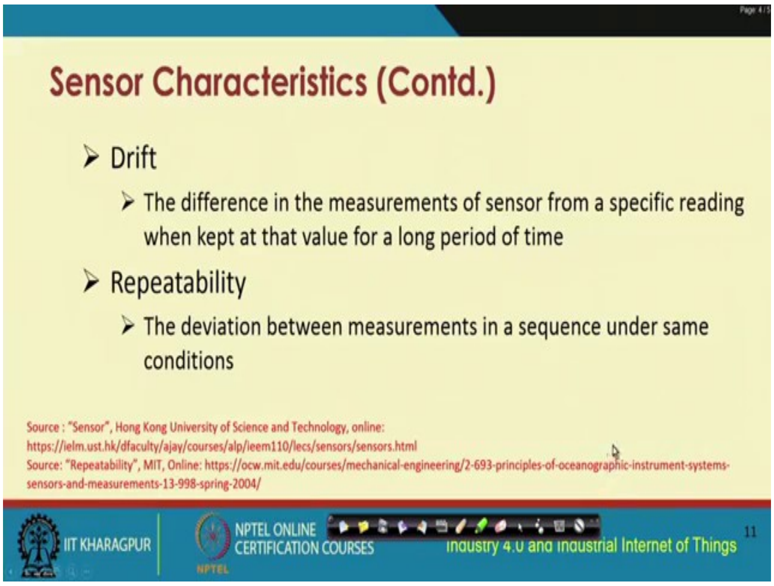


Drift is the fluctuation in the value of a sensor, if it is kept at the same conditions for long duration. For example, in case of temperature sensor or any other sensor for a particular reading condition, if you are keeping it for a sufficiently long duration of time, then the difference in measurements that it will show over the period of time is the drift. Then we have the repeatability characteristic, which is the deviation from the measurements, in a sequence, under the same conditions.

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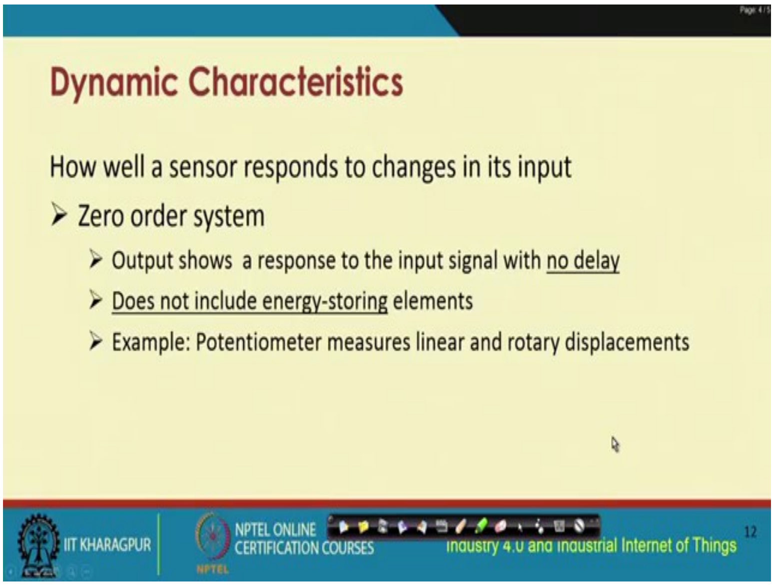


Dynamic characteristics is about if the inputs are changed, how well the sensor responds to its changes in the input. The transients are received or captured through the dynamic characteristic. For example, zero ordered system, which is basically a system where the output shows a response to the input signal, without any delay. These zero order systems do not include energy storing requirements. For instance, a potentiometer measures the linear and rotary displacements, so this is an example of a zero order system.

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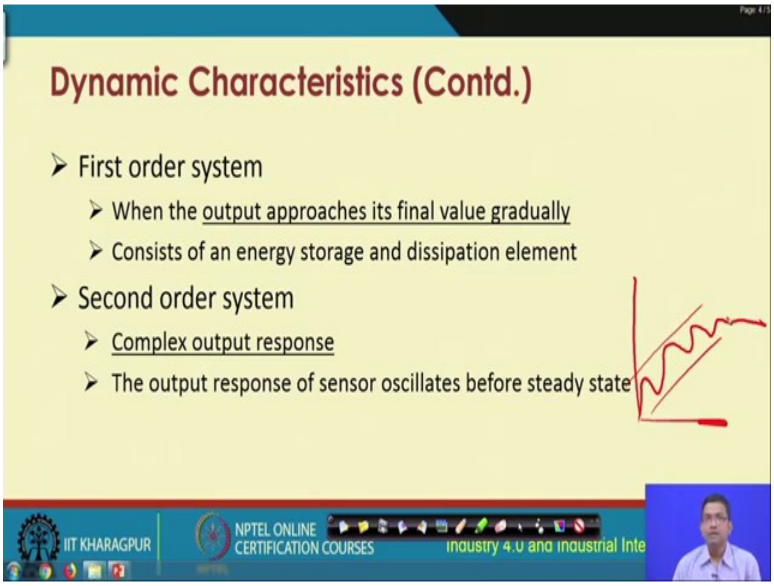


First order systems are when the output approaches its final value gradually. These systems will have some kind of mechanism for both energy storage and dissipation. For example, a capacitor will store this energy and dissipate over a duration of time, in these systems.

Second order systems will have complex output response not gradually, but a complex output response. And this output response of these sensors will typically oscillate before the steady state is arrived. So, this oscillates between certain values. These are the output response of these second order systems.

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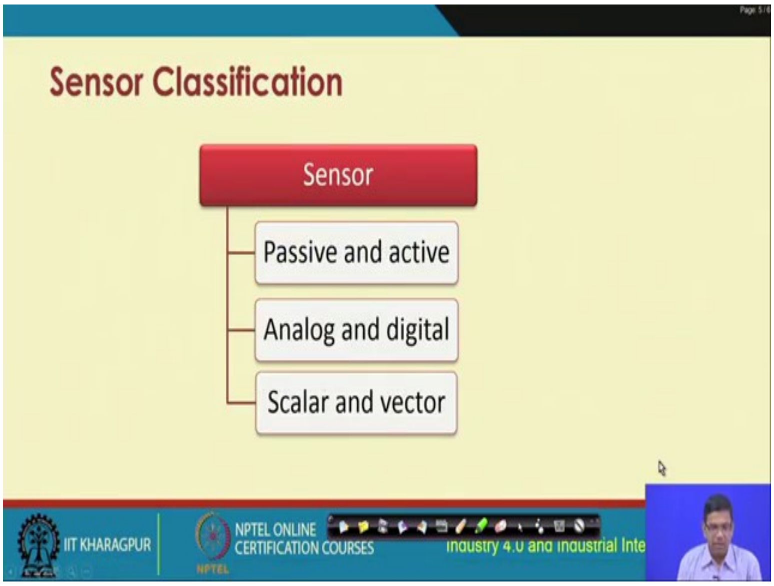

The sensors could be classified in different ways. They could be classified as either passive sensor or active sensor, analog sensor or digital sensor, scalar sensor or vector sensor.

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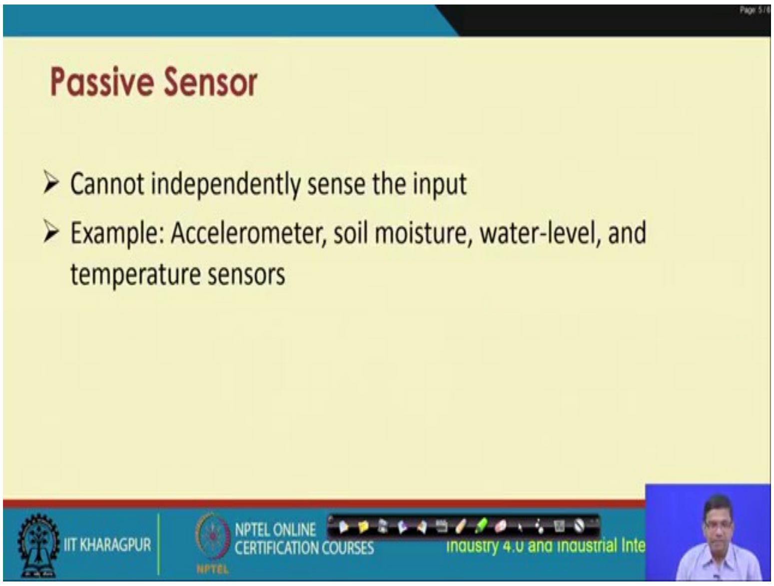


A passive sensor cannot independently sense the input. So, examples of passive sensors are accelerometer, soil moisture, water level, and temperature sensor.

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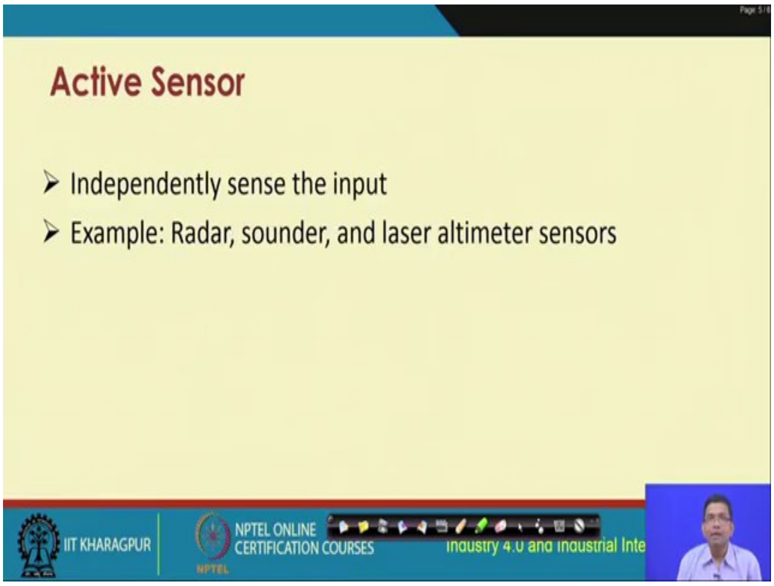


Active sensors are the ones, which can independently sense the input. For instance, radar, altimeter sensors are examples of active sensors.

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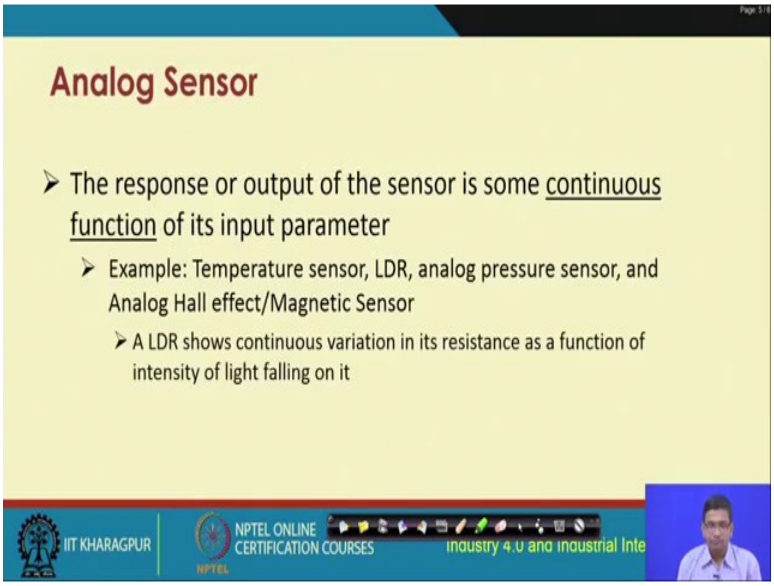


Analog sensors produce output which is some continuous function of the input parameter. For example, temperature sensor, light detection sensor, LDR, pressure sensor, analog pressure sensors, the analog variants of these pressure sensors, analog Hall effect sensor or magnetic sensors. A LDR shows continuous variation in its resistance as a function of intensity of light falling on it.

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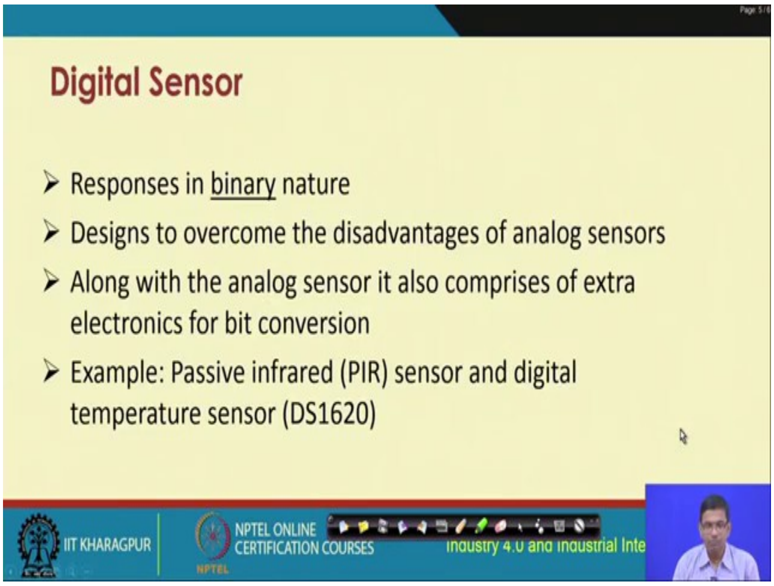


Digital sensors are basically the ones where the response is of binary nature. These have been designed in order to overcome some of the limitations of the analog sensors which produces continuous function of the output with respect to the changes in the input characteristics. Examples of digital sensors are PIR sensor, digital, and temperature sensor.

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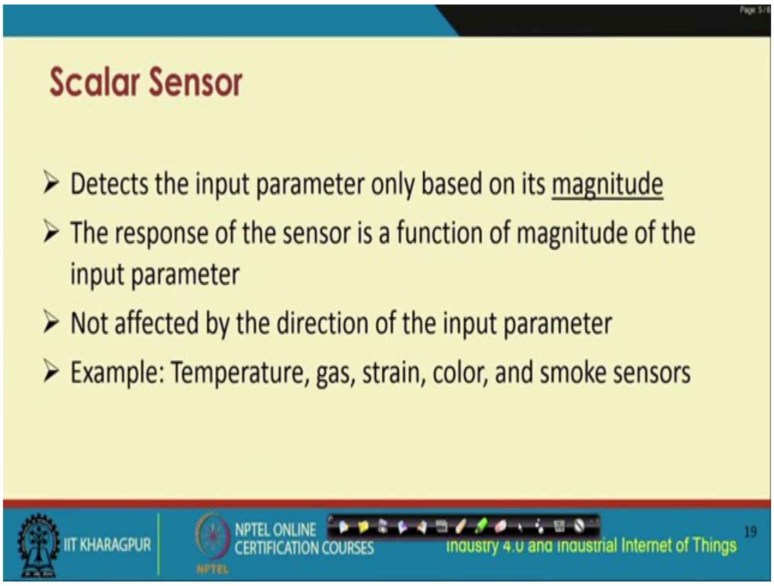


Scalar sensors are basically the ones which will measure only the magnitude of the input parameter. The response of a sensor is a function of the magnitude of the input parameter. And these are not affected by the direction of the input parameter. Examples are temperature sensor, gas sensor, strain sensor, color sensor, smoke sensors. The detection of these parameters do not depend on the change in the direction of the input, change in the direction of temperature, change in the direction of gas etc.

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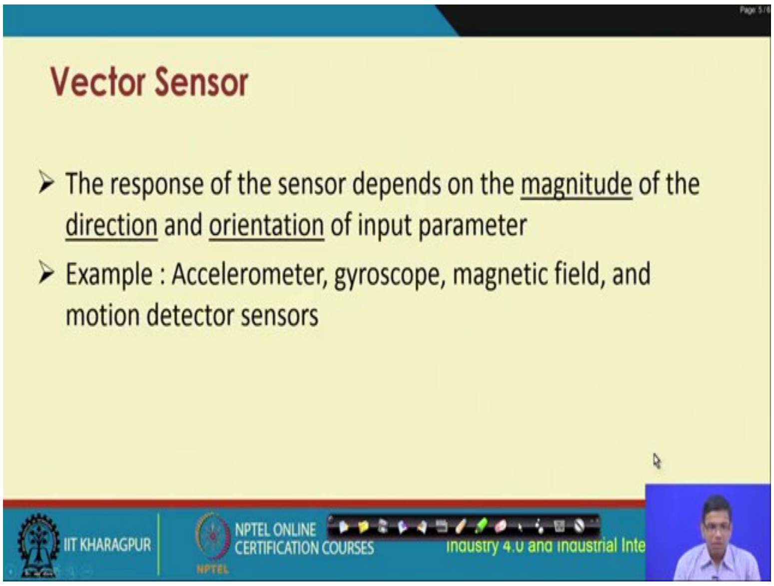


Vector sensors are those sensors whose response depends on the magnitude, the direction and the orientation. Examples are accelerometer, gyroscope, magnetic field, and motion detector sensors.

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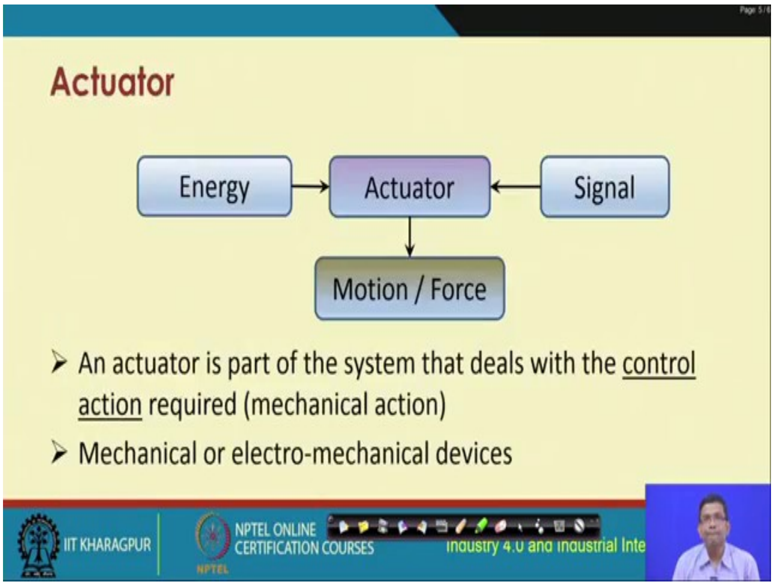


In this particular figure, an actuator takes two inputs, one input is the energy. And together the actuator produces some kind of a motion, such as the force or whatever.

So, an actuator is a part of the system that deals with the control action required, the mechanical action. There are many others, but these are some of these pictures of actuators.

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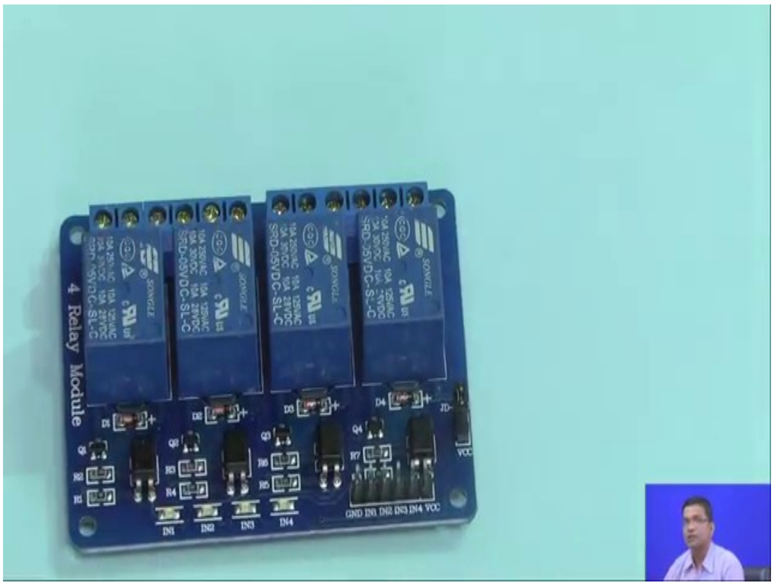


So, this is an actuator; an electric relay.

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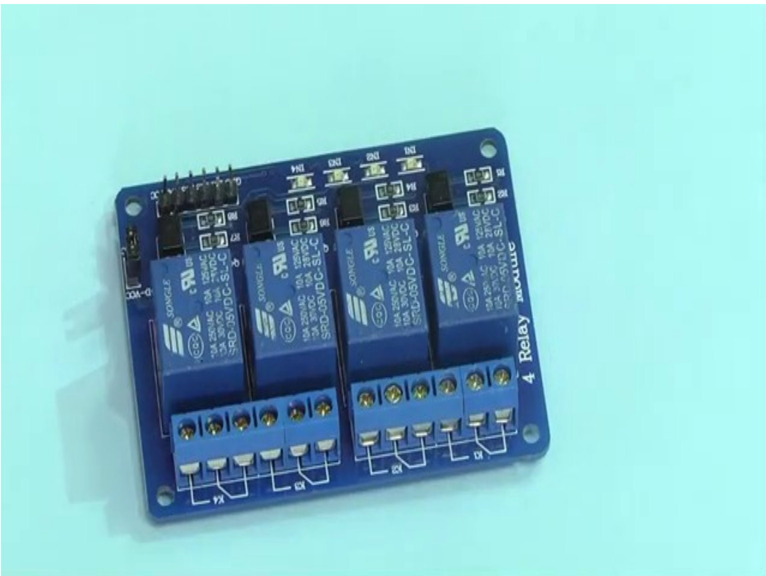

This relay transforms the electrical energy into some kind of mechanical action, or it could be electromechanical as well. These relays are useful for performing, taking an electric signal and performing some kind of mechanical operation such as turning on a particular valve, turning off a valve, turning on a device, turning off a device such as a compressor.

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Then this is a motor - a dc motor. There could be different types of motors, and each of these is basically an example of actuator.

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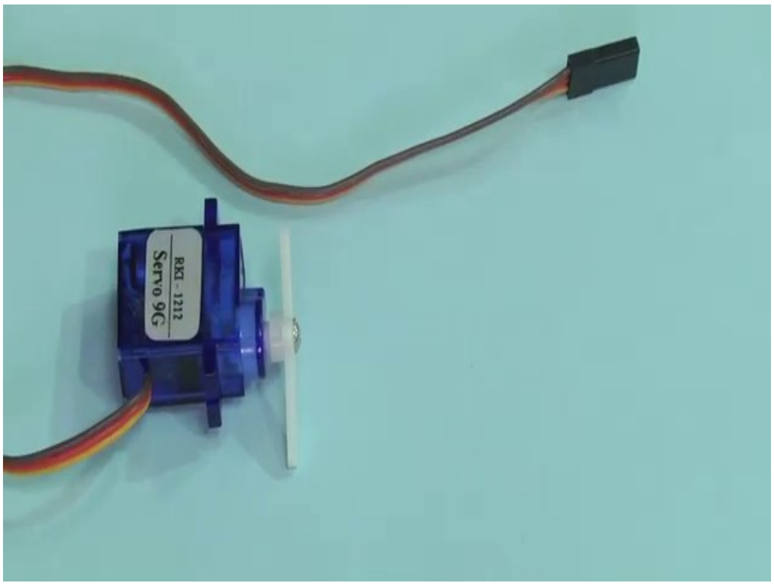

And let me show you another actuator which is basically another type of motor, which is known as the stepper motor.

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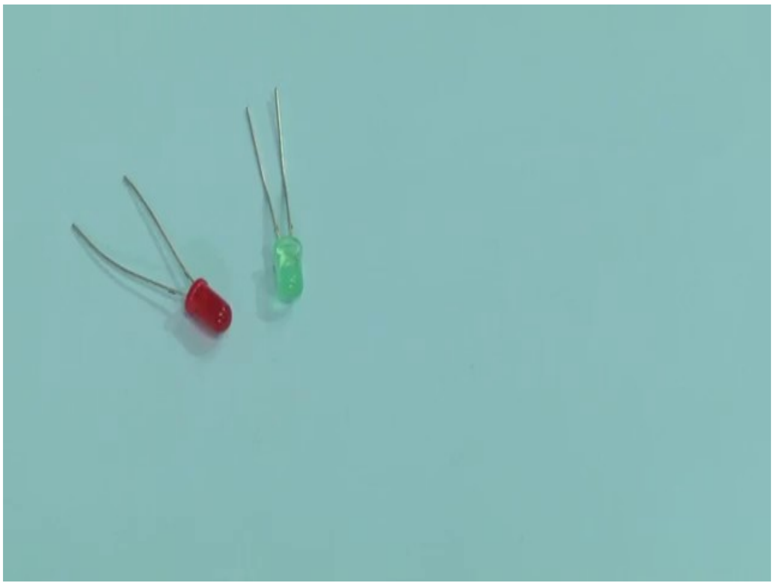

You could also have actuators like these which I think most of you have already seen right. These are the LEDs. So, an LED could be turned on or off in response to something, something being sensed. For example, a gas being present.

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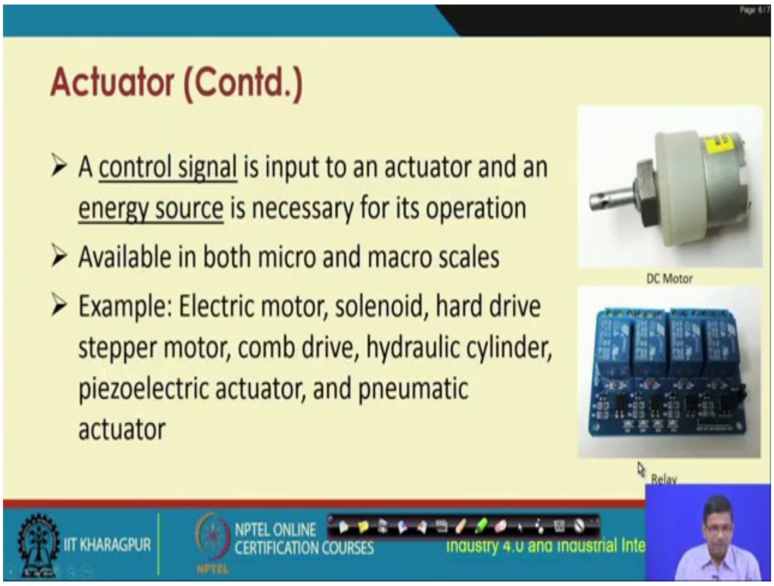


An actuator takes a control signal as an input and then it performs its operation. So, here is the picture of a dc motor. And I already show you showed you live the how a dc motor looks like. Similarly, a relay is another example, electric relay. These are different examples of actuators- electric motors, solenoid valves, hard drives, stepper motor, comb drive, hydraulic cylinder, piezoelectric actuator, pneumatic actuators. These actuators can come in different shapes and sizes. These could be micro actuators, macro actuators, and so on depending on the size of these actuators.

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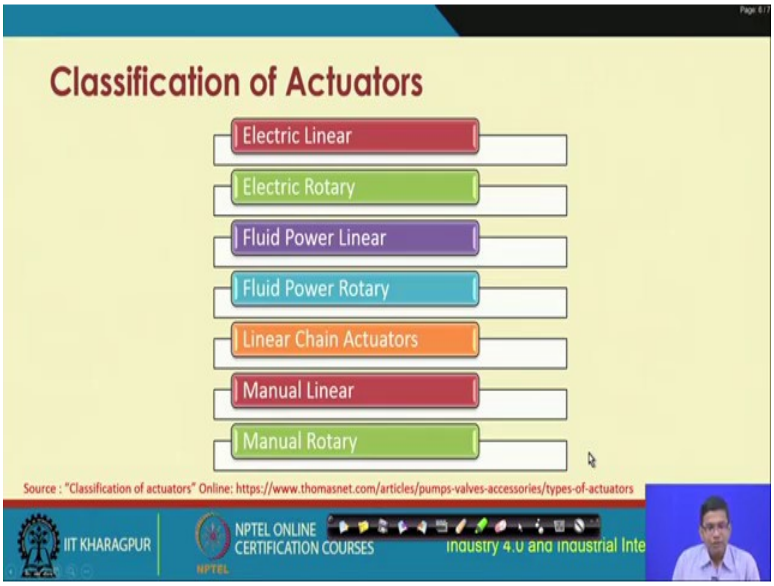


The actuators can be classified into different types, such as electric linear, electric rotary, fluid power linear, fluid power rotary, linear chain actuator, manual linear, manual rotary.

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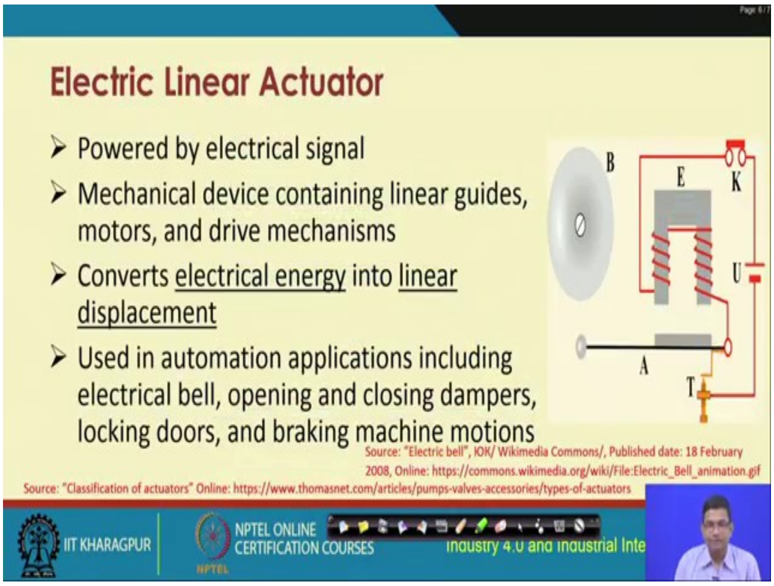


Now, let us look at this electric linear actuator. As the name suggests, these are basically powered by electric signal. The electric energy in these actuators is transformed to achieve some kind of linear displacement. For example, electric bell, opening and closing of dampers, locking doors, breaking machine motions.

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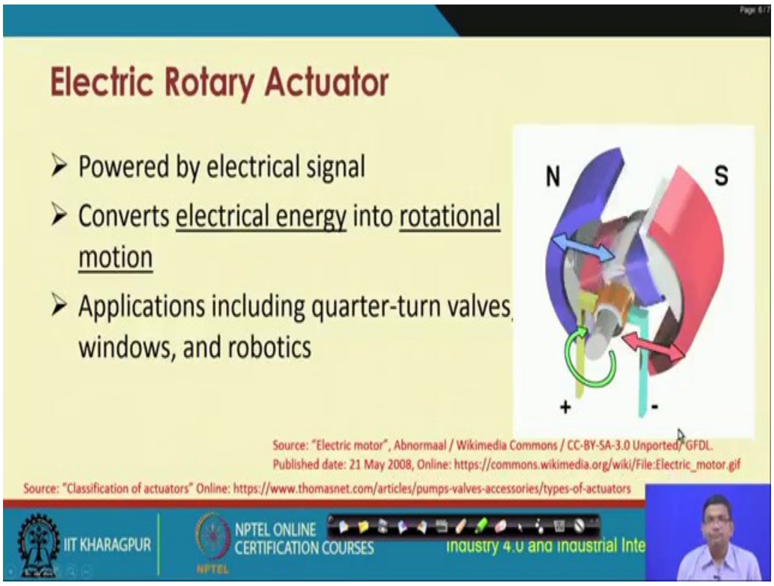


Then the next one is electric rotary actuator. These are powered by electrical signals. They convert the electrical energy into rotational motion. And this one is electrical energy into rotational motion. So, you know quarter turn valves, and other electrical motors are examples of electric rotor actuator.

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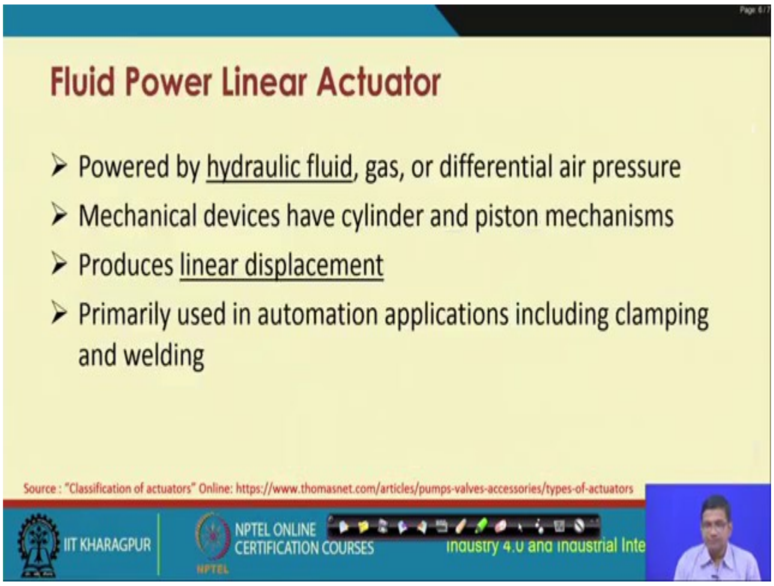

Then you have the fluid power linear actuator. These are powered by different electric fluid sorry hydraulic fluids, gas or air pressure, and produces linear displacement.

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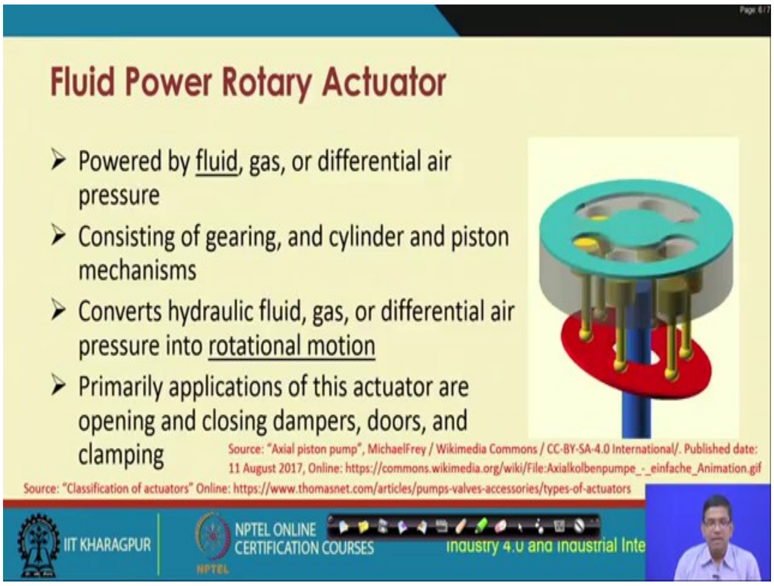


Then you have fluid power rotary actuator again powered by fluid, such as gas and liquids. They produce rotational motion, like the example that you see the picture that you see in the slide, rotational motion is produced as an output of these actuators.

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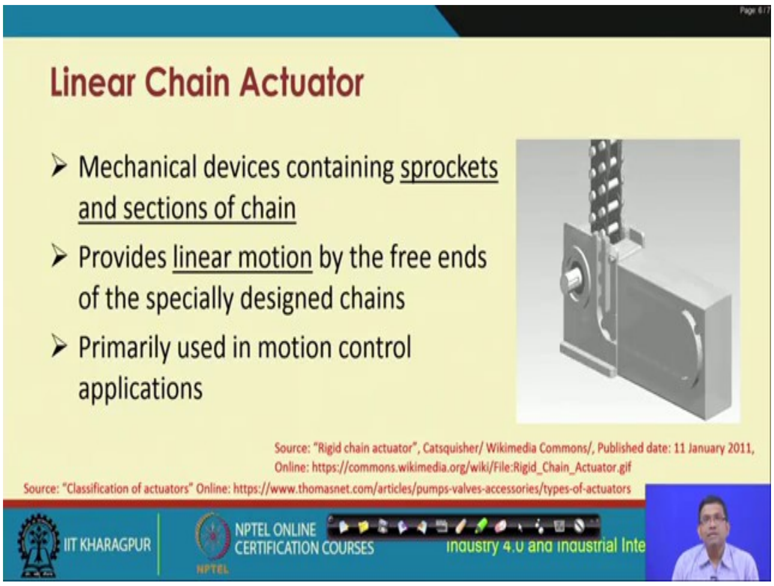


Then you have the linear chain actuator, consists of mechanical devices such as sprockets and sections of chains, which produce linear motion by the free ends of the specially designed chains. And the slide helps to understand how these work. So, these are primarily used in motion control applications.

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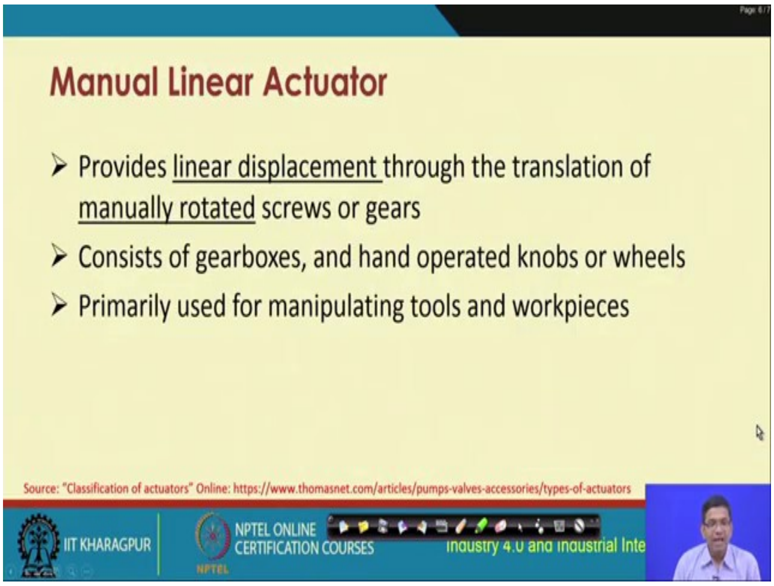


Then we have the manual linear actuator which provides linear displacement through the translation of manually rotated screws or gears. So, manual rotation is performed on some screws and consequently there is some linear displacement. Examples are gear boxes, hand operated knobs, wheels. These are primarily used for manipulating tools and work pieces.

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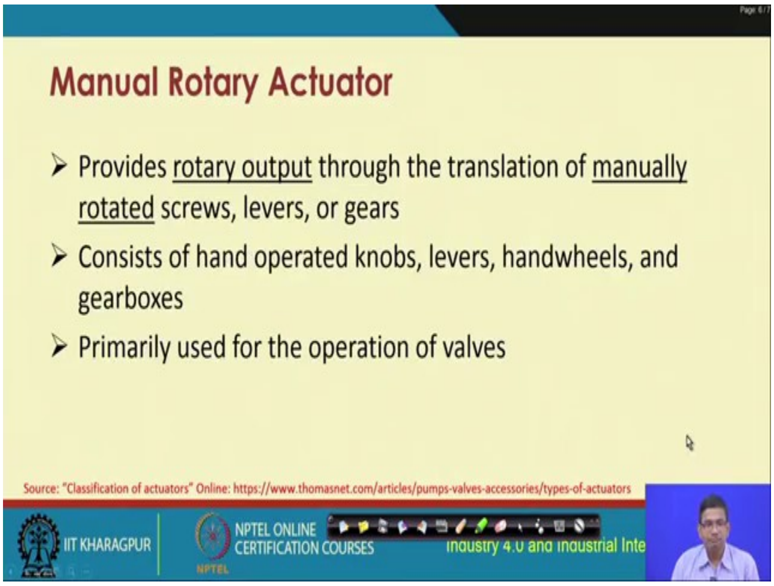

Then you have the manual rotary actuators which provide rotary output through the translation of manually rotated screws, levers or gears, gears. These are primarily used for the operation of valves.

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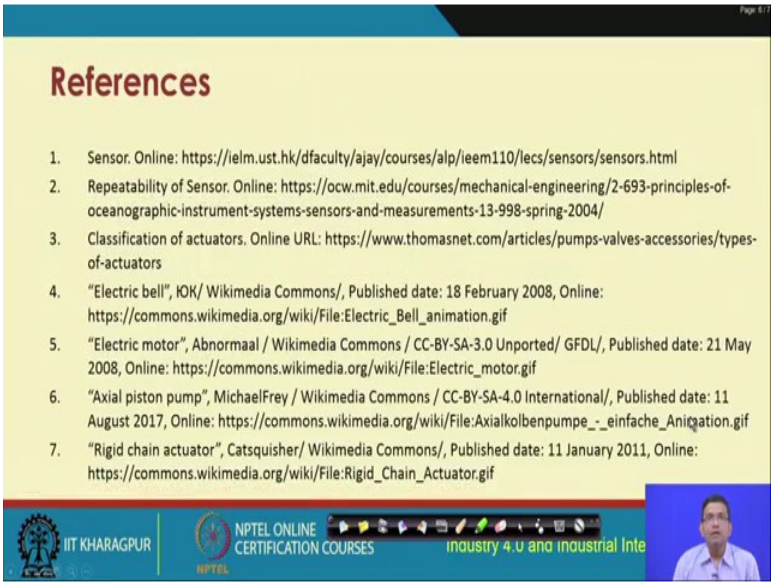


So, with this we come to an end of this particular lecture on sensors and actuators. And as I told you at the outset sensors are, and, actuators are basically key to the building of IoT and IIoT based systems. And, you know, everywhere throughout you will see that in this course, we are talking about the use of sensors and actuators, and this preliminary understanding about each of these, the sensors and actuators, is necessary for you to have an in-depth understanding about how IIoT works.

These are some of these references given in the slide.

Thank you.

**Introduction to Industry 4.0 and Industrial Internet of Things**
**Prof. Sudip Misra**
**Department of Computer Science and Engineering**
**Indian Institute of Technology, Kharagpur**

**Lecture – 02**
**Introduction: IOT Connectivity – Part I**

In the previous lecture, we have seen the key technologies, which are heart of IoT or IIoT, which is basically sensing and actuation. The sensors can sense some physical changes in the characteristics of the environment in which it is operating. Let us see the temperature sensor. The temperature sensor can sense the changes in the temperature characteristics of the environment where it is operating. The different communication protocols are used for the transmission of the data sensed by the sensor.

So, connectivity is the bottom line. The different available connectivity technologies discussed in the context of IoT, in general, applies to IIoT also.

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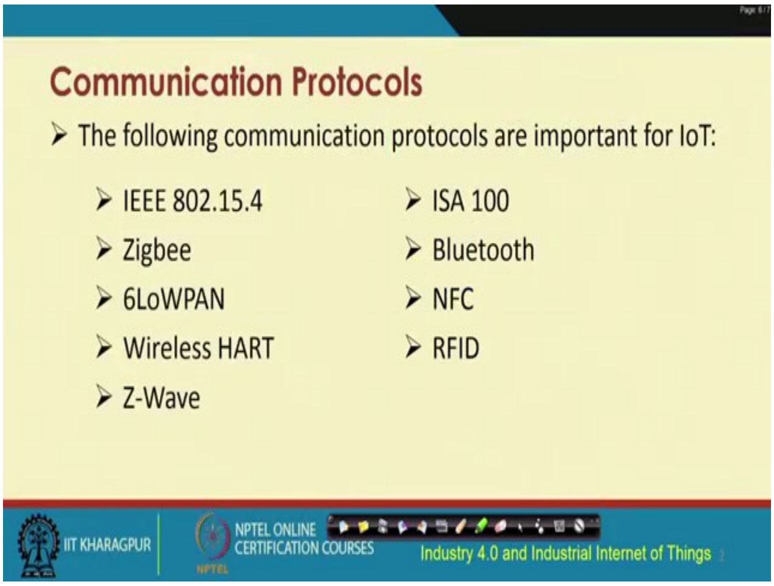


These are some of the communication protocols that are typically used for IoT. The first one is the IEEE 802.15.4 standard. Then you have different other protocols such as the ZigBee, 6LoWPAN, Wireless HART, Z-Wave, ISA 100, Bluetooth, NFC, and RFID.

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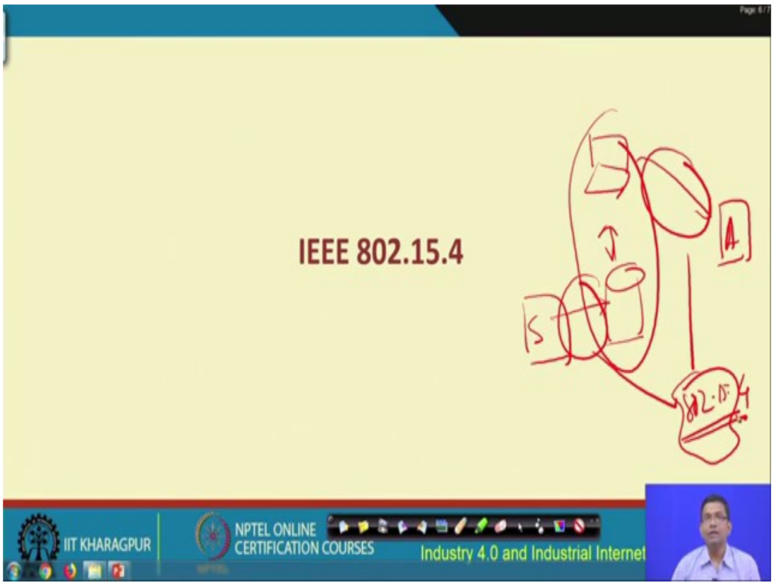


The 802.15.4 IEEE standard is used heavily for connectivity purposes in IoT. The sensed data are to be sent over a network to some remote device, for further processing. And, based on that processing again that signal has to be sent from that processor to some remote actuator, which will do some actuation that will turn on the lights of a room. Let us say, a laptop or something you know a processor or whatever. So, some signal might be required to be sent to the actuator right. We are talking about these different protocols that will be used over here and IEEE 802.15.4 is one such very widely used standards for offering connectivity in IoT.

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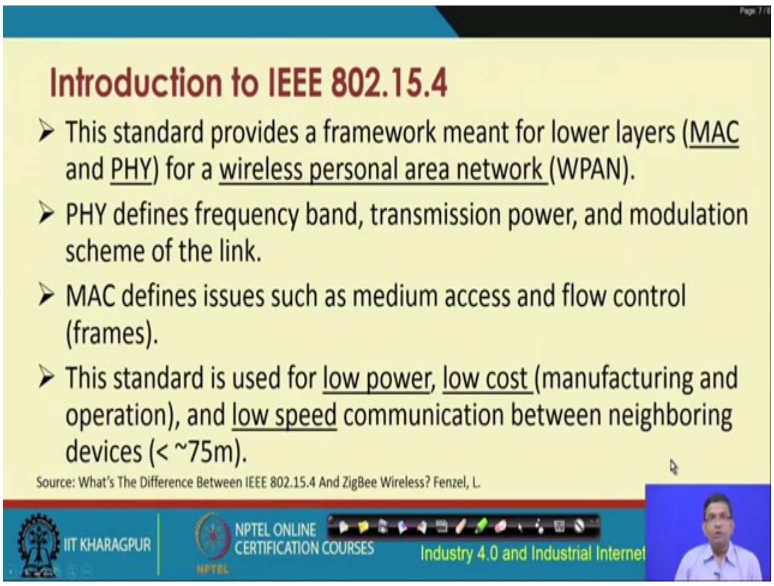

IEEE 802.15.4 basically provides the framework meant to be used particularly for networks such as the wireless personal area networks. Personal area networks means the network which operate in a very small scale and small range. IEEE 802.15.4 basically defines how these physical and the MAC layers are going to be used.

The physical layer defines things like the frequency band in which the communication is going to happen and the transmission power modulation scheme which is going to be used. On the other hand, the MAC layer discuss about different devices, the medium for communication, which protocol is going to be used, how they are going to send, when they are going to send, and what is the discipline that is going to be followed. The frames that are the PDUs in the data link layer, are going to be sent and the flows of the frames are to be maintained.

IEEE 802.15.4 standard is typically meant for use in communication where there is low power, low cost, low speed requirements. The communication between devices which are separated by typically less than 75 meters, 10 to 75 meters. But, you know different operating conditions will result in different ranges.

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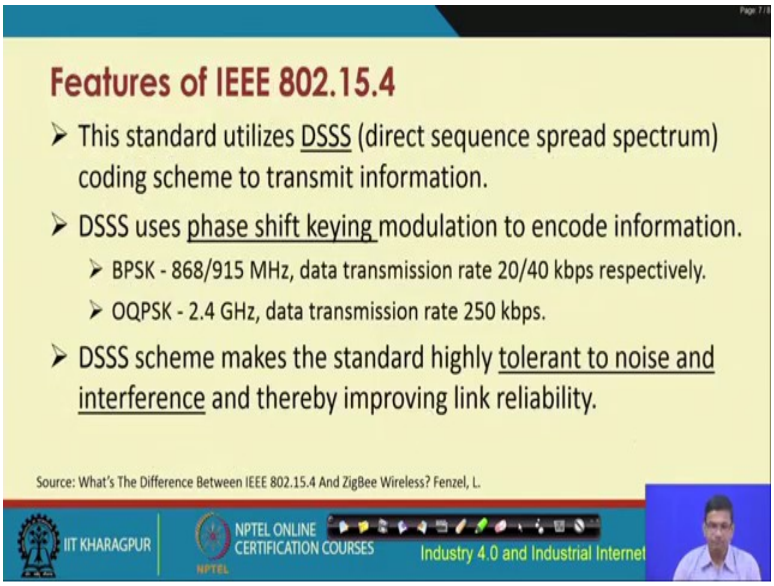


DSSS, the direct sequence spread spectrum coding scheme, is used to transmit information. The coding scheme which will encode the data and it will be sent. The reason DSSS is used is that it offers increased security and reliability. IoT systems typically operate in noisy environments interference where there is a lot of interference. Therefore, DSSS is a kind of encoding scheme, good for sending information in these kind of channels exhibiting these noisy characteristics. DSSS uses phase shift keying modulation known as the PSK modulation. Phase shift keying modulation encodes the information and the different variants of it.

The first one is the BPSK modulation. Binary phase shift keying and this is typically used for data transmission rate of about 20 to 40 Kbps and in this particular frequency band, 868, 915 megahertz frequency band. There is another one, which is used for the 2.4 gigahertz frequency band, which is the OQPSK. The offset quadrature phase shift keying offers a higher data transmission rate of about 250 kbps. So, this BPSK offers 20 to 40 kbps and OQPSK offers about 250 kbps, a higher data rate, in the 2.4 gigahertz frequency band.

DSSS is a standard that will be highly tolerant to noise and interference. So, ultimately DSSS offers link reliability. Link reliability means that you have to ensure that whatever you are sending reliably and which is the destination.

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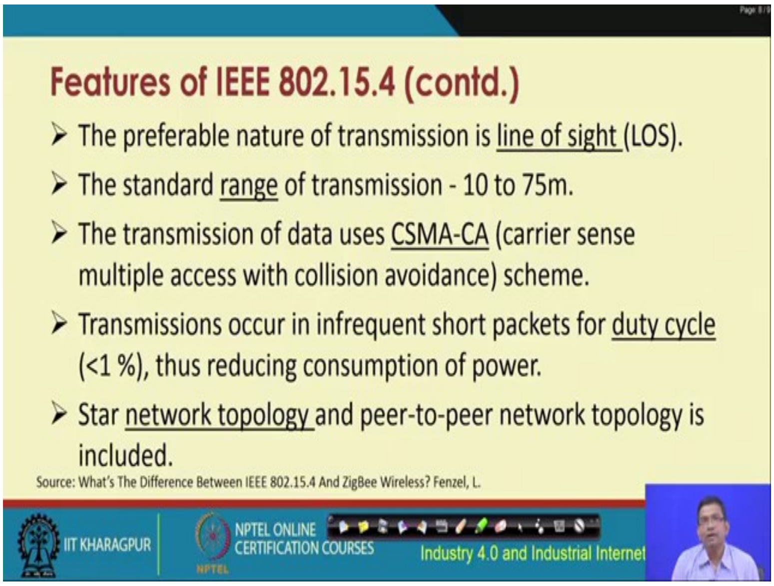


These are some of the features of 802.15.4 that it operates in the line of sight and that is the preferred nature of transmission. The range typically is about 10 to 75. The MAC protocol, that is typically, used if the CSMA-CA protocol carrier sense multiple access with collision avoidance and 802.15.4 has a requirement because it has to work in systems with low power. Therefore, it is used in transmission systems where there is a requirement of producing or using low duty cycle, low duty cycle. Low duty cycle means the sensor will be active for a short duration of time because that will reduce the power consumption. So, in this kind of environment 802.15.4 is useful. The topologies that are typically used are network topologies such as the peer to peer topology and the star topology.

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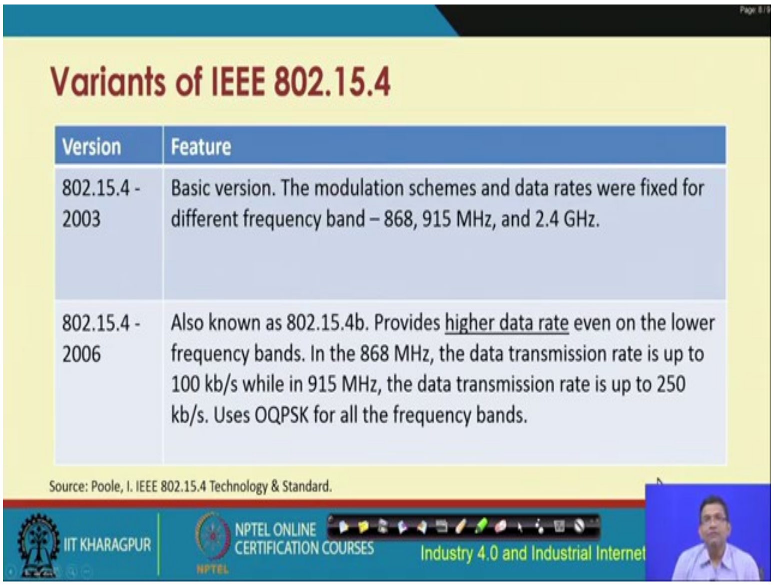


The basic version of IEEE 802.15.4 is the 2003 version, where the modulation scheme and data rates were fixed for different frequency bands as 868, 915 megahertz and 2.4 gigahertz. In 2006, the next variant came, which is popularly known as the 802.15.4b, which offer higher data rates compared to the previous version.

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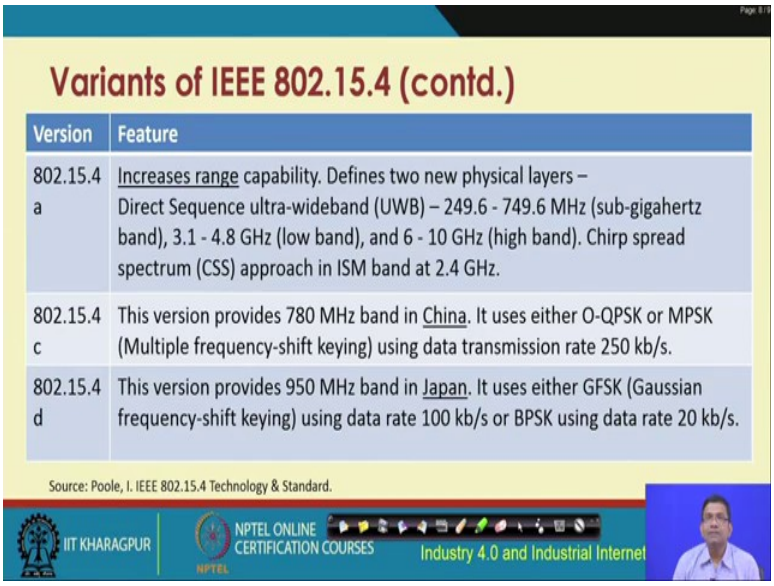

We have the next one, 802.15.4a, which talks about increasing the range capability. Then came the 802.15.4c which talks about using the 780 megahertz band in china for offering connectivity and communication. So, this basically uses O-QPSK or MPSK multiple phase frequency shift keying mechanisms for data transmission with data rate 250 kbps.

The IEEE 802.15.4d provides 980 megahertz band communication in Japan and it uses the GFSK and BPSK with different data rates.

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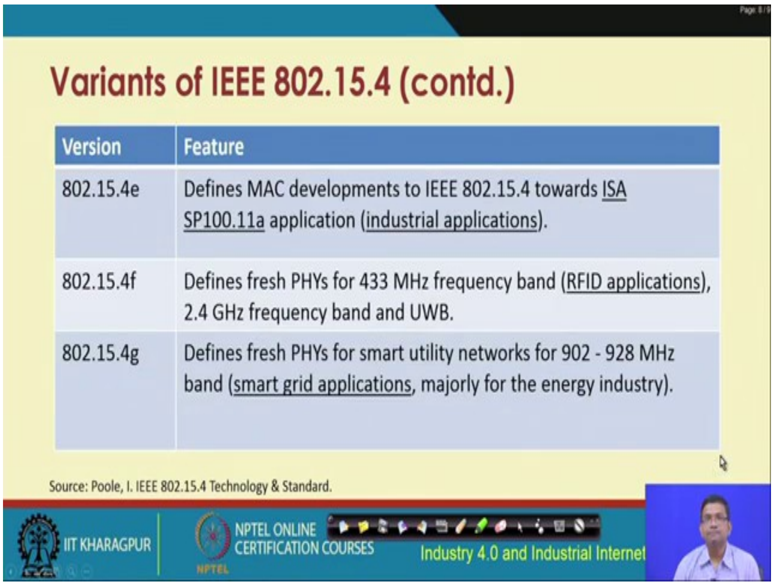


The e-variant (802.15.4e) is particularly meant for serving MAC applications for industrial environments, f-variant (802.15.4f) is for particular use in RFID applications, g-variant (802.15.4g) for smart energy smart grid etc. So, these are the different variants of 802.15.4.

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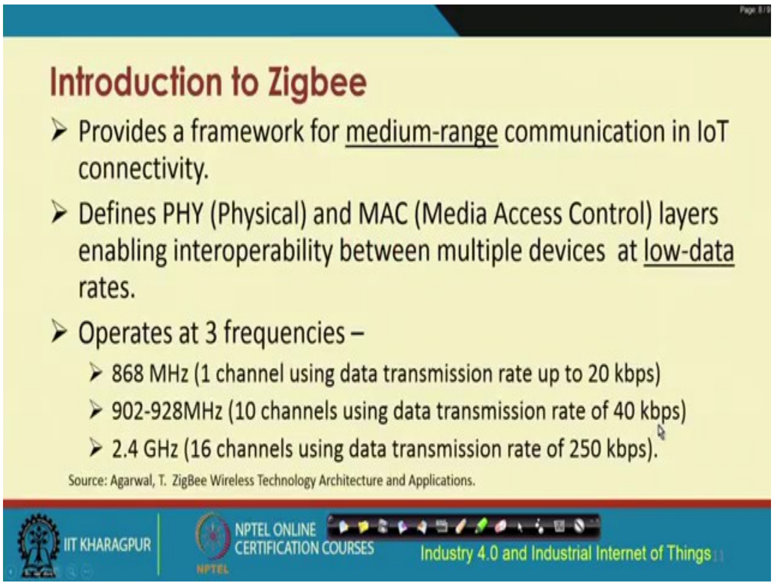


There are different protocols like the ZigBee protocol which is primarily based on 802.15.4. The ZigBee protocol provides a framework for medium range communication to offer IoT connectivity, it defines the physical layer, and MAC layer characteristics enabling interoperability between multiple devices at low data rates. ZigBee operates in three frequencies: 868 megahertz, 902 to 928 megahertz and 2.4 gigahertz.

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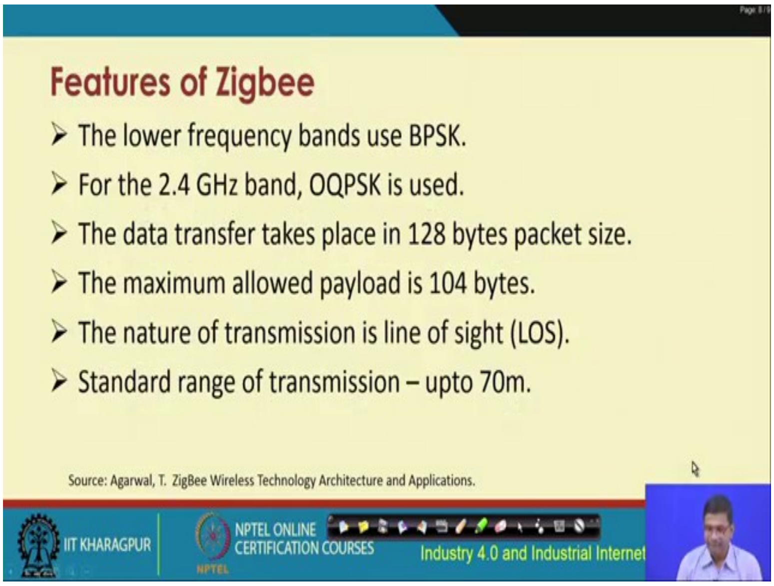


The lower frequency bands in ZigBee use BPSK, the 2.4 gigahertz band uses OQPSK, the offset QPSK, and then the data transfer takes place in 128 bytes packet size. So, each of these packet size in ZigBee is typically 128 bytes and the maximum allowed payload is 104 bytes. The nature of transmission is not necessarily to be line of sight (LoS). ZigBee works with reduced data rate to some extent for long distance. The standard range of transmission is about 10 to 70 meters in ZigBee.

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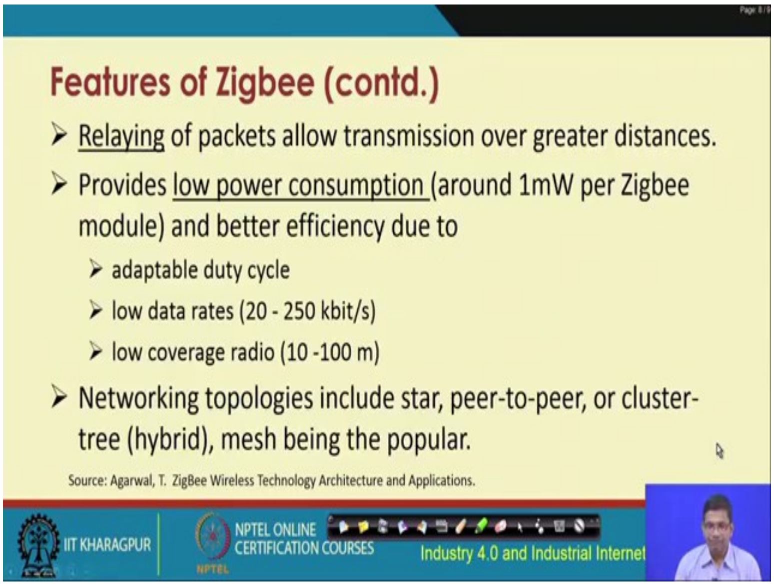


ZigBee basically helps in packet transmission over greater distances with the help of the concept of relaying. A ZigBee device, which receives a packet, sends the data packet to one of its neighbors and through multi-hub process communication from the source will be received at the destination node. ZigBee supports the relaying concept, virtually communication range can be increased. ZigBee provides low power communication around 1 megawatt per ZigBee module and it has different features such as offering adaptable duty cycle, low data rates of about 20 to 250 Kbps, low coverage ratio of 10 to 100 meter and so on. ZigBee supports different network topologies such as the star topology, P2P cluster tree topology and mesh topology and the mesh.

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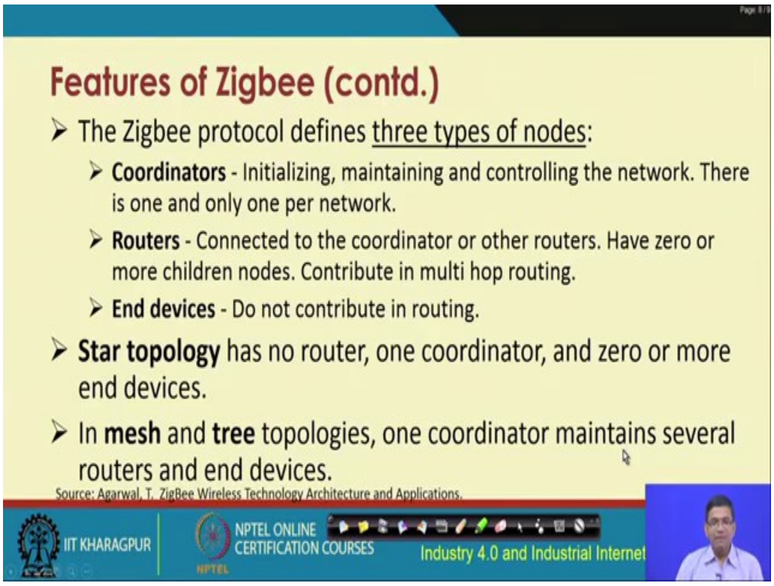


ZigBee protocol defines three types of nodes: the coordinator node, the router node and the end devices. The coordinator takes care of issues of initialization, maintaining, and controlling of the network. There is normally one controller per network. There are routers, which are typically used for multi-hop routing, to transmit the data packets received. The end devices are the recipients of the data which do not contribute to further routing.

The topology used are star topology and there is one coordinator, zero or more end devices. If the mesh and tree topologies are used, there is one coordinator that maintains several routers and end devices.

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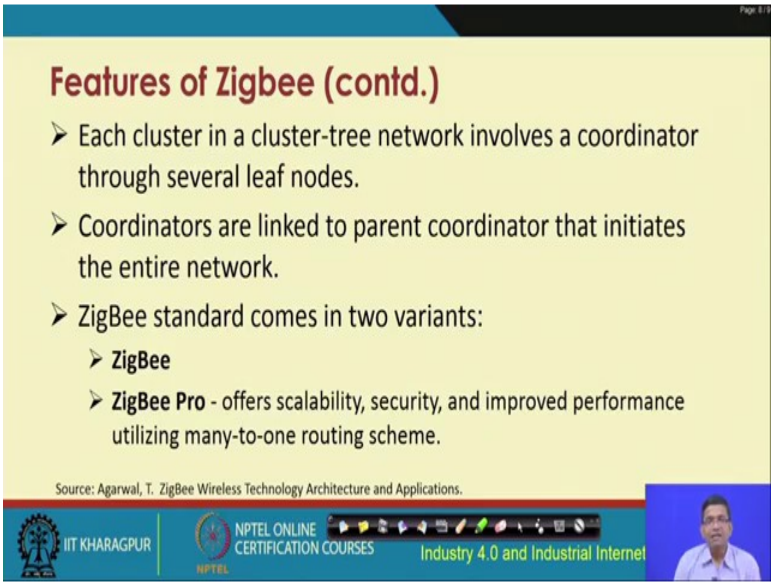


Each cluster in a cluster tree network topology is used involves a coordinator through several leaf nodes. So, there is some cluster and there is a tree kind of structure. The coordinators are linked to the parent coordinator that initiates the entire network.

ZigBee standard comes in two variants: the regular ZigBee and the pro variant. Pro is attractive, because it offers you know issues of scalability. ZigBee pro offers better security; improved performance utilizes many routing scheme.

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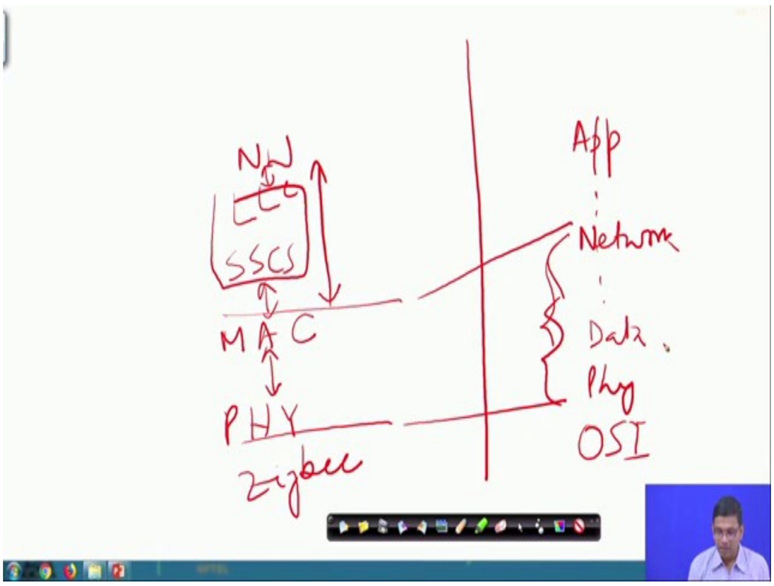

In ZigBee, the physical, then the MAC, have different layers such as the SSCS, the LLC, and the network layer. Traditional OSI is used for the internet. The physical layer has the data link layer all the way up to application.

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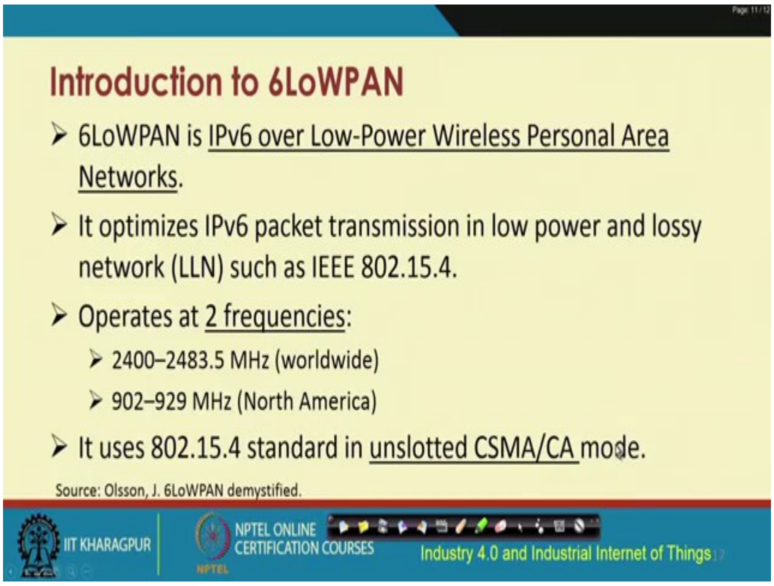


6LoWPAN, you must be wondering, that what is this 6, with a numerical value the name of a protocol starting with the numeric value. 6 stands for the letter 6 in IPv6. 6LoWPAN is about use of IPv6 over wireless personal area networks. The personal area network, the wireless one and there is low power. This optimizes 6LoWPAN optimizes IPv6 packet transmission in low power lossy networks. 6LoWPAN operates at two frequencies: one is the 240, sorry, 2400 to 2483.5 megahertz frequency band which is used worldwide and the other one is in North America which is the 902 to 929 megahertz band. IEEE 802.15.4 standard in the unslotted CSMA/CA MAC protocol mode.

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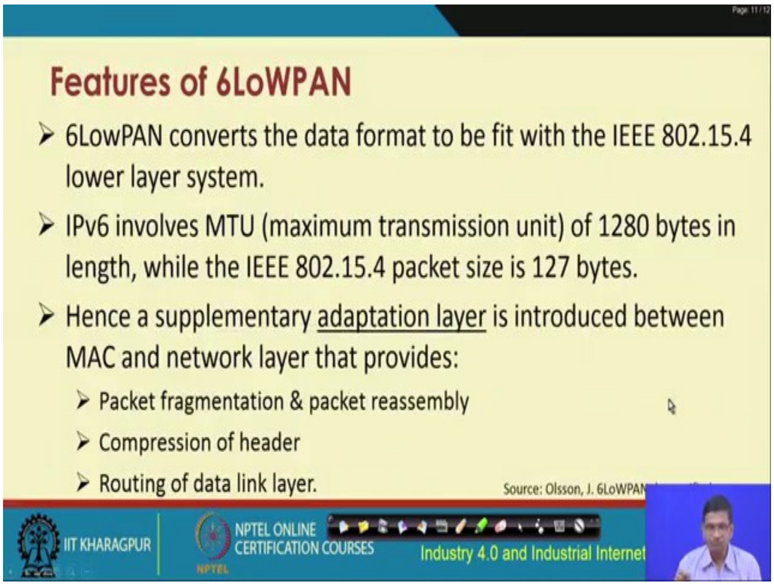


6LoWPAN converts the data format to be fit within 802.15.4 lower layer system. IPv6 basically involves MTU of 1280 bytes in length, while 802.15.4 permit a packet size of upto 127 bytes. Therefore, there is a big mismatch, 1280 is permitted by IPv6 and 802.15.4 allowing 127 bytes only. This can be achieved with the help of a layer which is known as the adaptation layer, which is introduced in between the MAC and the network layer. This helps in packet fragmentation. Fragmentation has to be done because, 1280 and 127, there is a mismatch in the sizes. This adaptation layer will help in few other things such as the compression of header, routing of data link layer. So, routing help with the routing on top of the data link layer, with the help of this particular adaptation layer.

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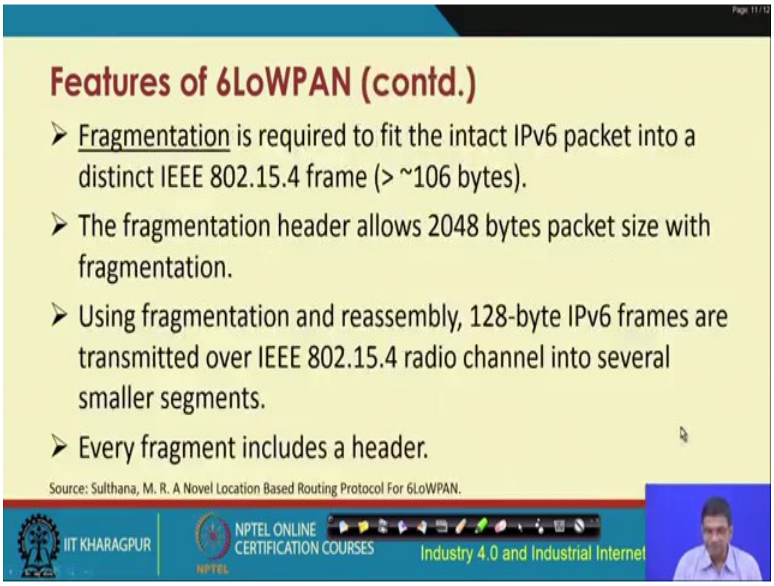


So, fragmentation is required to be able to fit the intact IPv6 packet into the IEEE 802.15.4 frame. So, this fragmentation header allows 2048 bytes packet size. Using fragmentation and reassembly 128 bytes, IPv6 frames are transmitted over 802.15.4 radio channel into several smaller fragments. IPv6 will take care of the 6LoWPAN protocol, the adaptation layer will basically take care of both the fragmentation as well as the reassembly.

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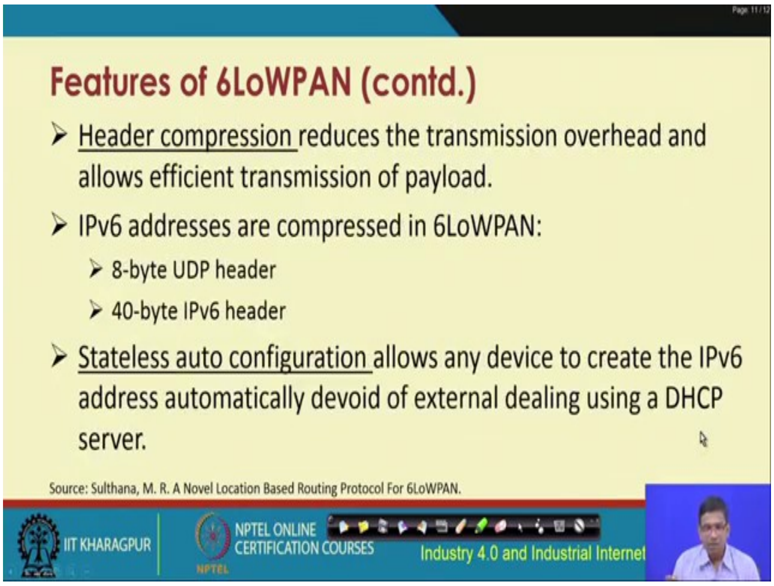

The header compression reduces the transmission overhead and allows efficient transmission of payload. So, IPv6 addresses are compressed in 6LoWPAN into two types: 8-byte UDP header and 40-byte IPv6 header. DHCP is not used in 6LoWPAN.

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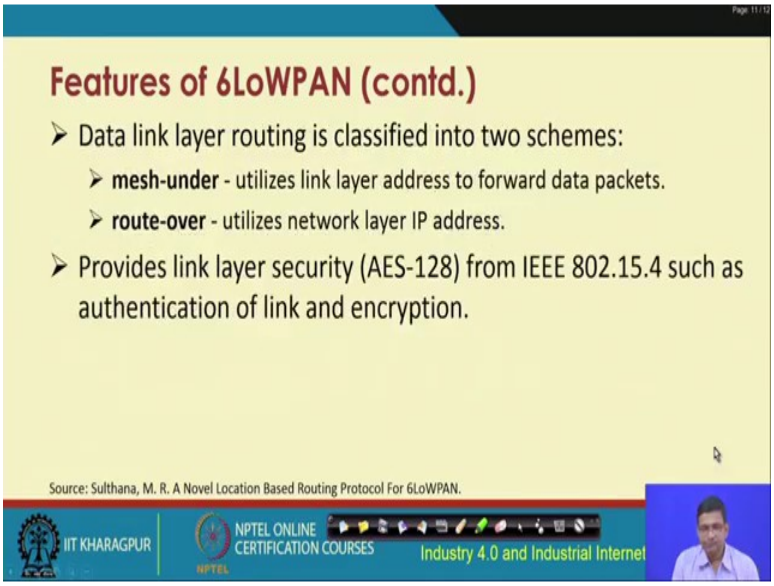


The data link layer routing is classified into two schemes: one is the mesh under which utilizes the link layer addresses to provide to forward data packets and the other one is the route over. So, route over utilizes network layer IP address.

Let us look at one more thing is that this AES-128 link layer security is used.

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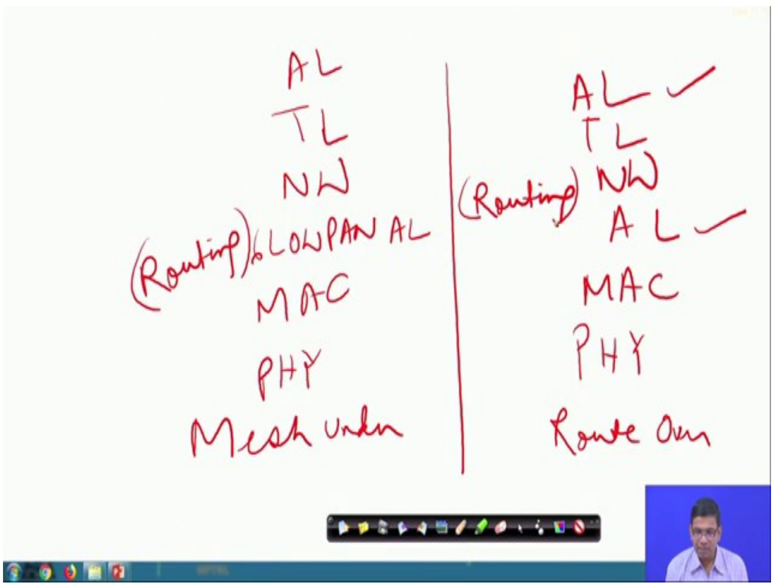

The physical layer, then the MAC layer, the adaptation layer which is the 6LoWPAN, the network layer, the transport layer, and the application layer are placed.

The difference in case of mesh under this routing is done in the adaptation layer.

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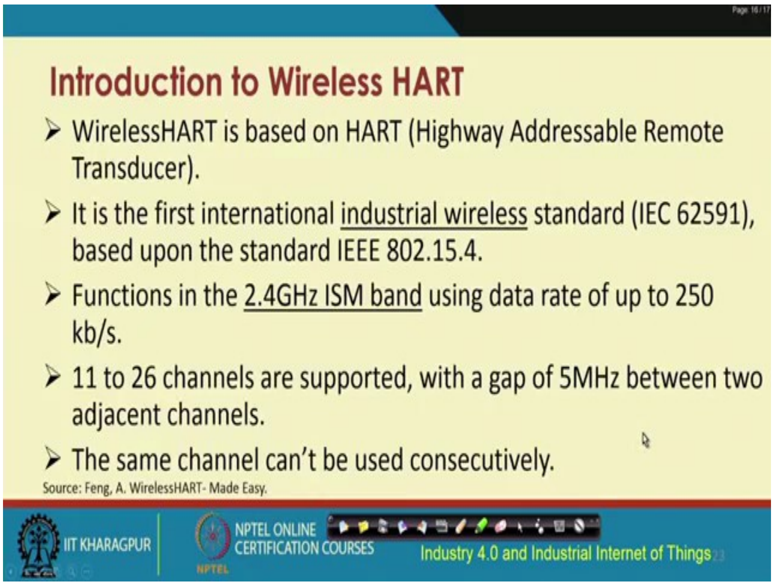


Another protocol, which is the wireless HART protocols, are used particularly for industrial applications. The full form of HART is Highway Addressable Remote Transducer and is based on IEEE 802.15.4 standard.

It functions in the 2.4 gigahertz ISM band using data rates upto about 250 kbps and there are 11 to 26 channels with a spacing of about 5 megahertz between two adjacent channels. HART wireless protocol makes it mandatory that the same channel cannot be used consecutively.

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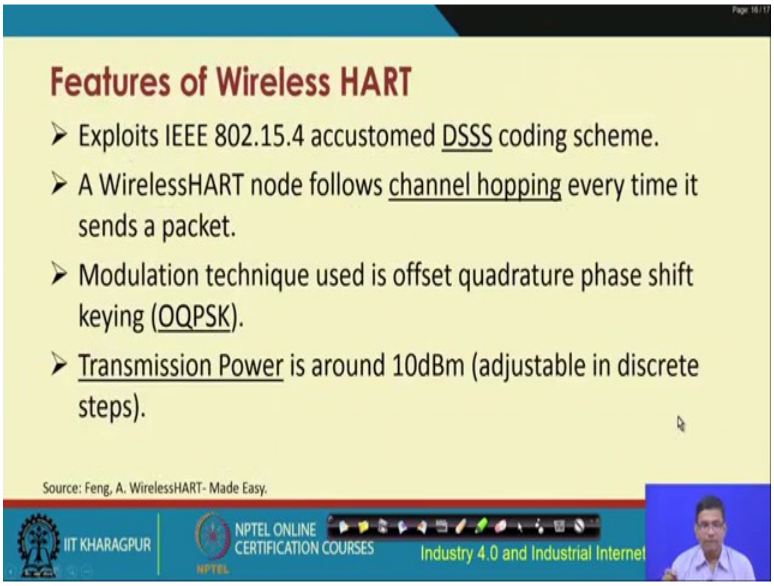


These features of wireless HART is it uses DSSS based on IEEE 802.15.4. Wireless HART protocol follows the channel hopping every time it sends a packet. And, the modulation scheme is used is the OQPSK offset quadrature phase shift keying and the transmission power is around 10 dBm.

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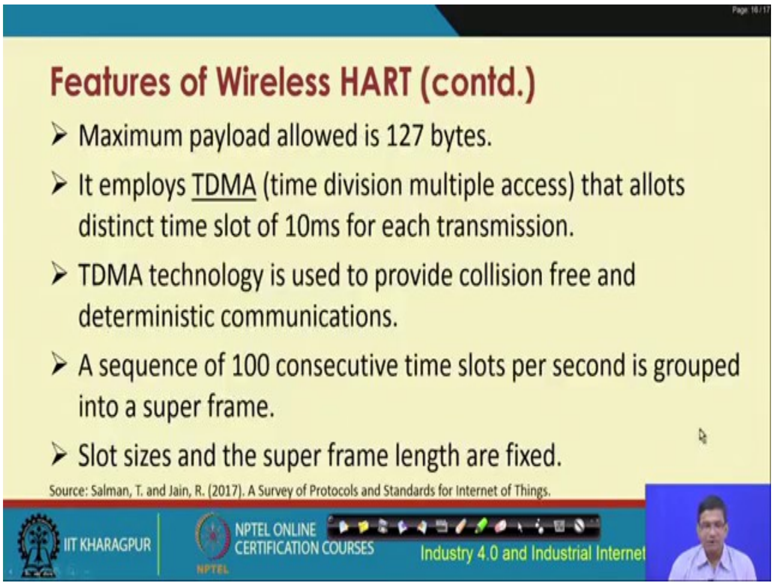


There are other features such as the payload size that is allowed is 127 bytes. The MAC protocol used is TDMA. This TDMA technology is used to provide collision free and deterministic communication. There are different time slots in which the communication takes place, so, there is no collision. A sequence of 100 consecutive time slots per second is grouped into something known as the super frame. This super frame concept is very important.

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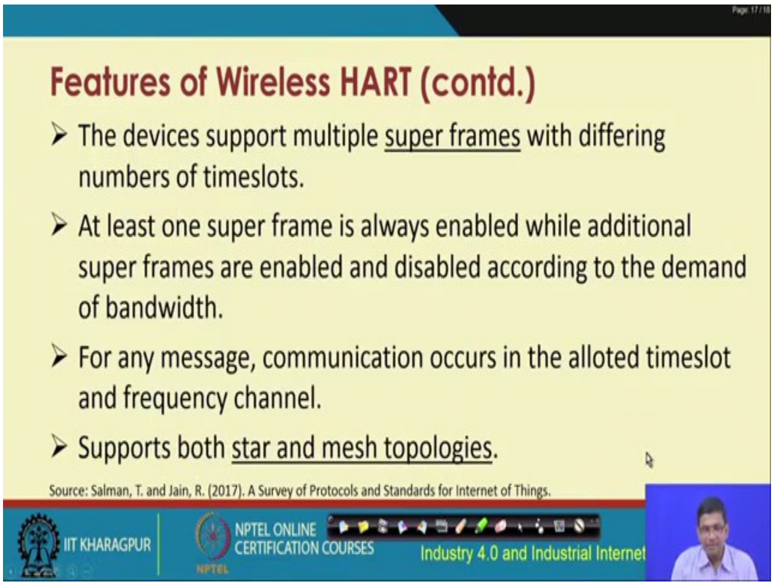


The devices support multiple super frames which will have differing number of time slots. At least once per frame is always enabled while additional super frames are enabled and disabled according to the demand of the bandwidth. For any message the communication occurs in the allotted time slot. So, wireless HART basically supports both star and mesh topologies.

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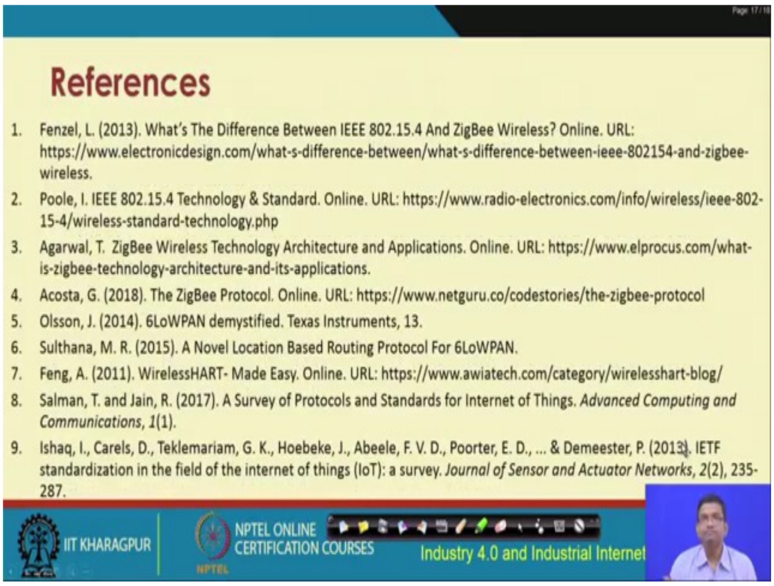

These are the some of these features of the wireless HART and as we have seen industrial applications are the ones where wireless HART is very attractive for use. It is based on IEEE 802.15.4 standard. And, it is a very attractive protocol for industrial applications. If you want to know further about wireless HART and the other protocols and the standard 802.15.4 in more detail, these are some of the references.

This lecture introduces you to only these protocols, but if you need to know this kind of understanding will be sufficient for you to go ahead with the further lectures. But, in case you need to go ahead these are some of these references that are listed which you can go through in further detail and gain even more in depth, an understanding if you require to.

Thank you.

**Introduction to Industry 4.0 and Industrial Internet of Things**
**Prof. Sudip Misra**
**Department of Computer Science and Engineering**
**Indian Institute of Technology, Kharagpur**

**Lecture – 03**
**Introduction: IoT Connectivity – Part II**

We have gone through the IEEE 802.15.4 standard in the previous lecture and the different protocols that are based on this particular standard like ZigBee and wireless heart ZigBee.

In this particular lecture we look at one of the very popular technology, basically the Z-wave. The protocol is useful particularly, for home automation application, home automation application, and security systems.

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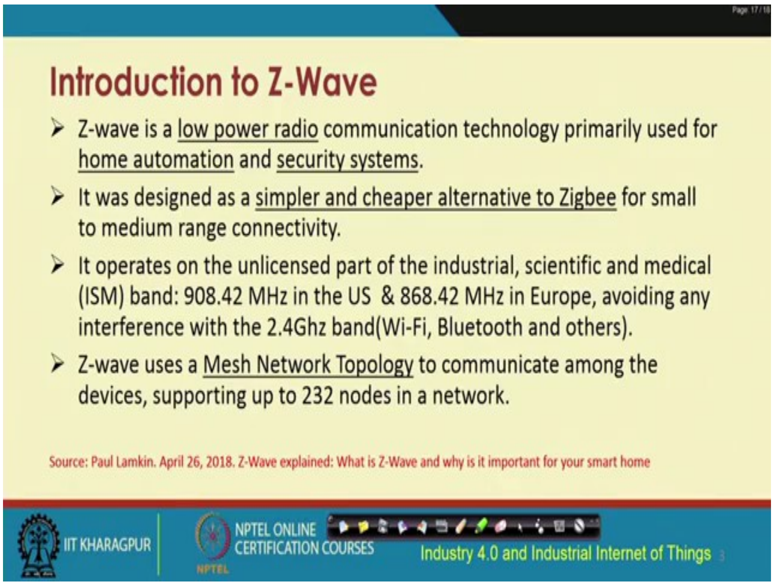


IEEE 802.15.4 are based on the communication technologies which require low power, which have low power, radio communication requirements. Home automation nowadays is very important to build home automation kind of applications. Even for industrial applications, you might be able to find the usefulness of using this particular technology.

Unlike, ZigBee, Z-wave is simpler and cheaper, used for small and medium range applications. Z-wave operates in the ISM band like in the US, it is specifically the 908.42 megahertz band, in Europe it is 868.42 megahertz band and it avoids any interference with the 2.4 Gigahertz band that is used by Wi-Fi, Bluetooth and different other protocols and standards.

Z-wave uses a mesh network topology to communicate among the devices, supports up to 232 nodes in a network. This is quite sufficient for home automation application, even for industrial applications Z-wave supports about 232 nodes. So, let us look at how Z-wave works.

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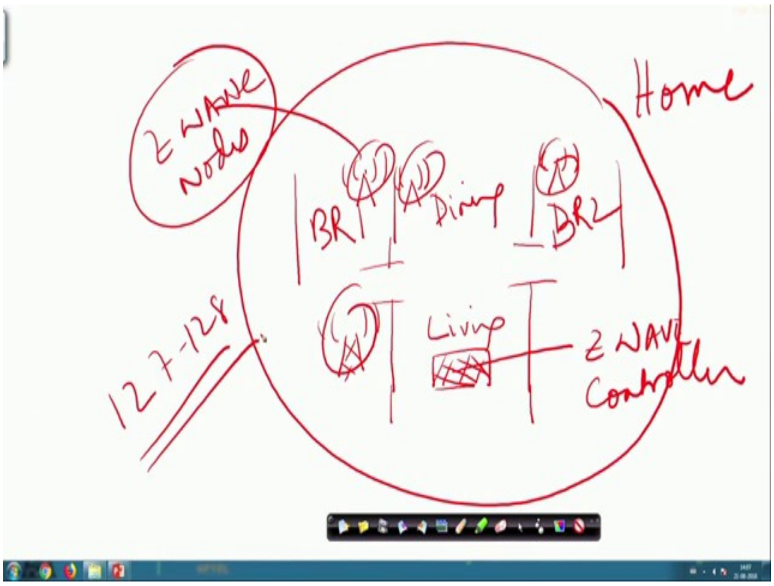


Let us say, we are talking about some kind of a home with a living room, two bedrooms, and a dining room. In home automation, using Z-wave you can install something known as the Z-wave controller device, which can be a single controller device in the entire home. And there could be different Z-wave compliant communication devices in the different rooms. So, these are like Z-wave communication devices or the Z-wave nodes commonly known as Z-wave nodes. Therefore, one Z-wave controller in the entire home and multiple such Z-wave nodes in the different rooms, and up to about 127 or 128 Z-wave nodes can be connected using a single controller.

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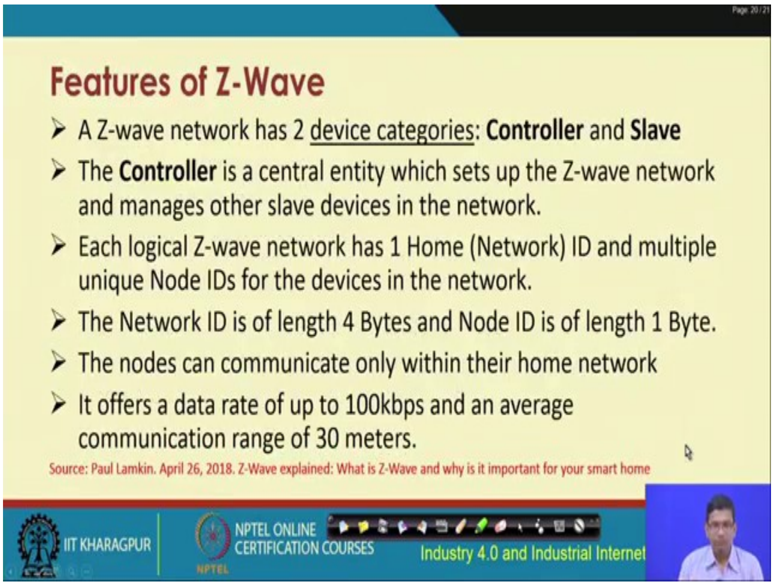


There is the controller node and the slave node. The controller is a central entity which sets up the Z-wave network and manages other slave devices, the Z-wave nodes, in the network. Each logical Z-wave network has one home ID, the network ID, and multiple unique node IDs corresponding to the slave devices in the network.

The network ID is of length 4 bytes and each of these node IDs will be a length of 1 byte. The nodes can communicate only within their home network and the data rate that is supported is up to about 30 meters. The data rate is offered is up to about 100 kbps. 100 kbps in a range of 30 meters is good enough for home automation applications, small industrial applications. So, that is why Z-wave is a very popular technology. It is low cost, simpler technology compared to ZigBee and can be used to support different home and industrial automation applications.

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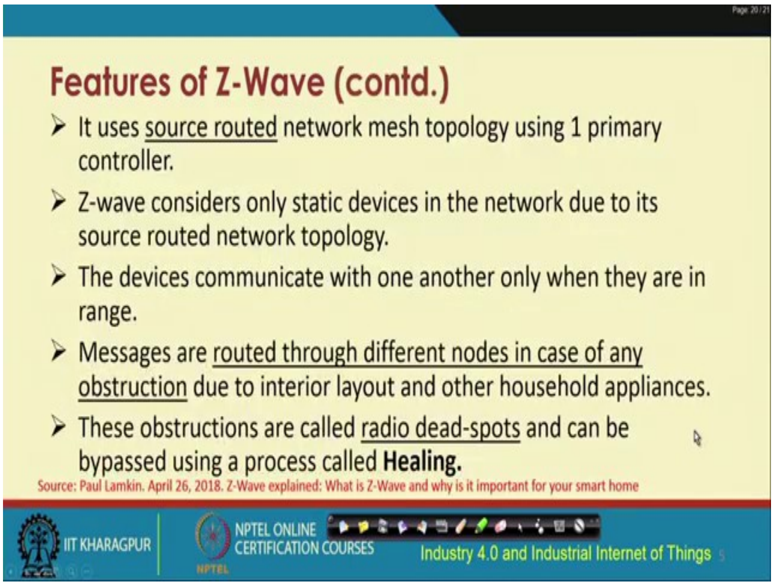


The routing scheme used is source routing. Source routing means a source node sends, determines the route in the network and then sends the packet from the source node to the entire network using the routes.

Z-wave considers only static devices in the network due to its source routed network topology. So, messages are routed through different nodes in Z-wave, in case of any obstruction, due to the interior layout and other household appliances. These obstructions are known as radio dead spots, and these can be bypassed using a process in Z-wave which is known as healing.

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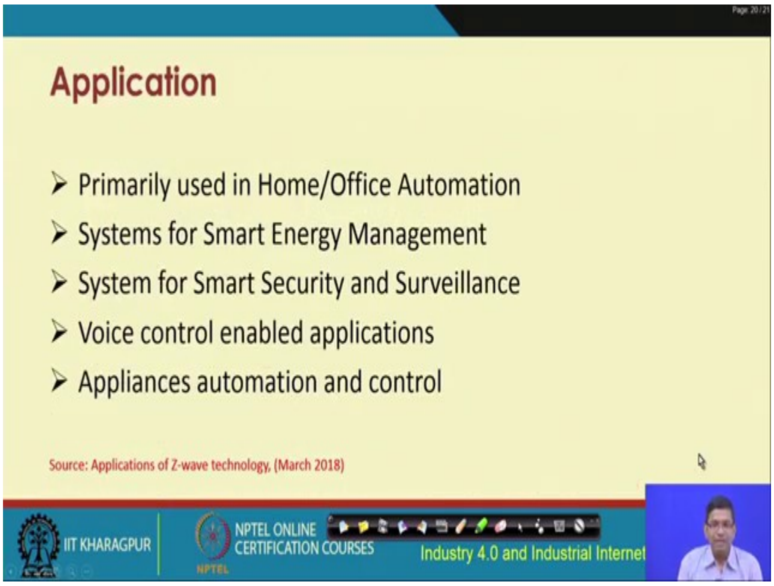


Applications where it can be used are home and office automation applications, smart energy management applications, home security, industrial security, industrial surveillance applications, voice control enabled applications, and appliance automation and control.

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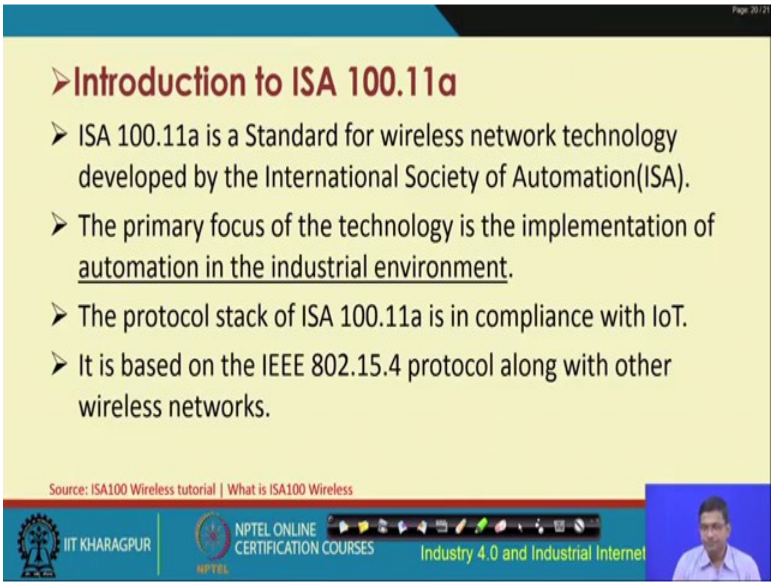


Now, let us look at another very interesting and popular standard which is known as the ISA 100.11a, which belongs to the ISA 100.11 series. This is used for wireless network technology and was developed by international society for automation. So, this standard primarily focuses on automation in industrial environments and obviously, this standard is based on 802.15.4.

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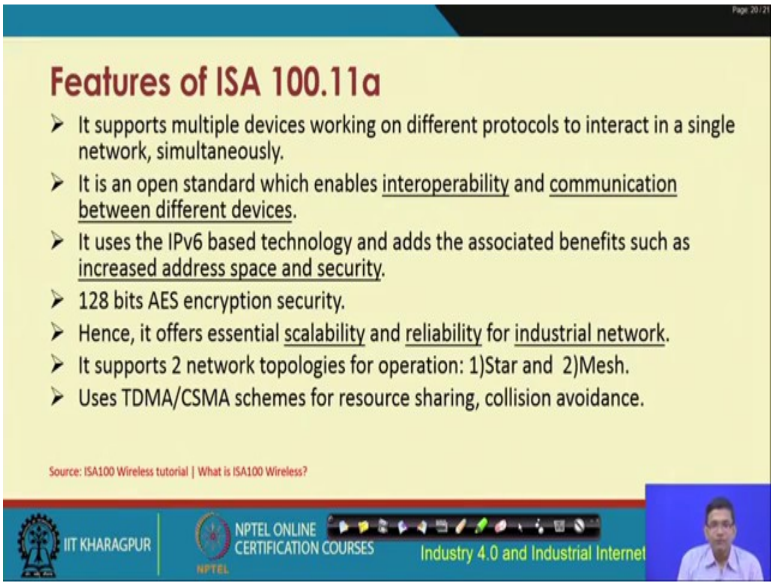


Some of the features of 100.11a ISA standard are listed in the slides. The first one is that it supports multiple devices working on different protocols to interact in a single network simultaneously. A good protocol for supporting interoperability and communication between different agents and devices. It uses the IPv6 based technology and adds the associated benefits such as increased address space and security. The encryption scheme that is used is AES encryption for offering security over 128 bits. Because of the different features of this technology is good for use in industrial of applications, it supports scalable and reliable solutions.

The kind of network topologies that are supported are star and mesh. The MAC protocols used are TDMA or CSMA/CA based MAC protocol.

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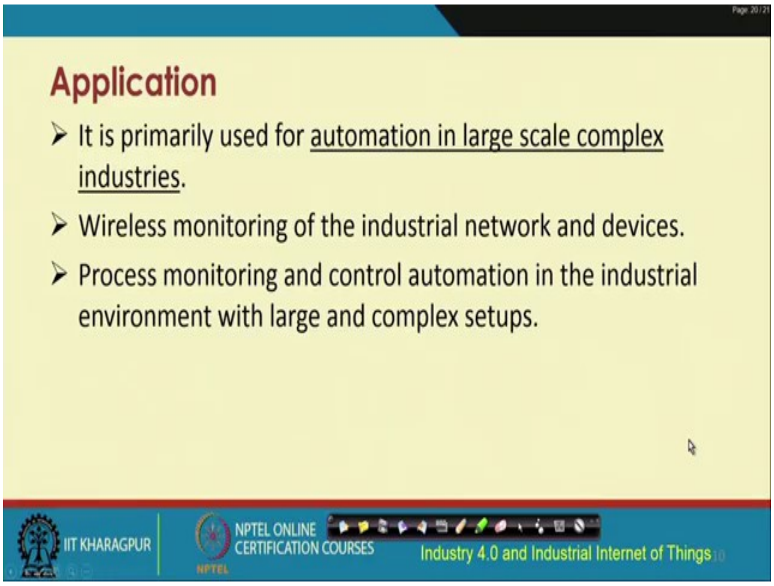


So, applications are automation in large scale complex industries, wireless monitoring of industrial networks and devices, process monitoring and control automation in the industrial environments with large and complex setups.

Now, let us come to another very interesting popular technology for implementing IoT which is the Bluetooth.

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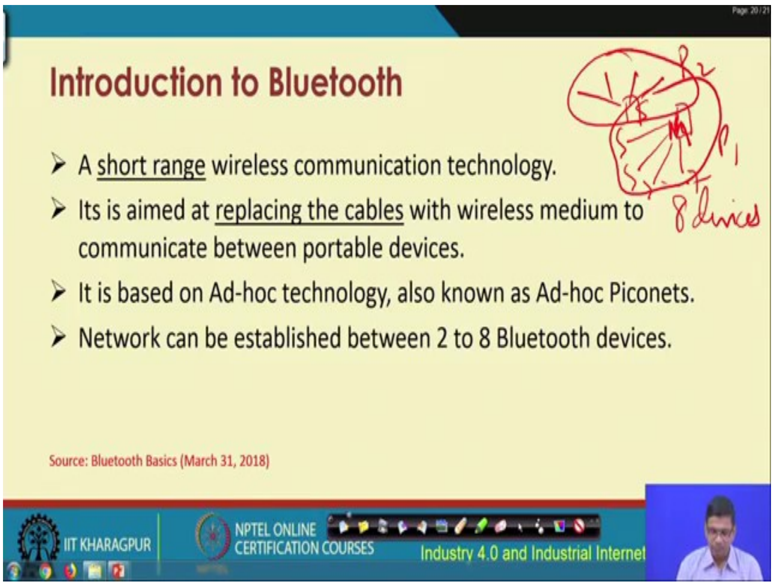

Bluetooth is used for setting up wireless network of different peripherals of a particular computer, headphones, and mobile phones. Bluetooth is a widely used technology which can help in setting up IoT based networks and network systems.

Bluetooth technology offers wireless communication in short range. Unlike ZigBee, which we discussed earlier, is good for medium range communication. However, ZigBee does not offer good data rates. On the contrary, Bluetooth offers better data rates much more improved data rates compared to ZigBee. So, there is a tradeoff.

Bluetooth is particularly aimed at replacing the cables. So, there is a cable replacement protocol which I am not going through over here. If you look at the Bluetooth protocol stack, you will see that there is a cable replacement protocol that is supported by Bluetooth. So, this cable replacement protocol will help for communication between these different wireless portable devices. Bluetooth helps in forming Ad-hoc networks where there is no centralized controller. The devices can connect with each other in short range using this Bluetooth technology.

There is a concept of Piconet, called scatter nets. In a particular Piconet, like this, a very similar to the cells in a cellular network, are present within. In a Piconet, there are master and up to about 7 devices. Within a Piconet 8 devices can be supported. There are different slave devices, up to 7 devices can be connected to the master.

For example, Piconet 1, Piconet 2, can have different Piconets, all of which are interconnected together. So, this forms the scatter net.

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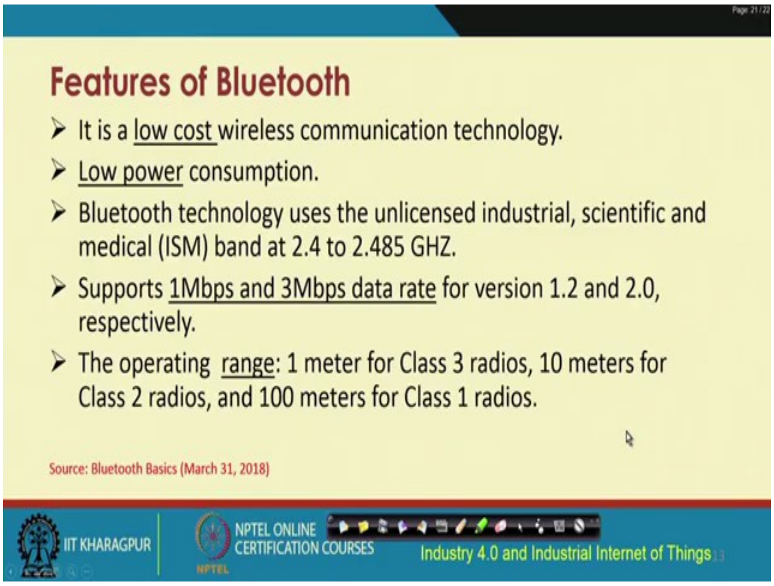


Bluetooth offers low cost wireless communication, low power consumption. Because of the lower power consumption, Bluetooth is attractive among IoT applications, which are typically power starved, energy starved. It is used in the ISM 2.4 to 2.484 gigahertz, 2.4 to 2.484 gigahertz band.

It supports data rate of between 1 Mbps to 3 Mbps depending on the version of the Bluetooth that is used. 1 Mbps in the version 1.2, 2 Mbps for version 2, and 3 Mbps. The operating range is 1 meter for class 3 radios, 10 meters for class 2 radios and 100 meters for class 1 radios. Therefore, different radios will give different communication range of Bluetooth.

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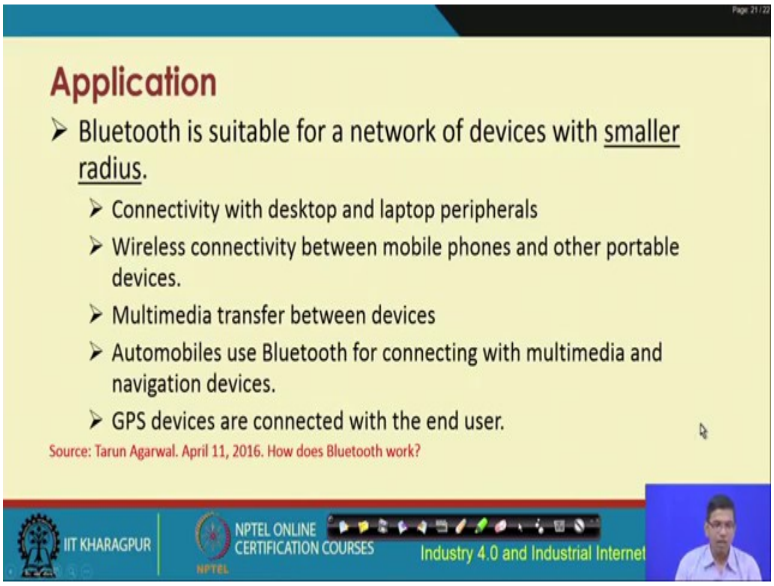


Application where Bluetooth is suitable for use are networks or devices which will have smaller radius of communication range. Therefore, connectivity with desktop and laptop peripherals can be supported with the help of Bluetooth. Multimedia transfer between devices is also a very attractive and widely used application of Bluetooth. Automobiles will use Bluetooth for connecting with the multimedia and navigation devices, GPS devices, are connected with the end user.

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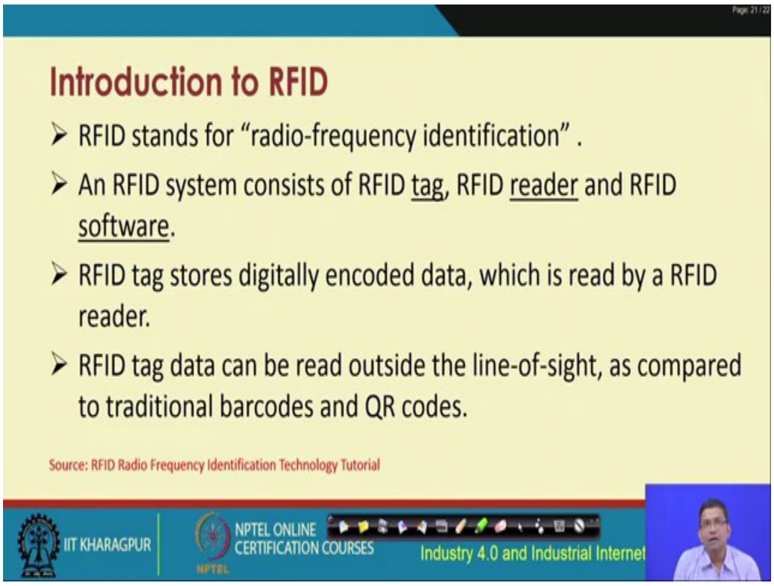

RFIDs are very attractive, popularly used. RFID tags are also used in shopping malls. For example, RFID tags are attached to different items such as clothing, other items on sale in the shopping malls. RFID reader can read from these RFID tags. This is how the RFID works. RFID stands basically for radio frequency identification. There are 3 components, one is the tag itself - the RFID tag attached to different things, RFID reader which can read from the tag, and the RFID software which will power this entire thing to operate. RFID tag stores digitally encoded data which is read by RFID reader. RFID tag data can be read outside the line of sight as compared to the traditional bar codes or the QR codes that are frequently used.

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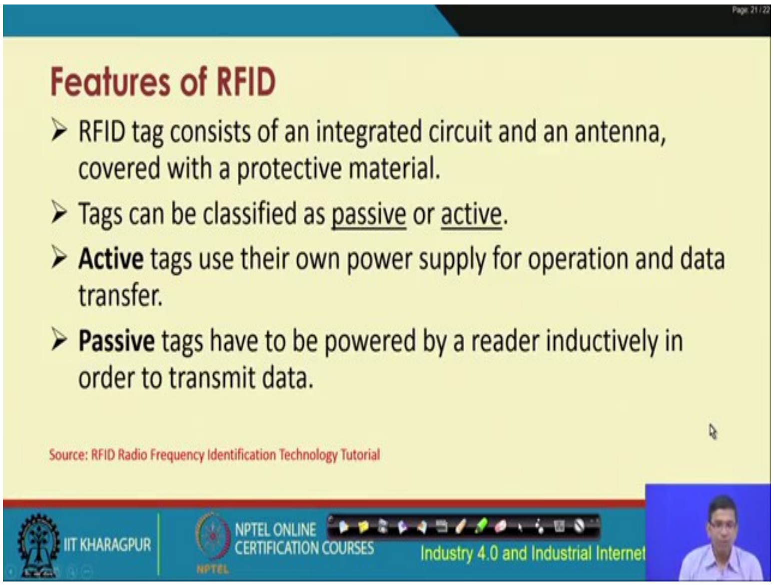


RFID tag consists of integrated circuit and an antenna, which are covered with a protective material. RFID tags can be classified as passive tags or active tags. Active tags are the ones which has their own power supply for operation and data transfer. Passive tags are the ones which do not have so and these will have to be powered inductively in order to transmit data.

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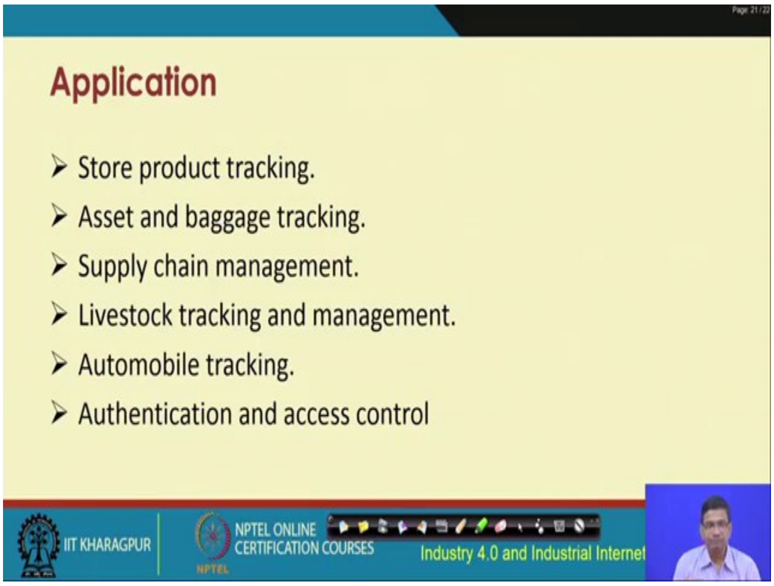


Applications of use of RFIDs are-storing, product tracking, store product tracking, asset and baggage tracking, supply chain management, livestock tracking and management, auto mobile tracking authentication and access control.

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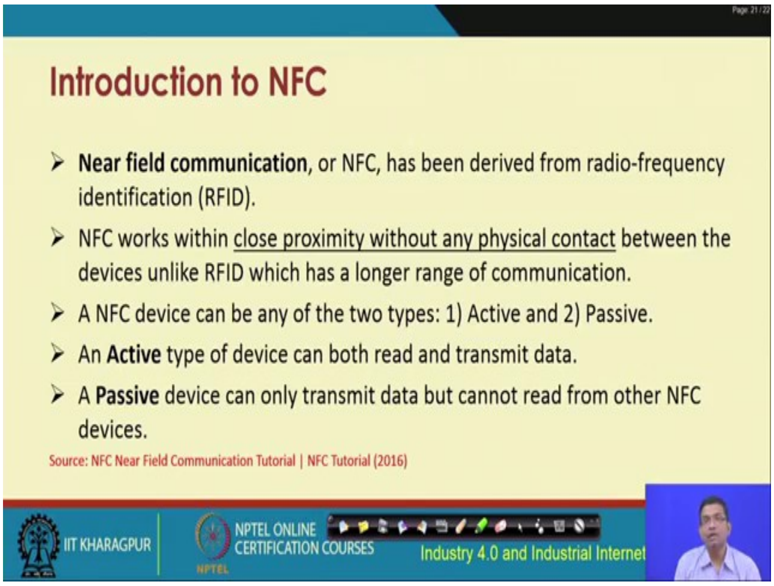


NFC technology also work very similarly, but has a difference. This NFC technology has been derived from the RFIDs. The NFCs unlike RFIDs will work within close proximity, with any physical, without any physical contact between the devices. RFID reader and the tag can keep little bit separated, but NFC devices will have to be kept in very close proximity.

NFC device can be of two types-active device or passive device. An active type of device can both read and transmit data, and a passive device can only transmit data, but cannot read from the NFC devices. So, this is the difference between the active and passive device concepts.

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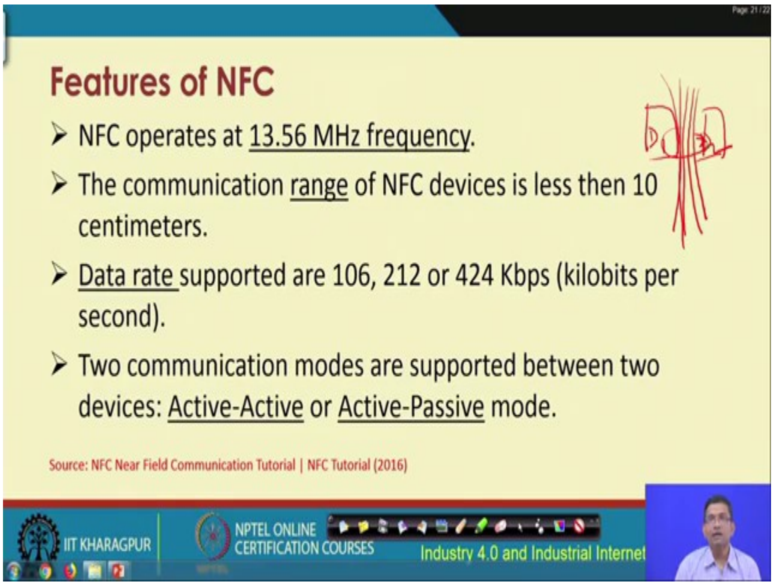


NFC operates in the 13.56 MHz frequency band, and the range of communication in NFC is less than 10 cms. Let us say, that you have in one of these devices D1 NFC device, you have another device, D2. The magnetic field will be generated, thus, D1 and D2 are kept close to each other, less than 10 centimeters apart.

NFC supports various data rates, 106, 212 or 424 kbps. The two communication modes supported between two devices, one is the active-active and the other one is the active-passive mode.

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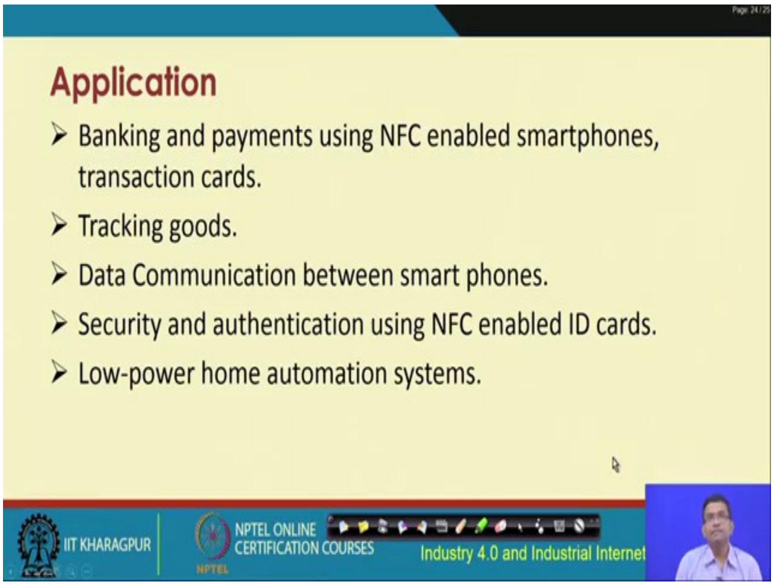


Applications of NFCs are very similar to RFIDs tracking of goods, banking sector, NFC enabled smartphones, data communication between smartphones using NFC, security and authentication, and low power home automation systems.

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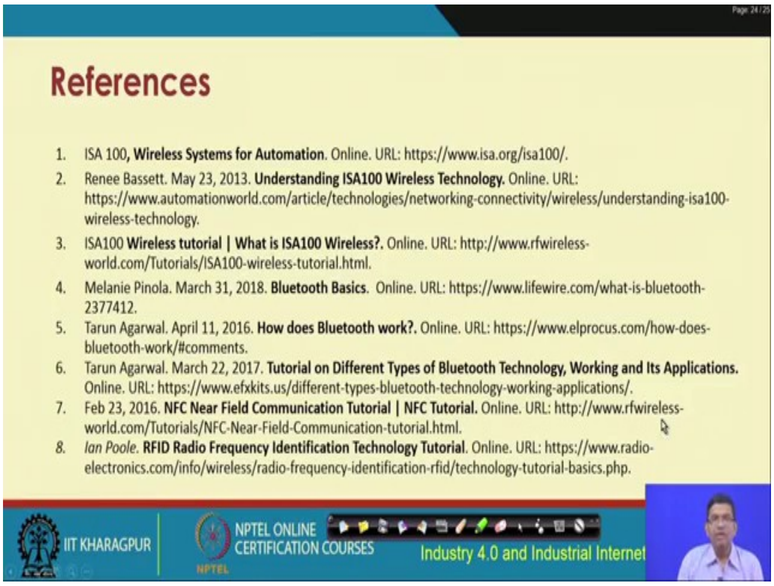


So, with this we come to an end of this thing. We have gone through different connectivity technologies in the previous lecture and this one it started with going through the standard IEEE 802.15.4. Then we discussed about ZigBee, Z-wave, ISA, RFID, NFC and Wireless Hart also.

These are some of these references that you can go through further in more detail. So, with this we come to an end.

Thank you.

**Introduction to Industry 4.0 and Industrial Internet of Things**
**Prof. Sudip Misra**
**Department of Computer Science and Engineering**
**Indian Institute of Technology, Kharagpur**

**Lecture – 04**
**Introduction: IoT Networking - Part I**

In this lecture, we are going to discuss the networking issues in IoT. In the previous lectures, we looked at the connectivity issues, what are the challenges, what are the solutions, that are available.

From a networking point of view, we will look at the different other aspects of setting up IoT systems, what are the solutions again that are there, in order to address.

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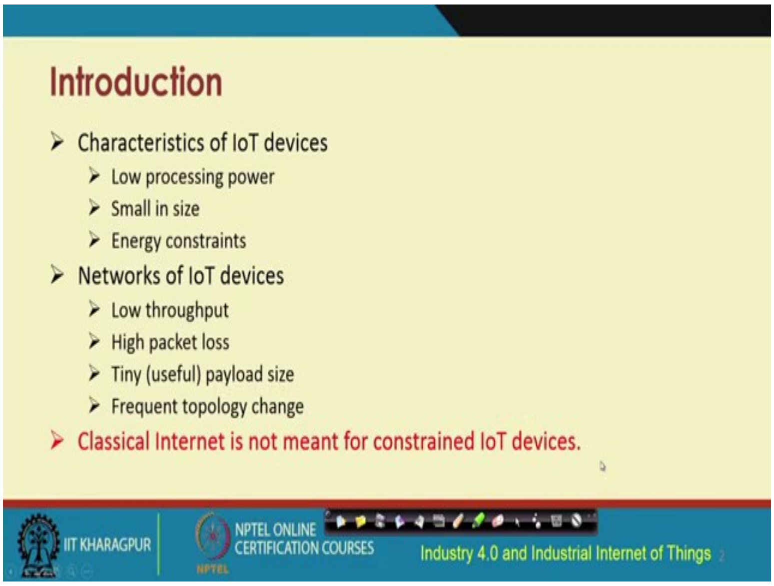


The typical network, that is encountered, consists of a source, a data source or multiple data sources consisting of sensors, typically sensors, RFIDs, which collect data and interact with the physical environment, and then the data is sent elsewhere for further processing. Based on the processing the data is analyzed.

Some system would be actuated; it may or may not be actuated or there may not be any actuation associated with the system at all. We have seen both of these types in the previous lectures.

From a network point of view, how to set up the network let us try to understand. These IoT devices will have very low processing power. They are very small in size, energy constraints, typically, battery operated. Because of the small size, the batteries that are used are also small. And due to the electrochemical limitation of the batteries; these batteries will have a very limited lifetime. So, you need to have solutions at the hardware, software, and algorithmic level, which will consume very low power.

From a network point of view, specifically, we need systems, protocols, solutions, algorithms, which will consume extremely low energy. IoT devices are energy constraint; they are small in size, and have very limited processing power. So, network protocols that are designed for use in IoT should be designed accordingly keeping these constraints in mind.

These networks typically support very low throughput; they have high packet loss. These networks typically operate in environments which are very much noisy, there are a lot of interferences, consequently the packet loss is also high. And they have small, useful payload size and in most cases, these networks also exhibit the behavior of frequent changes in their topology. Therefore, it is a highly constraint dynamic kind of scenario and coming up with networking solutions is a huge challenge in these in these systems. So, classical internet that is based on TCP/IP; the classical internet that we all use is not meant for these constraint IoT devices.

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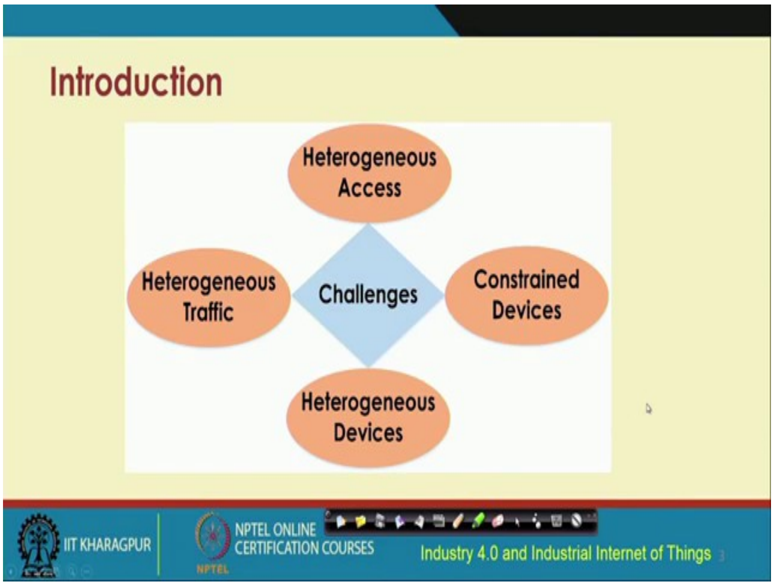

From a holistic viewpoint, the challenges can be classified into different types. We have challenges with respect to access; there is heterogeneous access, heterogeneous traffic flowing through these networks. There is heterogeneity in the devices, vendors, specifications, standards, protocols, that are used by these devices working in the networks. In all respects these are constraints.

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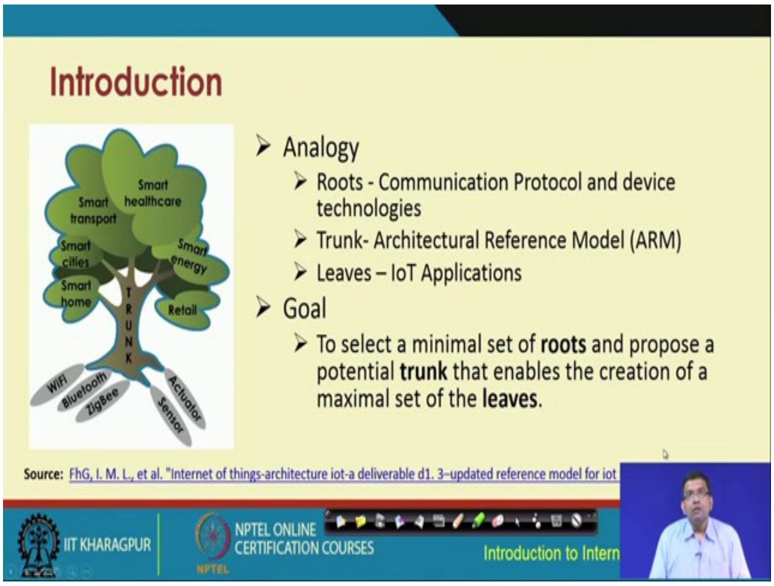


To think about IoT; let us think about let us you know think about a tree. So, this analogy has been taken from the source that is given on the slide. The tree has the roots, trunk, and leaves. The different IoT applications like smart health care, smart transportation, smart cities, smart energy, smart retail, smart home, smart cities overall. All these smart things that we talk about in the context of IoT are analogous to the leaves of a tree.

At the very bottom of the tree are these roots; these roots are like communication protocols and device technologies. So, these protocols and device technologies are sort of like the roots of the tree; technologies such as Bluetooth, ZigBee, Z-Wave, Wi-Fi, sensors, and actuators are the different roots of the tree.

Considering the IoT applications, on the very top and the roots like the technologies, protocols that I just mentioned; the objective is to come up with a suitable trunk that will support these applications and we will connect with the roots of the tree. The trunk is basically the architectural reference model of IoT, the arm model of IoT. So, overall from a optimization kind of viewpoint; the goal can be stated that we need to select a minimum set of roots and propose a potential trunk that enables the creation of maximum set of leaves. This can be thought of like the overall objective; the optimization objective.

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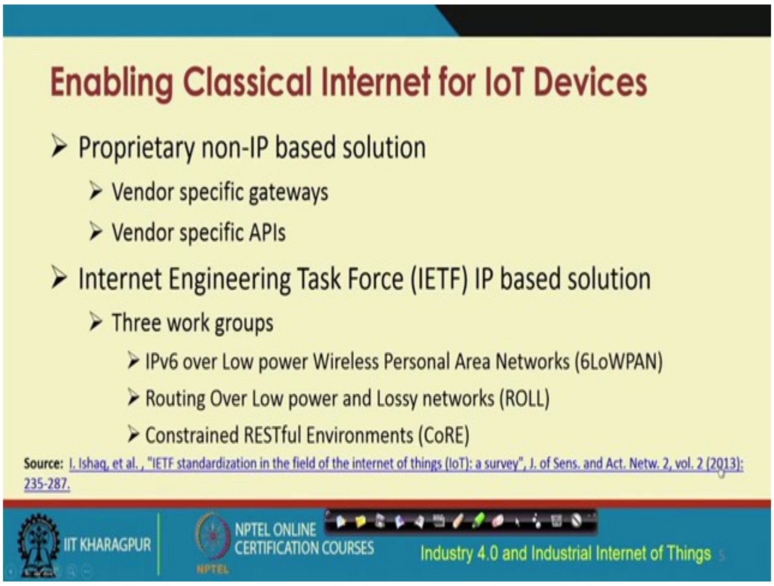


IoT offers non-IP based proprietary, remains like vendor specific solutions or we can think of using the IP based solutions, based on the IETF protocols. On the contrary, IETF IP based solutions; where there are different initiatives to support IoT like; the 6LoWPAN; which talks about IPv6 over LoWPAN, which is low power wireless personal area network.

So, IPv6 over 6LoWPAN is one such technology; one such protocol, which is being worked upon by a specific 6LoWPAN working group. Likewise, there are other working groups talking about the adaptation of IoT requirements to the internet.

ROLL is basically routing over low power lossy networks. CoRE is constraint restful environments. 3 different working groups are there, like this there are multiple different initiatives in order to have support of IoT over IP; that means, the existing internet.

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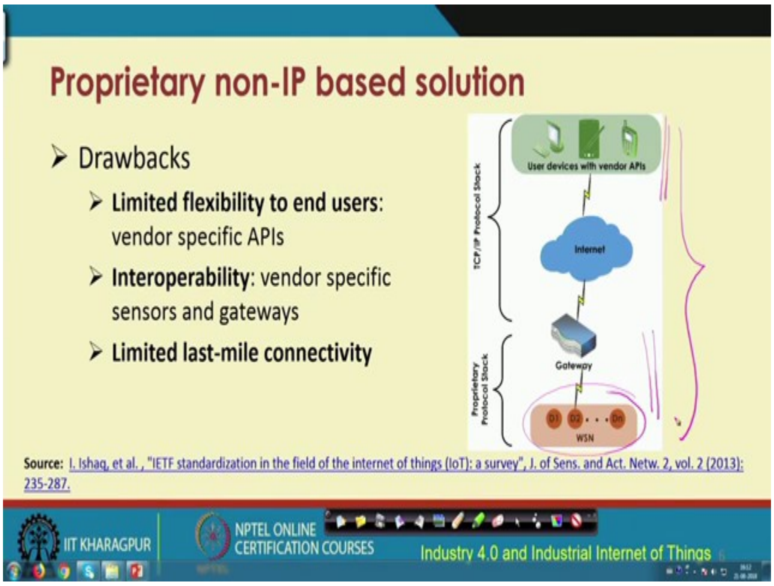


Different sensor systems could be using proprietary solutions, proprietary protocol stack. On the other side, different devices such as laptops, desktops, then these PDAs and many others, which typically in the existing framework use the existing TCP/IP protocol stack of the internet.

We need to come up with a solution which can fit these proprietary solutions to the existing framework of the internet; which is supporting laptops, PDAs and different other wireless devices. This is holistic framework that we are talking about, but the drawback of this non-IP based solutions is limited flexibility to end users. These are vendor specific API's, so there is limited flexibility to the end users.

In terms of interoperability there are vendor-specific sensors; vendor-specific gateways. You know it is like some sensor nodes, some IoT devices pick one vendor specific language. Let us say, that somebody speaks English, somebody speaks French, somebody speaks Hindi; how they can talk to each other? There is no common language, there is no interoperability between them.

So, in order to conquer this kind of heterogeneity; you need to have a common framework which will make these disparate devices follow different proprietary standards talk to each other. Interoperability is this issue which talks about conquering this challenge of heterogeneity in all different respects.

Because these are not models which are supposed to scale up; so that the scalability can be maintained. There it is a IP scalable solution; unlike this proprietary vendor specific solutions, which are non-scalable.

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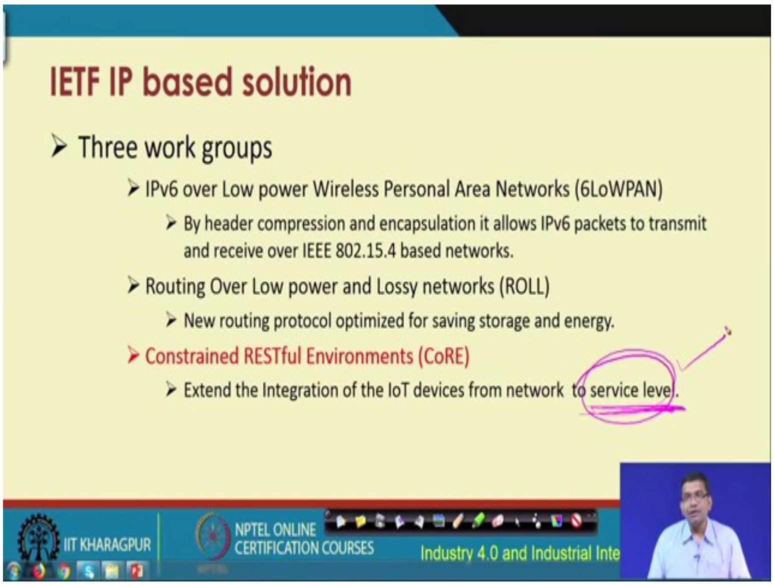


So, we have different IP-based solutions as well typically follow different initiatives by IETF, 6LoWPAN, ROLL and CoRE are 3 different important ones.

IPv6 talks about header compression encapsulation, these in order to allow the IPv6 packets from the network layer to be transmitted over IEEE 802.15.4 based networks. ROLL is a new kind of routing protocol that can be used that can be used for IoT-based applications.

Constrained RESTful Environment extends the integration of IoT devices from networks to the service level. And this is very essential, it is a important thing, service level; typically about the networks, collecting data from these networks in the context of IoT. CoRE is very crucial and an attraction in the IoT community.

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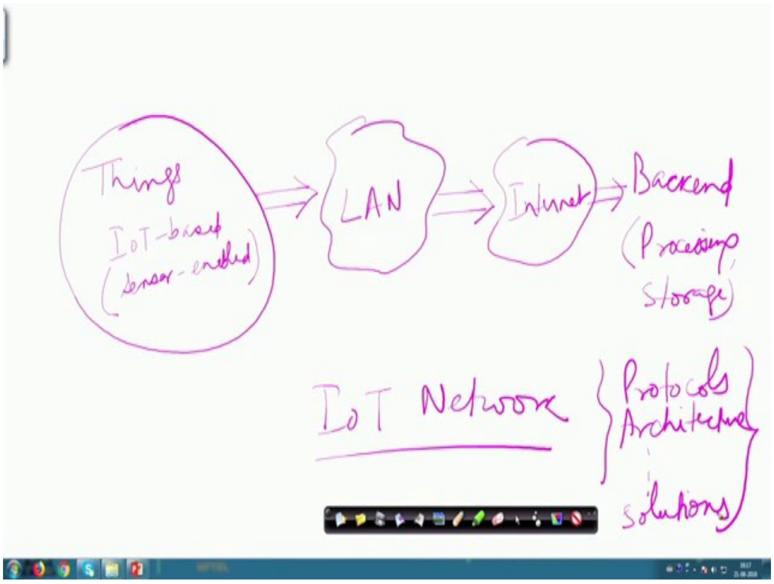


We have different IoT devices, which are the things. And these things are sensor enabled, sensor based, these are IoT-based.

IoT-based things are sensor enabled; this data are collected from these things, which are fitted with different sensors, these will transmit that collected data through something like a local area network; data further through the internet to the back end. The back end will would have all kinds of processors like servers; you will have storage devices including cloud etc. In the modern context; cloud-based services for processing storage.

This is the network and the corresponding protocols, architecture, and other aspects of solutions that we need to understand in considerable detail. So, here in this lecture we are simply introducing you about the overall concept of the networking aspects.

There are different IETF initiatives on supporting IoT over existing internet. Let us talk about the CoRE, which is Constrained RESTful Environments. REST is  an acronym.

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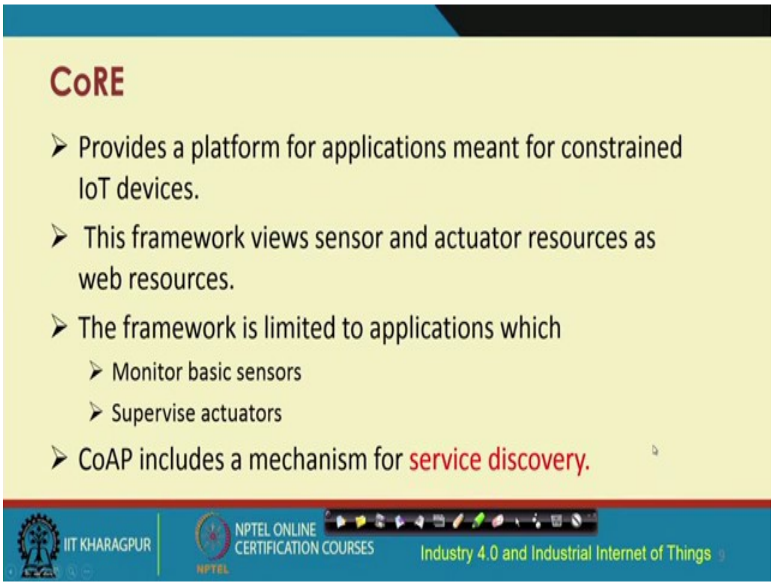


CoRE provides a platform for applications meant for constrained IoT devices and useful for IoT environments. This framework views sensors and actuator resources and web resources. The framework is limited to applications, which monitor basic sensors and supervise the actuators. CoAP includes a mechanism for service discovery and this service discovery makes it very interesting.

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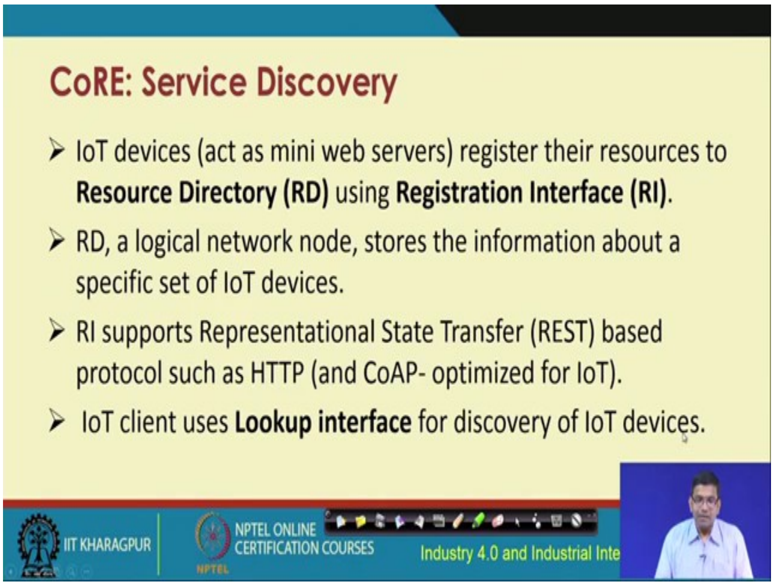


CoRE devices are mini web servers that register their resources to the resource directory and registration interface.

Resource directory is a logical network node that stores the information about a specific set of IoT devices. In any logical IoT node storing the information about a set of IoT devices. The registration interface, on the other hand, supports the REST-based protocol. The full form of REST architecture is REpresentational State Transfer architecture which support protocols such as http for the existing internet. For IoT, the equivalent of REST which is the CoAP; we will talk about in a little bit, further detail.

IoT client uses the lookup interface for discovery of IoT devices. Now everything is fine network has been built, but then whether the network is able to offer the quality of service guarantees or at least some acceptable levels of quality of service.

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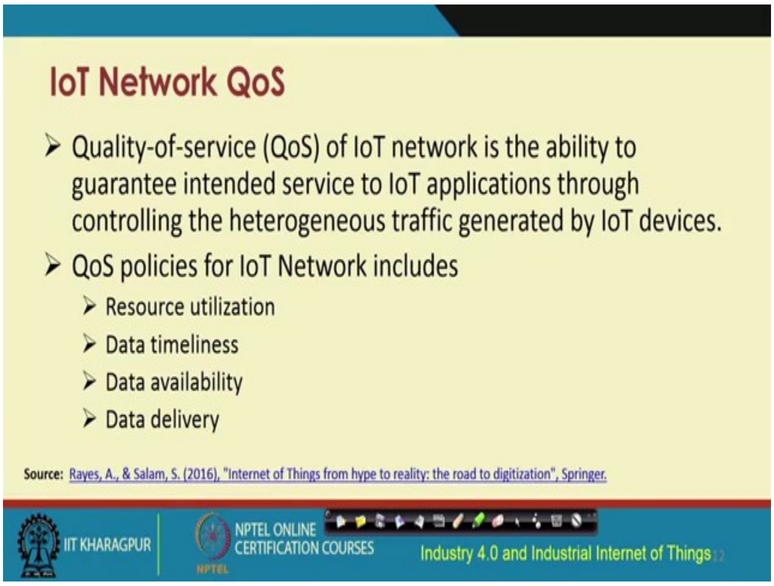


Quality of service of IoT network talks about offering different surfaces to the IoT applications through controlling the heterogeneous traffic generated by IoT devices.

QoS policies for IoT networks includes resource utilization, data timeliness, data availability, and data delivery. These are the 4 different attributes which are of prime consideration, in the context of QoS and ensuring QoS for IoT networks.

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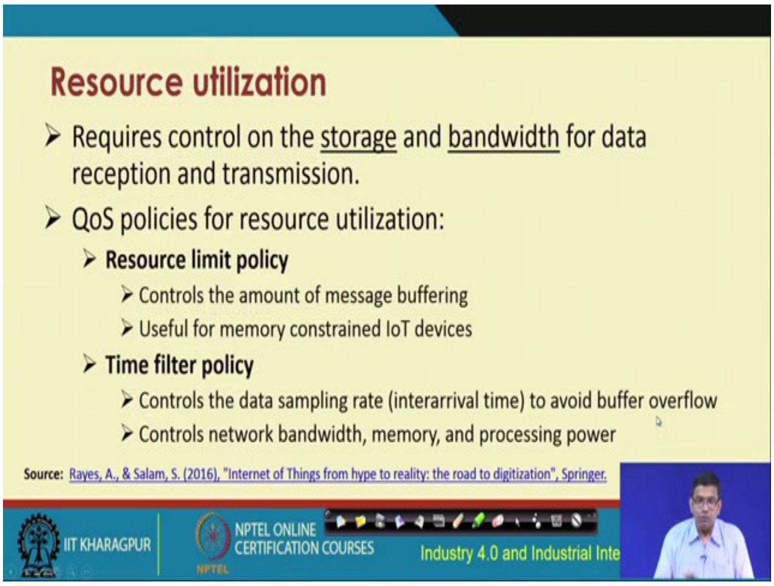


Resource utilization is the first among the 4. It talks about the concept of control on the storage and bandwidth for data reception and transmission.

Resources in the context of networks mean different things such as storage, bandwidth etc. The control over these resources such as storage and bandwidth for reception and transmission is something that has to be considered as a QoS criterion.

QoS policies for resource utilization include resource limit policy, which controls the amount of message buffering and this is useful for memory constraint IoT devices. The second one is the QoS policy for resource utilization is time filter policy, which controls the data sampling rate and talks about the inter arrival time to avoid buffer overflow. These talks about the control over the network bandwidth memory and processing power.

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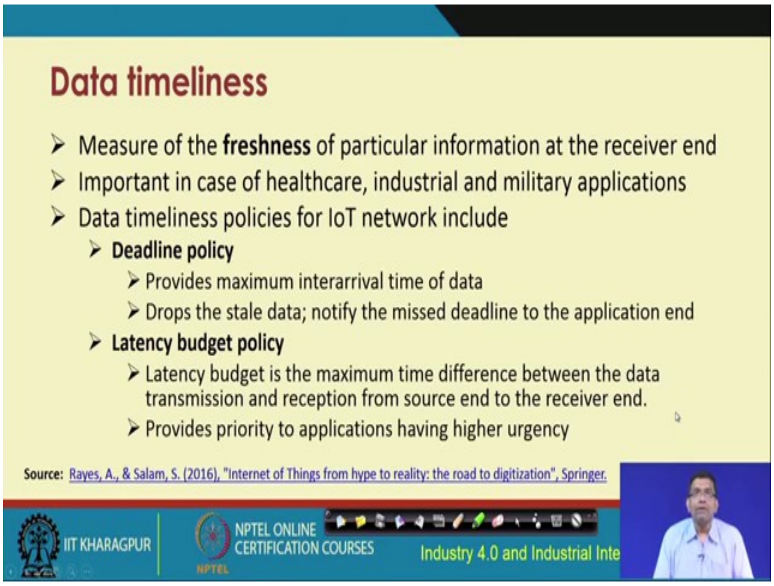


Timeliness the second attribute is the measurement of the freshness of a particular information; when it is received at the receiver end. From the source, the data that is sensed is sent at the receiver it is received, but then when it is received at the receiver, how much fresh that data is? And this is a very important consideration particularly for applications, where safety criticality, where there is real time requirements.

For example, healthcare the patient having heart attack. QoS criterion measure whether the data that is received at the receiver end. May be somebody having a heart attack; the packet containing that information whether that is fresh enough, whether the data has been received timely or not. This is a very important consideration in many of these applications.

Data timeliness policies for IoT networks include the deadline policy; that means, the maximum inter arrival time of data; how much is the maximum inter arrival time? This is a very important policy reconsideration. The second policy consideration is the latency budget policy consideration; which is the maximum time difference between the data transmission and reception from source end to the receiver end. So, these are the two different considerations for data timeliness.

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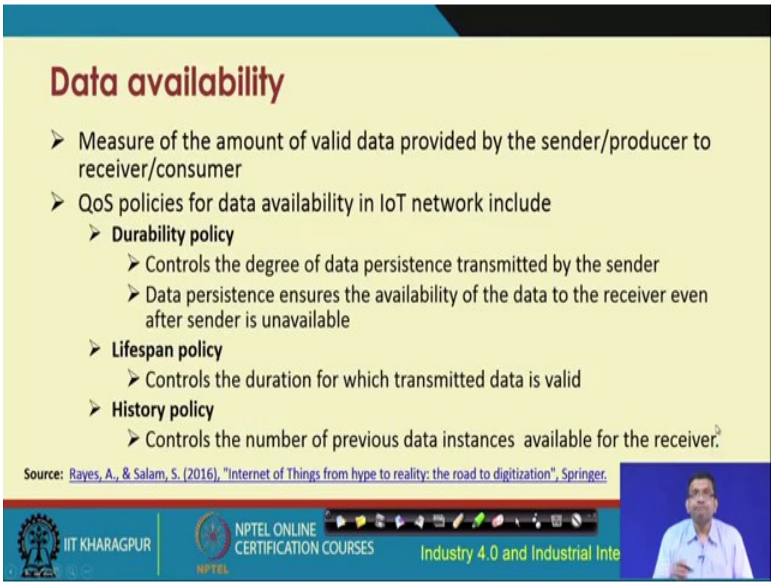


The next attribute is the data availability, as this name suggests, is a measurement of the amount of valid data, provided by the sender or the producer to the receiver or the consumer. QoS policies for data availability in IoT networks include durability policy, life span policy, and history policy. Durability as this English term suggests; is the control of the degree of data persistence transmitted by the sender.

Data persistence is important; that means, ensuring the availability of the data to the receiver even after the sender is unavailable. The persistence of the data at the receiver is a very important durability policy consideration. Lifespan policy talks about the control over the duration for which the transmitted data will be valid. How much the data that has been sensed and is being circulated through the network, how much time it is going to survive, how much time it is going to live? This is a lifespan policy.

History policy is about controlling the number of previous data instances available to the data. In the history of the data, how many such instances are available to the receiver.

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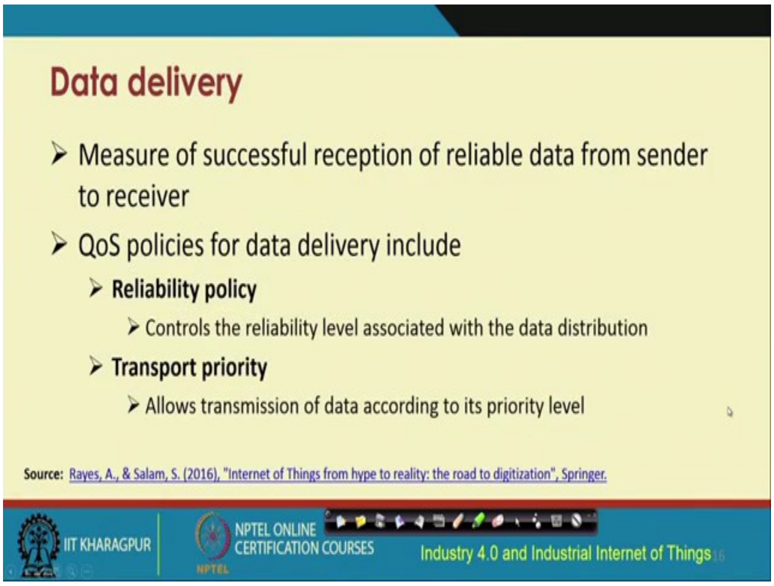


Data delivery is the last one, which measures successful reception of reliable data, from the sender to the receiver. QoS policies for data delivery are the reliability policy, which talks about the control of the reliability level associated with the data distribution and the transport priority. This allows transmission of data according to its priority level.

With this we come to an end of the first part of IoT networks. We will continue with the different other aspects of networking in IoT. And before we talk about those things, in detail, there are a few other issues that also need to be considered and that is what we are going to talk about in the next lecture.

Thank you.

**Introduction to Industry 4.0 and Industrial Internet of Things**
**Prof. Sudip Misra**
**Department of Computer Science and Engineering**
**Indian Institute of Technology, Kharagpur**

**Lecture – 05**
**Introduction: IoT Networking - Part II**

We, now continue our discussions from the previous lecture on IoT Networking and the different issues governing it.

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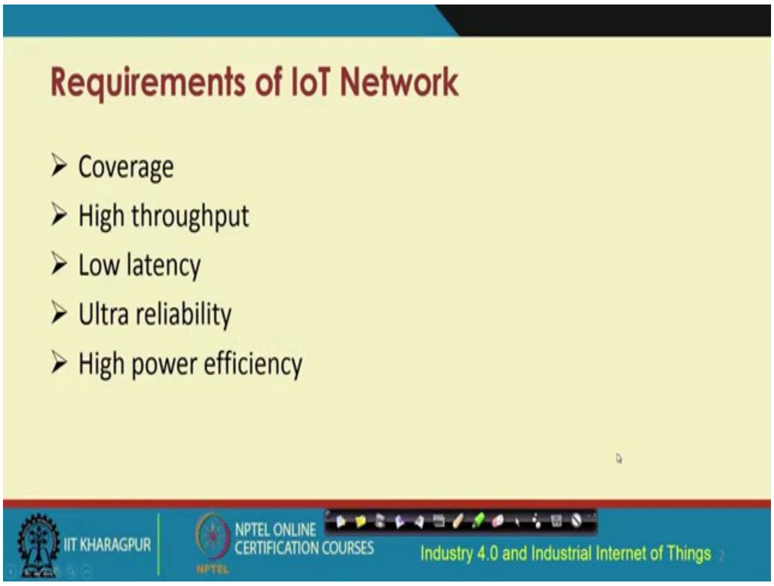


The requirements of IoT networks include coverage, high throughput, low latency, ultra-reliability and high power efficiency. We need to ensure that there is adequate coverage, coverage in terms of the deployment of these sensor nodes. And, then ensure that there is sufficient coverage in terms of sensing, communication throughout the territory of interest where the IoT devices are deployed.

The second thing is throughput that the network supports. Throughput essentially talks about the data rates, high data rates ensures that through the network, typically a lossy network; you have higher throughput, higher data rates can be supported. Then, low latency is very important, you need to have an assurance that from the source to the receiver intended receiver the time that is spent is minimum. But, in most cases IoT networks would have to support real time traffic, where the timeliness of the data as we said previously in the previous lecture is very important. These packets if not received on time, then that data is not going to be useful for supporting the adequate quality of service of the network. The next one is reliability ultra-reliability in the face of lossiness, in the face of interference, noise etc. The next one is high power efficiency, we are talking about low powered nodes, low battery power, highly energy constrained environments. So, it is very essential to ensure that whatever solutions we are talking about from a networking point of view, for IoT networks, these have to be highly power-efficient.

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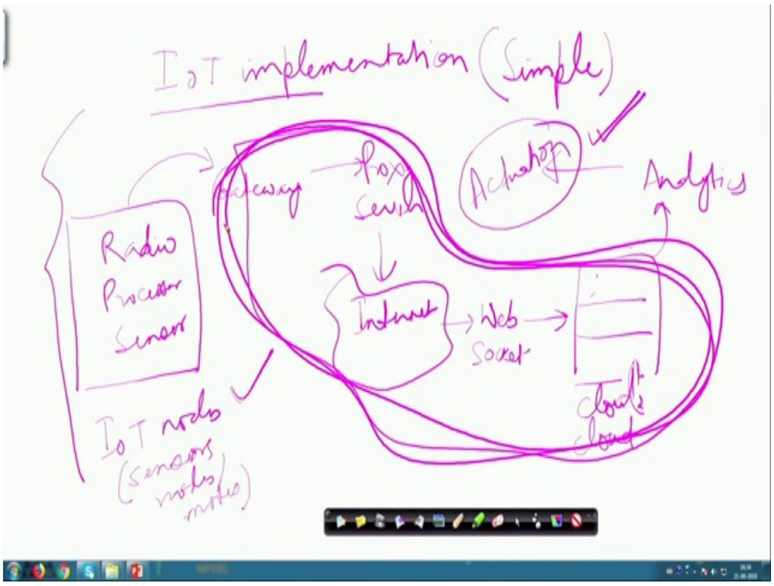


So, before we talk about any further detail, let us again talk about a sample implementation of IoT. So, this is a very simple kind of example that I will give you. Let us say, that these different IoT nodes are like different sensors. These IoT devices will have different components such as the radio interface, the processor, the sensor and few other components. These IoT devices will collect data, which will be sent through the gateway, maybe a proxy server, or through the internet. The cloud will do storage, processing etc and at the cloud there could be different types of analytics; that could be executed. Based on the analytics, there could be some actuation.

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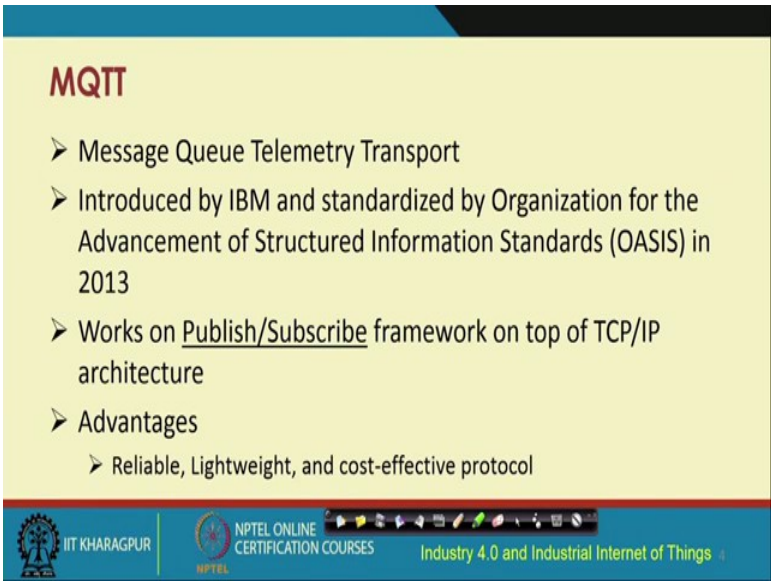


Let us talk about some of the solutions. One of which is the MQTT protocol. MQTT- the full form is Message Queue Telemetry Transport which was introduced by IBM and standardized by OASIS in 2013. MQTT is based on the concept of Publish/Subscribe. This is the key thing over here in MQTT and this works on top of the existing TCP/IP, the way MQTT has been designed to work right.

So, Publish/Subscribe, but this you know the way MQTT works is basically to work on top of TCP/IP, but you know you could have a different variant of MQTT, where TCP/IP framework may not be used right; you could come up with something else. So, the advantages of MQTT is that a Publish/Subscribe framework has been proposed, which is very suitable for IoT, because IoT devices typically would be publishing data, sensing data, publishing the data. And, you need to take help of the subscribers and the clients, who will try to pull the data out of the published, data that is buffered somewhere in some agent.

So, this kind of architecture is suitable for IoT and it has the advantage of being reliable, lightweight, and cost effective.

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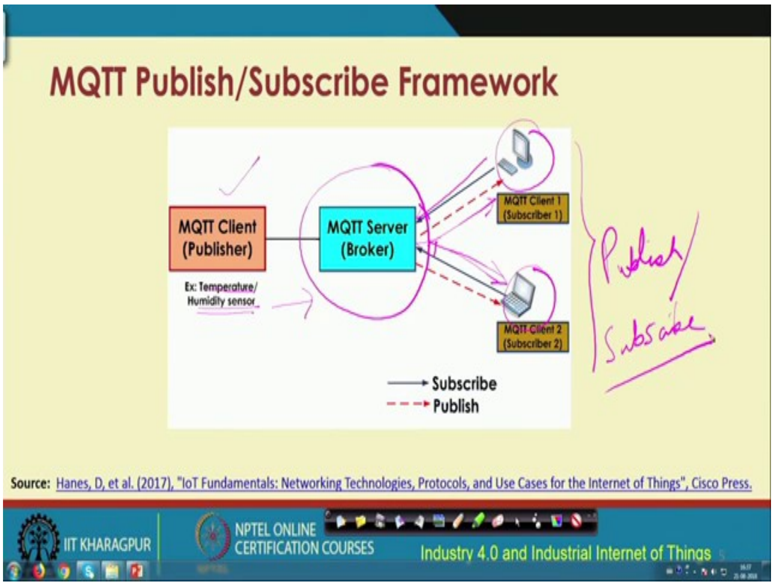


This is an example of how the MQTT publish/subscribe framework works. So, look at this particular picture. We have the MQTT client, which is the publisher on one hand. So, this publisher will publish different sensed data such as temperature, humidity etc. And, this data that will be published in the MQTT broker. MQTT broker, which is a server stores this data.

Now, different clients would subscribe to, depending on their interests, and based on the subscription this MQTT broker, the server is going to respond with the published information. This is based on publish/subscribe model and this is how this MQTT protocol works.

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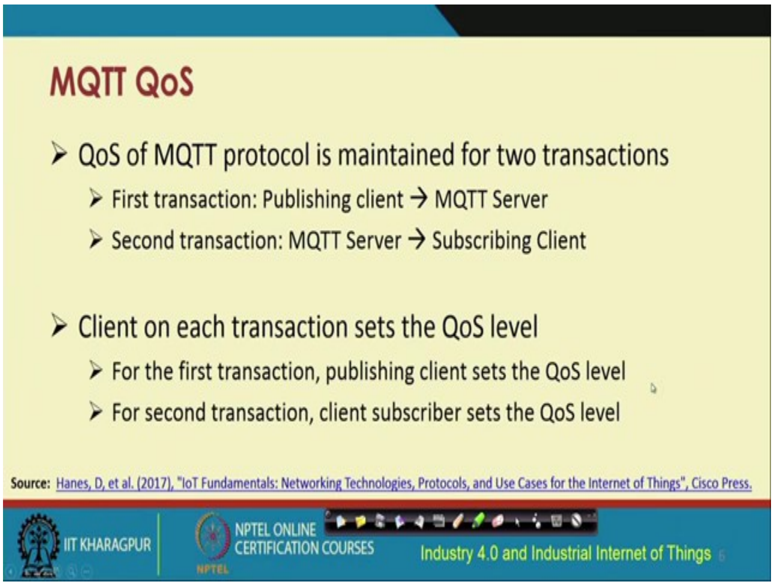


Now, let us look at few more concepts before we talk about few other things. In MQTT we are talking about different components.

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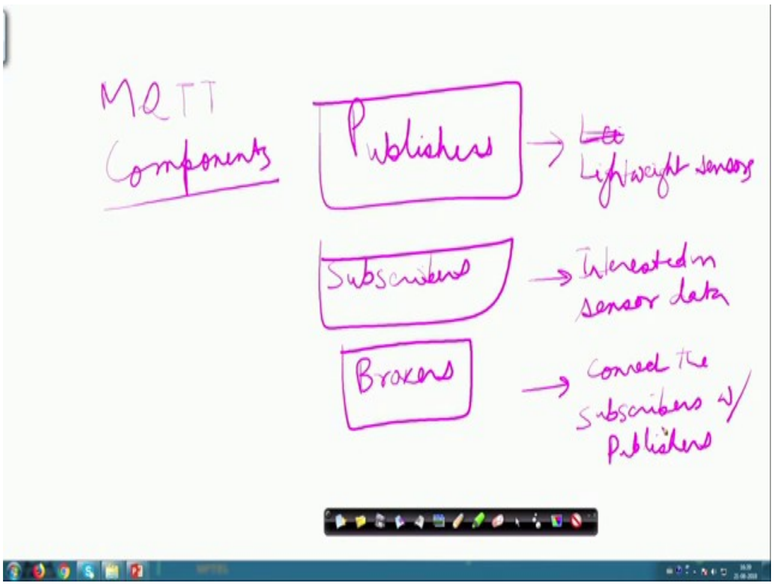


MQTT components: what are these components? We are talking about publishers, subscribers, and brokers. These publishers are lightweight sensors.

The subscribers are the applications, which are interested in sensor data. These brokers would help to connect the subscribers with the publishers. So, this is how it is going to work. Now, let us look at in this kind of backdrop what are the different models for this connectivity.

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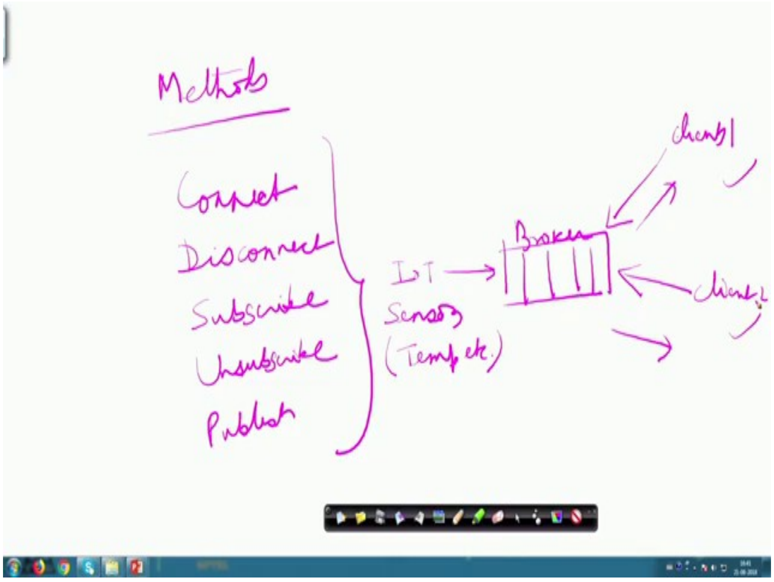


MQTT provides different methods that are used to connect, disconnect, subscribe, unsubscribe, and publish.

We have some kind of this publisher, which are like different IoT sensors like temperature sensor. These will send the data to the broker which has this queue, where the data will be queued at the broker. And, then based on the subscription from clients, the data are going to be sent.

These could be laptops, PDAs, mobile phones etc. We need to talk about QoS, because without QoS we cannot think of IoT. Quality of service (QoS) is very important. So, for QoS of MQTT protocol, there are different transactions that will have to be taken into consideration. The first transaction is basically between the publishing client and the MQTT server. The second transaction is between the MQTT server and the subscribing client.

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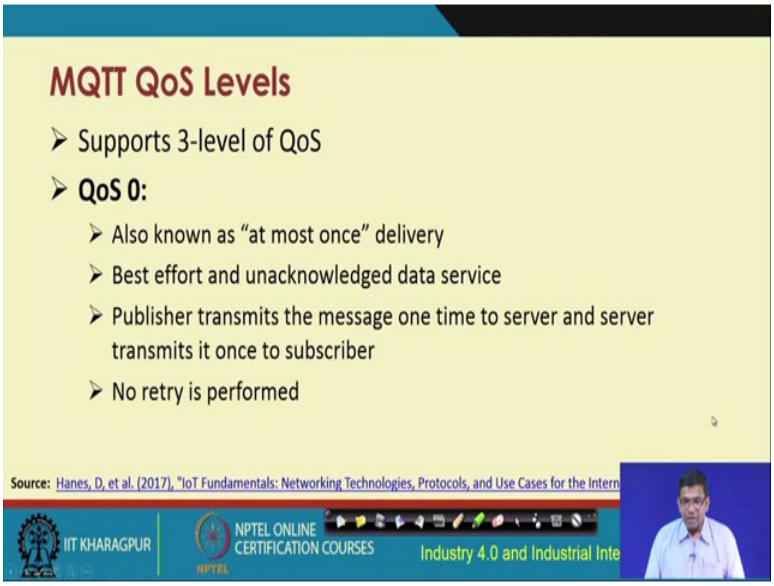


There are different levels of QoS; the first one is the QoS 0 which is about ensuring at most once delivery. So, this is kind of a best effort and unacknowledged data service. And, here the publisher transmits the message one time to the server and the server transmits it one time to the subscriber. There is basically no scope for retry.

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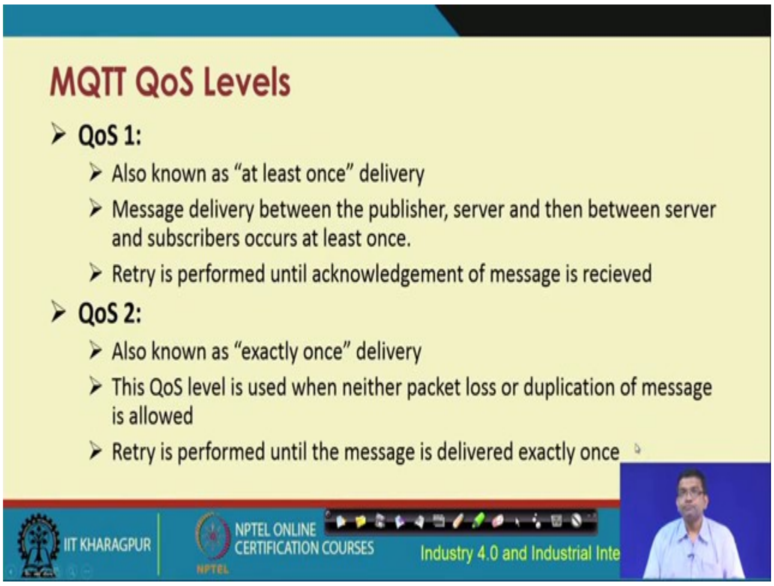


QoS 1: on the other hand, talks about at least once delivery, where retry is performed until the acknowledgement of the message is received. QoS 2 is further different; it is about exactly

once delivery and ensuring that the retry is performed until the message is delivered exactly once. So, this is how this MQTT protocol works.

Let us now look at the CoAP protocol. CoAP is kind of an application layered protocol. It is kind of session protocol. CoAP is a protocol, which helps ensure running different APIs, different applications in IoT.

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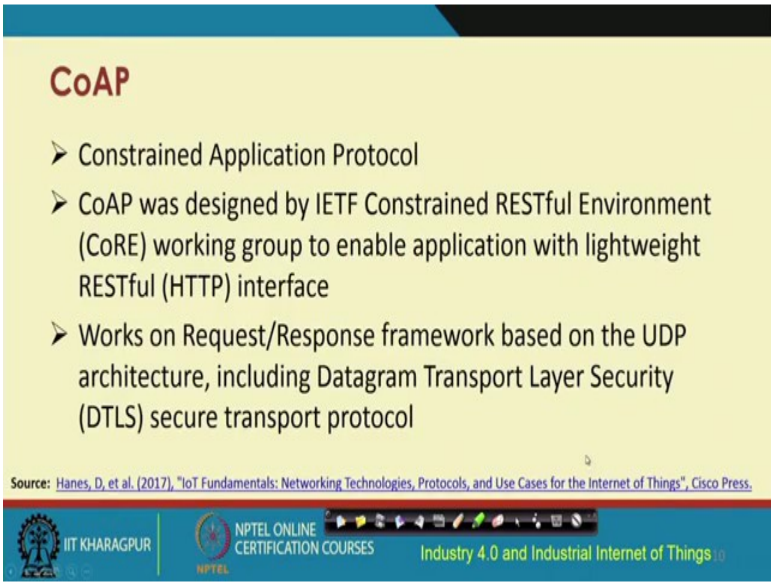


The full form of CoAP is Constrained Application Protocol, which was designed by IETF. The full form of core is Constrained RESTful Environment. So, this particular working group has come up with this core to enable applications with lightweight interface to run in place of HTTP.

It is a restful service, which is equivalent of the HTTP. So, instead of  HTTP, you run CORE. Core basically works on top of UDP, in the transport layer. This is a protocol, which is called the Datagram Transport Layer Security Protocol; for securing the transport layer.

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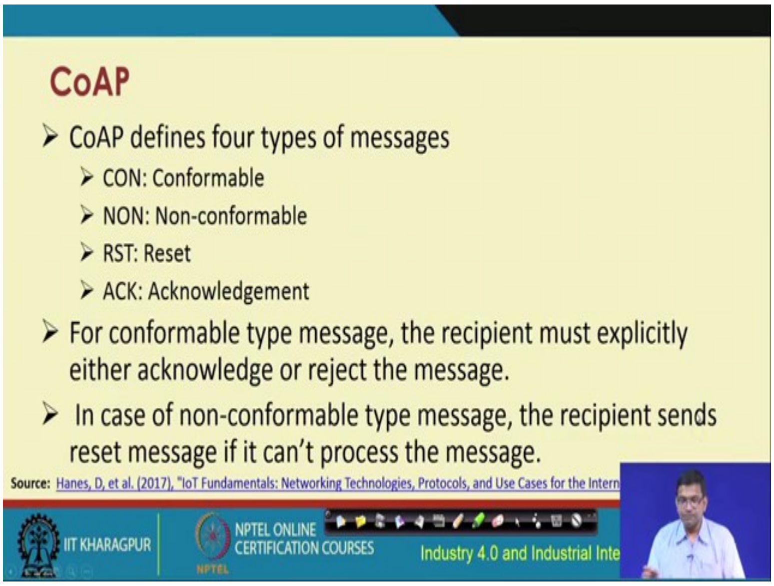


CoAP defines four types of messages: conformable message, non-conformable message, RST is the reset message, acknowledgement. For confirmable type message, the recipient must exactly explicitly either acknowledge or reject the message. So, some confirmation has to be received. And, in case of non-confirmable type message, the recipient sends the reset message, if it cannot process the message.

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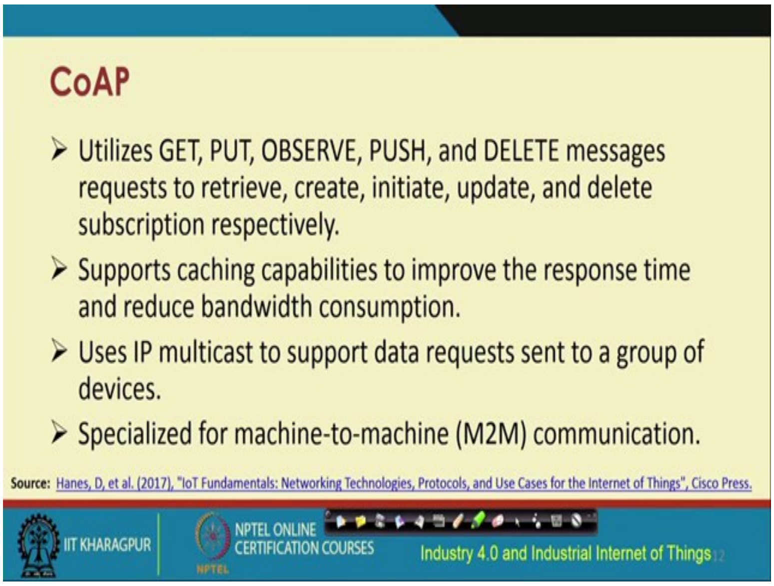


So, it utilizes different message messages, such as GET, PUT, OBSERVE, PUSH, DELETE etc like the MQTT. Similarly, all these different message types like GET, PUT, OBSERVE, PUSH and DELETE, together are used in order to perform different-different things such as IP multicast, in M2M communication for IoT.

There are lot of things available, if you have further interest to dig into this particular protocol. But, from an expository point of view I think this kind of information whatever I have provided to you is sufficient.

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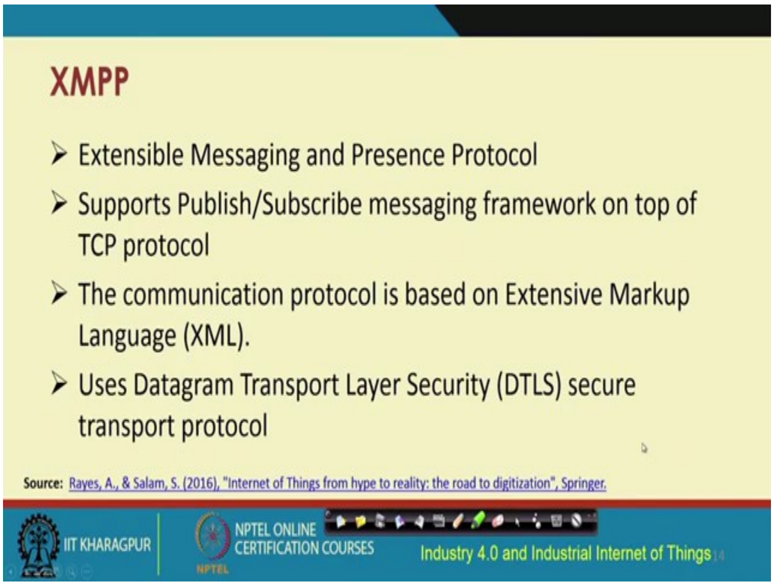


From another point of view, there is another protocol which is called the XMPP protocol. The full form of which is Extensible Messaging and Presence Protocol, which is again based on publish, subscribe, model that we talked about in the context MQTT. The communication protocol, XMPP is based on XML, and it uses DTLS secure transport layer at the bottom in the transport layer for transport layer security.

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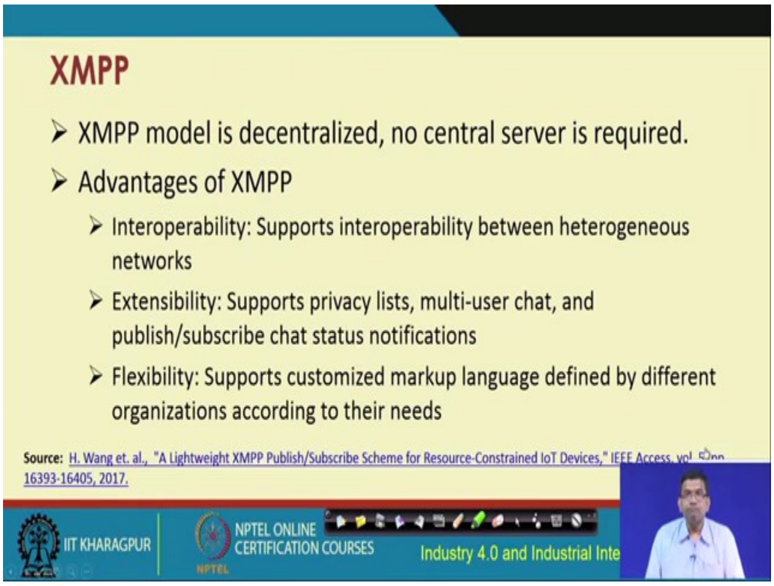


This model is decentralized; that means, there is no requirement for having a centralized server. And, it has manifold advantages such as it supports interoperability between heterogeneous networks, heterogeneous devices, and heterogeneous agents. It supports extensibility; that means, supporting privacy lists, multi-user chat, publish/subscribe chat, status notifications etc.

And, it also talks about the advantage of having flexibility of supporting customized markup language defined by different organizations according to their needs, because it is based on XML. Some of these are very high level. Another one at a very high level is the AMQP protocol.

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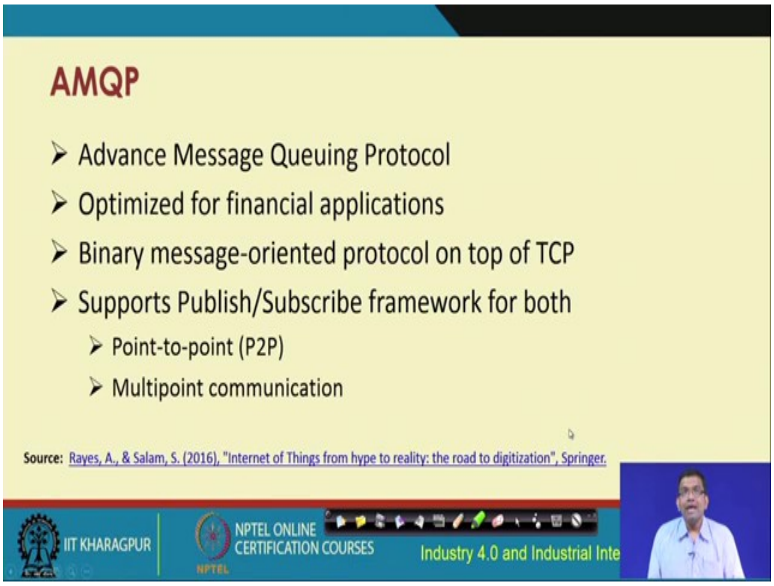


AMQP-full form is Advanced Message Queuing Protocol. This is also based on the publish/subscribe model like MQTT and XMPP. And, it supports two types of framework: one is the point to point communication and the other one is multi-point communication and is typically used for application such as financial applications, and digital finance. It uses token based mechanism for flow control, which ensures that there is no buffer overflow at the receiving end. So, flow control is all about use of a token-based mechanism.

The details of which you know I am not going through, at a very high level this is the kind of feature that is there with AMQP to ensure that there is minimal buffer overflow at the receiving end and the flow control is preserved. The message delivery guarantees are of different types using AMQP: one is at least once; that means, offering guarantees in terms of message delivery. But, these guarantees may do so, multiple times at most once which is about each ensuring that each message is delivered once or never. And, exactly once which talks about ensuring no message gets dropped and is delivered only once.

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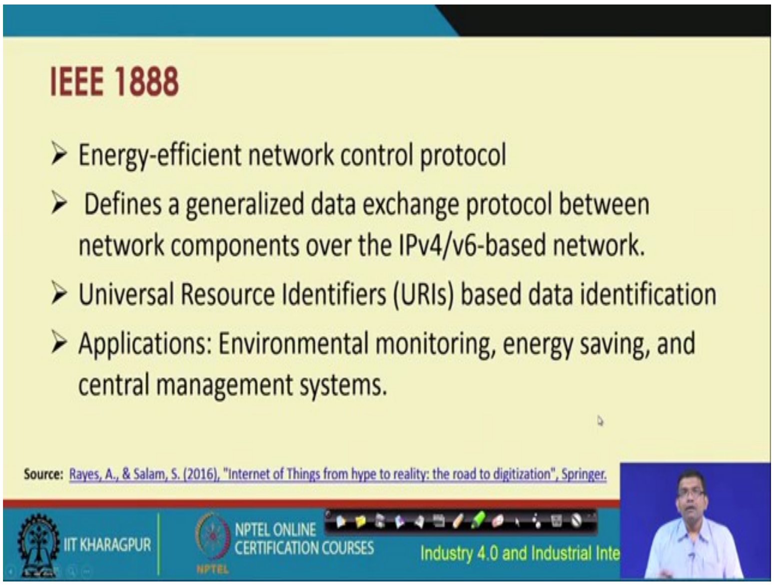


IEEE 1888-this one is an energy-efficient network control protocol, which defines a generalized data exchange protocol between the network components over IPv4 or IPv6. It talks about the use of resource universal resource identifiers and supports different applications for environmental monitoring, energy saving, central management systems, and so on.

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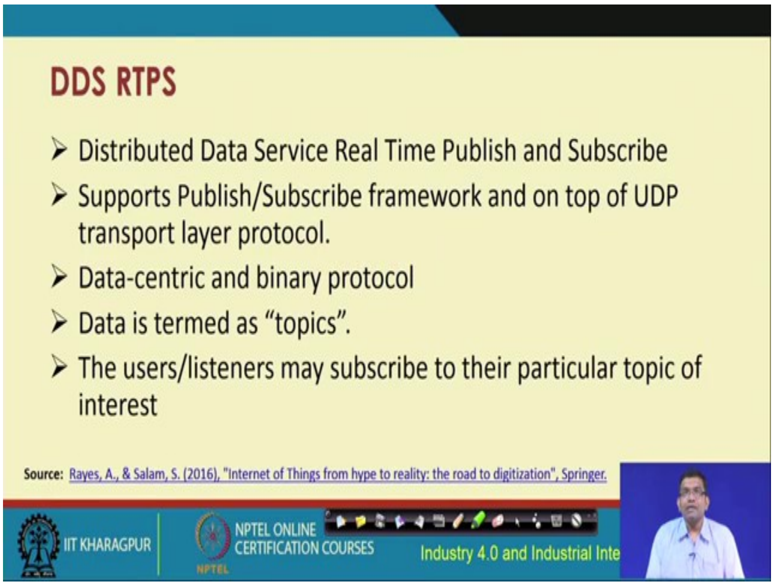


The full form of this thing is Distributed Data Service Real Time Publish and Subscribe; again we are talking about publish/subscribe. Because of its inherent characteristics, it is very much attractive for use in IoT networks, this support Publish/Subscribe framework on top of UDP transport layer protocol. So, it is a data centric binary protocol and this data in this context are termed as "topics". There are topics means like there are users, which subscribe to a particular topic of interest and the listeners listen to these.

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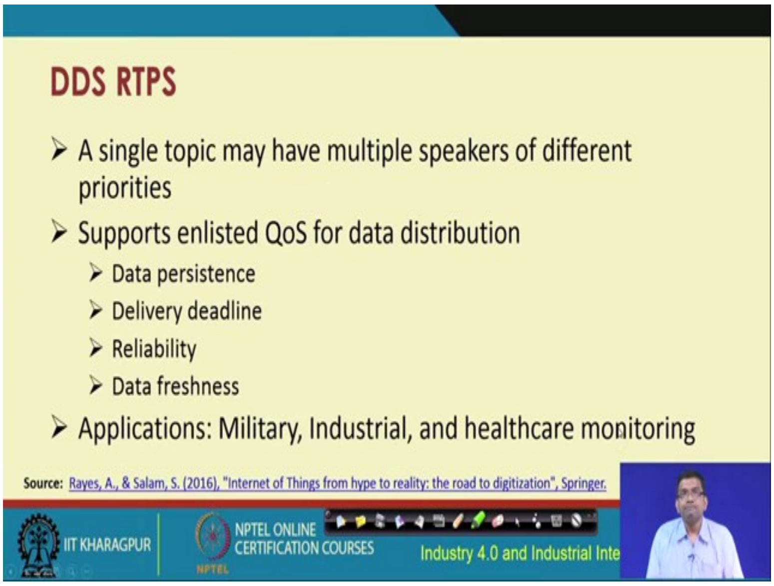


There is a single topic that may have multiple speakers of different priorities and this supports enlisted QoS for data distribution in terms of data persistence, maintaining, ensuring, delivery deadline, reliability, freshness of data and in a different protocol, earlier in the context of IoT networks. The application such as military, industrial and healthcare monitoring are the ones that find this particular protocol to be of use.

With this we come to an end of both the lectures on IoT networks. All these protocols that we have talked about are very much attractive for use with any kind of IoT applications and IoT and industry 4.0 applications these protocols are very attractive.

One of the very key requirements is connected behavior. And for this, all these protocols these publish, subscribe based protocols that we have talked about in this lecture and the previous one these will help you to build this kind of connected system, connected network, and the behaviors content within it.

With this we come to an end of this lecture.

Thank you.

**Introduction to Industry 4.0 and Industrial Internet of Things**
**Prof. Sudip Misra**
**Department of Computer Science and Engineering**
**Indian Institute of Technology, Kharagpur**

**Lecture - 06**
**Industry 4.0: The Fourth Revolution**

In this lecture, and in the subsequent modules, we are going to go through an understanding of what is this industry 4.0 and what are the different changes in the revolution that is happening in order to transform the industries towards Industry 4.0. So, Industry 4.0 basically corresponds to the fourth revolution in the industries.

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Revolution, as you know, that English meaning of this term is basically some kind of shift, some abrupt change that is required in order to transform the way things have been happening. An abrupt change in the way things are being done, so that is the revolution. If you look at revolutions in the past earlier, if we go back more than 10,000 years ago, our predecessors used to collect food through foraging techniques. So, basically wandering around collecting food, bringing them, eating the food through the collected food materials like fruits, vegetables, etc whatever they used to find.

Further, foraging behavior was transformed to farming. Different crops were grown, different vegetable plants, different fruits, food plantations were started. The result of this transformation from foraging to farming was increased production, and increased communication between different humans. There was growth of food production as the population growth increased. We are talking about this more than 10,000 years back.

Then came the industrial revolution where new technologies, new machines were produced, new approaches to the production processes were introduced. This shifted the economy from the primitive economy with simple agrarian-centric economies to more aggressive machine-oriented production systems. So, that was the industrial revolution.

Consequently, the economic models changed, the social architecture, everything changed with the revolution in the industries, with the introduction of new technologies, and new approaches.

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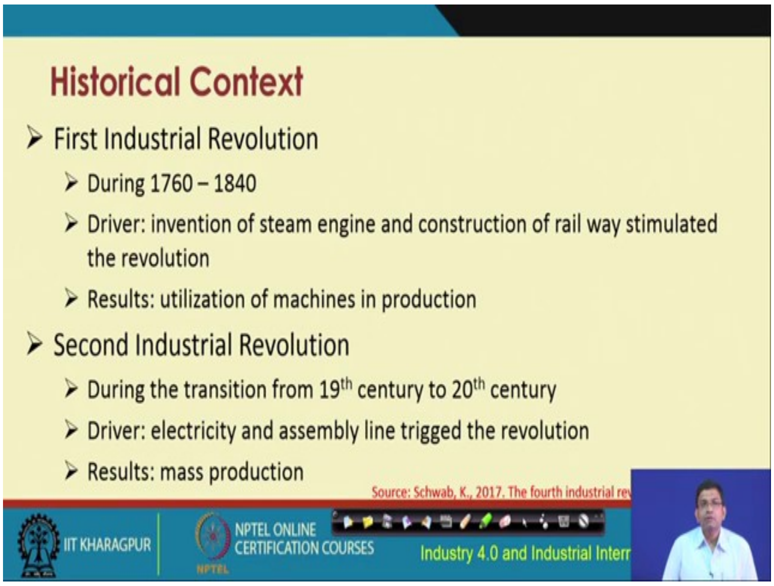


The industrial revolution again went through different stages. Back in 1760s to 1840s, it was the first industrial revolution. And this first industrial revolution was started with the invention of steam engine, introduction of trains, mobility increased, construction of railways stimulated the overall revolution. So, this resulted in the utilization of machines in production, during the first industrial revolution in the 1760s to 1840s.

Then came the second industrial revolution, which was during the transition from the 19th century to the 20th century, with the advent of electricity and increase of electricity in the society. This resulted in mass production, machineries could use electricity for large scale and faster production.

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Then came the third industrial revolution that was in the 1960s and so on. It was around that time that computers were starting to get popular. So, gradually with the increase of computers, different computers, and computing devices, peripherals, etc, the transformation in the industries also happened. There was increased use of digital technologies in the industry. The use of computers in digitization and so on was another revolution--the third industrial revolution, which again increased the production of goods and commodities in the industry.

The production was due to the increase in semiconductors and semiconducting devices, which was almost in parallel with the growth of computers. The result was increase in computing technologies such as mainframe computers, and personal computers. And eventually the connectivity between these different computers, internet, world wide web gradually started, and these basically were introduced in the industries to improve the efficiency of the machinery, processes in the industries, manufacturing processes and other processes in the industries. So, that was the third industrial revolution, which was basically the introduction of computers and information technology in the different machinery and manufacturing processes in the industry.

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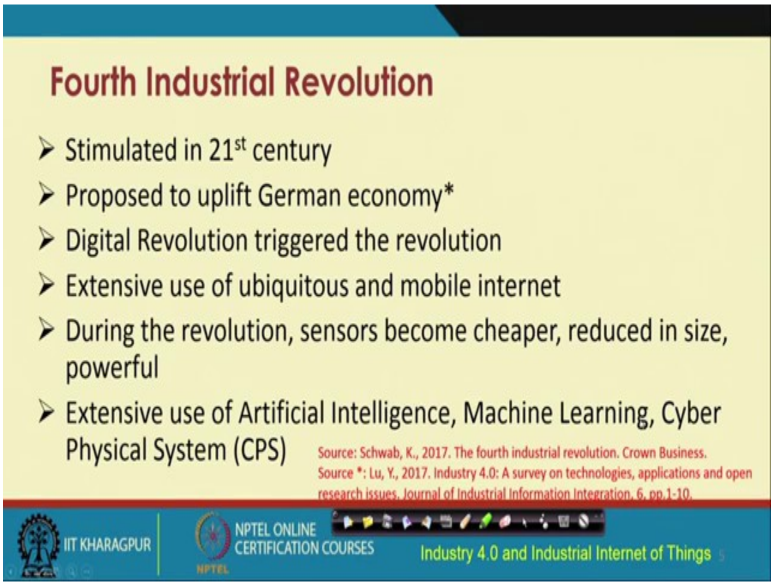


The fourth industrial revolution or this industry 4.0 is something, which has the origin in the German economy. So, it was required in the early 21st century to uplift the German economy. The individual industries having individual IT infrastructure everything was through the third industrial revolution. But how could we improve the production even faster and make the processes even more efficient.

So, people thought about how things could be done. There were different sensors and sensing technologies, which were becoming very popular. With the introduction of sensors, actuators, along with the regular infrastructure, the IT infrastructure, the internet together basically was able to transform the existing IT-based infrastructure in the companies to more efficient ones to connected, sensed machinery and so on, so that was the fourth industrial revolution. And this is fourth industrial revolution or the Industry 4.0 that we are going through at this moment.

So, this industry 4.0 or fourth industrial revolution started. The sensors and actuators are very small in size, cheap, and powerful. So, small sized, sensors, actuators, much more powerful internet and IT infrastructure together, and autonomous monitoring, use of technologies such as artificial intelligence, machine learning, cyber physical systems, use of all of these together is basically how this transformation is happening in Industry 4.0.

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Computers have become more sophisticated. They are smaller in size, but much more powerful, less energy consuming. These computers can be integrated and connected together. This has resulted in the radical transformation of the global economies, the societies, and the different industries. So, the fourth industrial revolution, this term was coined as the second machine age by Prof. Erik from MIT and Andrew McAfee from the same institute.

So, Industry 4.0, which is the synonym of industrial fourth industrial revolution; the term Industry 4.0 was coined in the Hannover fair in Germany in 2011. So, only a few years back, in 2011, the whole thing started. Now in the industries, through this kind of transformation, with the help of sensors, actuators, computers, IT infrastructure, much more efficient one, smaller in size, cheaper, and everything connected together, this fourth industrial revolution started.

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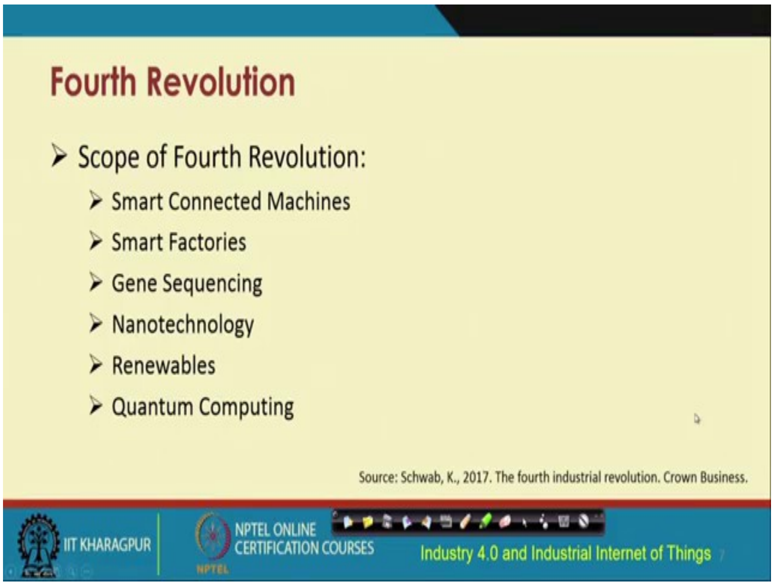


So, what is the scope of the fourth industrial revolution? Smart connected machines. Internet work, communication, connecting different standalone machinery, typically which used to be all IT driven, computer driven; and smart means we are using different for smartness, we need autonomous behavior things, which can be detected, corrected and taken forward in an autonomous manner that is basically the smartness. The introduction of small, cheap, energy-efficient sensors, and actuators have made it possible to make machines and connected machines smarter.

The smart factories are basically similar kind of concept extended beyond simple machinery, but having the entire factory operations, machinery in the factory, all of which made smarter with the introduction of connected sensors, connected machines and so on in the industries and so on.

Then came technologies such as nanotechnology, renewable energy, quantum computing, biotechnological interventions innovations like gene sequencing and so on. Everything together has helped in the overall growth. IT, sensing technology, sensor networks; then we have the biotechnology - gene sequencing, DNA sequencing, and so on; nanotechnology and quantum computing, everything packaged together is helping in the transformation to the fourth industrial age which is Industry 4.0.

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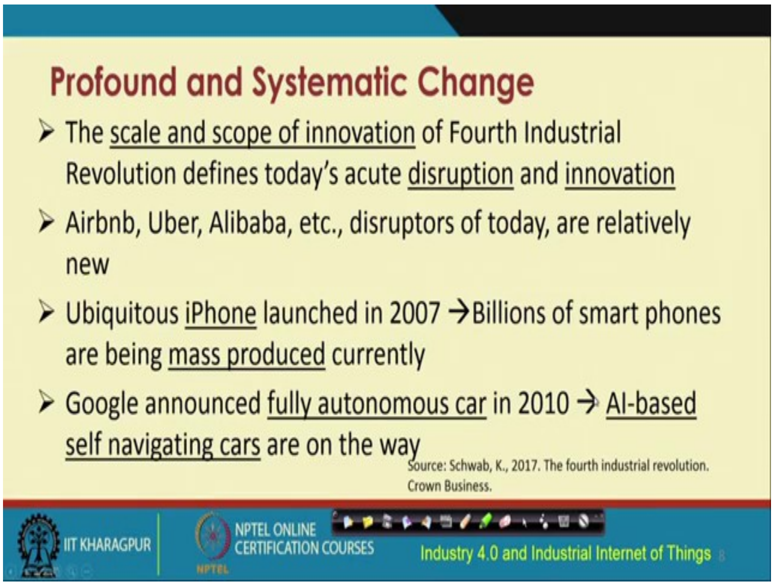


There has been some profound and systematic change in the fourth industrial revolution. This change has been in innovation disruption; disruptive technologies have been introduced. And this disruption and innovation has happened in both the scale and scope. The scope has increased manifolds, and has increased.

The scale and scope of innovation of fourth industrial revolution has basically defined today's acute disruption and innovation in technologies and the transformation of industries accordingly. Companies like Alibaba, companies like Uber, Airbnb, Amazon and Flipkart in India, so all of these companies are essentially transforming the way the operations, delivery, have been carried on in the past. Everything has changed the way things are happening at present.

These are using different state of the art technologies such as cloud, sensor networks, technologies such as drones, networked drones and many different other technologies are being used in order to transform the industries and their operations. So, these are newer ways in which these companies are working.

For example, iPhone was launched in 2007, but since then only within few years, billions of smartphones are being mass produced at present. So, you see that how this disruption and penetration of these technologies are happening and how fast they are happening and in what scale they are happening right. So, these are all like different phenomena that are happening in terms of change, systematic and profound change, that are happening in this fourth industrial age.

Take the company Google we all know how Google is transforming the world at present. In 2010, as many of us know just still few years back, Google basically announced the fully autonomous car. And already we have seen that self navigating cars, fully autonomous cars are already in the roads. But what is very important also is the increase in the use of technologies such as artificial intelligence and machine learning, that is making these kind of newer technologies, a reality.

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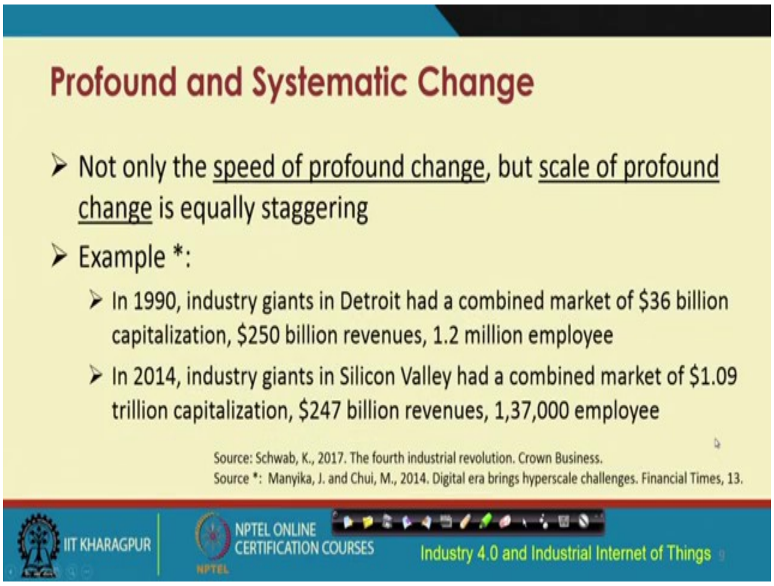


So, not only the speed of change, but also the scale of change, the profound change, both are very equally important and are increasing in rapid pace. So, like going back to the 1990s, there were different industry giants in the Detroit area, in US, which had a combined market value of 36 billion dollars, in terms of capitals. Their overall revenues were in the order of about 250 billion US dollars and the number of employees working in that area was about 1.2 million.

In 2014, if you look at in the Silicon Valley, the different industry giants together had a combined market of about 1.09 trillion dollars. So, the capital has increased manifold. On the other hand, if you look and compare with these industry giants in the Detroit area in 1990s, in the Silicon Valley area, the number of employees was only 1,37,000. There is a drastic reduction in the number of manpower that is being used in the industries, 1.2 million employees to 1.37 lakhs employees being used.

On the other hand, capitalization has increased manifold. With the reduced number of workforce, we are able to increase the number of the value of capitalization and growth of the industries. Consequently, the revenue that is obtained from the different sales has also increased.

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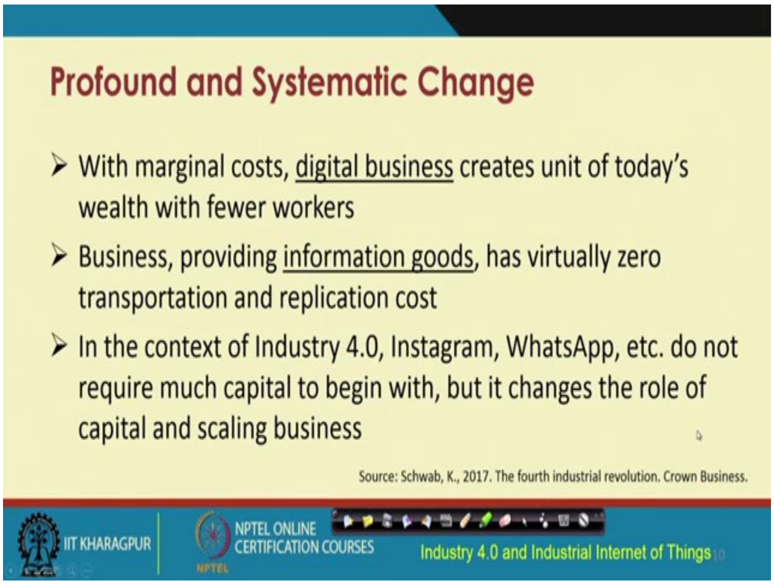


With marginal costs, the digital business creates unit of today's wealth with fewer workers. We are able to increase the wealth, but with the use of fewer workers and that has been possible with the introduction of digitization.

Business provides information goods, which has virtually zero transportation and replication cost. Consider companies such as Instagram, WhatsApp, Facebook, Twitter. They are able to supply information-centric products, and goods. There is almost like zero transportation cost involved and that is unlike the manufacturing industries which have lot of capital goods, lot of transportation costs are involved, shipping from one location to another, and logistics. The transformation to the introduction of digitalization and advanced IT and different other technologies is making the scaling up a possibility in this Industry 4.0 revolution.

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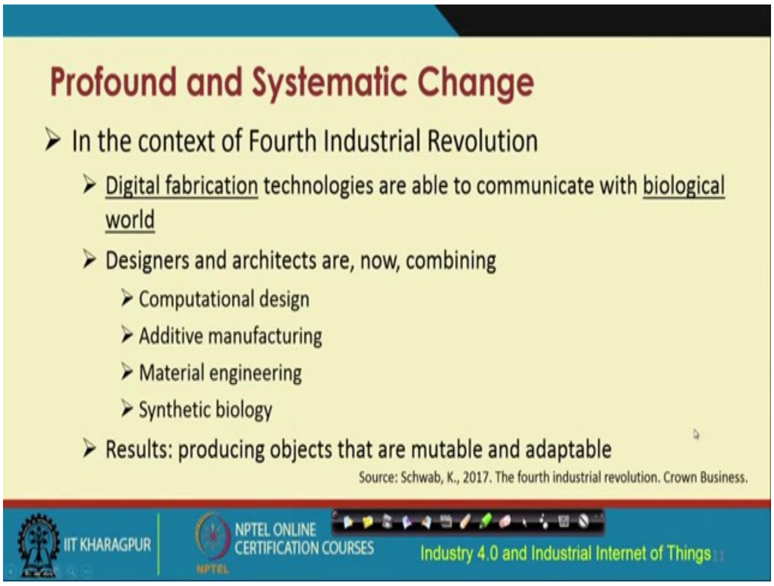


In this context of Industry 4.0, digital fabrication technologies are able to communicate with biological world. Now, it is possible that through the advancement in technology, it is possible that we can have different sensors inside the physiological systems.

These sensors and different other advanced technologies are able to communicate with the outside world that means outside the human beings. This is now possible that remotely signals are send to the human body to perform certain physiological operations within a human, without basically having the human go through or rather the human being or the patient being able to know what is actually happening. These things are possible with the introduction of all these new technologies. Consequently, transformation has been possible in this fourth industrial revolution, transformation of the biological systems, and physiological systems.

Now, it is also possible to manipulate the way biomolecules within a human body operate. It is possible to sequence the different genes in the body. It is also possible to manipulate the DNA within a body. These things are possible due to profound change with the introduction of all these different technologies, IT, biotechnology, nanotechnology, and quantum technology.

So, designers and architects are, now, combining, computational design, additive manufacturing, material engineering, synthetic biology and so on. Consequently, they are able to increase the number of production of the number of objects. These different technologies will be used in order to increase the production of number of objects and these objects are also being produced, because of the use of these different types of technologies. It is now easy to mutate these products, and have these products adaptable to different changes in the environments of their operation.

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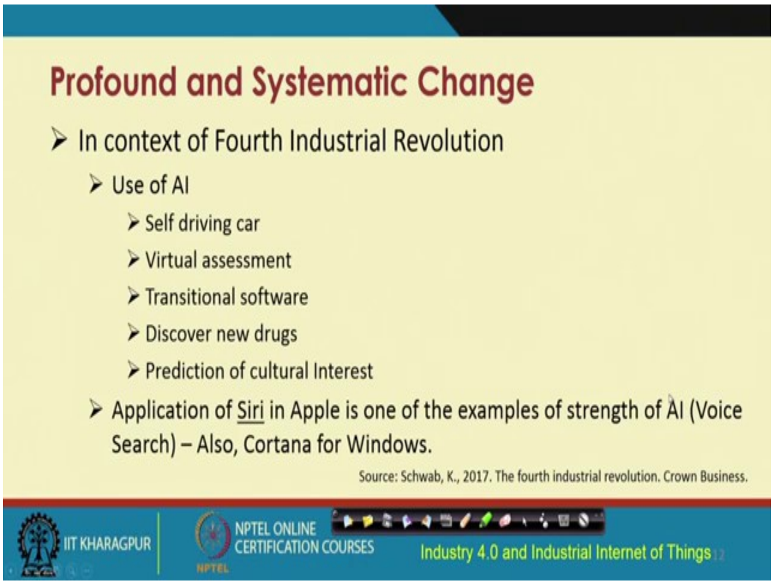


In the context of the fourth industrial revolution, use of AI or artificial intelligence, machine learning, also has made it possible to have self driving cars, virtual assessment, transitional software, discovery of new drugs, and prediction of cultural interest, have been made possible with the use of artificial intelligence.

Everybody knows about the application Siri. Siri basically is nothing, but an application of voice search, it is an Apple product, which basically uses artificial intelligence techniques in order to have and in order to perform voice search. Somebody speaks and this application will automatically recognize the voice and make searching in the internet possible. And it is very similar to the Cortana by Windows. This is basically the voice search with the introduction of use of strength of AI machine learning.

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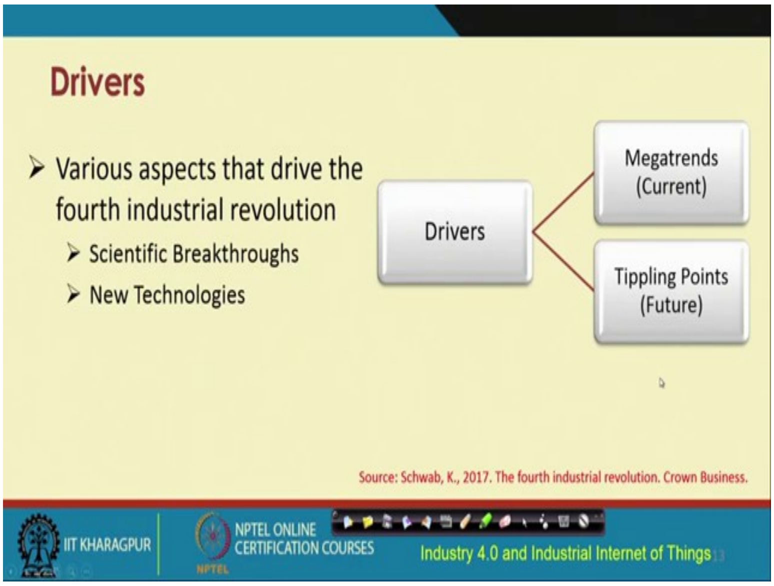


So, there are different drivers. These drivers are basically driving this change. Change in terms of scientific breakthroughs. Introduction of newer technologies, current transformation in terms of changes in the megatrends are happening, future transformation, the tippling points, everything are happening at present with the introduction of all of these technologies.

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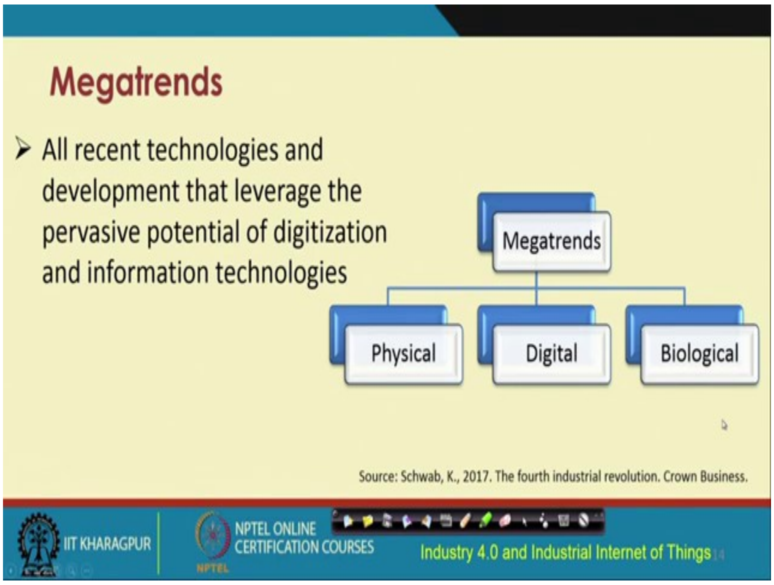


These megatrends are due to the introduction of recent technologies and using or leveraging the pervasive potential of digitization and information technologies. In terms of physical transformation of machinery, manufacturing machinery, digital transformation, in terms of the introduction of IT, biological transformation through the introduction of biotechnology, biotechnological systems, all of these are newer megatrends are happening at present.

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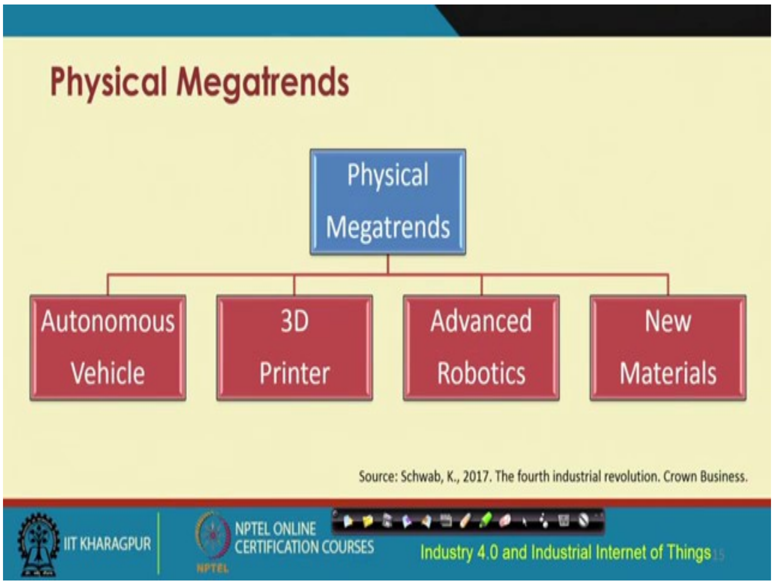


In terms of the physical megatrends, we have now autonomous vehicles, 3D printing, advanced robotics, connected robotics, new materials, lightweight materials, cheaper materials, and stronger materials.

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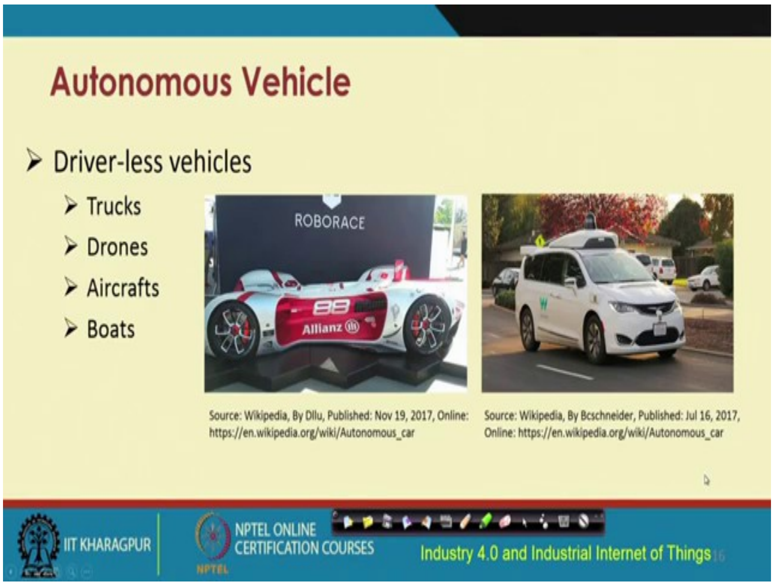

Autonomous vehicles are already in place. We now have autonomous trucks, autonomous drones. Drones are basically autonomous self-driven, airborne vehicles, where there is typically no pilot or any kind any kind of human pilot or machine pilot. Aircrafts, driver-less aircrafts are a reality now. And also driver-less boats and many other like particularly in agriculture people are now talking about use of driver-less, driver-less tractors right. So, all these are possible with the introduction and use of artificial intelligence and advancement in robotics.

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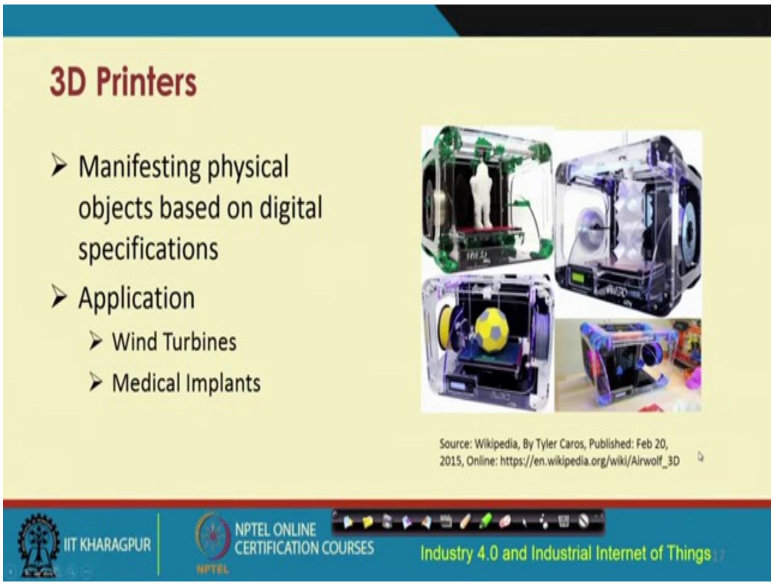


3D printers, basically, give any shape these machines 3D printers. They will manufacture a particular product according to the specified shape. 3D printers have applications in wind turbines and medical implants.

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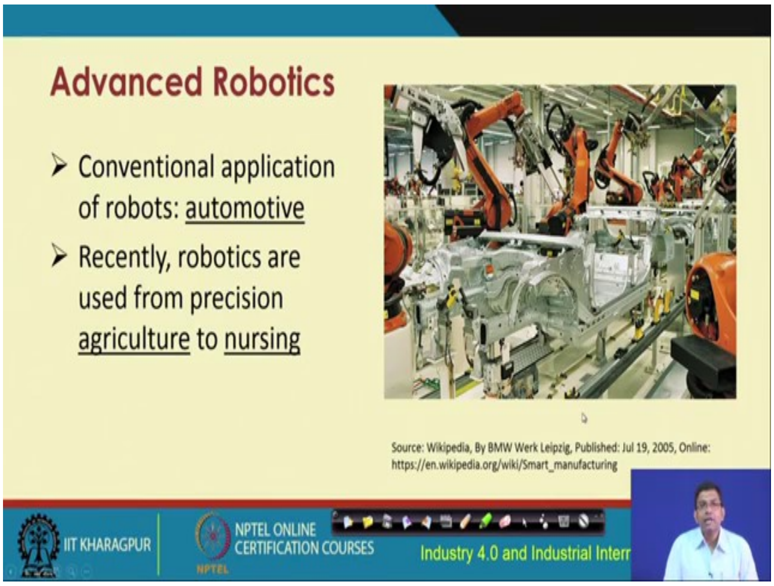


Advanced robotics, different robotics, robotic equipments, connected robotic equipments are being used in the automotive industries. Robots are also used in medical domain for robotic surgery. Robotic surgery is basically something that is happening worldwide. Robots and their use in agriculture robots and their use in nursing. Connected robotics is something that is quite common now in automotive industries in agricultural fields. We ourselves have developed some robots, which will go and plant some seeds in the agricultural field. So, these are all these advancements that are happening in different industrial fronts with the advancement of robotics and connected robots.

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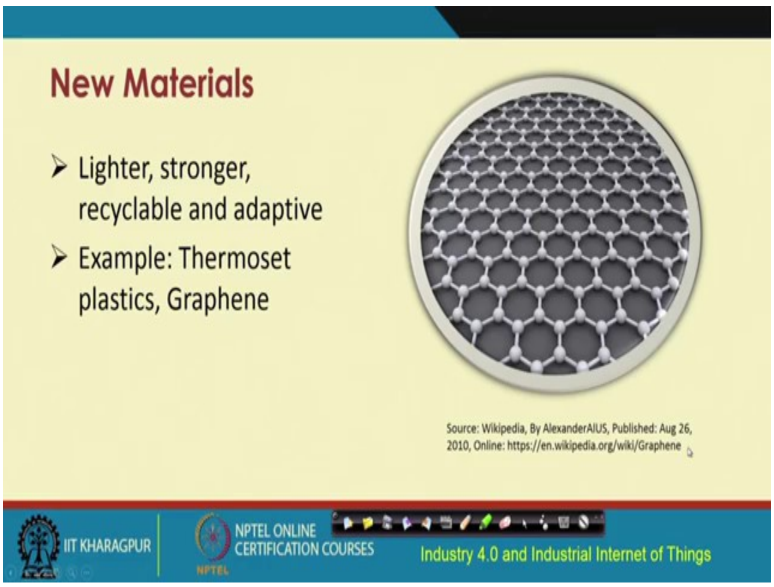

Newer materials, lighter materials, stronger materials, materials that are recyclable, recyclable plastics are basically a reality now. Use of nanotechnology, Graphene, carbon, nanotubes these are also making these materials lighter, stronger, having different advanced properties for being used in different application domains such as aviation industries, for different other manufacturing industries.

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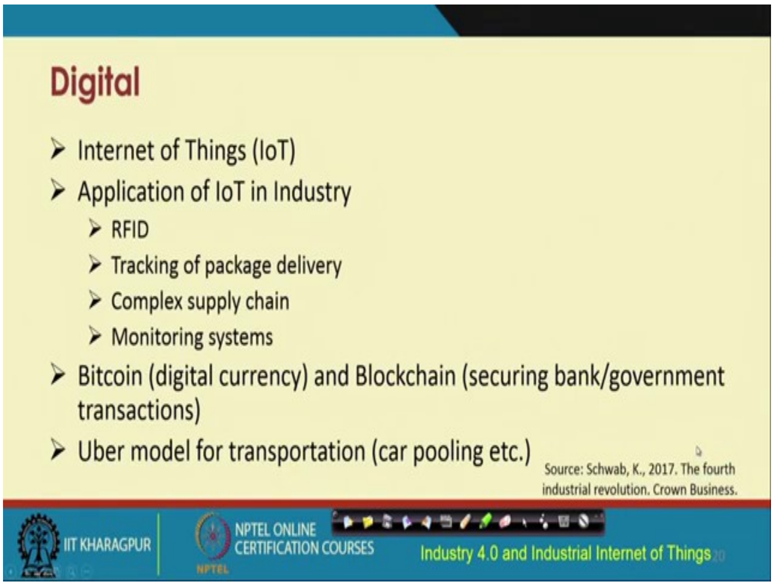


This digital transformation has been happening. The introduction of sensors, connected sensors, connected actuators. These are all about the use of internet of things. Sensors being used RFIDs, NFCs, tracking of package delivery, typically by courier companies this is quite common. Complex supply chain, monitoring systems are all a reality in this fourth industrial revolution.

We have all heard about use of digital currencies. Bitcoin for example is one such, and use of Block chain, for securing bank transactions and government transactions and so on.

Companies such as Uber are transforming the models of transportation. Car pooling has increased the revenues that are earned by these companies. So, the reduction in fuel consumption overall and also consequently reducing the pollution in the environment through the use of car pooling, reduction in fuel consumption, increase in revenue, making everything very smart in the sense that have all of these different cars and vehicles connected to each other. Instantly, which car is where, and what is the availability status, and protecting the environment from unnecessary pollution all of these things are now possible.

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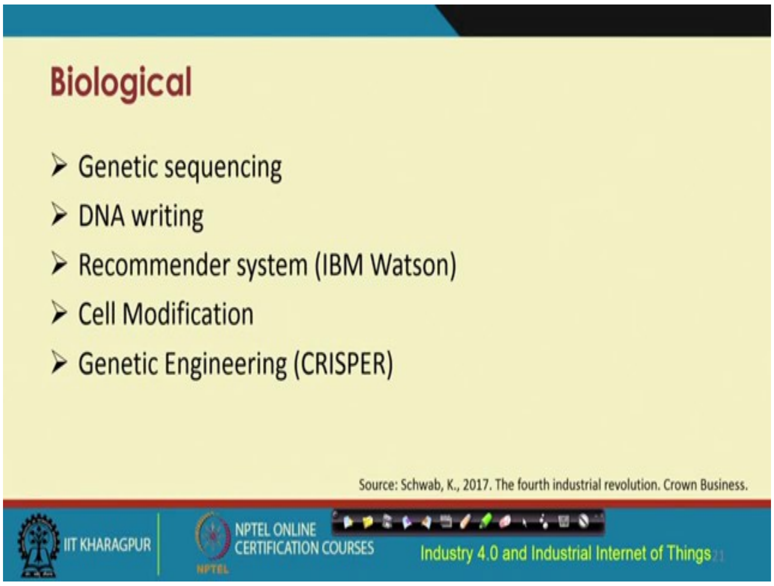


Biological transformations adoption of different technologies such as gene sequencing, DNA writing, recommender systems, so recommender system in the physiological domain is about like if you tell some of the molecular level, composition of a human being then what is the best precise drug that should be administered to that particular human that recommendation can come in through the use of different advanced systems that have been produced now. Cell modification is possible now, and also advanced genetic engineering is a reality.

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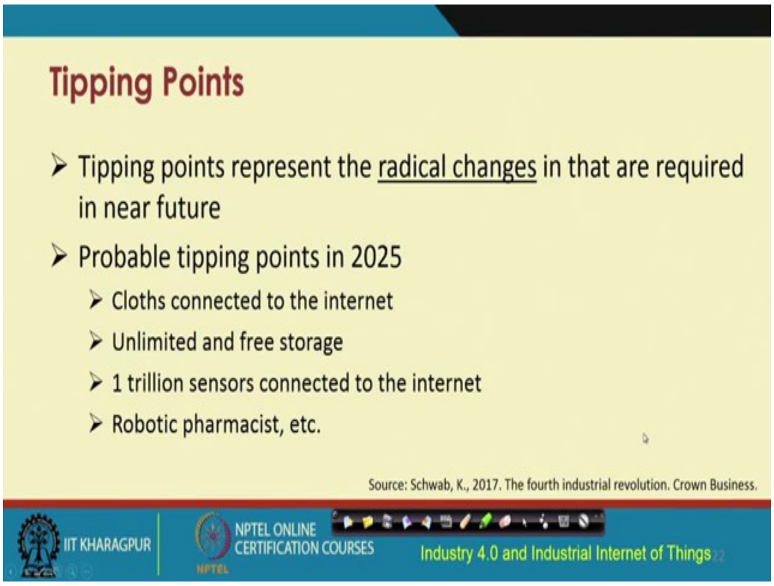


Tipping points or the changes that are coming in the future. So, basically by 2025, it is expected that we will have the different clothing, the different fabrics, connected to the internet. There would be unlimited and free storage available to everyone. There would be trillions of sensors connected to the internet. And we are going to have a world, where there would be some robotic pharmacists, which is going to help in the pharmaceutical industry.

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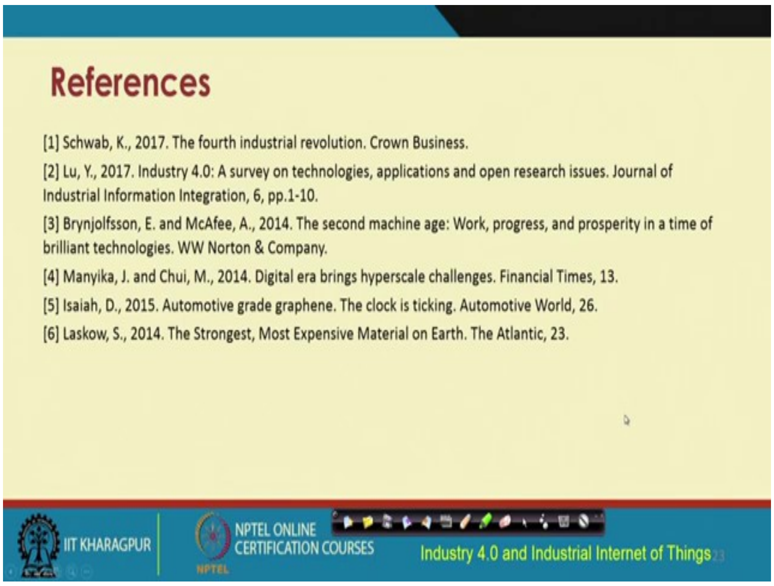

With this we come to an end of the fourth industrial revolution lecture. We have understood, what is this fourth industrial revolution, what were what were the previous three industrial revolutions that we have seen. And in this fourth industrial revolution age, what are the new things that have come in technologies such as self driving cars, technologies such as AI enabled Siri.

Technologies such as connected robots, standalone robots, smart robots being used in different application domains such as agriculture, medical industries, manufacturing industries. Technologies that are going to come in the future and people worldwide are lot of research words that are going on in different labs in the academia and in the industries R & D industries. All of these things we have gone through. And we have also seen how these transformations are happening gradually and what is the benefit of all these transformations that are happening.

So, with this we come to an end, these are some of these references that you might want to go through if you are interested to know further about any of these. There are many more references that would be there if you search in the internet or if you look at relevant books like the ones that are listed over here. With this we come to an end.

Thank you.

**Introduction to Industry 4.0 and Industrial Internet of Things**
**Prof. Sudip Misra**
**Department of Computer Science and Engineering**
**Indian Institute of Technology, Kharagpur**

**Lecture – 07**
**Industry 4.0: Sustainability Assessment of Manufacturing Industry**

In this lecture, we are going to go through some of the very important concepts for sustaining the Industry 4.0 revolution. So, basically what is required is not just the development, development in terms of introduction of new technologies, new types of services, and so on, but what is also required is to be able to sustain the newer systems, newer methodologies, newer techniques that are introduced. So, what is required essentially is to ensure that the sustainability of the newly introduced concepts, technologies, methods.

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The term sustainability means to continue at a fixed rate. A sustainable industry provides energy efficiency, conservation of resources, and low waste production. So, the last one particularly is very important. Energy efficiency is very important because there is a global concern about saving energy and thereby saving the environment. So, energy efficiency is definitely very important to reduce carbon footprint on the environment. But what is also very important is to ensure that the amount of resources that are used are all conserved and the amount of waste that is produced should be reduced significantly.

So, that will be a sustainable method of manufacturing, sustainable method of production or development. So, let us consider the context of sustainable manufacturing industries.

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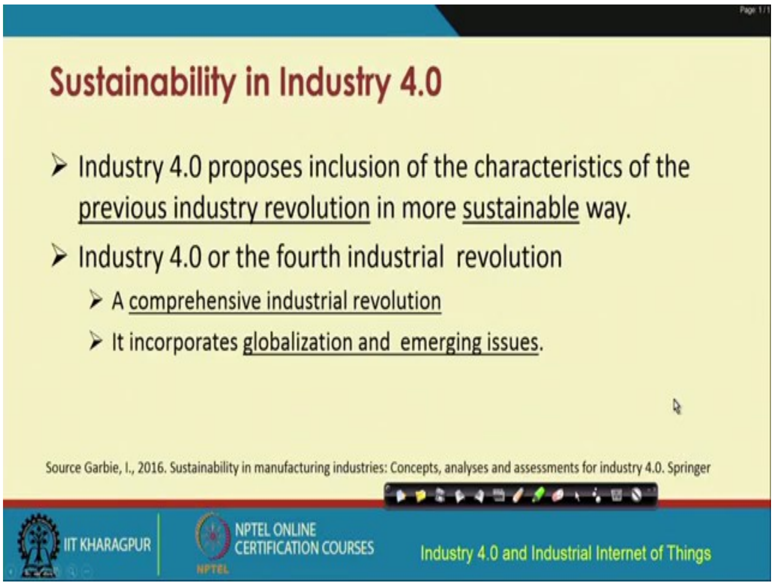


In the context of Industry 4.0, the proposition is to include the characteristics of previous industry revolution in a much more sustainable way. So, not only that we want to introduce newer things, we have to ensure that whatever has been existing from the previous industrial revolutions continue in the same form that it was before. To introduce newer techniques methods and continue the same things in a much more consistent, sustainable manner, so that it does not become a one-time kind affair.

Industry 4.0 or the fourth industrial revolution is a comprehensive industrial revolution, which takes into account this sustainability issue because it introduces newer concepts, newer technologies, but also to ensure that there is sustainability in the long run. Industry 4.0 incorporates globalization and emerging issues as well.

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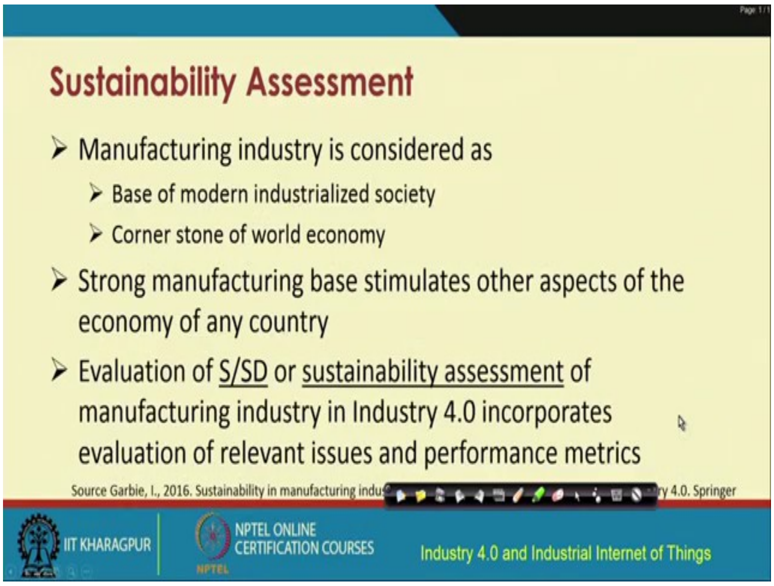


So, when we talk about sustainability first, what is required is to consider some industry in our case, the manufacturing industry and assess the sustainability issues. First of all you have to assess, how much sustainable that is in particular industry, in terms of the processes, that are existing or the processes or the product, that is being manufactured.

A manufacturing industry is considered as a base of modern industrial society and is the cornerstone of the world economy. In order to estimate this sustainability and assess it, it is required to evaluate this term S over SD.

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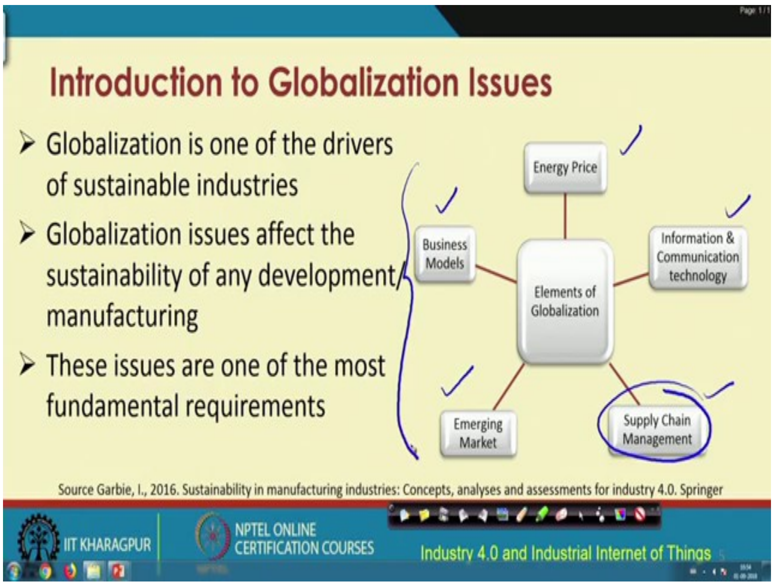

This S over SD considers different issues, different parameters, which are linked to the issue of globalization, are considered as one of the important drivers of sustainable industries, globalization issues affect the sustainability of any development or any manufacturing or any production system.

There are five different elements of globalization that are depicted. So, the first one is the business models, the next one is the energy price, information and communication technology adoption, supply chain management, which is a very important thing, particularly, in the manufacturing context, and the inclusion of emerging markets. So, these are some of the important issues or the cornerstones behind globalization.

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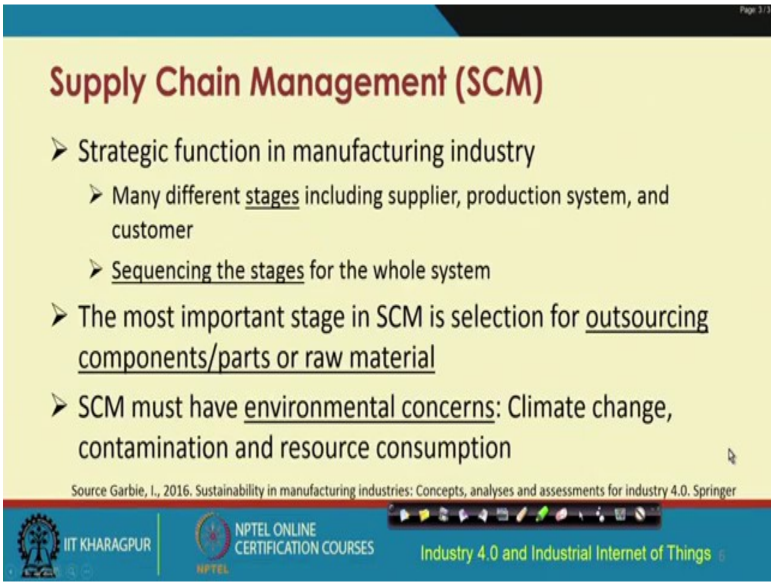


We will start with the supply chain management. So, supply chain management talks about consideration of the different stages through which the production system starting from the production till the supply goes through. In these manufacturing industries, there are different suppliers, the production system as a whole and different customer. Each of these together go through different stages. The sequencing of the stages for the whole system is what SCM basically talks about, supply chain management.

The most important stage in SCM is the selection for outsourcing components or parts of raw material. So, supply chain management has many additional environmental concerns as well. So, these are the issues that basically contribute to the overall sustainability. Issues of climate change, contamination – contamination of through the introduction of different wastes to the environment, contamination resource consumption, how much resources are consumed, different human resources, non-human resources. It is required basically to optimize the resource consumption. These are the different supply chain management issues.

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The second thing is the introduction of ICT -- Information and Communication Technology. As we know that ICT overall is the backbone of most of the modern manufacturing industries today. So, if there is no information technology or communication technology there is no communication within the enterprise and across enterprises. This communication technology is required even to distribute we have distributed communication between different people, distributed communication between different people, distributed communication between the different labs of the same organization, across the different locations, or different campuses of the same organization or even it is also required for having proper communication between the different partners of a particular organization, who contribute to the manufacturing of the products or the services.

So, overall ICT is very important and we are talking about ICT, as a whole, in the bigger context, not just the introduction of computers and communication technologies, but also different other things that we talk about in the industry 4.0 context like sensors, actuators and the connectivity between them and the different other things. So, it is very required to have communication between the customers, the producers, and the suppliers.

They need to be able to share the information between themselves and with the help of these computers, computing technology, and communication technology. It is required to enable Enterprise Resource Planning, ERP-based systems, then wireless communication technology, which is sort of like why wireless is; wireless is something that makes portability a reality, portability of different equipment, then mobility across different parts of the company, that are being used in the manufacturing process.

Wireless communication technology is very important thing, a third one is the GPS and the fourth one is the radio frequency identification system. With the help of RFIDs we have gone through in the introduction. You need to tag the different parts in a production system or different equipments that need to be tracked or different items or elements or agents that need to be tracked and that basically helps to have a complete and efficient monitoring, of the mobility and portability of these different parts and constituents of the whole production system.

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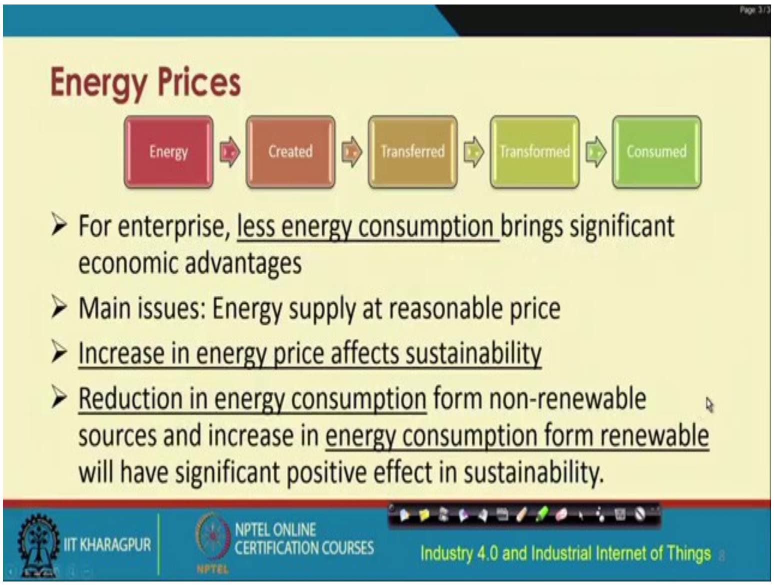


The second, the third one is the energy prices. If you are talking about large-scale enterprises there is a consideration of the energy consumption as a whole. So, larger enterprise means larger energy consumption, but that is sustainable and beneficial for the environment more energy consumption basically leads to bigger impact on the environment and which is not very desirable. So, for enterprises it is very important to ensure that there is reduced energy consumption, through the introduction of these newer technologies.

Energy has to be first created, then transferred, transformed into a different form, and then gets consumed. For instance, if you are talking about electricity; electricity gets generated in the generating power plant, then it is transferred through different grids and transmission lines it is transferred from one location from the generation station to elsewhere to this station to the electricity substations and different other points. So, one form of energy is transformed to another form of energy.

In our example, electricity is transformed, let us say that if we are talking about lighting lamps and bulbs in the warehouses, then electricity is getting transformed into light energy.

So, what is required is whatever be the cycle, however, the energy consumption and this transformation takes place, whatever be it what is important is to ensure that there is reduced energy consumption overall and that basically we will also have an impact on the economy and the environment as I said earlier.

So, it is required to have energy supply also at reasonable price. The increase in the price of energy is not good, because if you are increasing the price of energy then that will affect the overall price of the product or the service that is being created and that is not going to be sustainable over all from another perspective.

Increasing energy price effects sustainability and we have seen that different ways it is affecting, it is not sustainability has different facets. So, what is also not desirable is to increase the cost of the product or the service that is being generated or being developed and also it is also the cost of energy, if it increases, it is not very useful from the environment point of view as well.

The reduction in energy consumption is also required and energy consumption, energy production can be done not only from the non-renewable sources of energy, but also from the renewable ones like solar, wind.

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The next one the next globalization issue is the emerging markets and its consideration. So, markets are able to meet the standards of newly developed innovative products. If you think about the emerging markets, whenever a particular product is being introduced. So, it goes through typically a phase of dictatorship; dictatorship means like it is a monopoly kind of thing. The company which introduced the product basically has monopoly. And, then gradually it has to transform towards the free market and free economy where it will be made accessible to the greater part of the world. So, the consideration of emerging markets is very important, particularly for developing countries.

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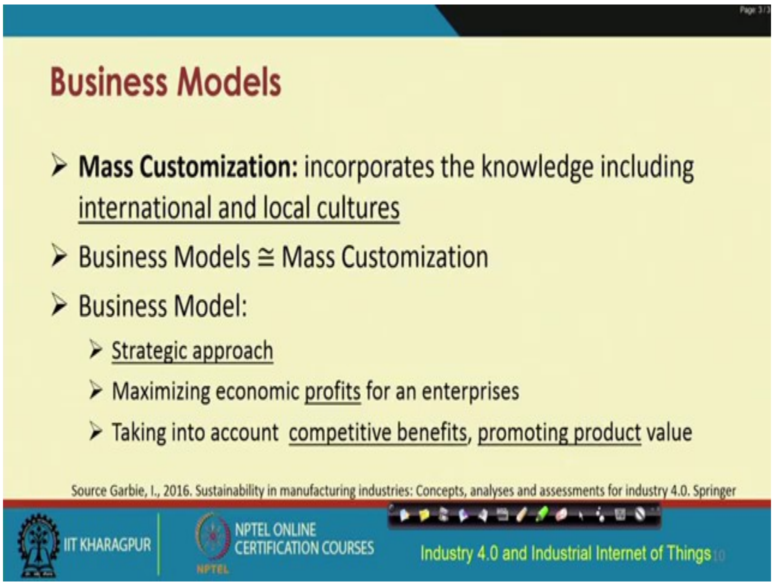


Business models: we need to think about business models which will be helpful for the greater society. So, it is required to have mass customization, which will incorporate the knowledge including the consideration of international culture across different countries, different societies, and so on and also the local culture where things have been introduced and produced first. So, business models basically have direct linkage with the mass customization. So, what is required is from the globalization point of view the product that is manufactured should not only cater to the needs of the local community, but also to the international community.

So, business models are to be developed which should take the strategic approach by considering the bigger issues the strategic issues; that means, high level issues for a particular organization business and the greater issues overall. It is also required to have the business model, which will maximize the economic profits for an enterprise by taking into account the competitive benefits and promoting the product value.

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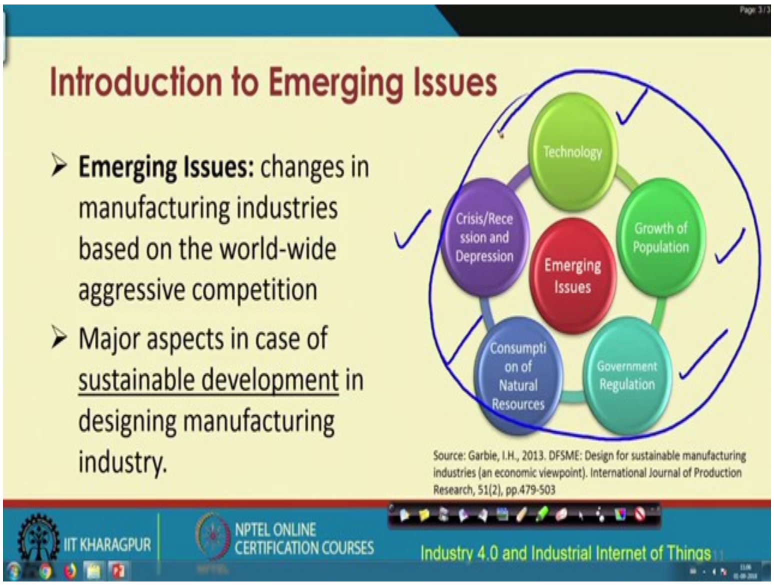


Emerging issues are also there like the globalization issues which also contribute to the sustainability factor. There are many of these emerging issues which contribute to such sustainability. One is technology, growth of population, government regulation, consumption of natural resources, and consideration of crisis, recession, and depression. These are the five different contributors to the to the sustainability factor from an emerging issue viewpoint.

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So, the first one is the technology. Technology considerations are very important. So, if we are talking about technology, let us say, technology broadly can be classified as hardware and software. Within hardware we have different types of technologies that are used commonly technologies such as computer. When we are talking about technology, we have the hardware technology and the software technologies.

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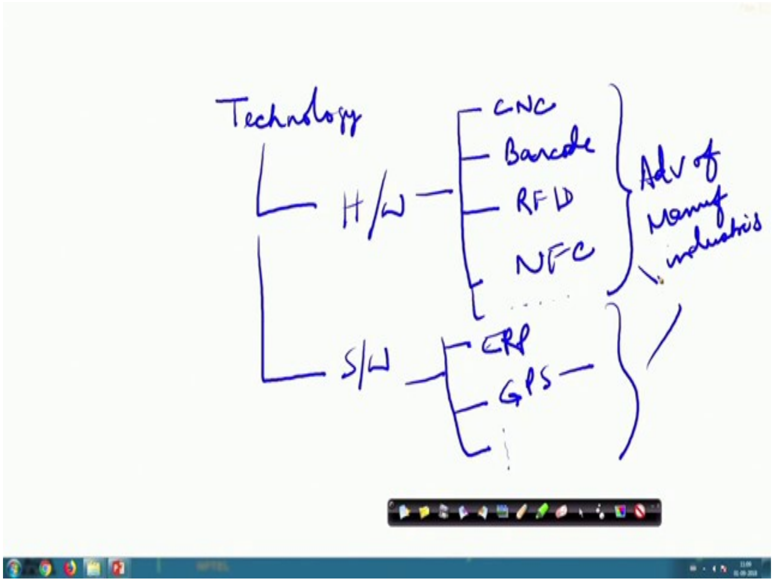


Within hardware we have different technologies in the manufacturing industries such as the computer numeric control machines, we have the barcodes, barcode base technology barcode, we have different technologies such as RFID, NFC, all of these are used quite widely and these are the technologies that have also contributed to the overall advancement of the manufacturing industries.

In terms of software, we have technologies such as ERP, the GPS-based software technologies. GPS itself is hardware, but the GPS-based software technologies and like this there are many other software technologies that have emerged and contributed to the advancement of manufacturing industries.

These are very important and what we need to ensure is that all these different newer technologies should be included in order to have better sustainability. Advancement in technology facilitates manufacturing with higher quality products, lower cost products and products which are manufactured in reduced time. So, these are very important. So, the quality of the product that is developed should be improved with the introduction of these newer technologies, then the cost of the production should be less, so that the overall product comes to the market at a reduced price and comes faster to the market, the production lifecycle should be reduced. So, there is reduced manufacturing time.

The role of technology advancement in the global market is about converting from the traditional system of manufacturing to the automated system. Technology can help in having greater agility, faster development, and flexible, changeable, maintainable products.

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In terms of government regulation, it is also required to be able to protect the public and the private sectors. It is required to protect the enterprises. So, for protecting the enterprises, different enterprises have their own different requirements, and those will have to be taken into consideration while arriving at different regulations and rules, which can help these organizations these enterprises to offer better services and low cost goods.

So, government regulation will help in basically avoiding unfair competition and also to promote sustainable environment considered development for everyone including the employees of the organization or the industry. Therefore, government regulations are very important.

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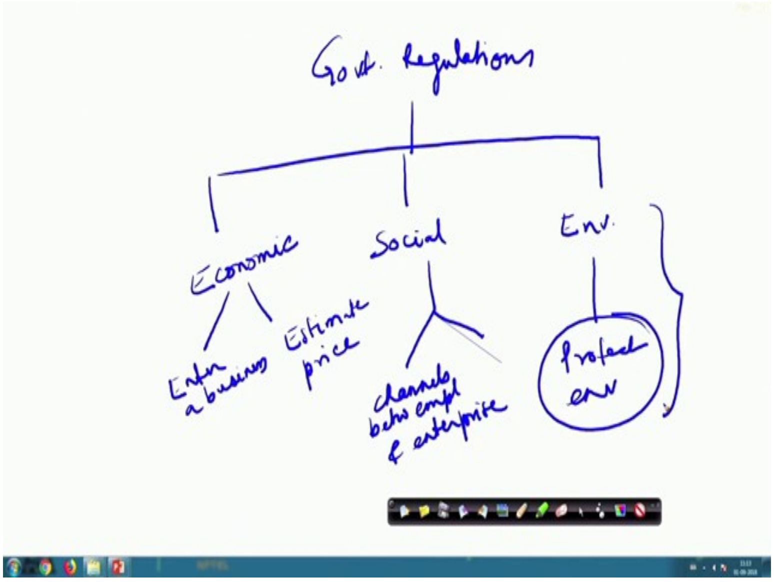


We are talking about government regulations, there are different considerations or the different types of regulations. Some of these regulations are basically having direct impact on the economic issues, some of them have considerations of the social issues, and some the environmental issues.

Economic issues talk about some of these regulations, when a business will enter, when an institution basically enters a business. Price estimations, there are government regulations typically, which will help in this price estimation. Then social issues, which will essentially help in opening channels between channels of communication, maybe between employees and the enterprise or the management and environmental issues will concern the protection of the environment.

Environmental issues are very important in the manufacturing process. Government regulations should be there to protect the environment, because if there is some kind of production process, which produces lot of waste and in turn harms the environment the water, the land, are full of different industrial wastes. There are government regulations, which talk about how to reduce these wastes and also the wastes that are produced will have to be handled properly.

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There are government regulations concerning employment, advertisement, labor – labor laws are there, environmental regulations are there, regulations concerning the safety of the workers, safety of everyone, health regulations are there, and privacy protection of individuals.

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Basically, the employment and labor rules represent laws concerning wages and salaries, things such as benefits to the workers in terms of retirement plans, compliance with health and safety issues, proper working conditions, issues of expatriate employees such as visas and so on. Equal opportunity in employment in terms of promotion and consideration of all workers from different ethnicity in the equal platform, provisioning of authority or higher ranking position; these are different types of classes of regulations that are typically there in any industry.

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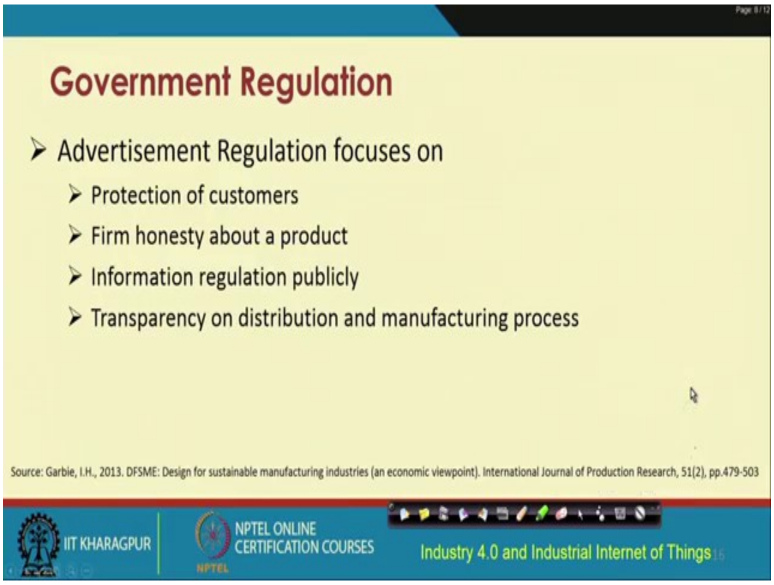


In terms of advertisement – advertisement regulations protect customers, firm honesty about a product, information regulation publicly, then transparency on distribution and manufacturing process.

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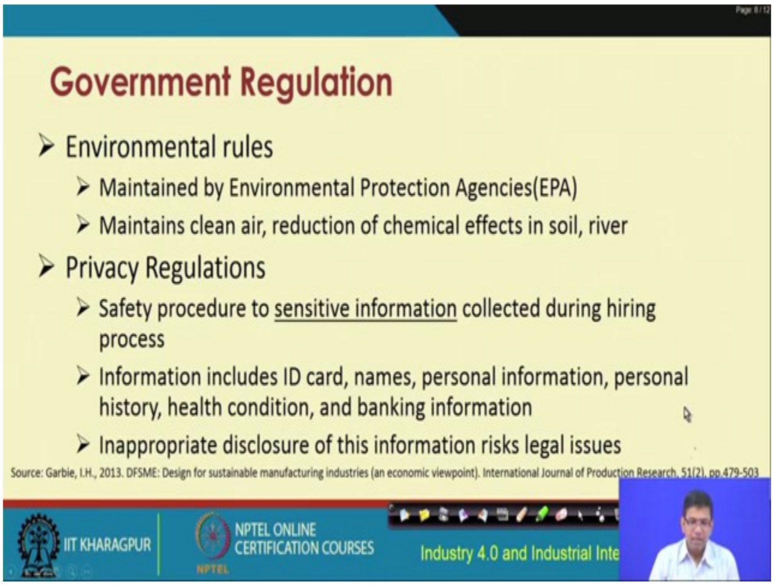

Environmental regulations or rules meant, are maintained by different acts, different agencies such as the environmental protection agency. Maintaining clean air, reduction of chemical effects in soil, river water of different water bodies, then privacy regulations concerned with the information of safety and security, particularly the sensitive information, that is collected about the different employees and the other stakeholders by a particular enterprise.

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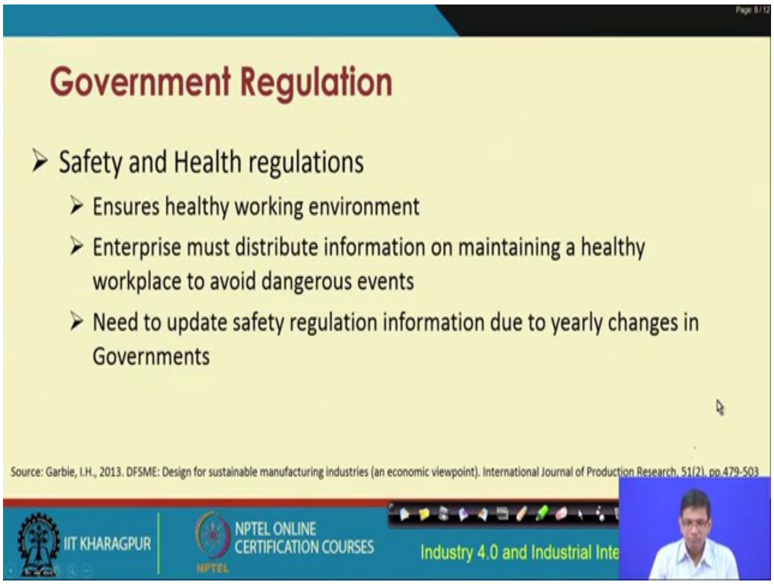


Safety and health regulations will concern the health issues providing healthy and working environment, overall safety, and workplace safety. These are the different types of government regulations.

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Population growth: monitoring population growth is important for manufacturing industry. It affects the industry growth, food supplies, fertility, sociology, economics politics, industry locations, and use of available lands.

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There are three different types of countries based on the population growth, developed countries then emerging countries, and developing economies.

So, the population growth of countries developing and disadvantage is typically greater than the population growth of the developed and advantaged countries.

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Based on the United Nations report the population growth is from 1950 to 2050, reduced between 32 percent to 13 percent in developed countries, increased between 8 to 20 percent in emerging and developing countries.

So, economic view on the population growth can be of two types: pessimistic view and optimistic view.

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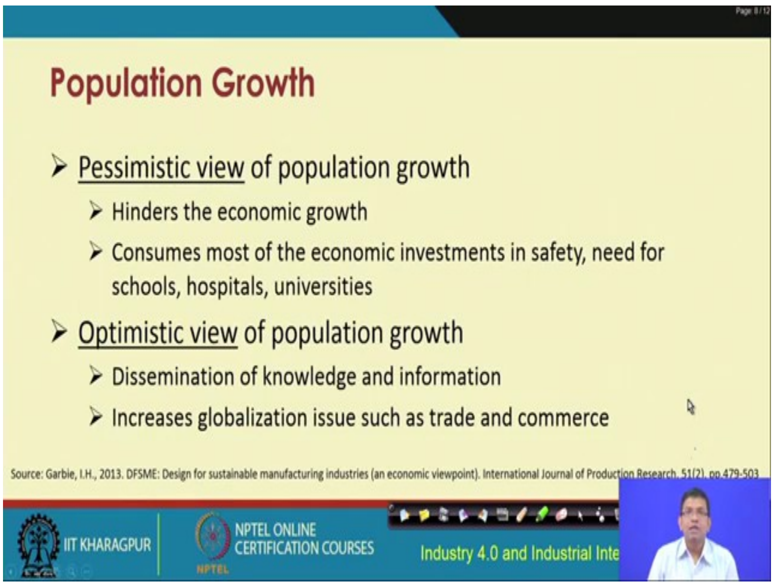


The pessimistic view of population growth basically effects the economic growth and the optimistic view basically on the contrary talks about increase of the globalization issues such as trade and commerce due to the growth of population. So, pessimistic view basically effects, hinders the overall economic growth, on the other hand, and the optimistic view on the other hand, basically, increases the globalization issues such as trade and commerce.

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Population growth is a very important consideration in terms of sustainability. So, basically, if the growth is not conformant with the overall growth of the economy then that will become a disaster for that particular economy.

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Then the last one is basically the consideration of economic crisis recession and depression. So, economic crisis basically takes place over a duration not more than a few months, so that is the crisis. Recession on the other hand, talks about the decline in the economic activity recession; that means slowdown of the economy, exponential decline happens.

When the economic activities again increase, then there will be commencement or the rise of the economy. So, basically from the recession, then there will be some kind of acceleration in terms of the growth.

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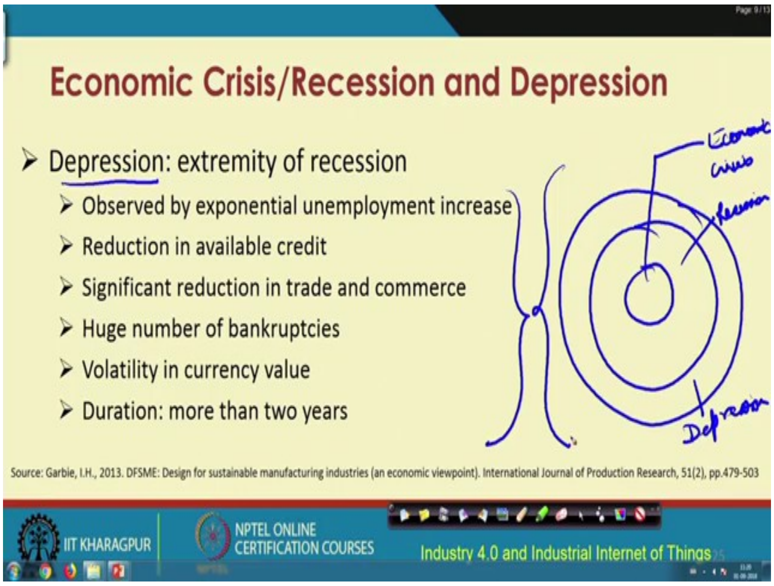


Depression is the extremity of recession, which is observed by exponential unemployment increase, reduction in available credit, significant reduction in trade and commerce and huge number of bankruptcies might also consequently happen and there is volatility in currency value and the duration is more than two years and this is basically the extreme case of recession.

So, we start with the economic crisis then that is that will take place for few months, then recession, a rapid slowdown of the economy and thereafter we have the depression. This depression basically is the extreme case of recession, where all of these things would happen.

So, let us now look at the view of each of these. So, basically if we talk about crisis so, let us say that this is the economic crisis. Then comes the recession phase, recession, and the next one is basically the depression. So, conceptually it would look like this.

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If there is economic crisis on recession, then there will be reduction in prices of different major commodities and what is important is to increase the productivity and reduce the overall cost that becomes the solution in such a case. So, it is very important to ensure and avoid this kind of crisis and recession as much as possible.

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In terms of consumption of natural resources this is one of the very biggest concerns, because that has impact on the sustainable development which is environment friendly. So, this is one of the biggest issues, in contrast, to economically sustainable development as natural resources are the main source of revenue in developing countries. It is one of the major sources of social conflicts. So, basically concerns about mining, extraction of oil and gas, demographic shifts, societal behavior, politics, technology, economic situations, difficult economic situations all of these are major contributors in terms of the consideration of natural resources.

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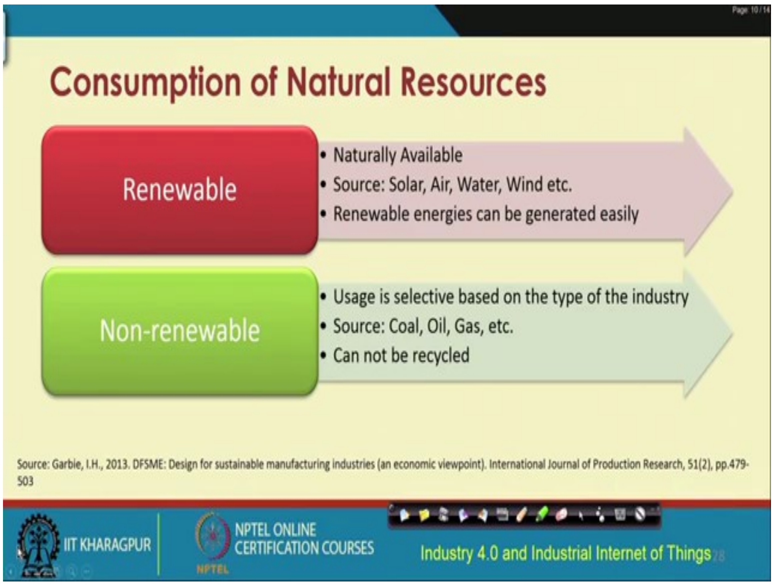


So, natural resources can be of two types, the renewable ones and the non-renewable ones. Coal, oil, gas, are the non-renewable examples of non-renewable sources of natural in energy and then solar, water, wind, are the examples of renewable sources of energy.

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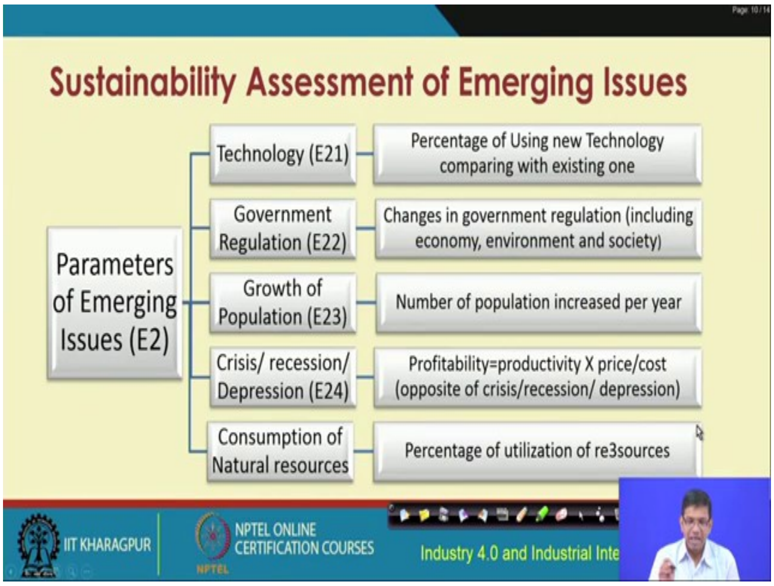


So, all of these things we have discussed because if you recall that we started with that formula S over SD.

So, for computing this S over SD, which is basically the sustainability factor we have gone through all of these different issues. Issues of technology, government regulation, growth of population, crisis, recession, depression, and consumption of natural resources, and they are corresponding things also we have understood that how these, what are these different issues and what are what is important for consideration of these different issues.

So, while we have understood all of these things we now need to basically look at this particular S over SD formula.

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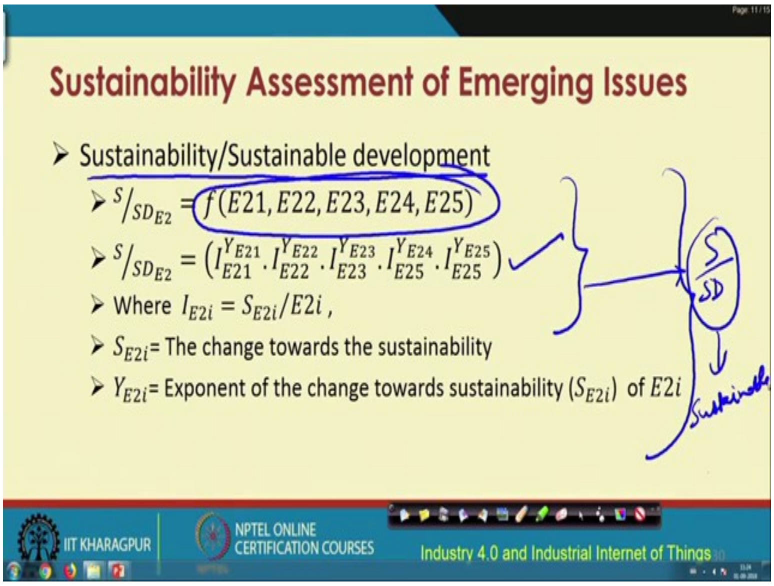


S over SD is basically sustainability over sustainable development and for this S over SD has all of it is a function of all these parameters, right. So, all these parameters that we have seen in the previous slide and so, this basically can be again rewritten as a function of all these is and where I equal to S over E and S is basically the change towards the sustainability and Y is basically the exponent of the change towards sustainability S of E.

So, this is basically the overall formula that we wanted to arrive at to start with we have looked at this S over SD formula and these are these different contributors to the different parameters that contribute to this computation of S over SD and this factor basically talks about whether a particular effort is sustainable or not.

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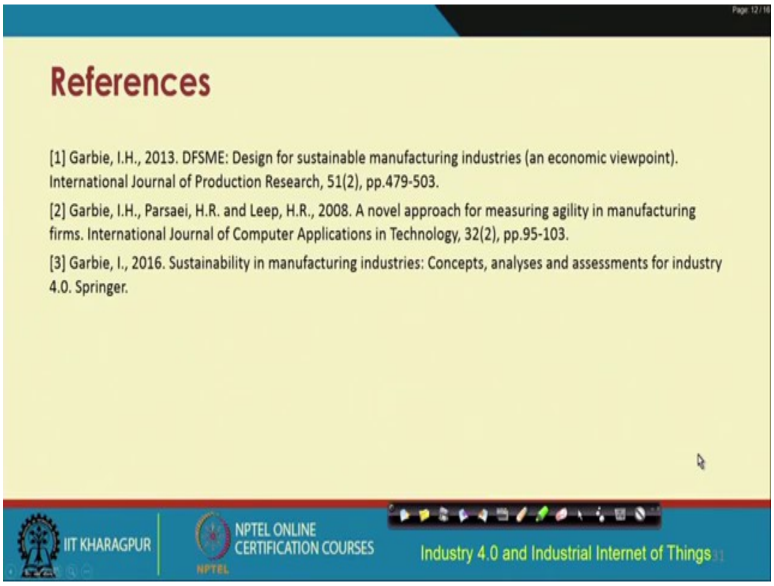


So, finally, these are some of these references that you could go through in order to understand these concepts, in greater detail.

Thank you.

**On Introduction to Industry 4.0 And Industrial Internet Of Things**
**Prof. Sudip Misra**
**Department of Computer Science and Engineering**
**Indian Institute of Technology, Kharagpur**

## Lecture - 08
## Industry 4.0: Lean Production System

We need to understand the sustainability issue that we have discussed in the previous lecture. There are different ways in the development of the product, the manufacturing of a product, it can be done in different ways. One of the considerations for sustainable development of a product is to have the adoption of lean production system. So, lean and thin production process should be adopted.

Therefore, we need to have a cheaper product of higher quality developed in reduced time. And in the consideration of lean, and ensuring that there is reduced waste disposal to the environment. Reduction in wastes is the prime consideration in the lean manufacturing process or lean production process.

The concept of lean basically has its origin in Japan. The major global automotive manufacturer, Toyota, adopted their own production of their own vehicles, a manufacturing process, which was known as the Toyota Production System, TPS. So, it was done only for within their company for basically having the advantages at the outset.

This became popular globally, for adoption across different industries concerned about manufacturing of different products. It become very popular to ensure that at the end you have a product of high quality, produced in reduced time, and is produced with minimal wastes. Wastes of all kinds not just the tangible wastes, but wastage of time, wastage of human resources. So, improving profits having higher quality products, produced in reduced time with reduced waste of resources is what is the overall goal of sustainability. And lean production contributes to this overall issue of sustainability.

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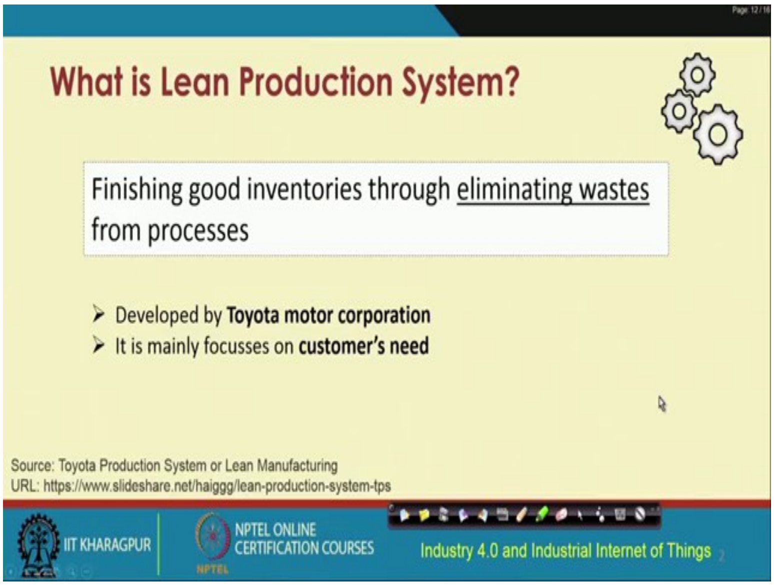


So, what is this lean production system? It is all about eliminating wastes from the processes, manufacturing processes in manufacturing industries for instance having higher quality products. So, it has its origin in the Toyota motor corporation company. This TPS or lean production system mainly focuses on addressing the customer's needs directly, which is key to this lean production process. Whatever the customer needs, eliminating the over usage of resources, use whatever resources are precisely required to eliminate all kinds of wastes, and finally produce a good which the customer basically would be satisfied in reduce time and having higher quality.

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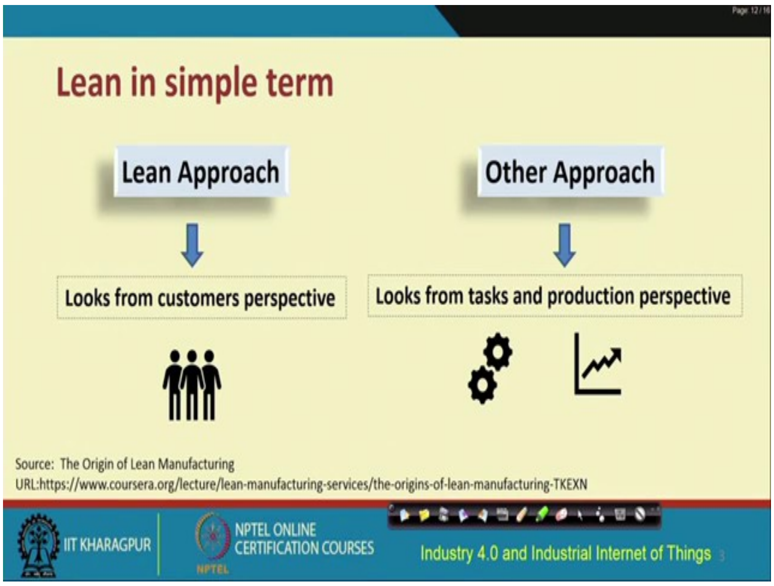

If you look at the comparison of lean approach versus other approaches, lean approach is basically look from the customers' perspective, whereas other approaches basically look from the task and production perspective. So, this fundamental difference between lean and the non-lean approaches.

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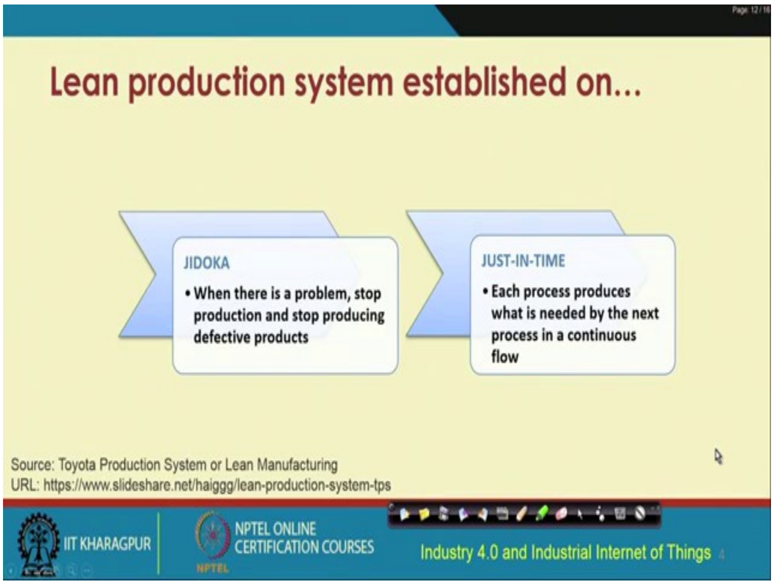


This lean production system has basically considerations of two different types of systems. One is the JIDOKA, which talks about that whenever there is a problem, problem of any kind with the machines, or in the process, or whatever be it. If there is a problem, stop the production, then and there, stop producing defective products in turn. So, this is this JIDOKA process.

And just-in-time basically talks about ensuring that each process produces whatever is exactly needed by the next process, in a continuous flow. JIT or just-in-time, is the short form, it is also known as popularly known as JIT. So, where each process produces what is needed by the next process in a continuous flow. There are different other components of this lean production process, such as the PPS, Toyota production system.

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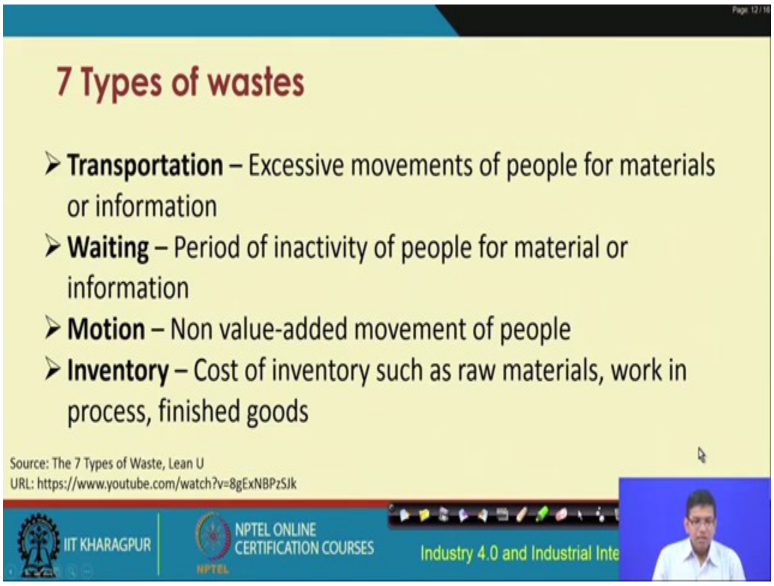


There are different types of wastes. And these wastes have to be minimized. So, these wastes are transportation wastes, which talks about excessive movement of people from materials or information. Transportation of different materials, transportation of information, in excess, that is not required. Second is the waiting, which is basically talking about the period of inactivity or people for material or information to arrive or to be able to use. It should not happen that the workers are waiting for something to arrive and the time gets wasted. So, this waiting has to be minimized.

Third form of waste is the motion, which is non value-added movement of people. Unnecessary movement of people from one point to another within the factory, outside the factory, across different locations of the same factory or organization, or between different organizations as the case may be. But whatever is required you should have only that kind of movement, non value-added movement should be reduced.

Inventory waste, which is the cost of inventory such as raw materials, work in progress, and finished goods. So, all of these things whatever inventory would be required should be used, and not unnecessary inventories should be used built up and procured.

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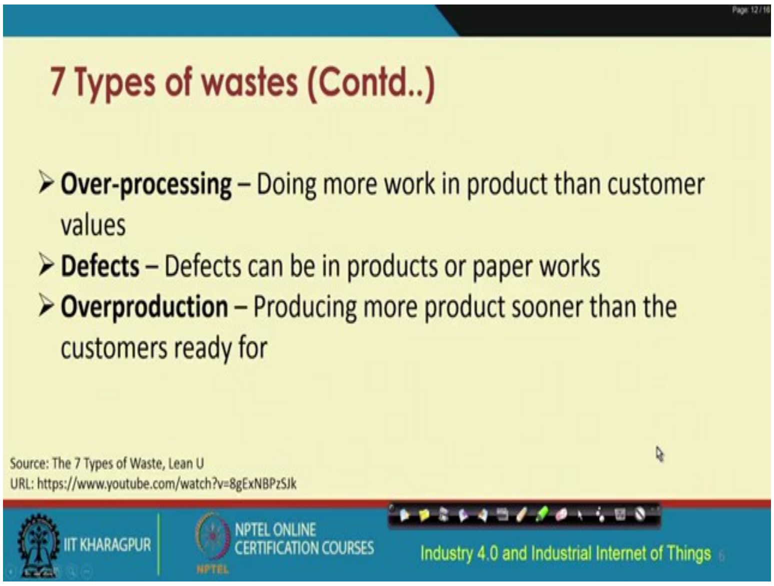


Over-processing - doing more work in the product, then whatever the customer finds value in. So, customer values, talks about what the customer needs precisely. And the production system should talk about only addressing the customers' needs. Producing exact product or the service that the customer needs, this is what has to be done. And over-processing doing more work for the product you know having different features, which customer will not need.

Defects can be in the product, in the service, in the process, or in the paper works. Defects of all kinds should be reduced. Overproduction - producing more product sooner than the customers' requirement, and that should be also reduced. So, these are the seven different forms of wastes.

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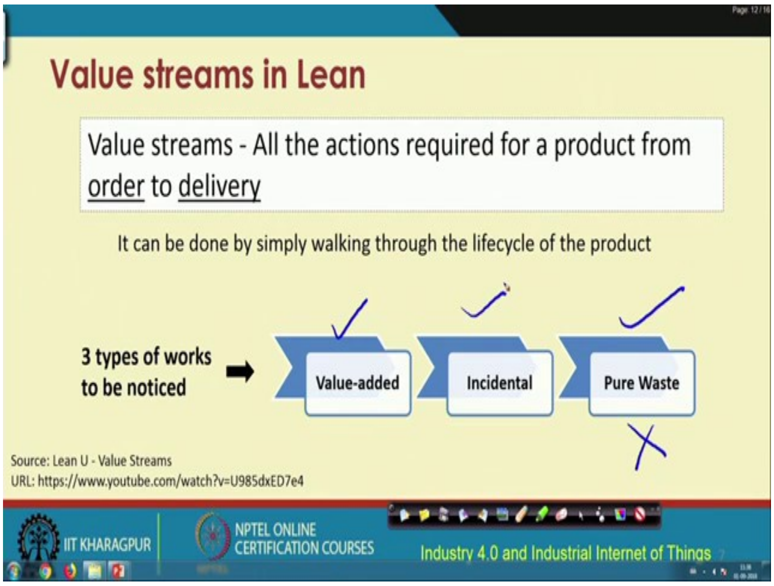


The overall lean system talks about this value streams. So, value streams are all the actions that are required for a product from order by the customer to the delivery of the product to the customer. And it is not just the product, it could be the service as well. So, starting from the ordering of the product or the service to the delivery of the product, the service is what the value stream basically talks about.

There are three types of works. One is value added; second is incidental, and pure waste. These are the different, which is very much desirable value added to the value stream, then pure waste is not desirable.

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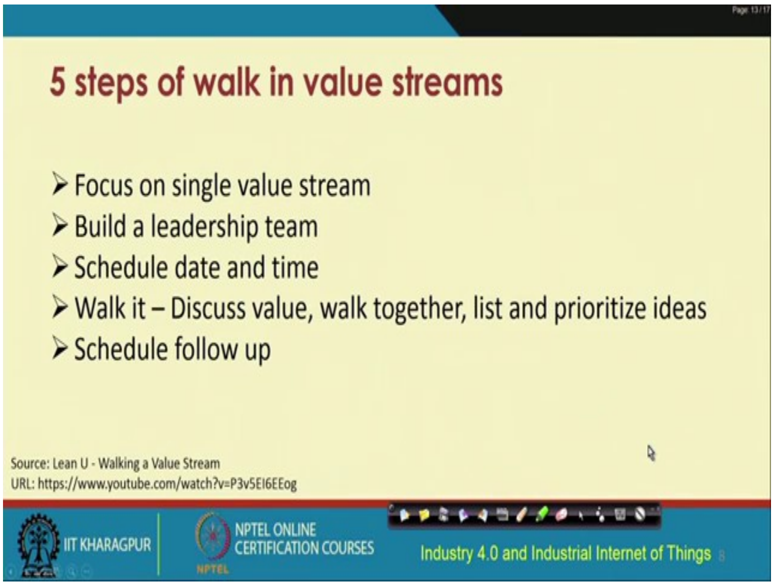


There are five steps of walk in the value streams. Focusing on a single value stream is very much desirable in building a leadership team. Scheduling the date and time properly for each, and everything whatever the customer needs. Walking it, that means, discuss the value, value in terms of the customer requirements, precise customer requirements, discussing the value of those walking together with all stakeholders, with the customer, listing, prioritizing ideas, and doing everything together what is desirable in terms of offering the value to the customer. Schedule follow up is the last one. These are the five steps of work in the value streams.

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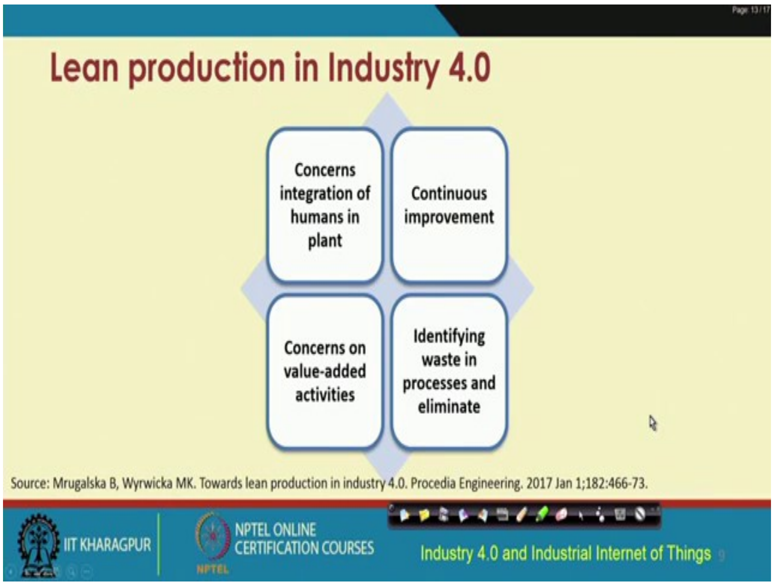

In the context of Industry 4.0, lean production is paramount; it is something very important. This lean production talks about four different considerations. Concerns about the integration of humans in the plant, continuous input improvement, value added activities, identifying waste in the processes, and eliminating them, as soon as possible, in an environment friendly manner.

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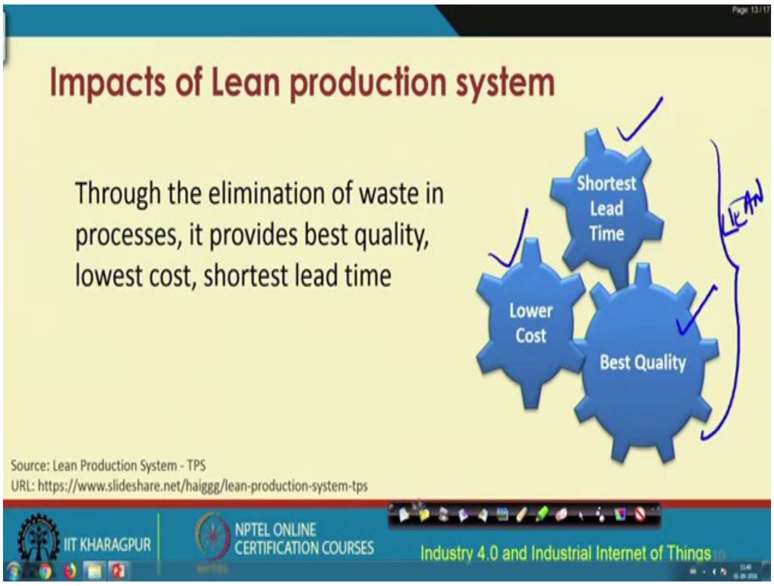


The impact of lean production system in terms of offering what is going to happen if you adopt this lean production system. You are going to have products of best quality, produced in lower cost, and with shortest time of production. These are the three different impacts of production using lean.

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Implementation of lean leads to the implementation of the full manufacturing system. It does not focus on just the adoption of the lean tools, but also it focuses on different other areas such as business requirements, operation improvement, operation of everything, operation of the machinery, operation of the product being developed, operation of the processes. So, overall production process, production operations of the overall production process, people management, and performance governance.

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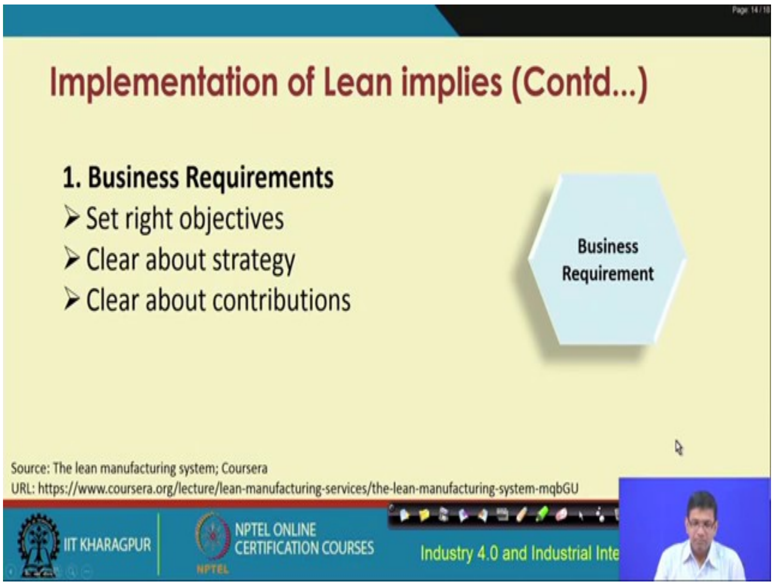

So, implementation of lean has different requirements. First is the business requirements, which talks about setting the right objectives. Clearing the strategy completely from a business point of view; business strategy should be clarified.

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Second, the performance management dimension in terms of lean implementation. Here, we are talking about people management, use of different KPIs to assess. KPIs means key performance indicators, so use of these different KPIs to assess the performance in the production process. Consideration of top-down management and we are talking about the use of KPIs to measure the performance in terms of productivity, quality of the goods and products, cost of delivery, cost of production, delivery time, and safety. These are the different performance attributes or the KPIs that have to be considered from a performance management viewpoint, in the lean production system.

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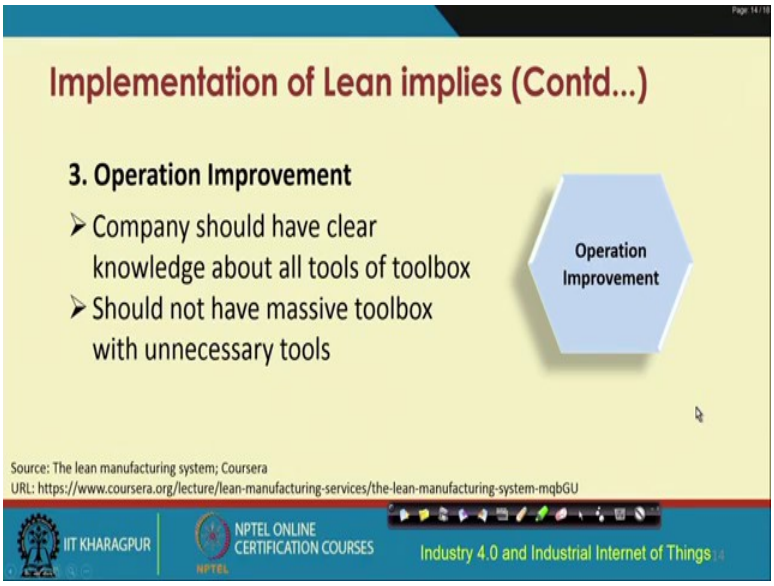


Operation improvement should have clear knowledge about all tools of the toolbox, and should not have massive toolbox with unnecessary tools. Then minimize the wastage in terms of all different resources, and overall improve the operations.

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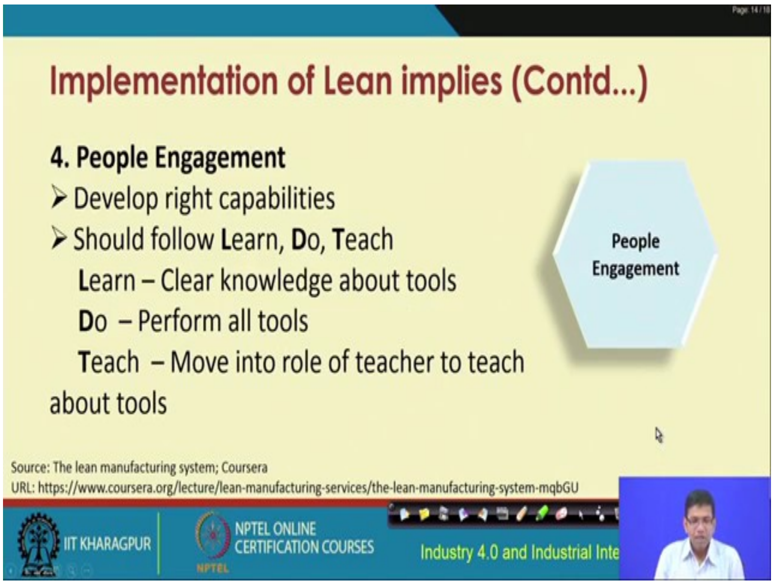


The other dimension of a lean production is basically people engagement. And as this name says it basically to ensure that people, the constant stakeholders are all engaged, and follow these different objectives learn, do, teach. Learn means having clear knowledge about the tools; do means perform, all the tools you know act with all the tools that are available, and teach into the role of a teacher about these different tools. So, engaging all these peoples in these three different directions is also very important.

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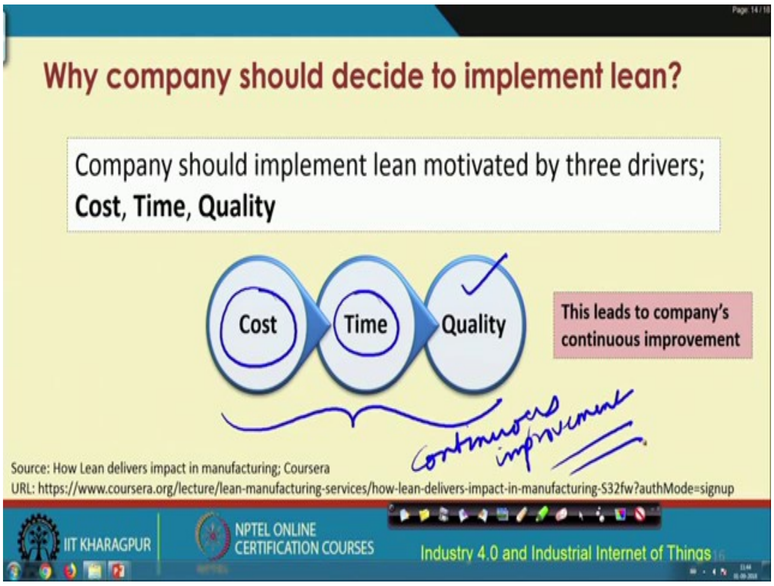


This is basically we have been talking from the starting. So, basically to reduce the cost, the time of production, and to improve the quality, would be the contributors to the overall continuous improvement, continuous improvement, in the manufacturing process.

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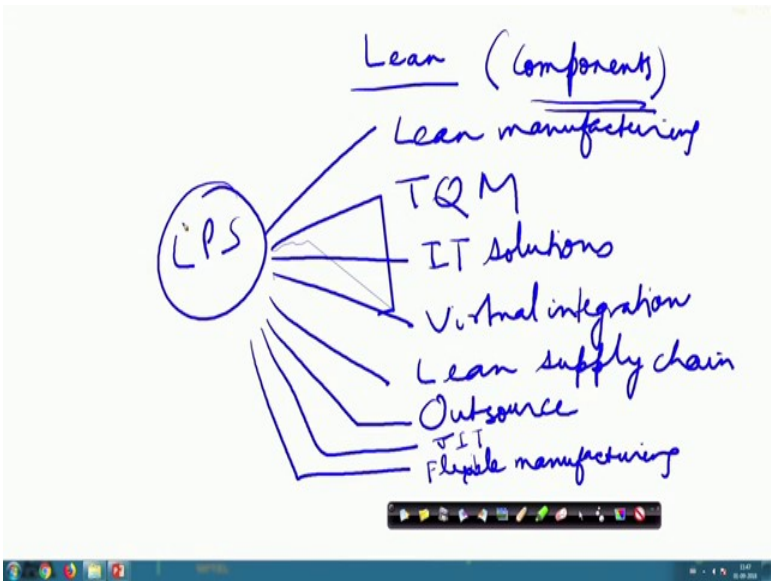


So, let us now look at it from another direction, holistically, what lean is all about. If we are talking about the lean production system, it is required to have these different components of the lean production system, lean manufacturing, adopting lean manufacturing methods, ensuring total quality management, and adoption of it solutions to improve the overall production, reduce time, improve upon everything, virtual integration of different machinery, and have a lean supply chain.

If required as much as possible to outsource some parts of the product or the components, as the case, may be if it is cheaper and can be done faster by some experts, who have more expertise in developing those components. And just-in-time is the another one that I have already mentioned before adopting just-in-time concepts, and having flexible manufacturing. These are the different components of the lean production process, lean production system.

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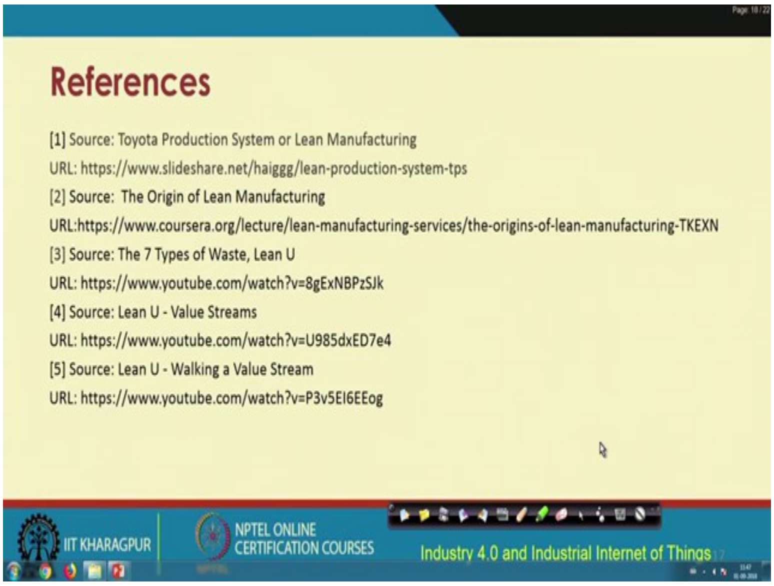


So, here are the references that you could go through in order to have further understanding about whatever we have covered with respect to lean production system, lean production process, and lean manufacturing.

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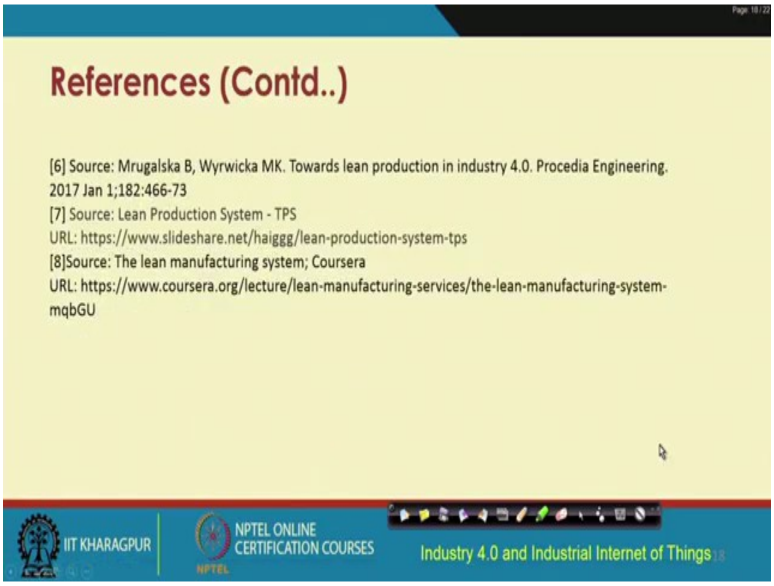


Thank you.

**Introduction to Industry 4.0 and Industrial Internet of things**
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**Department of Computer Science and Engineering**
**Indian Institute of Technology, Kharagpur**

**Lecture - 09**
**Industry 4.0: Smart and Connected Business Perspective**

Another very important aspect of Industry 4.0 is the business perspective; the Smart and Connected Business Perspective. From a business point of view, looking at the smartness and connectivity that we have been talking about in the context of Industry 4.0; trying to look deeper into these different issues concerning it.

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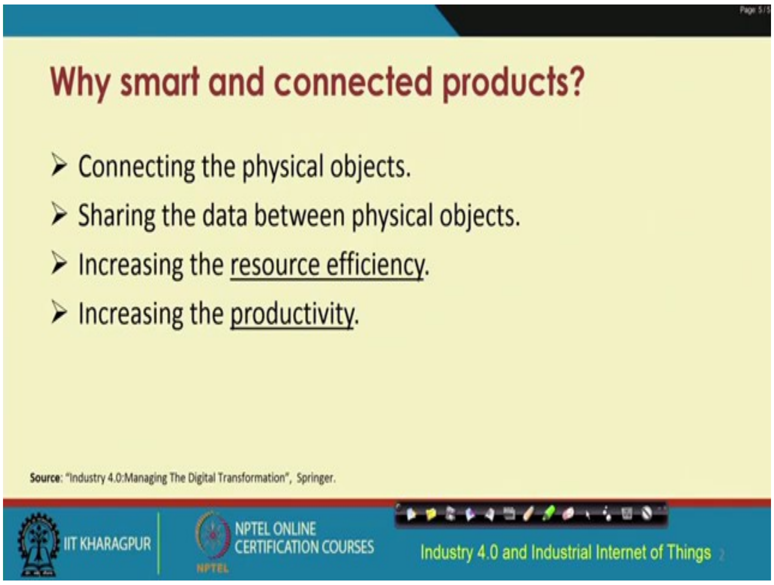


First of all, the question is that we have been talking about that in industry 4.0; we need this connectivity, connected machinery, connectivity everywhere, sensing connectivity, and so on.

So, the question is that why do we need this kind of connected products, what is so good about it? Why we want to transform ourselves from whatever we were doing in the past to connected products? Why do we need connectivity between these different products this machinery? Why at all we need to make these machineries smarter?

First of all, this connectivity is required in order to connect these physical objects, different machines in the industries. The second thing is that it is very important to collect these different data from these physical objects and share between themselves between themselves and also share the data through some network to elsewhere where it is going to be analyzed.

So, this connectivity is essentially going to be required, because through this connectivity and smart perspective; we are going to increase the overall resource efficiency. Overall efficiency is going to be increased in terms of resource consumption, resource utilization, and improves the overall productivity in the manufacturing process.

So, improved resource efficiency, improved productivity, are the reasons why we need to take smart and connected business perspective.

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So, what are the benefits once again? Faster we are going to have these products manufactured at a faster rate than before it was being done in the past without the use of IoT-centric solutions.

Cheaper products are going to be developed; these products will be used in a better way through the incorporation of these smart solutions. Improved recall process of the product, it happens that certain product will have to be recalled right by the industry. So, that recall process is a very complex process and hard to track. This recall process can be improved with the incorporation of smart and smartness and connectivity. Decreased environmental impact is the other one and finally, improved supply chain; smart supply chain, these are the different benefits of having smart and connected products.

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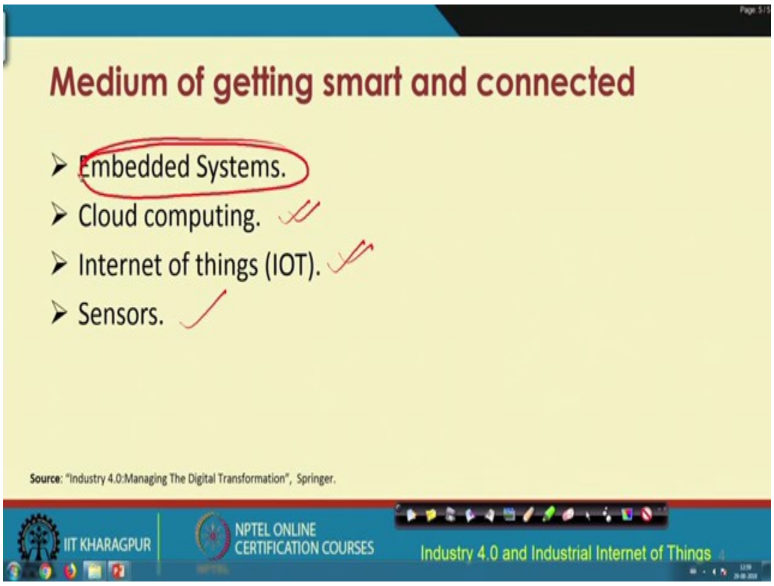


The medium of getting smart and connected are the use of sensors, the core of making smarter systems. Sensors are associated with the actuators, all these sensors and actuators will make these systems smarter. In IoT the network is important; cloud is also important, because lot of data are coming in, who is going to process the data; huge amount of data to handle.

So, cloud is going to handle so much of data in terms of storage, in terms of processing and so on. And this is the most important of all embedded systems. By the help of these embedded systems, fitting all of these different objects, the physical objects with different embedded devices, which again will have sensors communication device; so all of these are going to be embedded into each of these physical objects.

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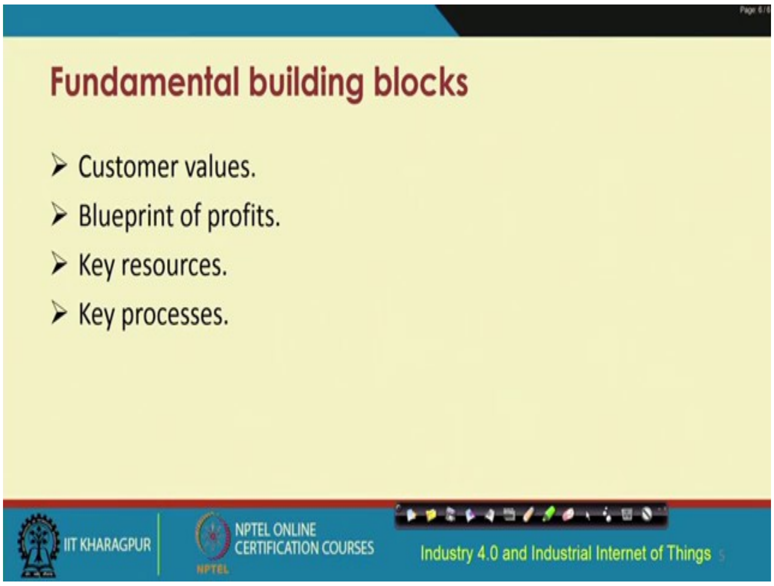


These are the fundamental building blocks for smartness and connectivity. Number one is the customer values, blueprint of profits; key resources and key processes. Customer values are about the value proposition. So, value proposition means like through the incorporation of all of these things that we are talking about; the smartness, IoT sensors, actuators whatever how the product is going to be improved; in terms of usage. From a customer viewpoint, how the product has improved, what is the value proposition and the services that the product offers; how these services are going to be improved, what is the overall value proposition.

Next thing is the blueprint of the profits. The smartness and connectivity is going to help in coming up with a blueprint for improving the profit. The efficiency of the key resources in the companies, industrial processes, manufacturing process will have to be improved, they will have to be tracked and optimized over time. And same thing goes for these different key processes as well.

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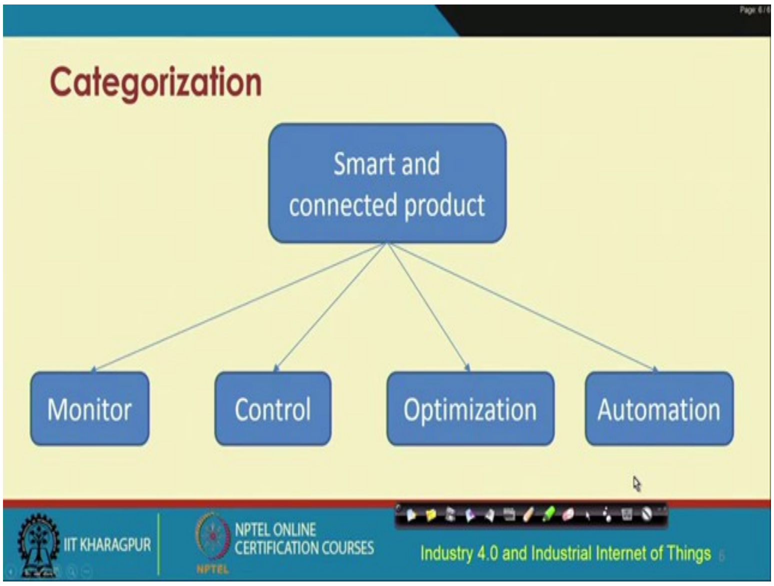


The next thing is that; what are the different categories of these smart and connected products; monitor, control, optimization, and automation; these are these different categories of smart and connected products. So, monitoring, control, optimization, and automation these are the ones, that are self-understood.

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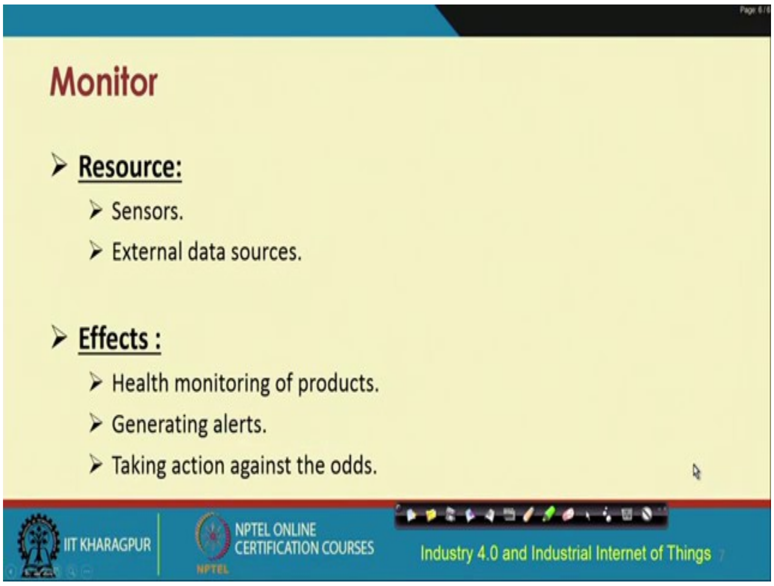


Monitoring the resources; resources such as sensors, sensor-equipped resources such as this machinery and monitoring the external data sources, these are important; so monitoring of all kinds of different resources and also the monitoring of the effects through the use of these different resources.

The effects such as the health monitoring of this machinery, health monitoring of the products; if something has gone down, if something is likely to increase the downtime in the future generating alerts, beforehand, is also something that will help in improving the overall efficiency. So, this is another effect and taking action against the odds; this is also the third effect in terms of monitoring.

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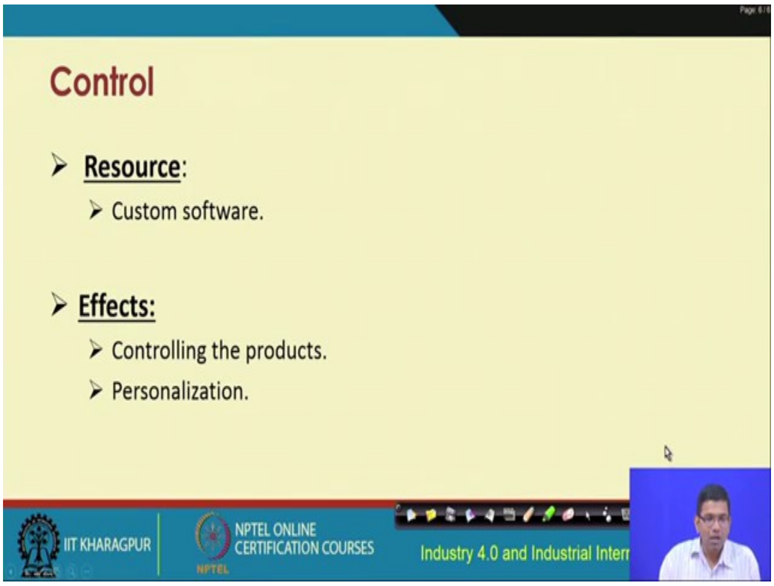


Control of these resources through the use of different custom designed, software or different other software used for the resource control optimization. And optimization of these resources through the use of these different software, this software can help in the optimization process and the effects; controlling the products and the personalization of the products based on the different requirements of the end-users.

We are discussing about the use of different optimization solutions and different algorithms. The effect is to increase or enhance the overall performance of the system, machinery, enabling remote services, and assisting in repairing the product.

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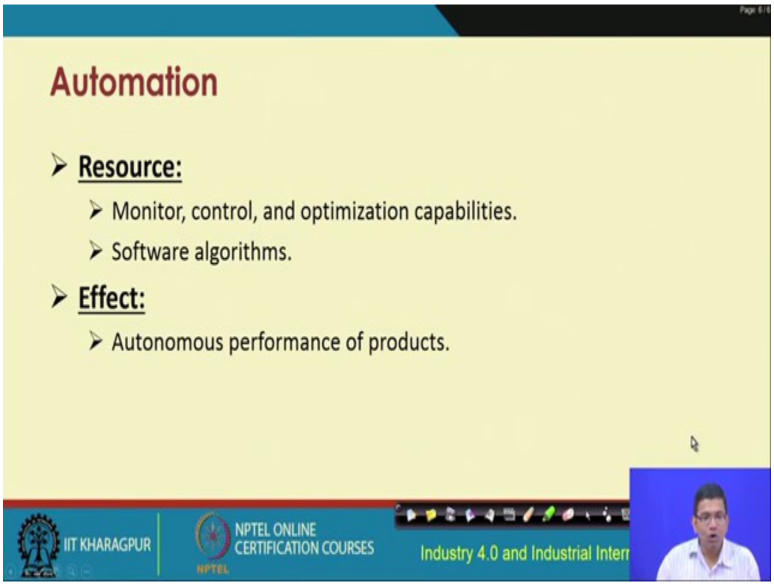


Automation of these resources, monitoring, control, and optimization capabilities, different software algorithms will have to be used for the automation, and the effect is having autonomous performance of these different products.

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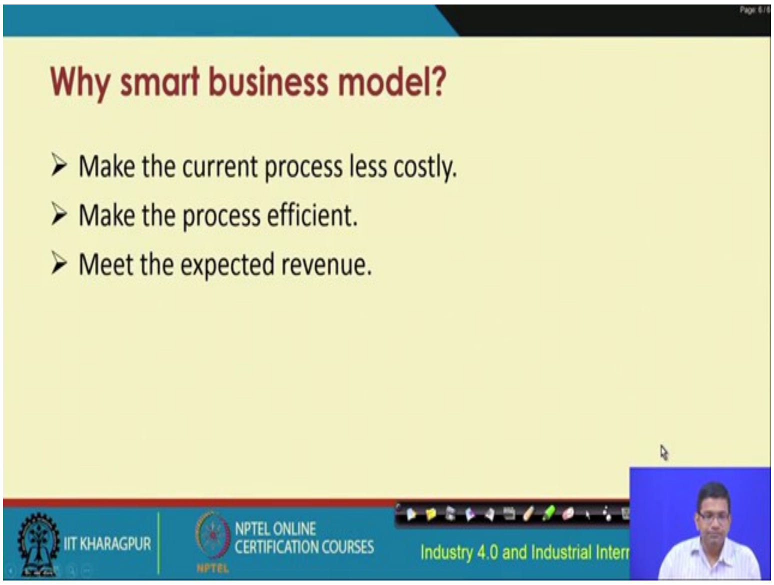


Smart systems from a business perspective, is very important. So, what is this business model? What is the smart business model? Why at all we need this smart business model?

So, we need the smart business model in order to make the current processes less costly, more efficient, and to improve upon the receiving of increased revenue. So, you need to achieve the expected revenue plus, to have some surplus that is also required often. So, you need to have a smart business model, that is, that will help in reducing the overall process cost, making the processes more efficient and meeting the expected revenue and in fact, exceeding the expected revenue.

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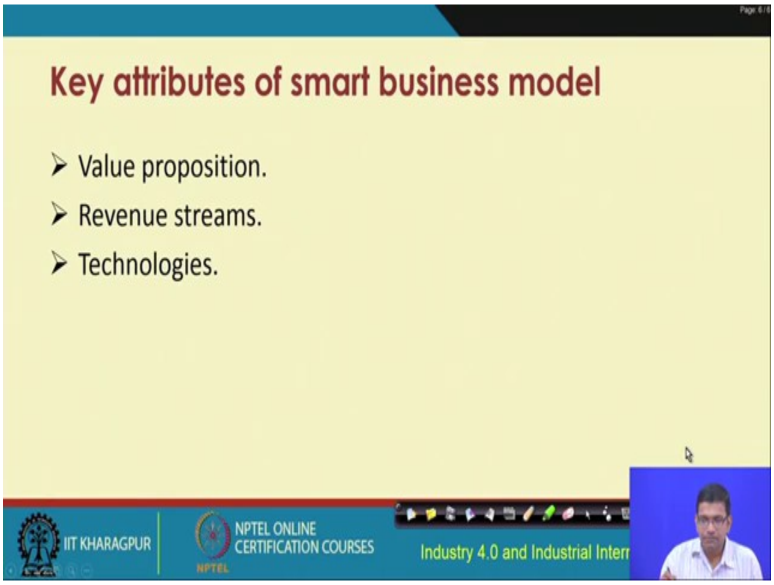


So, these are some of the key attributes of the smart business model value proposition, which I have talked a lot earlier. So, what value it is going to have to the customers in terms of the product and the services it is offering to the customer; value proposition. This is the first key attribute when you are trying to come up with a smart business model. Revenue stream means like what are the different sources of the revenues that are coming in, what are the different sources that from different sources the revenue can come for helping in the manufacturing process or undertaking a particular project.

So, what are the different sources of the revenues that is the revenue stream and finally, that revenue is going to be used in order to help in the manufacturing process; incurring the different costs. So, that is the revenue stream and the different technologies that are going to be used are the three different key attributes of a smart business model.

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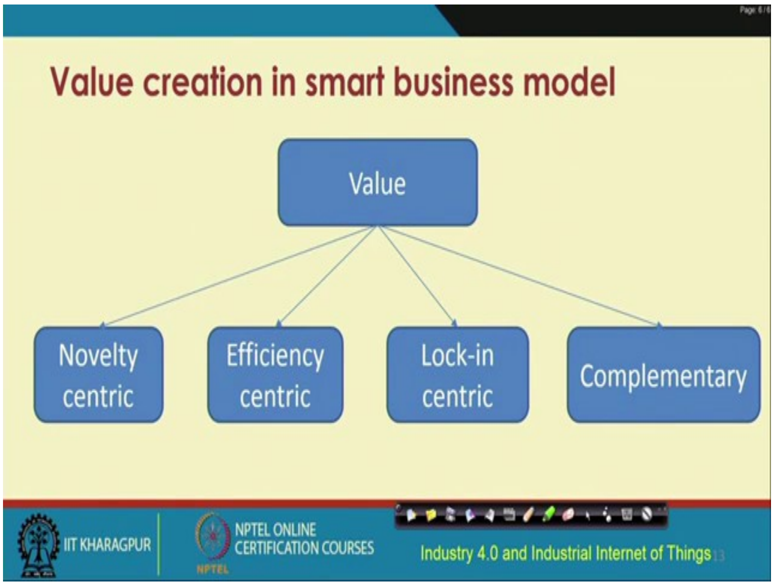


If we are talking about the value creation in a smart business model, there are different perspectives, different aspects, that will need to be understood.

One is the novelty centricity, second is the efficiency centricity, lock-in-centricity, and the complementarity; these are the four different perspectives that will need to be understood.

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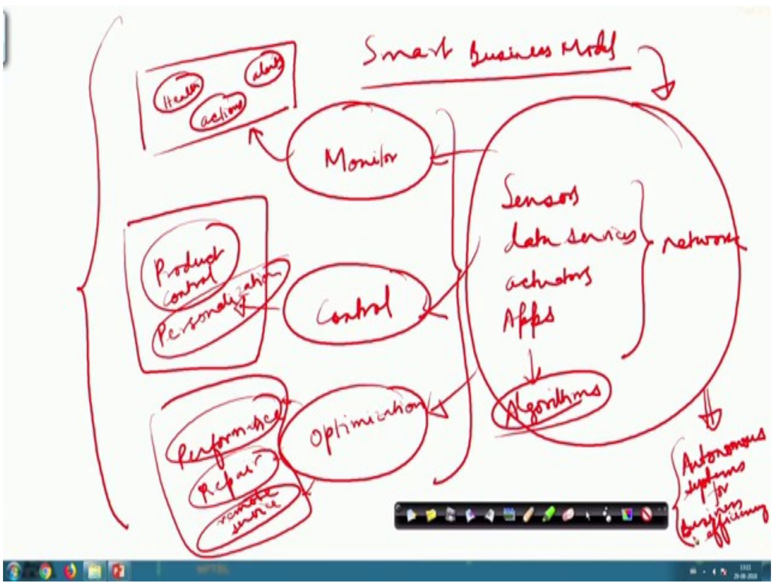

So, what is important is to monitor in a smart business model; if you have to come up with a smart business model. These are the key things that; we have seen we need to monitor, we need to have a control mechanism, and have some optimization.

We have things like monitoring the health of the machines. So, health of the machines, taking some actions, offering different alerts; then, for control we have what? Control of the product; personalization, so based on the custom requirements, this kind of control and personalization can be done. We have the optimization; here through the use of different optimization algorithms, we want to improve the performance of the system the process and so on performance, and then product repair, and also remote service.

This is one thing; so all of these things can be done with the help of what? What is the backbone? The backbone is use of different sensors, data services, actuators and in fact, the different applications and the network. One very important thing I have not mentioned is the algorithms, the different algorithms that can help in achieving all of these. Algorithms for monitoring, control algorithms, and optimization.

So, we need to come up with something like this; the business model, a smart business model that can help achieve this overall thing that we have talked about. So, a smart business model will need to take into consideration all of these different things. Why do we need a smart business model? Because in order to improve upon the efficiency, productivity, and essentially will help in achieving autonomous systems for improving business efficiency.

We were looking into the value aspect the value proposition where we have seen there is this novelty aspect, efficiency, lock-in, and complementarity, these are the different value creation aspects in a smart business model.

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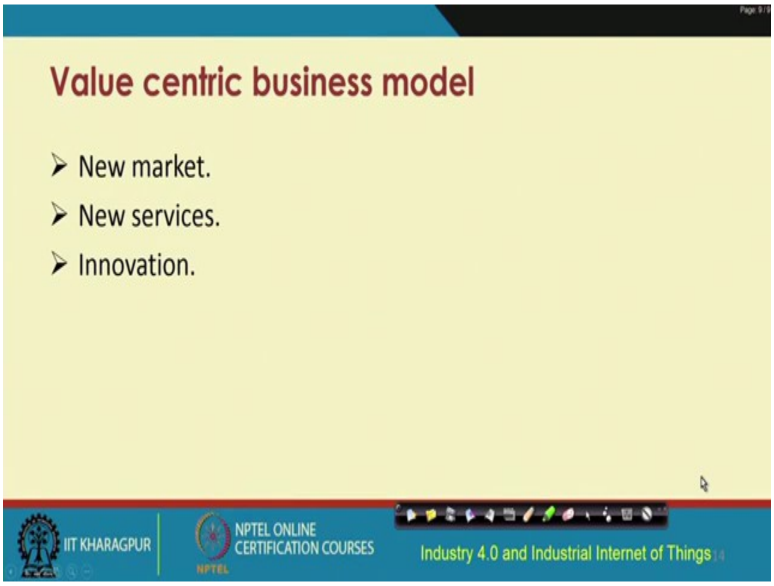


We need to have a value-centric business model, which the customers find to be useful to be of value to the customers. This kind of value-centric business model will open up new markets, new services will give solutions, which are innovative, new, which we are not there before customers find it useful exciting, so that is the value centricity.

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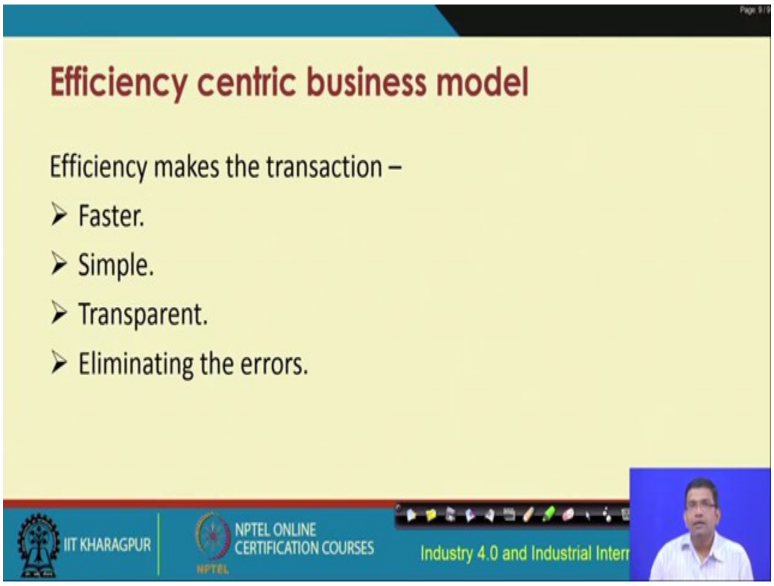


Next thing is the efficiency; efficiency in terms of improving the products, faster productivity, simpler production processes, transparent production processes, which will eliminate errors or reduce the number of errors from occurring; overall efficiency centricity.

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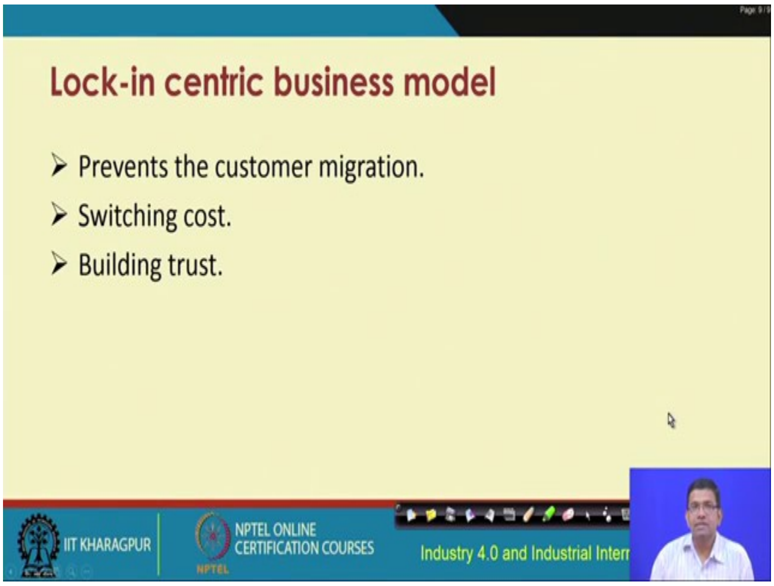


Lock-in centric business model prevents the customer from migration. There will be a lock in time period during which the customers will not migrate from one vendor to another. This will help in reducing the switching cost and improves building the trust between these different customers, suppliers or the vendors.

Complementary business model talks about things such as the product and services, online and offline assets, technologies, activities all these different complementary things, which are required in order to come up with the smart business model.

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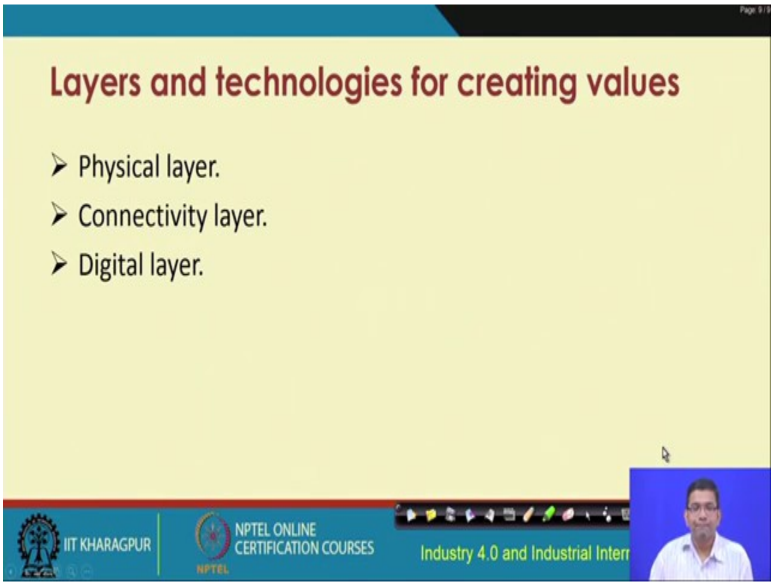


So, what are the layers and technologies that will help in creating values? Number one is the physical layer, second is the connectivity layer, and the third is the digital layer.

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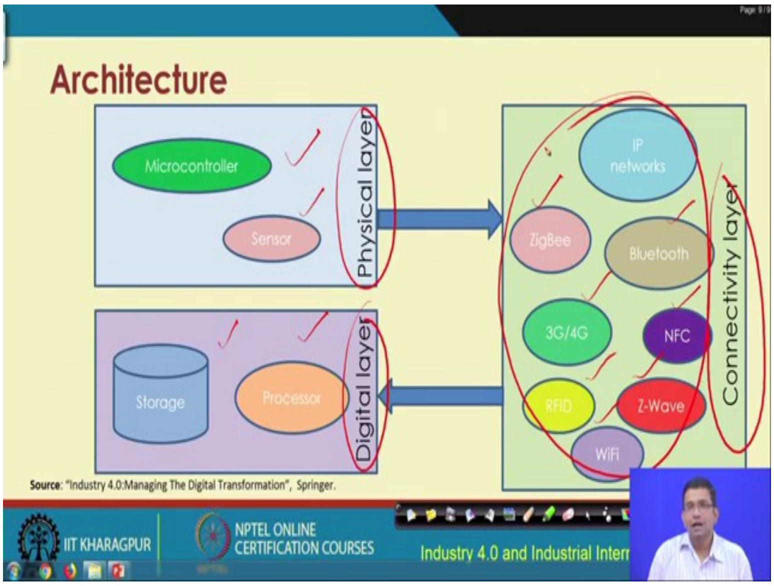


This is the overall architecture that can help in this thing and these are the different components in it; we have the physical layer, digital layer, and connectivity layer.

So, in each of these layers-we are talking about sensors, microcontrollers; digital layer we are talking about processors, which can help in execution of these different algorithms the in the processes overall the functionalities, that will have to be implemented. So, all of these things are taken care of in the digital layer by the processor.

The storage means the storage of these data. And in terms of connectivity all these different technologies ZigBee, Bluetooth, 3G, 4G, NFC, RFID, Z-Wave, Wi-Fi; is the basic introduction component of this course, all of these are the constituents of the connectivity layer. These are the three layers in the overall architecture.

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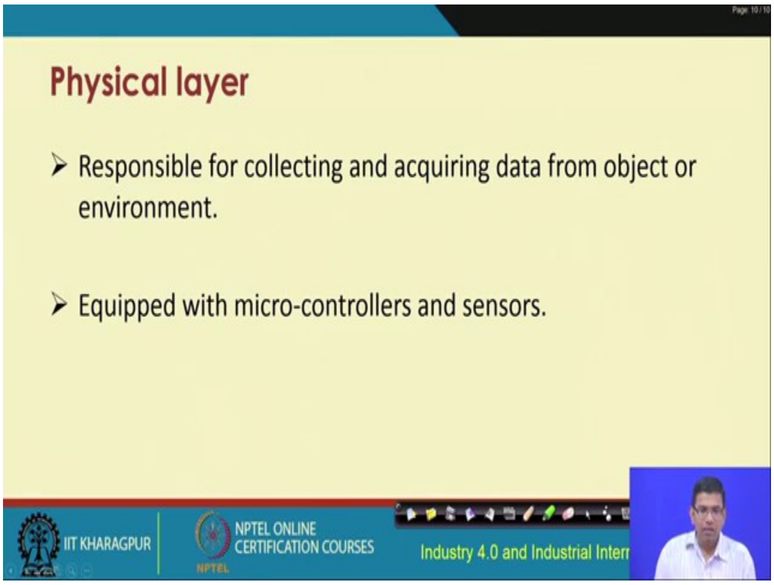


The physical layer is responsible for collecting and acquiring data with the help of sensors and are equipped with different microcontrollers and microprocessors.

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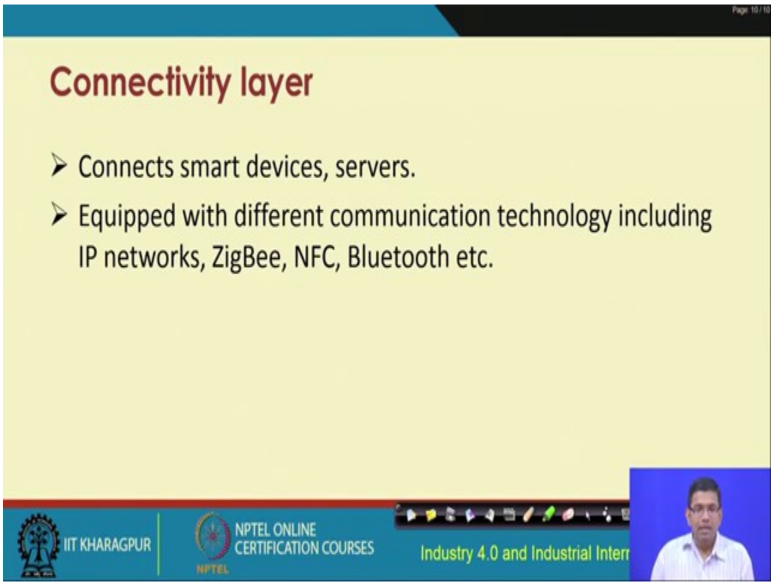


Connectivity layer talks about the overall connectivity, smart devices, smart services, using different connectivity technologies such as IP networks, ZigBee, NFC, and Bluetooth.

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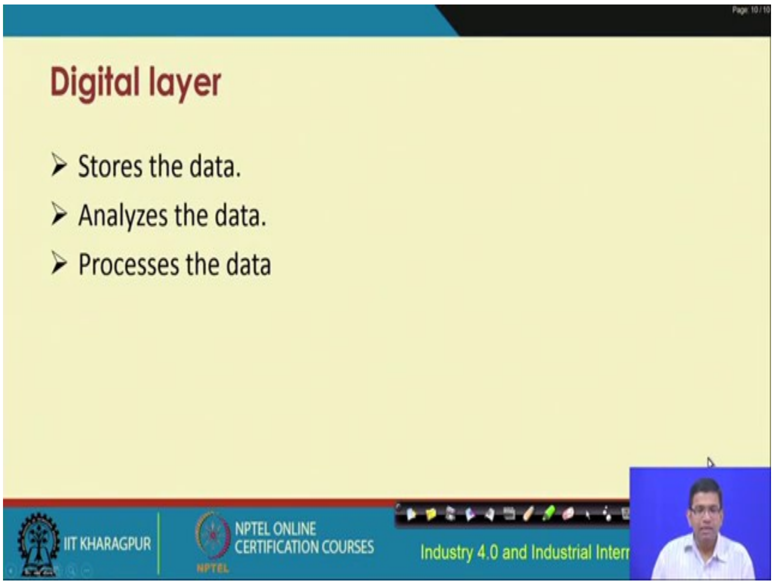


Digital layers talks about storing the data analyzing the data processing the data and so on.

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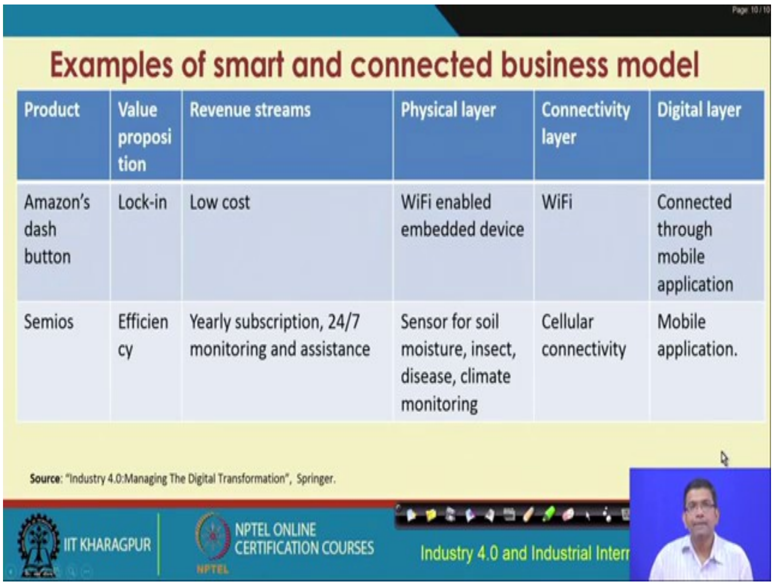


So, here are two examples of smart and connected business model; one is the Amazon's dash button, where the value proposition is the lock-in value proposition, the revenue streams are low cost revenue streams. Physical layer is equipped with Wi-Fi enabled embedded devices, connectivity layer is Wi-Fi enabled and the digital layer is connected through mobile applications.

Similarly, we have the other product the Semios, which talks about improving the efficiency overall, the value proposition is efficiency in improving the efficiency. The revenue streams are through yearly subscriptions 24X7 monitoring and assistance; the physical layer constitutes of sensors for soil moisture, insect, disease, climate monitoring and so on. The connectivity layer is cellular and the digital layer consists of different mobile applications. These are the two examples of smart and connected business models being implemented, in practice.

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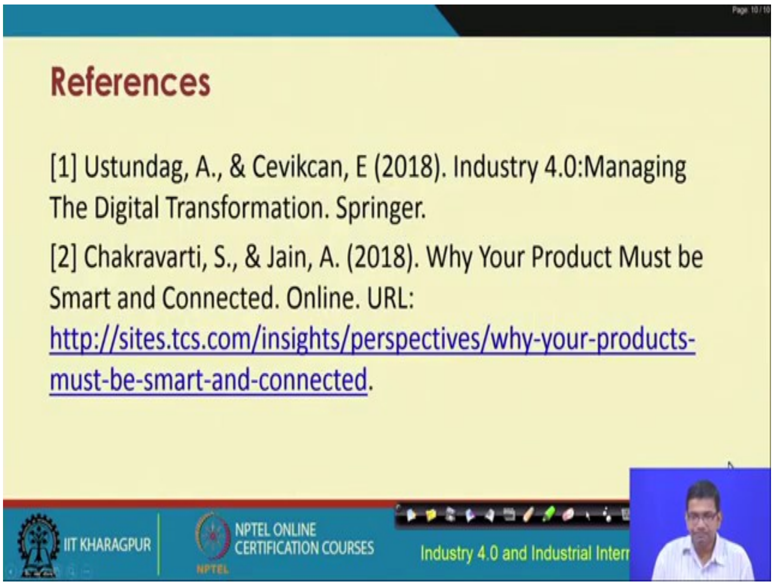


So, these are again some of the references.

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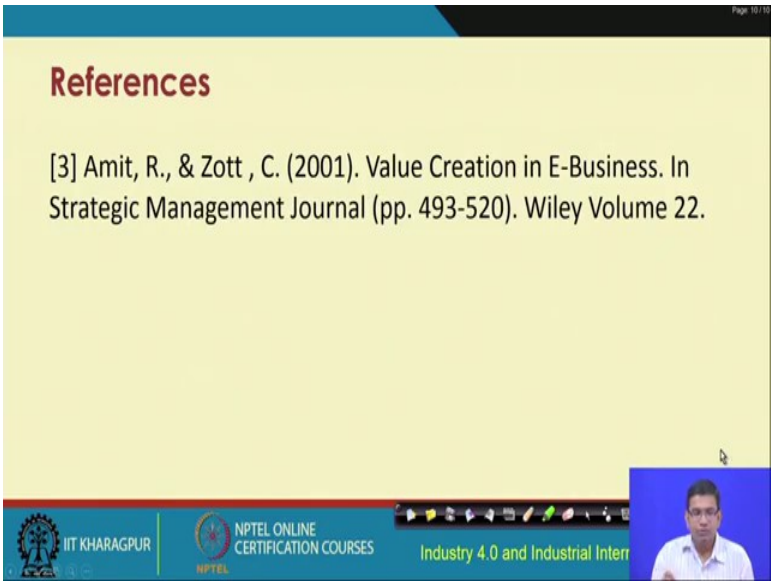


This lecture covers the concepts that are very important to understand the overall business perspective of why at all we need to do, whatever we intend to do; that means, transform towards industry 4.0.

We intend to transform towards industry 4.0, through the incorporation of all these smart devices and so on. We want to transition towards making everything smart by, but the question is that why at all we need to make smart? What is the value proposition? From a business perspective; what are the the things that are going to be improved through this kind of adoption, transformation from the traditional to the smarter ones through a connected one, and this is what we have discussed in this particular lecture.

So, understanding these things are very essential for the building of the industry 4.0. And this needs to be also educated to the industry workforce, who needs to get into this transformation to industry 4.0. Because until this value proposition and the use of all of these things the transformation is understood by the workforce; they will not be able to do this transformation, they will not be able to appreciate this transformation, and because of which the entire exercise might fail.

With this we stop over here and these lectures will these the concepts, that we have covered in this lecture will help in further understanding of the later lectures, that we are going to cover in this course.

Thank you.

**Introduction to Industry 4.0 and Industrial Internet of things**
**Prof. Sudip Misra**
**Department of Computer Science and Engineering**
**Indian Institute of Technology, Kharagpur**

**Lecture – 10**
**Industry 4.0: Smart Factories**

Smart Factory is a term that is used commonly in the context of Industry 4.0 revolution. People are talking about making smart factories in the industries. So, existing factory, factory operations, processes, products everything being made smarter, but then we need to understand that what smart factory is all about.

So, there are different definitions of smart factory that is available. Let us look at one such definition of smart factory.

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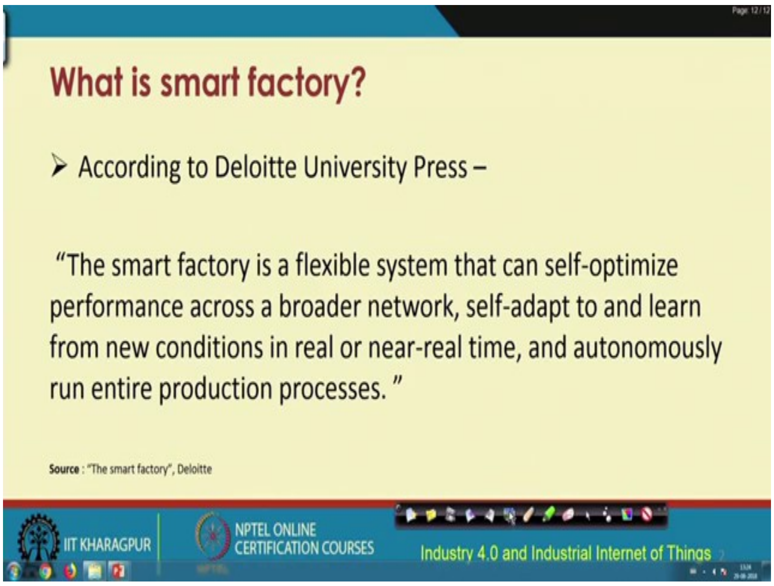


So, smart factory as per this definition, "The smart factory is a flexible system. It is a flexible system, that can self optimize the performance across a broader network and self adapt and learn from the new conditions in real or near real time and autonomously run the production processes". There are different aspects that are captured over here through this very good definition of smart factory, what are these different aspects. It is a flexible system; we need to have a system, which can be changed easily. If you need to introduce certain things in an existing process, the system should be flexible enough in order to incorporate in order to help in incorporating that particular change.

Self-optimizing the performance over time when the system is performing, this smart factory or some component of it in a smart factory is able to optimize its performance over time. As you can understand, realize based on whatever we have gone through in the previous lectures, this concept can be achieved, implemented with the help of incorporation of different algorithms; algorithms that can estimate how much the performance is going to be of a particular machine or a process in the future and then optimizing its performance. This is going to self-optimize the performance across the broader network. So, a network it has to be there, which will help in the process and self-adapting to the different conditions, which are coming in real time or non-real time, and automate autonomously running the different industrial processes, the production processes.

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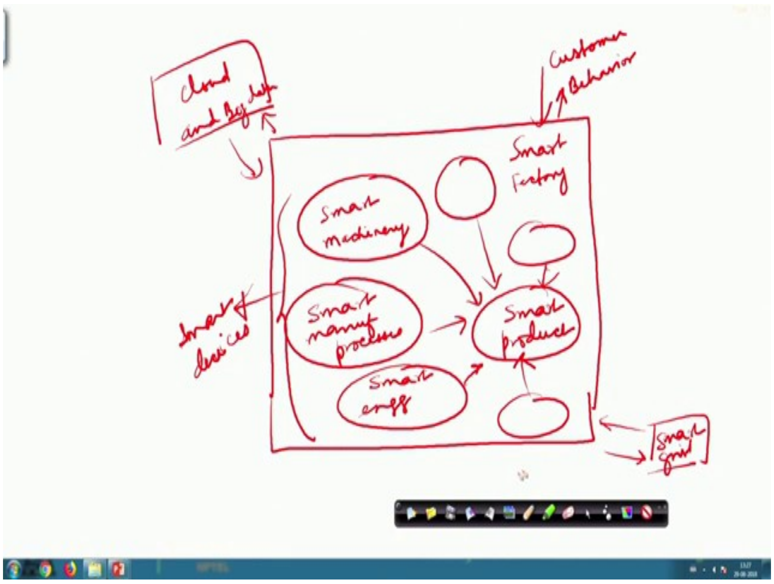


So, let us before getting into all of these things let us first try to understand this smart factory concept in little bit more detail. Let us say that we want to build a smart factory right.

So, what are the different components of it? We need to have smart machinery, smart manufacturing processes, smart engineering solutions, and these can help in arriving at the smart product. So, for all of these in order to make them smarter, we need to use smart devices. So, this is a smart factory and there are there could be few other things that you might be able to identify, which can help in making the product smarter.

Then we are talking about this interaction. This is the smart factory and the different interactions in terms of the customer behavior, interactions with the customer, the behavior of the customers on the factory, in the system. Smart grid is very important in terms of the energy management and another thing such as when we are talking about any kind of smartness, we have to deal with the analytics; cloud and big data.

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And try to understand the different other aspects. So, why at all we need to have smart factories? Why at all we need to have smart factories? In order to evolve our technologies, the market is highly competitive nowadays. If you have smarter machineries, smarter processes, smarter systems overall, it is quite likely through the use of these systems you are going to have improved productivity, efficiency, improved monitoring of this machinery, and reduce the down time. This will help in improving the competitiveness in the market. In order to deal with this competitiveness, we need to have the smart factories and high amount of production, within minimum timeline and this is quite self-understood.

The last one is very important is reducing the risk of failure, which will affect the productivity. So, reducing the risk of failure can be achieved through the use of smart factories.

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So, what are the advantages of running smart factories? Reducing the overall cost, cost of production; increasing the efficiency of productivity, efficiency of the product, that is being done that is being manufactured, improving the efficiency of the surfaces, efficiency of the production processes can also be improved. So, overall efficiency in all different terms can be achieved with the help of incorporation or transitioning to smart factories.

Improving the quality, improving the predictability of different things like the health of the machine; in the future predicting the health of the machine, predicting whether a fault can happen in the future, improving the safety of the machinery, and the overall safety of the workers in the factories.

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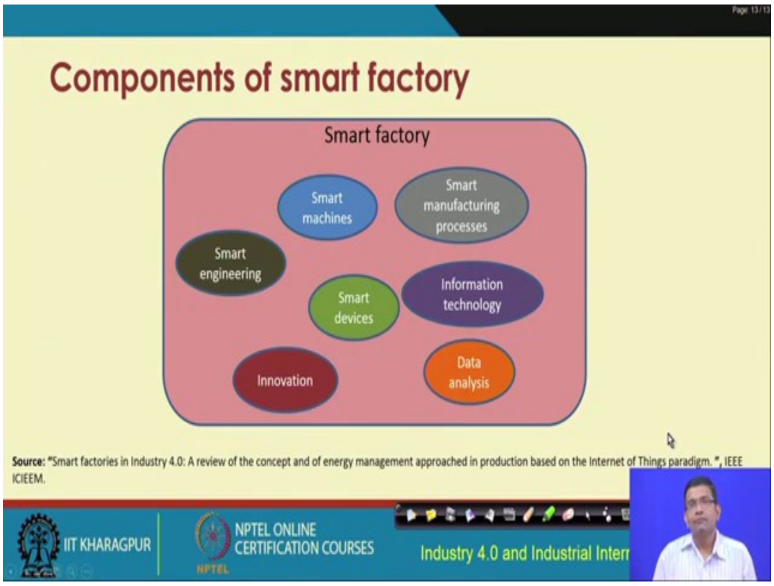


These are the different components of the smart factory, smart machines, smart engineering, smart devices, smart manufacturing process, then three things improving upon the innovation whatever was existing innovating the product, processes and all these things can be done with the help of information technology. Information technology can help in making the overall factory smart. So, this is a very important component, IT, use of IT in the factories can help in making the companies, the factory smart and the data analytics. The data of all these smart factories are the factories when you are incorporating IoT solution, sensors and actuators; they will throw in lot of data which will have to be analyzed in order to make them smarter.

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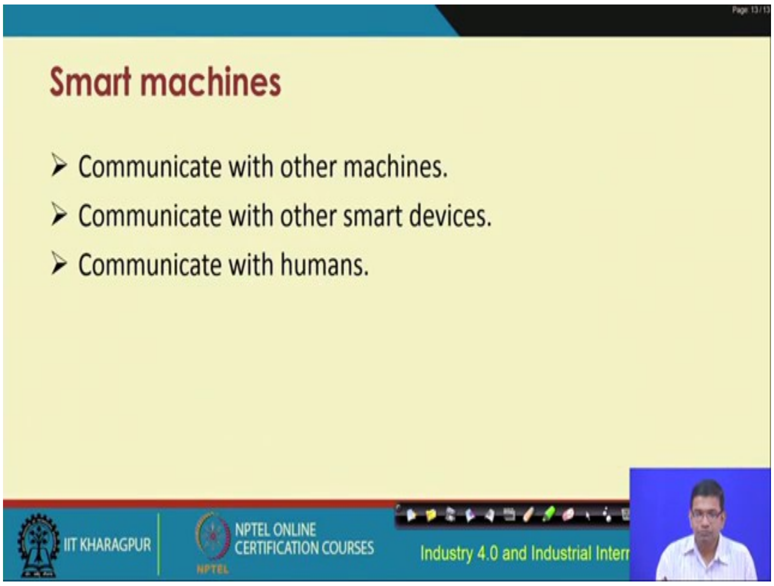


Smart machines help in communicating with other machines, communicating with other smart devices, and with humans.

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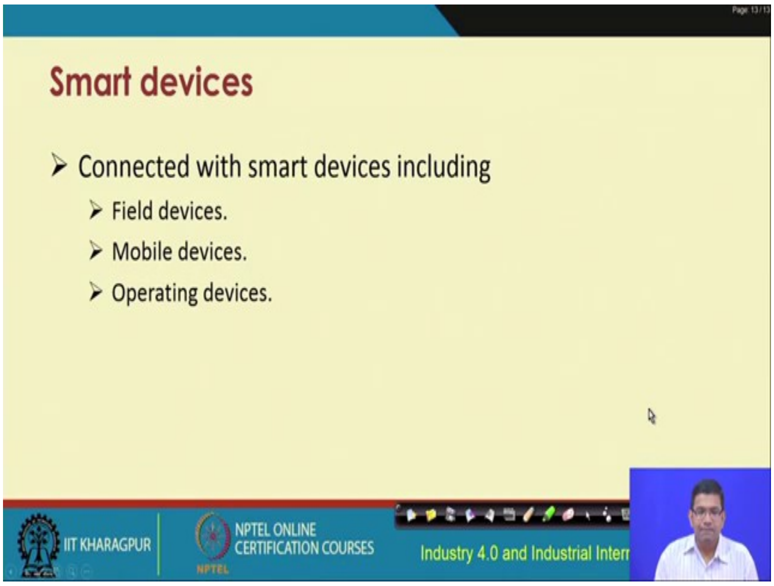


The smart devices will be connected. They will be connected between themselves and other field devices, other mobile devices, that are operating. So, this connectivity issue is very vital in the context of smart devices. Smart manufacturing process talks about the dynamism in the manufacturing. So, taking care of dynamic changes in requirements. So, autonomic autonomously the manufacturing is going to be done, without any human intervention.

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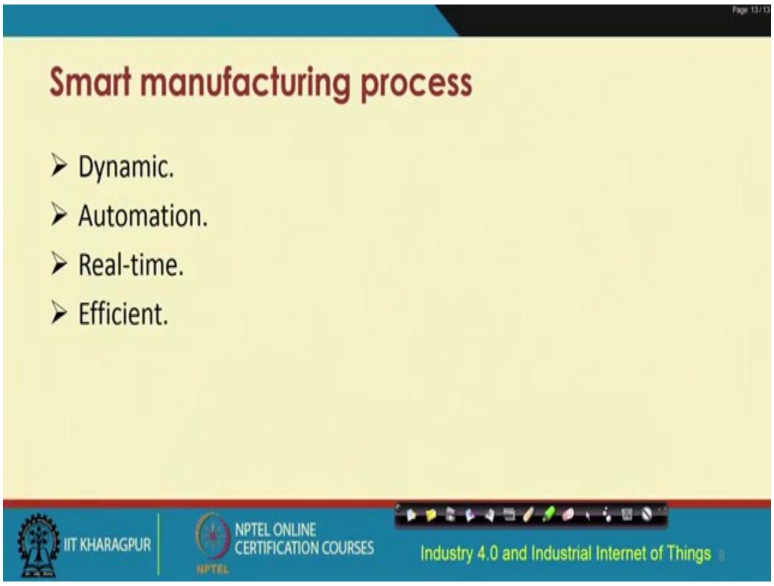


Real timeliness is very important; efficiency is very important; thus, all of these help in having smart manufacturing processes.

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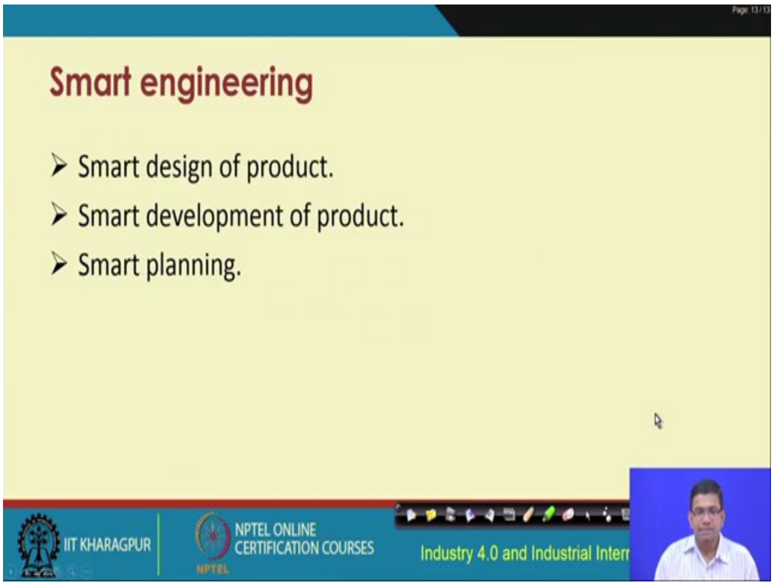


Smart engineering, smart design of the product, smart development of the product, smart planning all of these are different constituents of smart engineering.

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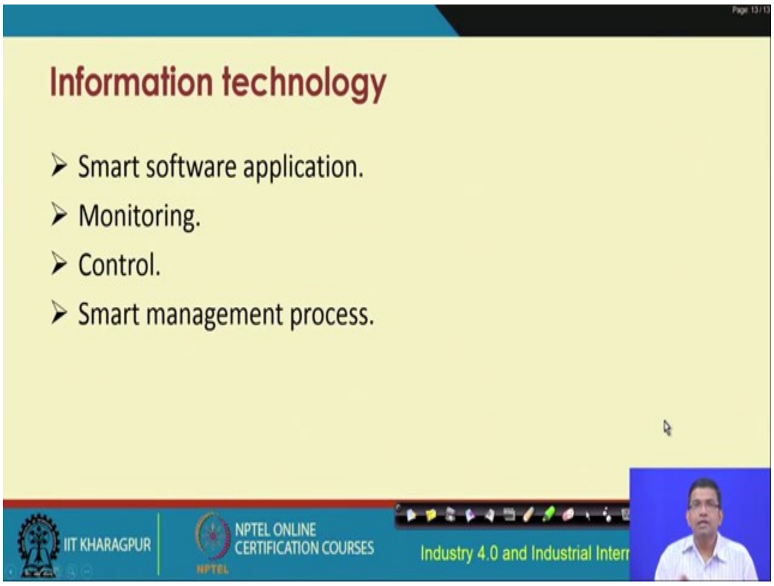


IT is something that I was also telling you, that it is very important in this overall business of or building smart factories, we need IT solutions in terms of smart software, smart hardware, smart management, smart monitoring, and smart control.

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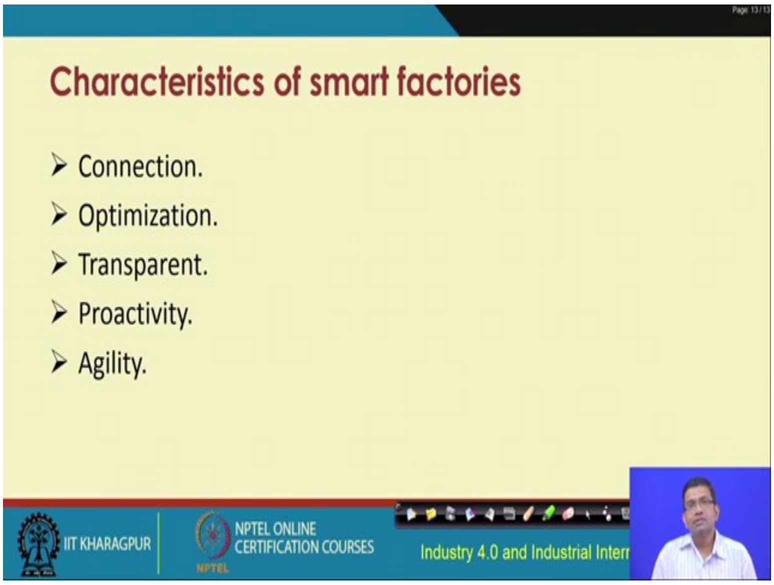


These are some of the characteristics of smart factories. Overall, when we are talking about smart factories there is connectivity between different machines, connectivity between machines and the different operators, connectivity between these different operators. Thus, we have machine to machine, machine to human, and then human to human. So, all this different connectivity is very important characteristic of smart factory.

Optimization, these smart factories are such that they will optimize their solutions, their productivity, their processes, and overtime. They will have some kind of self-learning behavior incorporated, implemented in them, through different algorithms. Thus, transparency is very important proactivity and agility in terms of moving very fast. So, moving very fast in terms of changes the dynamism, changes in the requirements, changes in the environment, and changes in the environmental parameters.

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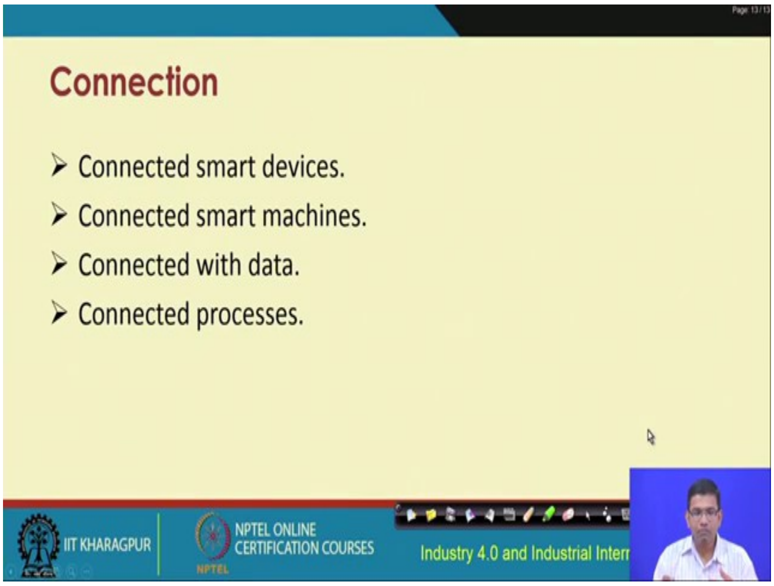


Connection-connected smart devices, connected smart machines, and all of these connected devices will bring in lot of data; so connectivity with the data center and connectivity between the different processes.

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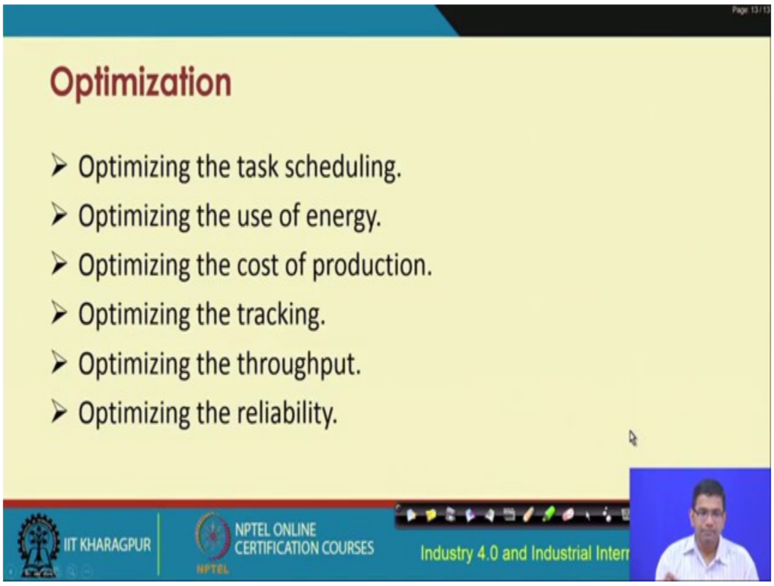


Optimization-optimizing the tasks, scheduling of the tasks, optimizing the usage of energy, optimizing the cost of production, optimizing tracking, optimizing throughput, optimizing reliability, and many different other things will have to be optimized in a smart factory.

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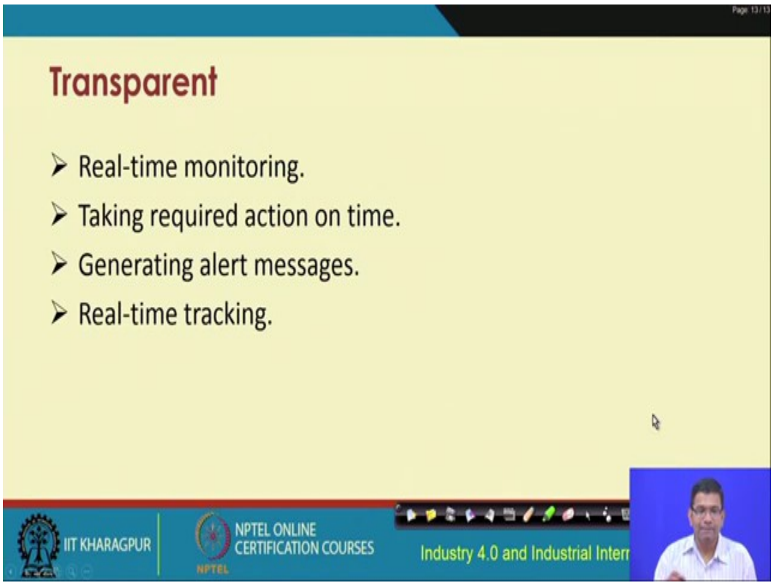


Transparency, because now you are able to track a particular component, a particular machinery, track some logistic item, which are done in real-time. This improves upon the transparency as well. In real-time, whenever it is required, in a smart factory that were in a particular location. Therefore, tracking becomes very efficient, it helps in improving the transparency.

Real-time monitoring and taking required action on time. If something has gone wrong trying to know about it as quickly as possible in real-time and taking the requisite action is very important and then generating alert messages to the people, who actually need to have this information.

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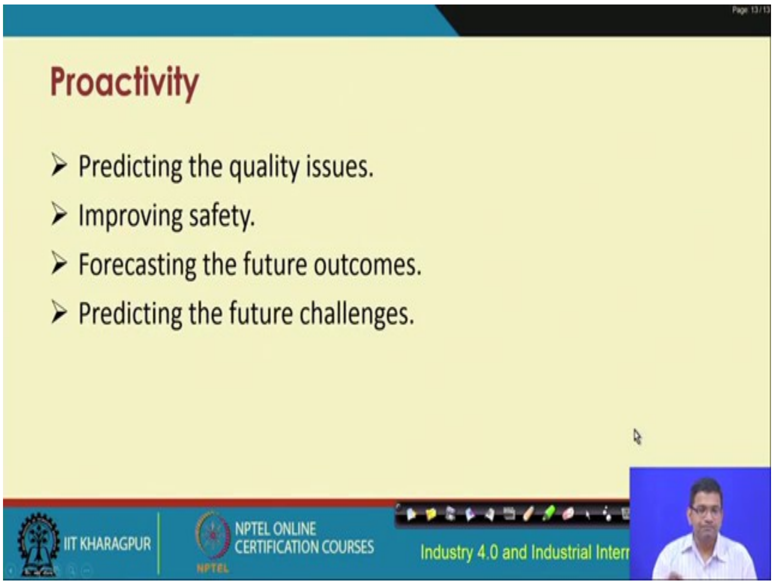


Proactivity-predicting the quality issues, improving safety, forecasting the future outcomes, and predicting the future challenges.

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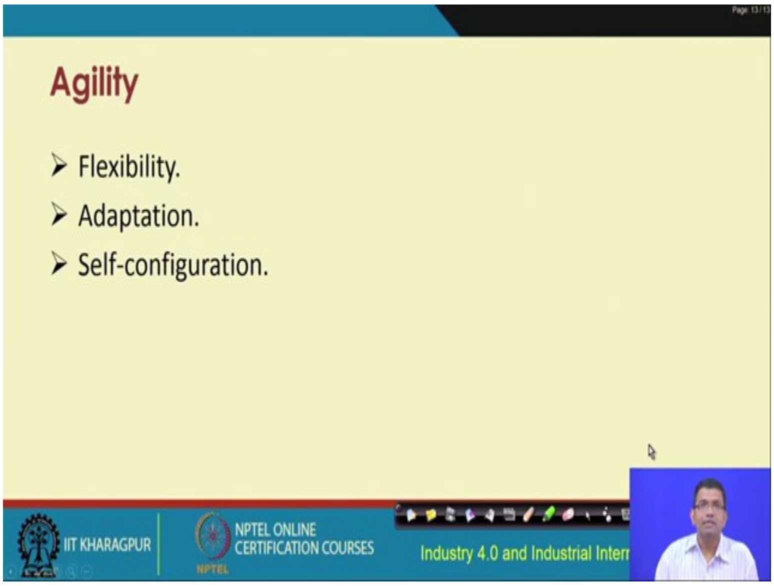


Agility talks about overall flexibility which I was telling you earlier, flexibility in terms of incorporating different changes, changes in requirements, maybe, changes in the different production processes, changes in the legal compliance, and there are many different things that might change over time, which are able to incorporate flexibly, what agility talks about.

Adapting with the changes in all these production processes, changes in the legal requirements, changes in the overall requirements. So, all these things are adaptation, which is a very important component of the agility attribute. Self-configuration the machines should be able to self-configure, whenever required they would be able to start up on their own, work on their own, and configure on their own.

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Supporting technologies for smart factories, big data technology is very important, cloud computing is very important. Big data is about getting lot of data, in huge volumes, in high velocity, having high variety, and many different attributes represented in terms of different Vs.

These data will have to be handled and smart factories have produced lot. They are the producers of lot of data, and these data will be useless until they are stored, processed, and analyzed in certain way. So, for this big data technologies like hadoop or different other big data technologies are used, different cloud computing platforms, public cloud, private cloud. Different companies nowadays also have their own private cloud, and public cloud services like Microsoft azure and Google cloud, all of these things are available, smart grid is a very important supporting technology, because we are talking about factories.

Factories are essentially the largest consumers, one of the largest consumers of electricity and different other energy. So, being able to efficiently use the energy is very important and having smart grids connected to the smart factories is very important.

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The use of cloud computing in smart factory helps in the processing capabilities, providing the capability of high performance computing, giving tools for running different applications, different development platforms, storing the data. In a more scalable fashion is what cloud computing provides in the smart factories domain.

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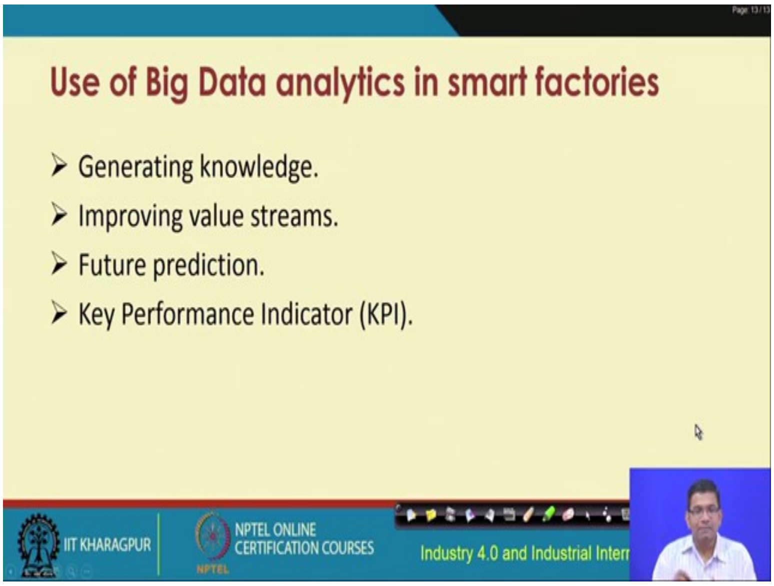


Big data is about big data analytics, generates the knowledge from the data that is received. So, we have the data, extracting information out of the data, generating knowledge out of the information, that is processed from the data. These are very important for improving the value streams, predicting the future, and taking care of the performance indicators, improving upon the performance indicators, the KPIs is also a very important aspect.

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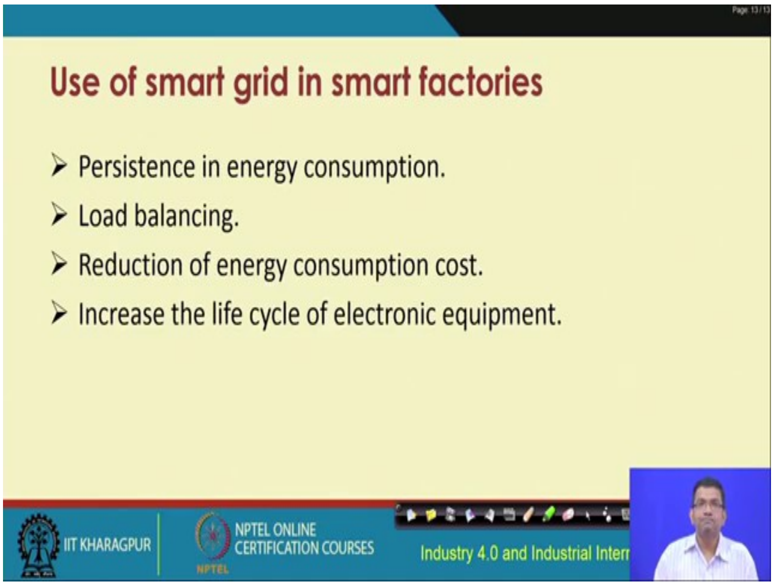


Use of smart grid in smart factories, persistence in energy consumption; if you are using smart grid with smart factories, energy consumption will be taken care of in a smarter way. There will be optimized energy consumption based on the exact requirements even the energy consumption can be balanced across different processes throughout the day or throughout the different times of the year.

Load balancing is very important, certain parts of the company might require certain types of load electric load. So, certain components, certain companies', certain parts of the factory will require more load compared to the other parts of the company. This differential loading and balancing the load throughout the day, across the different parts of the company. These are the important aspects of smart grid.

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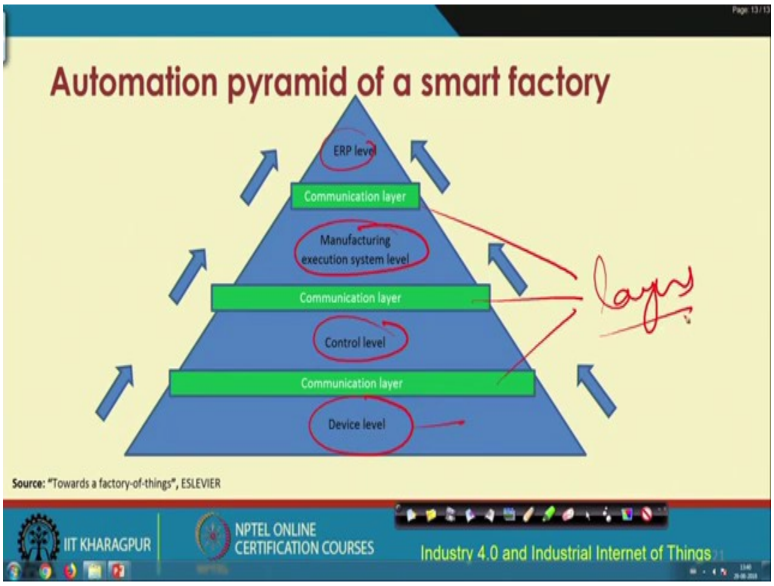


This is the automation pyramid of a smart factory at the very bottom, we have the devices in the device level, then we have the control level, then we have the manufacturing system level, and the ERP level, in between we have all these different communication layers.

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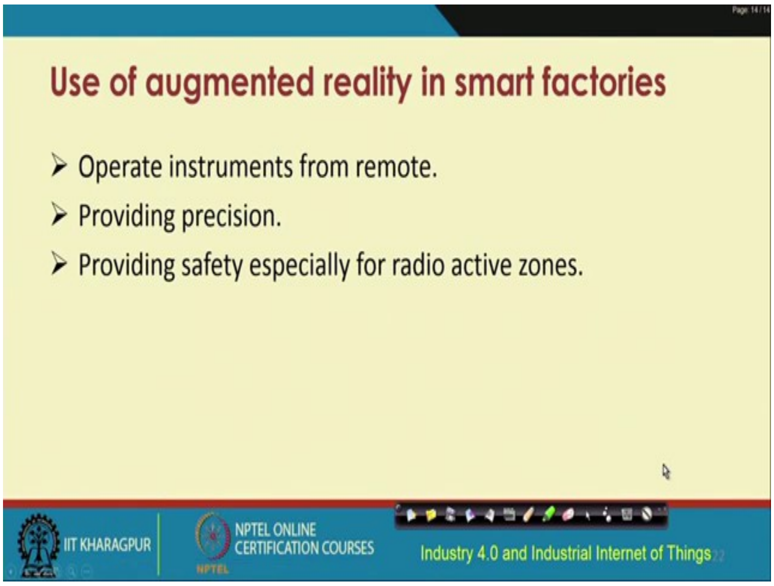


Use of augmented reality is quite rampant in smart factories. This will help in operating instruments remotely. So, remote monitoring of different machinery, different equipments in factory is possible, with the help of augmented reality.

In fact, there is another one which is the virtual reality, that we have discussed in another lecture, augmented reality and virtual reality together will help in remote monitoring, remote operations of instruments in a smart factory. These technologies can also help in improving the precision, providing precision in the processes, in the production processes, improving the safety especially for radioactive zones, and different other safety critical zones.

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So, with this we come to an end of the lecture on smart factory, I hope that you have some basic understanding about what smart factory is, and why smart factories are required, and what are the essential constituents of a smart factory.

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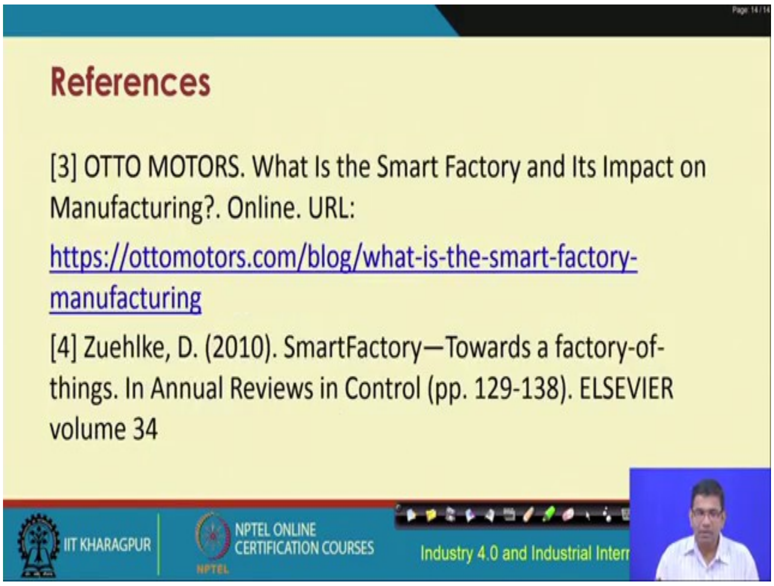


These are some of the references that have been given for you.

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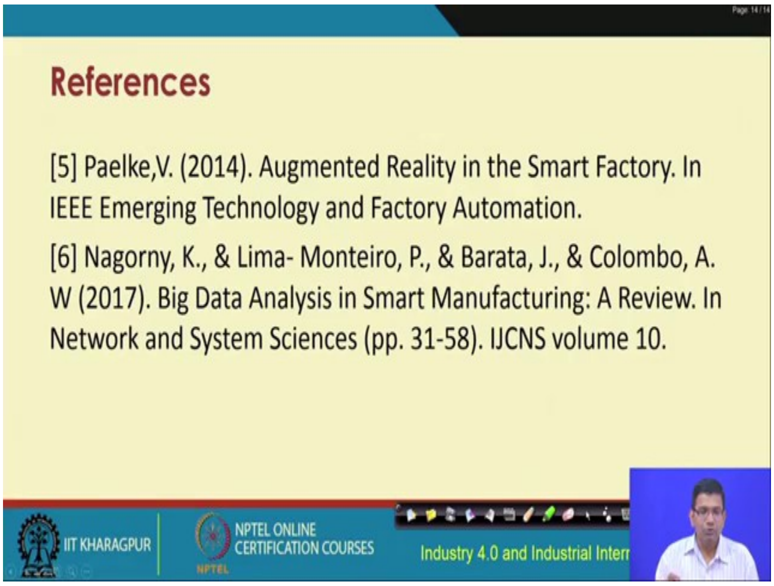


And if you are further interested you can go through, in the internet you will be able to find lot of different other lectures and different other materials on smart factories.

So, please feel free to go through them, if you are interested to know more about the smart factories. But smart factory is more of a concept there are different building technologies and different components. So, all these different technologies the enabling technologies for building smart factories, this is what we are trying to get a glimpse of through the different lectures of this particular course. And if you really need to build a smart factory you have to start implementing these concepts that we are going through in this course.

So, with this we come to an end of it, smart factory is a very important concept, in the context of Industry 4.0. Industry 4.0 one of the most fundamental, and central theme in Industry 4.0 is building smart factories. With this we come to an end.

Thank you.

**Introduction to Industry 4.0 and Industrial Internet of Things**
**Prof. Sudip Misra**
**Department of Computer Science and Engineering**
**Indian Institute of Technology, Kharagpur**

## Lecture – 11
## Industry 4.0 Cyber-Physical Systems and Next Generation Sensors

In this module, we are going to talk about Industry 4.0 and the different aspects of it. In Industry 4.0, first of all is a very popular wave, that is going on worldwide, among all different industries. Everybody wants to transform themselves into Industry 4.0 compliance. For Industry 4.0, there are different aspects that are important and should be understood in order for the industries to be able to comply themselves with the requirements. For instance, one of the very important aspects of Industry 4.0 is automation, full automation. Automation where there is no human intervention ideally or to a large extent, there is reduced human intervention.

So, the entire product line, the entire production process in a manufacturing plant, for example, would be made highly autonomous without any human intervention. And so, how can it be possible? It can be possible with the help of all these technologies that we have gone through so far like sensors, actuators different aspects of communication between them. So, these are going to be the enabling technologies for complying with the requirements of Industry 4.0.

So, we need sensors, actuators, communication, automation all of these things. But how these are going to be done? These are going to be done with the help of these IoT devices and something called CPS--Cyber Physical Systems and these Cyber Physical Systems is what we are going to go through in this particular lecture.

So, the idea is that there are different enabling components of cyber physical of Industry 4.0; Cyber Physical Systems is one of them. Likewise, there are different other ones, which we are going to go through in the next few lectures of this module on Industry 4.0 basics.

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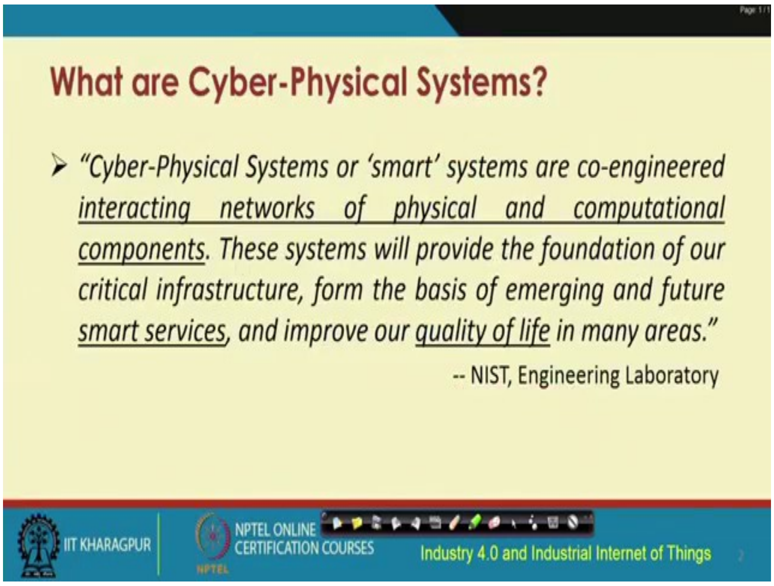


So, what is cyber physical system? There are different definitions that you will be able to find in the literature and people still confuse between what is IoT, what is CPS, what is the difference between them, what is M2M, like that there are different allied technologies, which have overlapping scope. But cyber physical systems is something that the scope is very clear. So, as this name suggests cyber physical. So, these are systems where there is a strong component of the cyber world and the physical world. There is a strong component of the physical world. So, there is interaction between the cyber world and the physical world together in these systems. So, how it is possible?

So, let us look at the NIST definition of what a cyber physical system is. So, cyber physical system also often known as smart systems are co-engineered interacting networks of physical and computational components. Interacting networks of physical components and computational. So, computational is the cyber one and physical is basically the physical world in which these systems are operating, physical world.

So, these systems will provide the foundation of our critical infrastructure; so, different infrastructure. All these public infrastructures that are there not only public, private industry infrastructure all this critical infrastructure that are there. These will be supported using these cyber physical systems in the next generation internet, the Industry 4.0. So, these are going to be all supported with the help of these critical structure will be supported with the help of these cyber physical systems. So, we need to understand really what these cyber physical systems are through the next few slides. But what is important is with the help of these critical, these cyber physical systems the quality of life will be improved because gradually we will be getting into smarter world, where there will be smarter systems offering smarter services.

So, for smartness autonomy in every respect is very important; autonomy and suggestions, based on the data that are collected are very important. So, that basically completes this definition of the cyber physical systems as per NIST.

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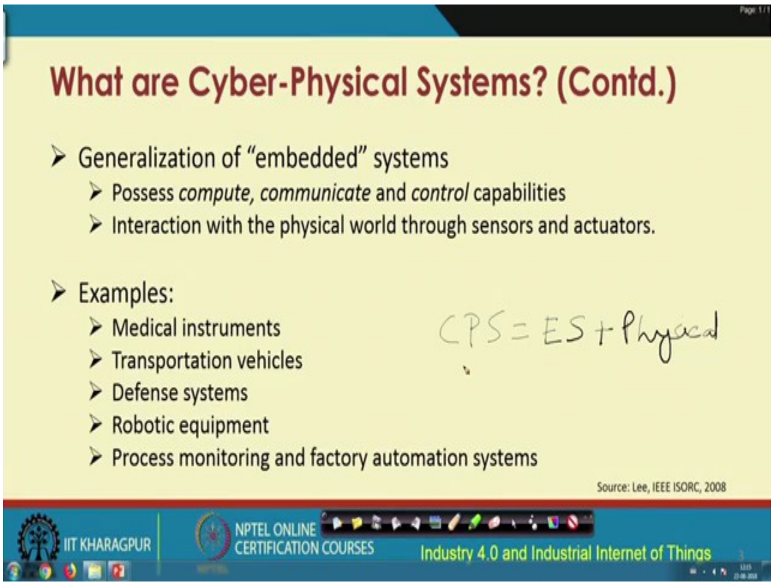


Now, the question is that what is a cyber physical system, but before that we need to really understand what is an embedded system. Cyber physical systems are embedded systems. So, these are basically cyber physical systems are you can think of conceptually as cyber physical system, conceptually as embedded system plus the physical system together you what you get is the cyber physical system.

So, what is an embedded system? So, you have some kind of software that is working on some kind of hardware. The software is embedded in the hardware. Embedded systems have found a lot in the cars; that means, vehicles, these are found in aircrafts embedded systems are found everywhere.

Nowadays, embedded systems are enabling technologies for making systems smarter and that is why these embedded systems are very popular. So, these embedded systems irrespective of where they are used, they possess certain capabilities of computation, communication and control, compute, communicate and control capabilities. So, where there is interaction with the physical world, through different sensors and actuators examples of it would be medical instruments, many medical instruments are embedded they have embedded systems in them, transportation vehicles, defense systems have embedded systems in them.

For example, the radar and different other systems, that are used even the aircrafts etcetera; they are all having different embedded systems in them. Robotic equipments likewise process monitoring and factory automation systems, all of these have embedded systems in them. So, this is the cyber physical system.

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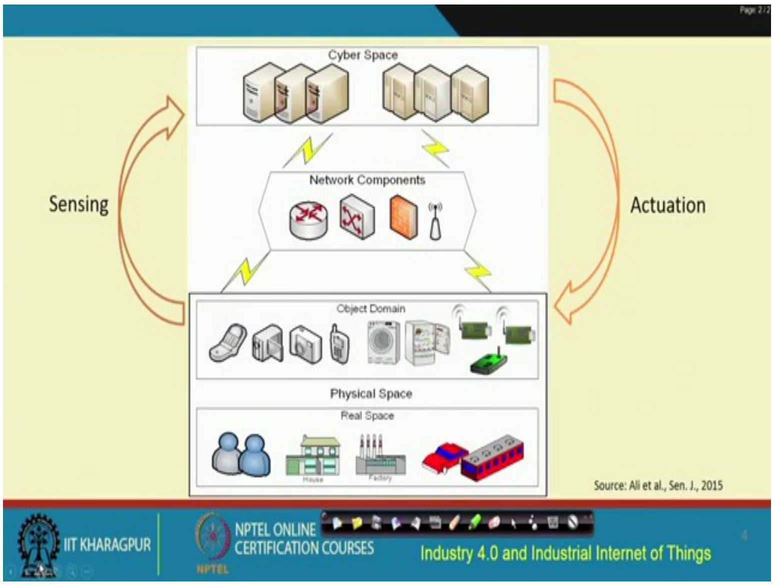


So, now let us move forward and see how an embedded system works. So, as I told you that an embedded system has the computational capabilities. They also have the processing capabilities, so, computation communication capabilities and so on. So these systems would help in building the cyber physical system. So, in the cyber physical system, you have the physical systems--the physical space. So, this is basically the cyber space. This is the physical space, and the interaction between them will make it the cyber physical system.

So, what does this physical space have? So, a physical space we are typically talking about different real objects like human beings, like houses, factories automobiles, buildings and so on. And different objects, these communication objects, for example different other household objects or even the objects that are in the industries like cell phone, cameras, washing machines, refrigerators. All of these are different objects these are different objects that work in the physical space.

So, these objects basically will sense certain data. They will sense different information in the place, where they are operating and then using certain communication devices like the ones shown over here. These data are going to be sent further. So, this sensing once it is done, this sensed data is sent for further processing. So, this processing will be done using different servers, server firms, cloud or, whatever. So, that becomes the cyberspace.

So, it will be done this processing will be done in the cyberspace and based on the results of this processing, those results will be sent back to the physical space for actuating different devices. So, these devices could be maybe, starting a washing machine, starting a refrigerator, if there is certain thing, that has happened; starting the air conditioning in air conditioner in the room.

So, let us say, that it has been sensed that the temperature has gone down in the room. So, based on their analysis that is performed in the servers over here maybe based on certain rules that are already pre-programmed in those cyber spaces. So, finally, based on that the actuation is going to happen and the physical space will be actuated with the intention of starting some device or operating some motor or anything like that.

So, these are some examples that I have given you. This could be generalized further and we can try to understand how, in general, a cyber physical system is going to work.

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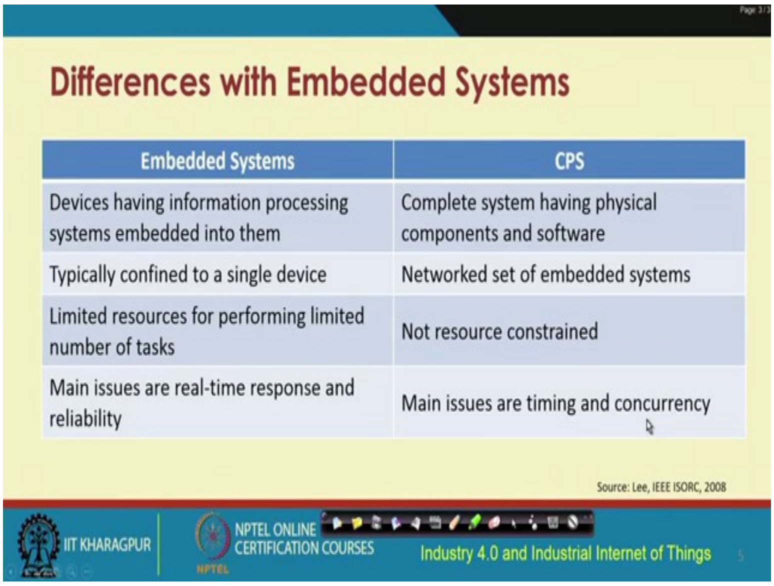


So, before I go any further, let us again try to understand in little bit of depth about how this cyber physical system, CPS is going to work; how the CPS is going to work.

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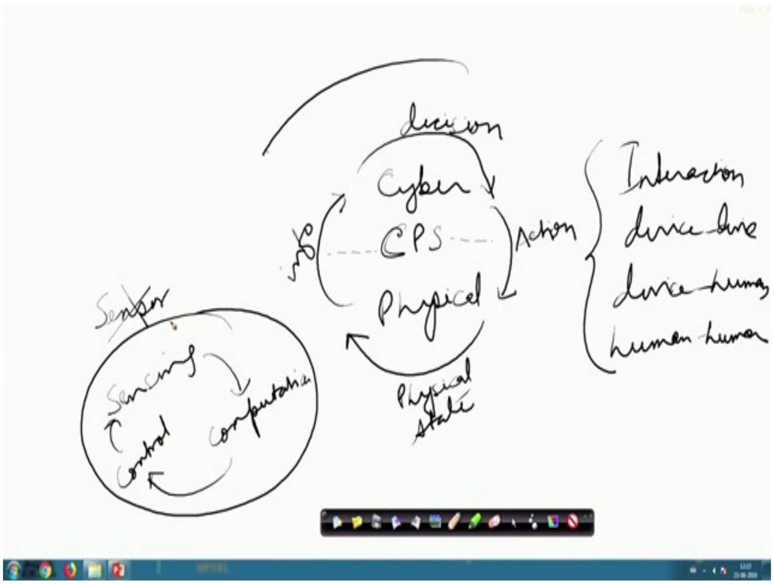


So, if you are talking about cyber physical systems, we have as I told you we have the cyber world, the cyber world, and the physical space. So, what is going to happen is this physical space is going to send some information. It is going to send certain information to the cyberspace and then some decision is going to be made over here some decision is going to be made. Based on this decision certain action is going to be performed and based on this action, the physical state of certain device, physical state of a device is going to be changed. Interaction primarily between devices device to device, but it could also be device to humans or it could be even human to human. So, all kinds of interactions are going to happen, but this is basically the kind of loop that we are talking about this loop is going to take into effect.

So, what we have essentially is some kind of a loop, some kind of a loop between the sensor. You have sensing, rather let me call it not sensor, but let me call it sensing. So, you have a loop between sensing, then computation, and then control. So, this kind of loop is going to exist in cyber physical systems. So, going back so, we need to understand that what is so, special about these cyber physical systems and how they differ from the embedded systems in general. So, we have in embedded systems we are talking about devices alone the devices that will process some information and this information are basically embedded in these devices, they are stored in these devices and so on.

On the other hand, the cyber physical systems, these are complete systems, where there is an interaction between the physical components and the software or, the cyber world. The next difference between cyber physical systems and embedded systems is in an embedded system, typically, you are talking about a single device and this tip the single device the embedded system is basically confined to this particular single device. On the other hand, in a cyber physical system, we are talking about a network set of such kind of embedded systems.

So, the networking of different embedded systems will typically exist in a cyber physical system. Embedded systems have limited resources for performing limited number of tasks. On the other hand, a cyber physical system may not be resource-constrained and there you can perform large number of different tasks at the same time. In an embedded system, the main issues are real-time response and reliability, on the other hand, in a cyber physical system in an addition to these the main issues are timing and concurrency. So, these are the differences, primary differences, between cyber physical systems and embedded systems.

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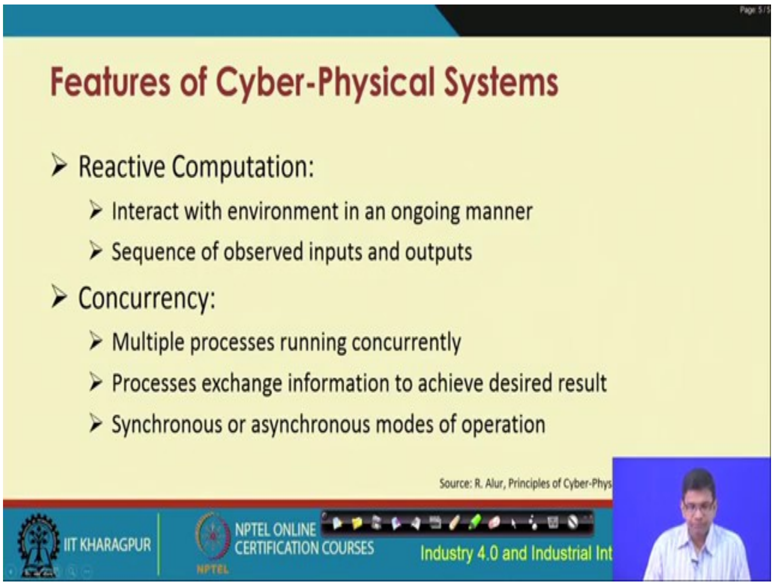


So, here are some features of cyber physical systems. Reactive computation is very important and that we have seen when I explained to you about this feedback loop, the control loop and so on. So, reactive computation means interaction of the system with the environment in a continuous fashion. So, basically there is a sequence of observed inputs and outputs in the process and that has to be dealt with by these systems suitably.

Concurrency is very important, concurrency as this name says we are talking about concurrency of execution of multiple processes at the same time. So, these processes, concurrent processes would exchange information to achieve certain expected result and these operations could be synchronous or, asynchronous in terms of their operation or, their modalities of their operation.

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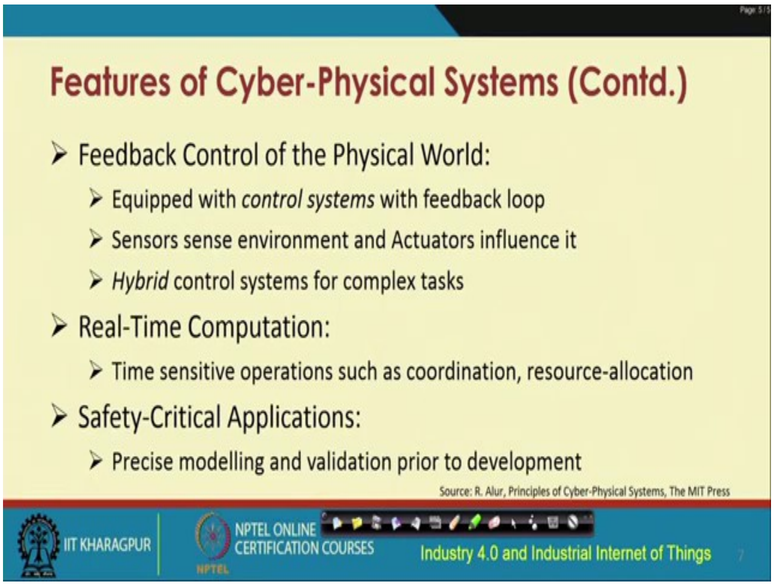


Some of the other features of cyber physical systems; there is a feedback control loop that I already talked about and these basically these systems will have some kind of a control system in them there is some kind of a control element in them with certain feedback loop. So, basically the sensors would sense the environment and these actuators will basically influence it and there is hybrid control system these are basically hybrid control systems for complex tasks. If there is a complex task, simple control systems will not work, it will be a network of different control systems it will be a hybrid control system, which will basically help in achieving the task. Real-time computation is quite well understood and supporting safety critical applications is what is very attractive of cyber physical systems.

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There are different applications of cyber physical systems. Healthcare is a very important domain where cyber physical systems are widely used. So, these basically in healthcare as that what is very important is to have medical devices and systems, which will measure things at a very high level of accuracy. Some physiological parameter of a patient, for example, has to be measured very accurately by different medical devices and systems. So, obviously, as you can understand if you think a little bit in deep you will be able to realize that cyber physical systems will be very attractive of use for healthcare.

For example, you must have heard about the use of robotic surgery or image-guided surgery. These are examples of cyber physical systems and they are used in surgery or healthcare, in general. Then we if we are talking about fluid flow. So, control of the fluid flow, control of blood flow into a patient, when required for medical purposes may be somebody having a bone marrow transplant or some kind of blood transfusion is taking place. So, cyber physical systems can find use to perform the tasks accurately. The system itself will be taking care of the accuracy to a great extent which if a human body. If a human was performing, then they would not be able to do it that much accurately; so cyber physical systems.

So, robotic surgery, already probably you must have heard that robotic surgery is very popular because of the precision, precision in surgery that can be obtained using robotic surgery or image-guided surgery, these are very precise and known. So, the doctors can perform this surgery very precisely accurately. So, that is where in healthcare this kind of cyber physical systems can be useful.

So, let us now talk about other kinds of engineered systems such as exoskeletons, orthotics, like entertainment robotics, therapeutic robotics, brain machine interfaces, prosthetics, and so on. So, these are like different other types of examples of cyber physical systems and their use in healthcare and these are based on cognition and neuroscience.

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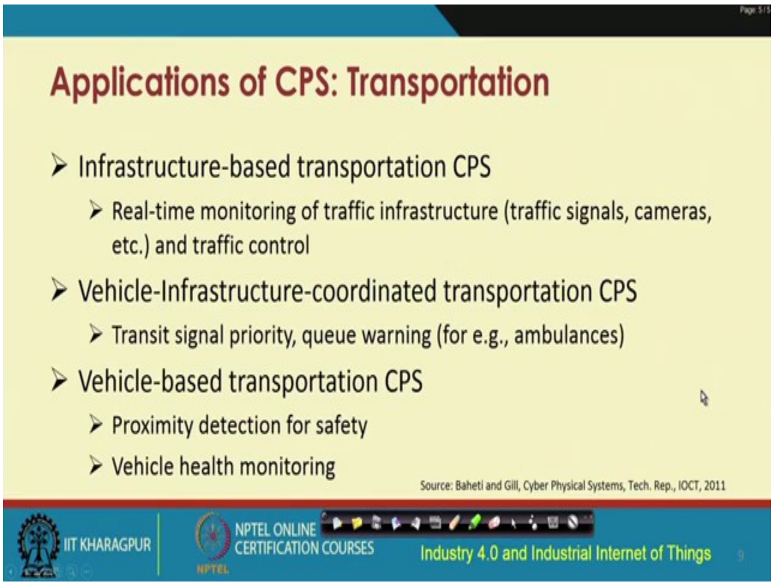


So, the next application domain of cyber physical systems and their use is transportation cars vehicles in general aircrafts they all use cyber physical systems. So, there could be infrastructure-based transportation cyber physical systems for real-time monitoring of traffic infrastructure such as traffic signals, cameras etcetera and traffic control vehicle infrastructure, coordinated transportation, CPS for transit signal priority, queue warning, example for ambulances etcetera. So, these are very important priority-based, priority-based queuing, priority-based system, integration and so, on. So, all these things in transportation could be addressed, with the help of cyber-physical systems.

Vehicle-based transportation cyber-physical systems, where proximity detection for safety. So, you must have boarded vehicles, where the vehicle will warn you if the vehicle is too close to the vehicle, another vehicle in front or if there is another vehicle coming from the back, which is close to that particular vehicle. So, all these things are examples of cyber physical systems operating on the road on the vehicles and so on.

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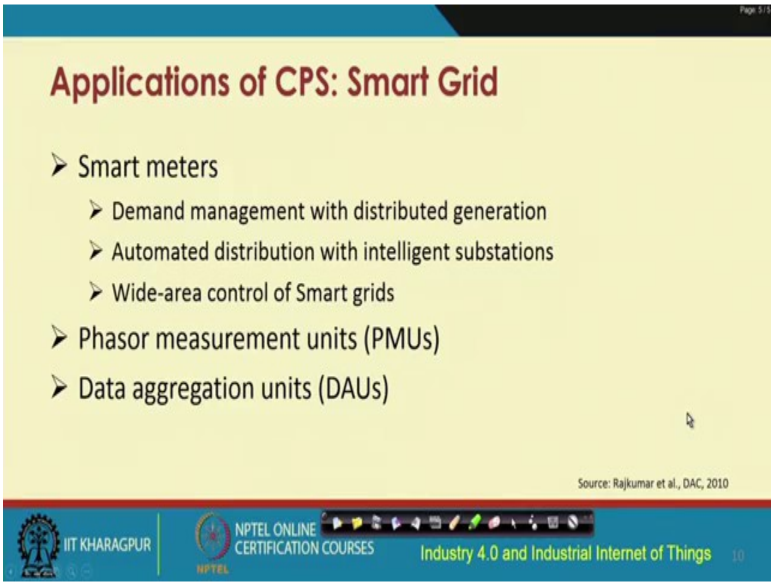


Likewise, other application domain would be in the energy sector, in the smart grid. Smart meters are examples of cyber physical systems smart meters can do demand side management with distributed generation, automated distribution with intelligent substations, wide area control of smart grid. So, all of these things can be performed with the help of smart meters and smart meters are good examples of cyber physical systems and their use in the energy sector. Cyber physical systems in smart grid smart meters is one, but then there are other examples also like PMUs Phasor Measurement Units, Data Acquisition Unit, and so on. So, all of these are basically examples of cyber physical systems in the energy sector for smart grid.

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In the industry, in general, manufacturing industries will use cyber physical systems. All these different machines that we talked about some of these may be robot assisted machines; some of these could be simple machines. So, machines, such as let us say the lathe machine in a workshop, milling machine in a workshop, the welding machine in a workshop. So, all of these could be equipped with different components to make them smarter for manufacturing, improved manufacturing, improving the efficiency of production using different sensors and actuators and different other processing. These could be made smarter and these would be also examples of cyber physical systems, in the industry, in the manufacturing industry.

So, these smarter cyber physical manufacturing systems can perform different things such as smart control, optimal resource utilization, smart diagnostics and maintenance, safety, safety of the industrial environment, safety of these machines, smart monitoring of the health of these machines. So, all of these things could be performed using cyber physical systems attached to or rather machines, which have been made cyber physical. So, these would be examples of cyber physical systems for use in the manufacturing industry.

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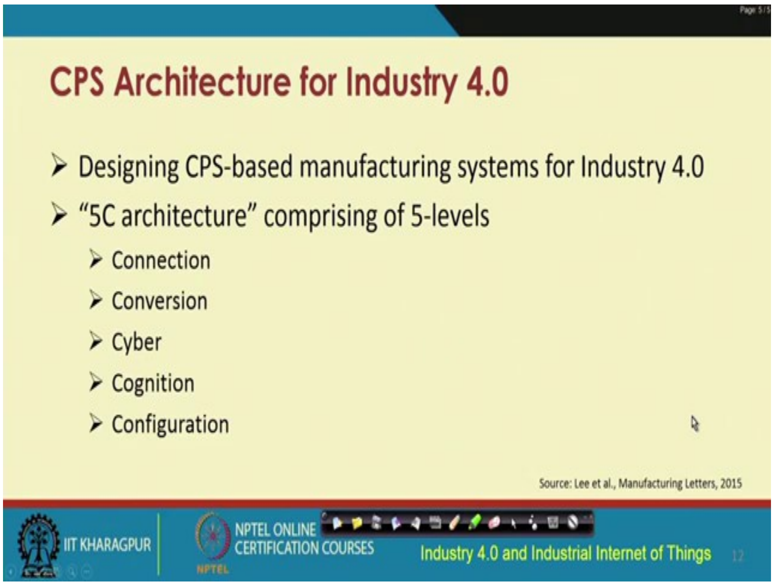


Basically we were talking about Industry 4.0 and we have seen that at the outset, I mentioned that cyber physical systems are very attractive for use in the manufacturing industry and other industries also for moving towards, for leaping forward, towards achieving Industry 4.0 goals, in general. So, in terms of Industry 4.0, there are 5C architecture goals, which can be achieved with the help of cyber physical system. Connectivity, conversion, cyber cognition, and configuration, these are the 5C architectural aspects.

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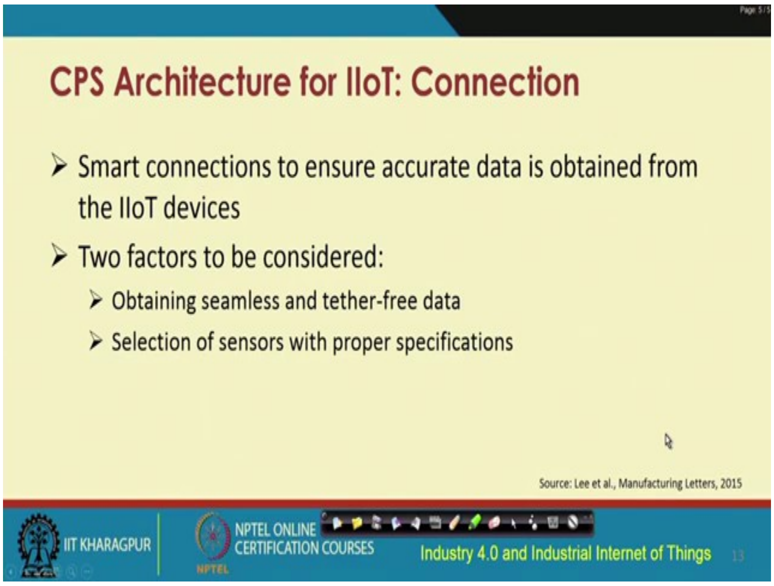

So, connection: so, we are talking about smart connections. To do what to ensure that the accurate data is obtained from these different IoT devices, IIoT devices, in the industry; these are obtained from these devices. So, here two factors should be considered obtaining seamless and tether-free data and selection of sensors with proper specifications.

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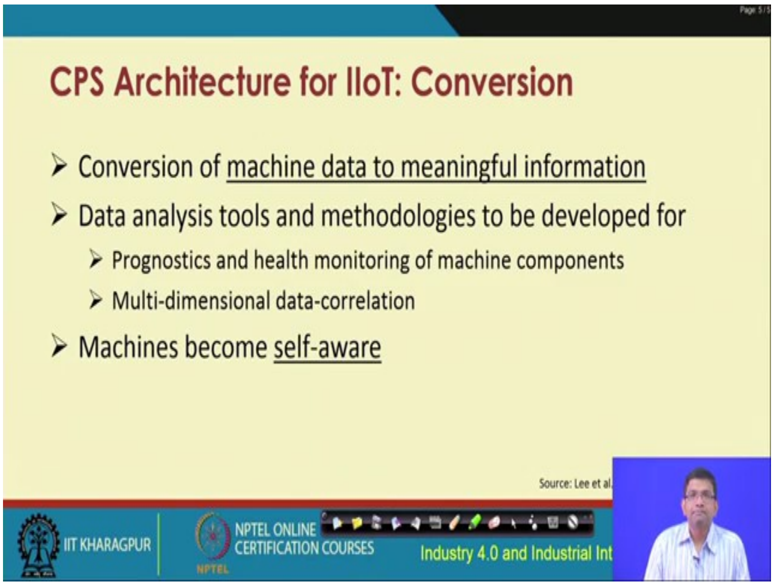


Conversion we are talking about by this term conversion. As the conversion of machine data to some information, that can be made meaningful and useful. So, data analysis tools and methodologies can be developed for the prognostics and health monitoring of different components, different parts of the machines, and for multi-dimensional data collection, and data correlation analysis. So, basically what will happen is these machines will be made smarter, they would be made self-aware.

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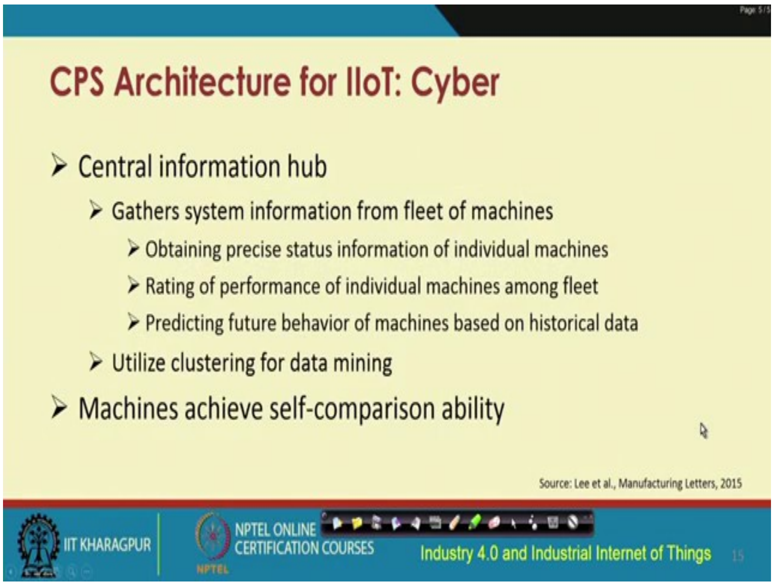


Then comes the cyber component and this is quite obvious. We are talking about analysis of the data that is informed that is received at some kind of a hub which will be comprised of different high end workstations, servers, cloud or whatever. So, that is the server component that we are talking about.

So, this data that is obtained can be used for analyzing the data, mining the data, storing the data and then based on certain algorithms that are run on it on the data or using the data. Then making others aware of what is going to happen next or deriving some useful information at the same time. So, this is basically done by the cyber component of it. So, this is the C of the 5Cs in the architecture of CPS for a IIoT for or Industry 4.0.

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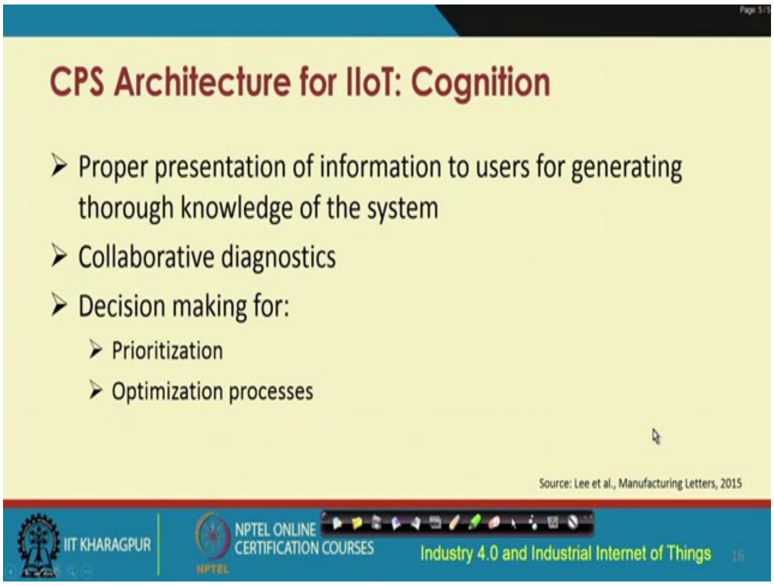


Cognition is another one. So, here by cognition what is meant is basically the proper presentation of information to users for generating thorough knowledge of the system. So, we are talking about collaborative diagnostics, decision making for prioritization, optimization of processes and so on. So, all of these are different aspects of cognition that come into picture in the CPS systems.

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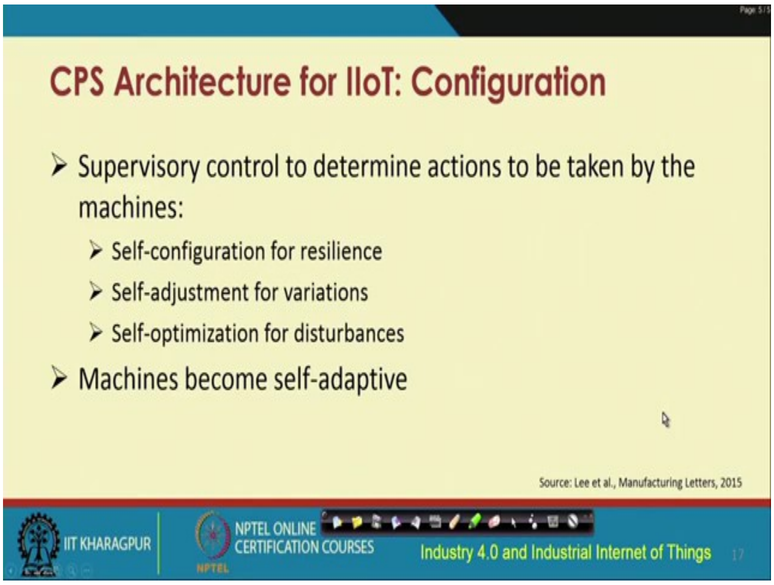


Configuration is the other one where we are talking about supervisory control to determine actions to be taken by the machines themselves. Examples would include self-configuration for resilience, self-adjustment for variations, and self-optimization for different disturbances. All of these self properties would help in the supervisory control for performing certain actions by the machines themselves. These machines are going to be self-adaptive consequently.

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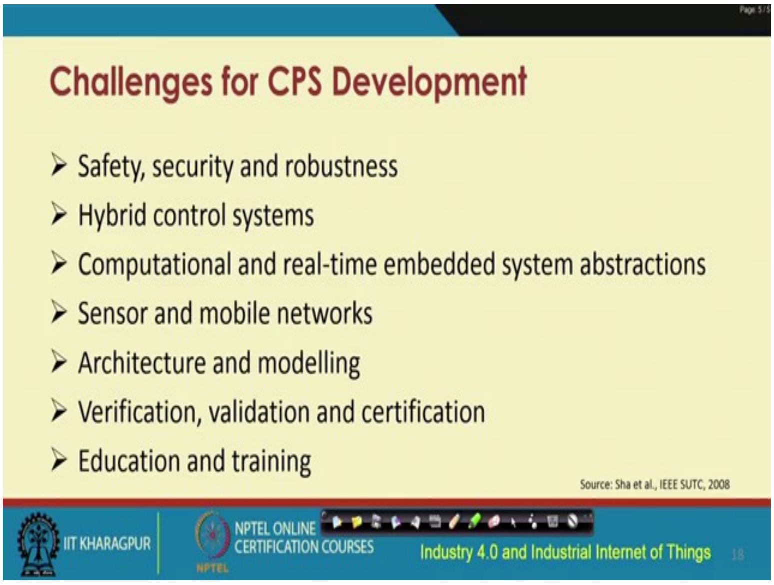


So, there are different challenges of cyber physical system development; challenges with respect to safety, security, robustness, computational challenges real-time embedded system abstractions sensing and mobility challenges are there architecture and modeling verification validation and certification and including education and training of these systems. These are all challenges for of the deployment of CPS for in the industries towards the compliance of complaints for Industry 4.0, the next little while we are going to discuss about the next generation sensors, that are going to be used.

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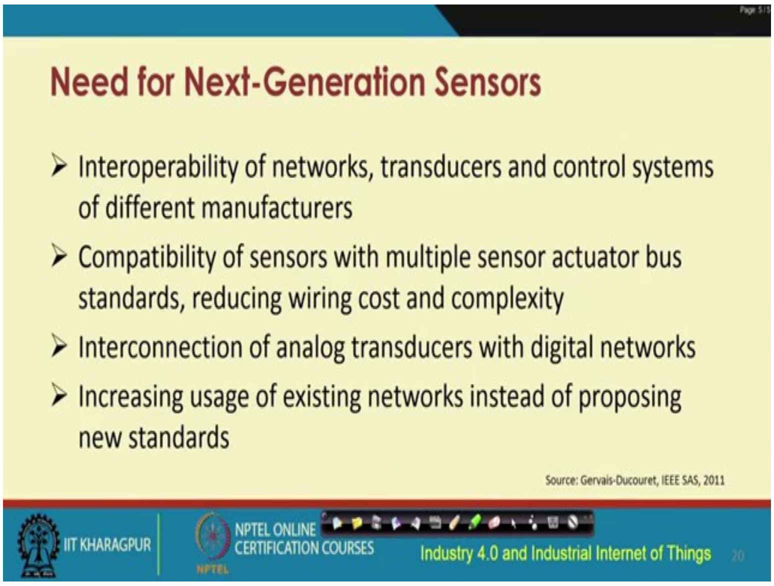


So, all these sensors that we talked about in the introductory module before these are simple sensors. These sensors can only sense and then send the sensed data forward. So, these can be thought of like smart sensors, but then for next generation sensors throughout the world industries academic labs and so, on.

They are working on making sensors intelligent. So, not only that these sensors the smart sensors would sense and send, but these would be made intelligent because certain small algorithms lightweight algorithms will be executed in these sensors to do certain tasks at the sensors themselves. So, these are, this is very important in the context of Industry 4.0.

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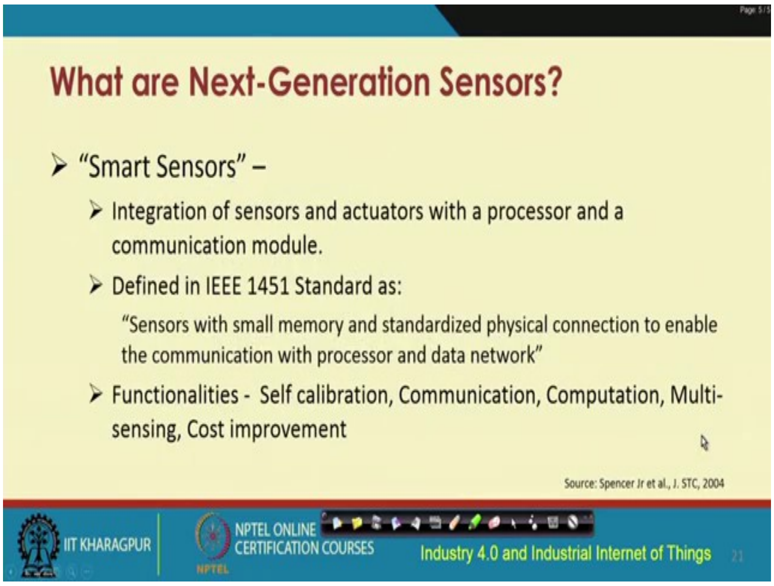


So, here basically you are talking about integration of sensors and actuators, with a processor and a communication module. This is basically these traditional sensors, how they look like. So, there will be a sensor component an actuated component optionally and a processor for processing certain, whether the data that is sensed and certain communication module for connecting these different sensors with a central hub for processing or the sensors themselves. So, these are the simple smart sensors these sensors will also have to do certain functionalities like self calibration, communication, computation, multi-sensing cost improvement of their own.

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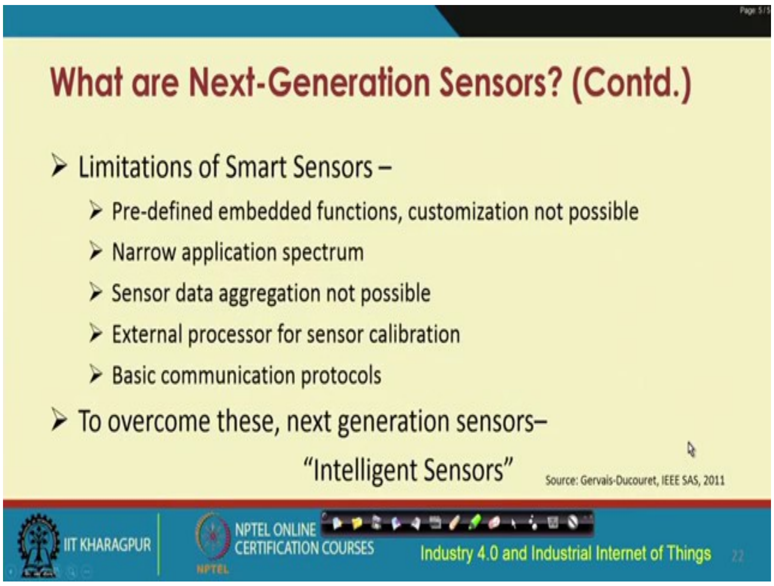

So, these are some of these different features of the smart sensors, but these smart sensors have severe limitations. They have predefined embedded functions that cannot be used for certain customized scenarios. So, you have to customize them based on certain requirements and that makes it difficult for use in real life industry scenarios. Narrow application spectrum is the second limitation sensor data aggregation using the sensors is not possible or limitedly possible and external processor for sensor calibration is required for these smart sensors and also they would support very basic lightweight communication protocols.

So, for overcoming all of these different limitations of smart sensors, next generation intelligent sensors have been proposed. They are in the works and these are the different features of these intelligent sensors.

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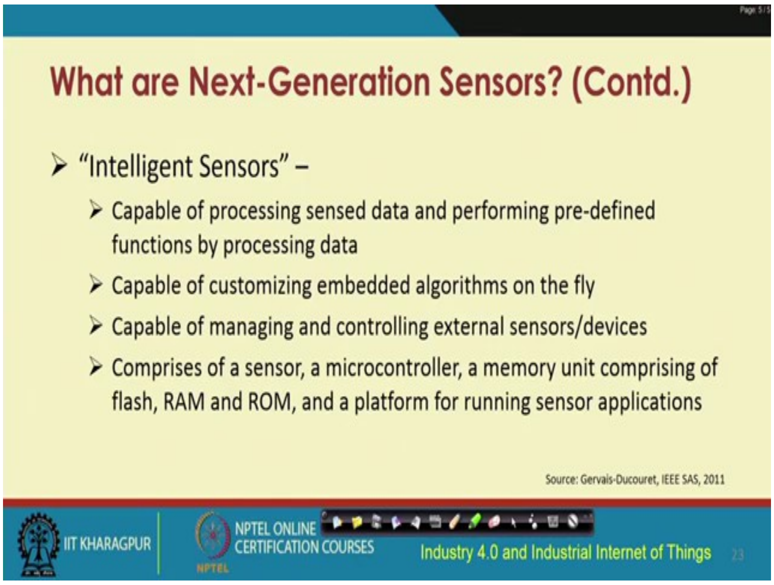


So, these intelligent sensors are capable of processing sensed data and performing predefined functions by processing the data. So, they are capable of customizing embedded algorithms on the fly unlike the smart sensors which were not able to do so. They are capable of managing and controlling external sensors and devices and they would comprise of a sensor, a microcontroller unit, a memory unit comprising of flash RAM, ROM, and a platform for running different sensor applications.

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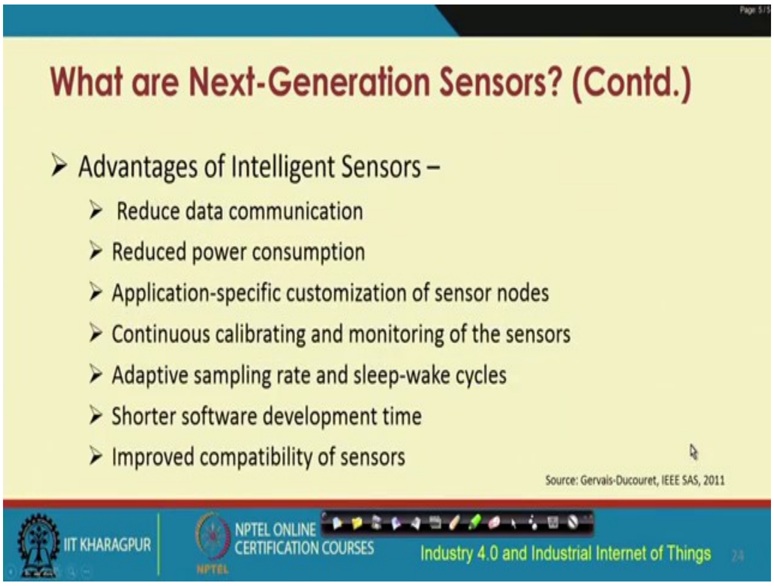


So, there are; obviously, different advantages of these intelligent sensors, in terms of reduced data communication, reduced power consumption, shorter software development time, improved compatibility of sensors, possibility of continuous calibration and monitoring of the sensors. These are the different advantages of these intelligent sensors and that is why these are very attractive.

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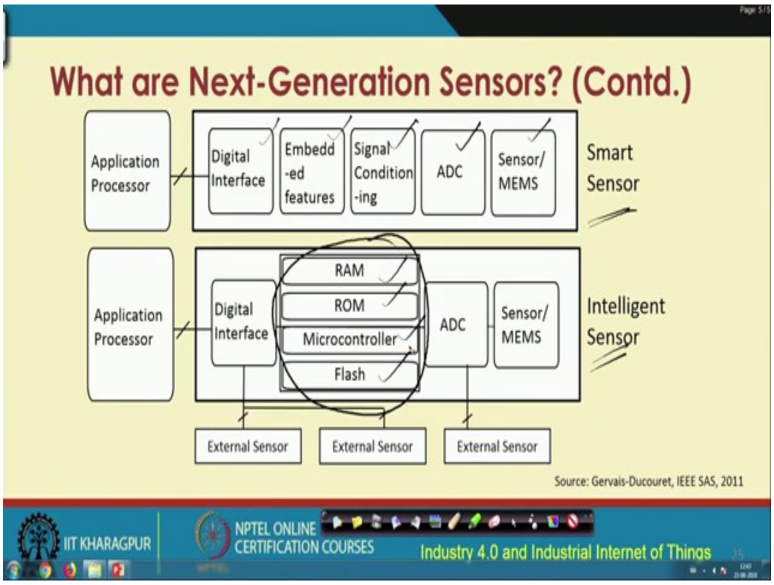


So, this is how is this is how a smart sensor would look like a smart sensor this is an example of it. So, as you can see over here, there is a digital interface and embedded there are different embedded features signal conditioning circuit, then you have ADC Analog to Digital Converter and the sensors or MEMs which actually sense the material, environment or, sense whatever it is supposed to sense.

So, in addition to all of these things in the intelligent sensor on the other hand, you have mostly whatever is present in the smart sensors, but also a component for processing and computation. So, you have this RAM, ROM microcontroller flash and so on. All of these basically make these smart sensors intelligent, by virtue of having these components in them.

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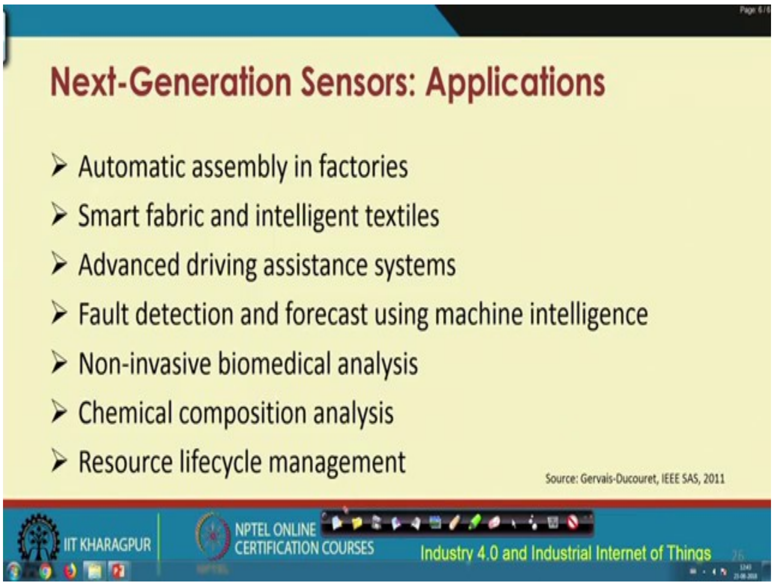


So, there are different applications of next generation sensors these intelligent sensors. Automatic assembly in factories, smart fabric and intelligent textiles, advanced driving assistance systems, fault detection and forecast using machine intelligence, non-invasive biomechanical analysis, chemical component analysis resource lifecycle management. These are some of these different applications of these next generation, intelligent sensors.

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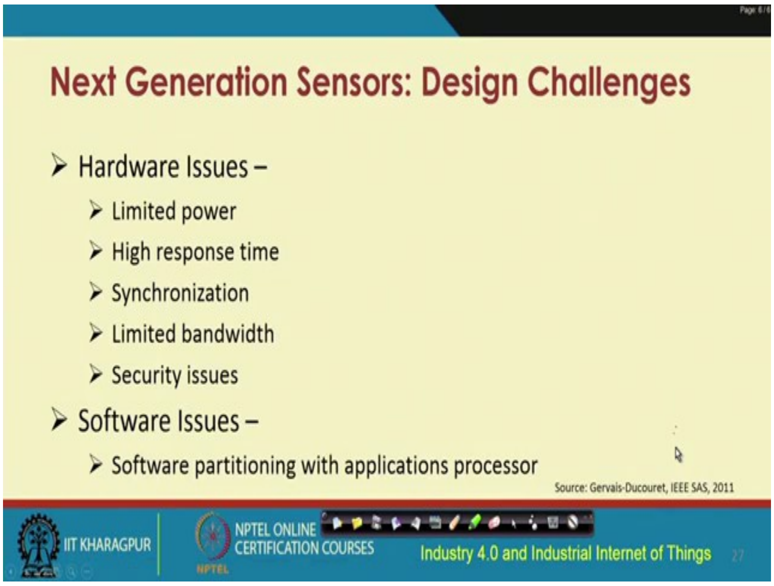


So, there are different design challenges in the manufacturing of these intelligent next generation sensors. There are different hardware issues. These sensor nodes, they themselves are already limited in terms of power, they have very high response time and there are synchronization issues, issues of limited bandwidth of operation, security issues are also there and there are different other software issues such as the issue of software partitioning for complying with different applications and their different processors in them. So, all of these are different design challenges with respect to hardware and software.

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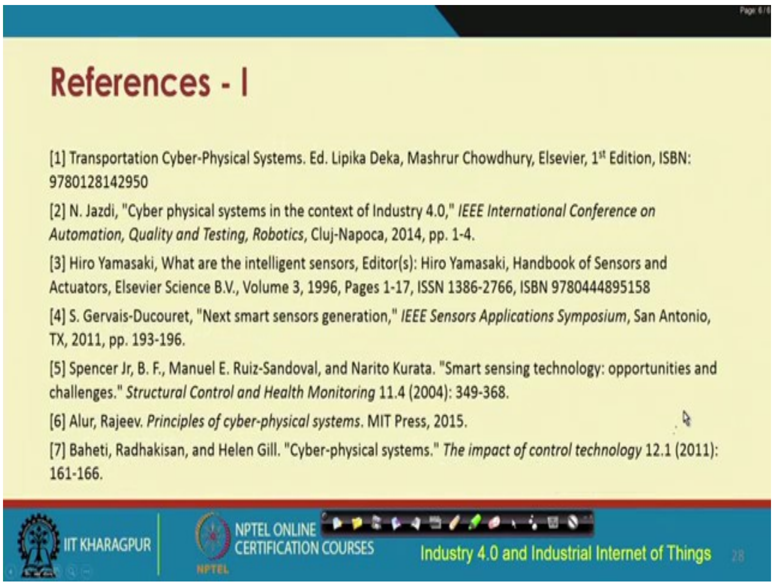

So, with this we come to an end of cyber physical systems and next generation intelligent sensors, discussions on them. So, this brief of brief idea about cyber physical systems and the use of intelligent sensors basically equips you with an understanding of how you can go forward in the years to come, if you have to make your industry compliant with Industry 4.0 expectations, the objectives of Industry 4.0 and so on.

So, cyber physical systems and IIoT are strongly interlinked. So, essentially what we are trying to do is we want to use these cyber physical systems. The abstractions of these cyber physical systems in the form of different objects; objects means we are talking about virtual objects not the physical objects. So, these different physical or virtual instances of the corresponding physical objects in the physical world, these could be networked together and the data would be received at the other end for further processing analysis and so on for making the industry smarter. So, we are gradually leaping forward towards building industrial internet of things and in the industrial internet of things IIoT using CPS, we are going to talk about in further detail later on.

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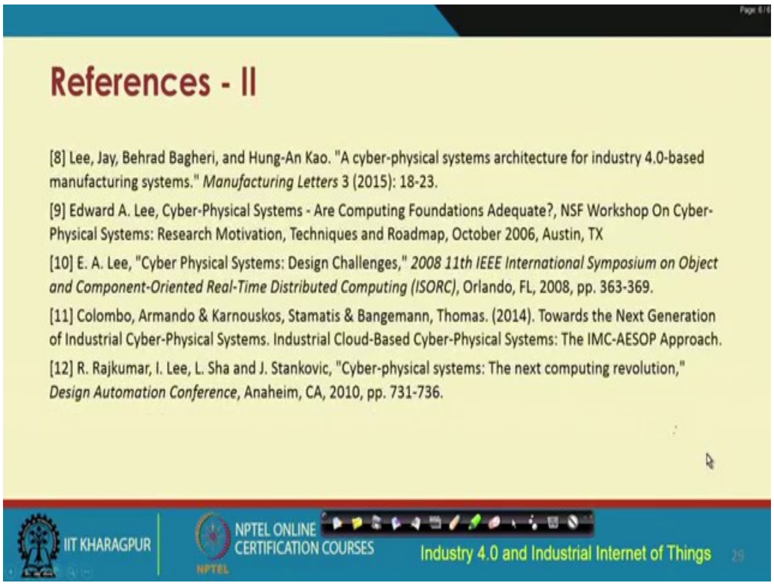


So, these are some of these references and if you are interested you can go through these references in further detail, to know what are the different other issues of the cyber physical systems and how next generation sensors could be developed; if you have to develop these next generation sensors.

So, these are different concepts knowing these concepts is required, but then if you have to develop a cyber physical system yourself or if you have to develop a next generation sensor, an intelligent sensor, that is a complete completely different ballgame. So, you need to be specialized, there are researchers who spend years together to build a sensor and intelligent sensors it will take even more effort to build these intelligent sensors.

So, obviously, that is a completely different ballgame, but here we are just getting an exposure to these different concepts of cps, next generation sensors, and so on which will be required for building Industry 4.0.

Thank you.

**Introduction to Industry 4.0 and Industrial Internet of Things**
**Prof. Sudip Misra**
**Department of Computer Science and Engineering**
**Indian Institute of Technology, Kharagpur**

**Lecture – 12**
**Industry 4.0: Collaboration Platform And Product Lifecycle Management**

For Industry 4.0, there are different technological considerations that are required. One thing that is often not looked upon seriously, but it is very important from our viewpoint for Industry 4.0 compliance is to take help of the knowledge base. Knowledge base from the same industry from a previous production processes, existing production processes in other units, or from the knowledge base that can be obtained from other industries following similar kind of production processes.

So, this knowledge base will be very helpful, that is why we need some kind of a platform that can help build a knowledge-sharing mechanism. Collaboration platforms are very important. And also in this lecture, we will talk about product lifecycle management. How you can achieve automation in PLM - products lifecycle management for trying to step forward to meet the Industry 4.0 objectives. So, let us look at some of these features, the high level understanding about each of these, in the next little while.

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So, what is a collaboration platform? So, basically we are talking about a platform which can be a software platform, which can be a software-hardware platform, which helps the employees to share information and solve certain business problems. So, employees can share information between themselves using a collaboration platform. The employees of one industry can share the information with employees of another industry by virtue of use of these collaboration platforms. And this thing you can generalize and extend to different scenarios, likewise.

So, collaboration platforms essentially are talking about building platforms that will include in the sharing of knowledge, a platform for managing the knowledge, knowledge management and including it in the business operation for renovation of the business processes, and improving upon the efficiency of these business processes in the future. So, this is what a collaboration platform will help in doing.

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So, what is a collaboration platform? There are some different perspectives to build collaboration platforms. There is a social layer component that is introduced in the business social layer; because we are talking about employees we are talking about users who will share their different knowledges with the help of these platforms. Social layer component is combined and integrated, with the provisioning, with the provision of business utilizations, but then you need some kind of a platform. So, you need some kind of a tool, which can be integrated with the existing products or the new products, that are being developed or, are being acquired and implanted in the industry.

So, there are some common attributes in business collaboration platforms. These collaboration platforms should be easily accessible, and this should be easy to use. And they require some familiar function, which help in the collaboration between the team members or across different teams. One such platform is named known as pro-work flow that is the name of a collaboration platform that is often used in the industries.

So, this is a web-based project management platform that is designed for managers. And then this platform basically helps employees to collaborate and improve upon the project delivery in the production process, in the project management process. So, this is an example of a collaboration platform. Let me now show you how this collaboration platform is going to work.

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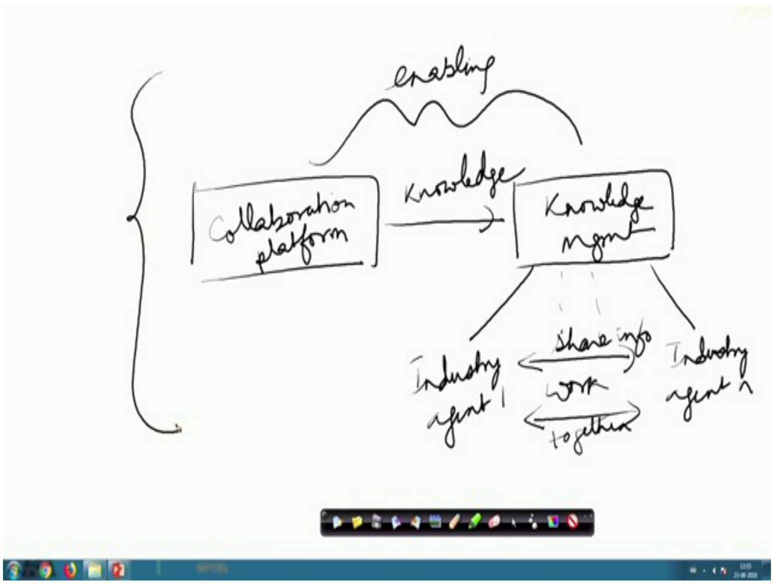


So, we are talking about a collaboration platform. This collaboration platform will help in collecting knowledge, collecting knowledge. So, this knowledge will be used in knowledge management. So, basically what is happening essentially is this collaboration platform is helping or, it is enabling knowledge management.

So, this knowledge management is important for different industry agents, there could be other industry agents, likewise, and industry agent. So, these industry agents would be sharing information between themselves, and they would be working together for achieving the objectives of the business. So, this is how a collaboration platform works, and how it is linked to the knowledge management aspect of it.

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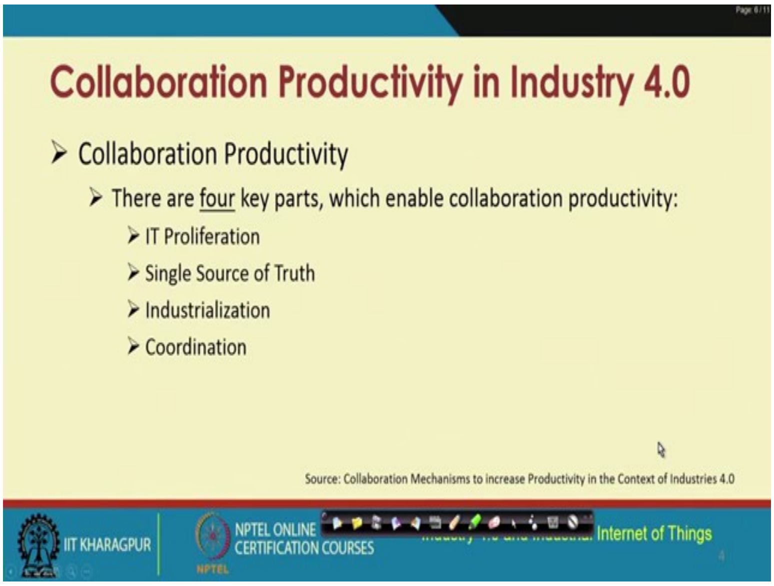


So, essentially, what is happening the idea is towards the objective of improving the productivity, improving the efficiency of these business manufacturing processes, and so on for fulfilling the overall objectives of Industry 4.0, we are saying that these collaboration platforms would be found to be useful. So, collaboration productivity is going to be improved, is going to be increased. So, there are four different aspects of increase in the collaboration productivity. And this will be enabled with the help of different key parts such as IT, single source of truth, industrialization, and coordination. Say let us look at each of these individually in little bit more detail in the next few minutes.

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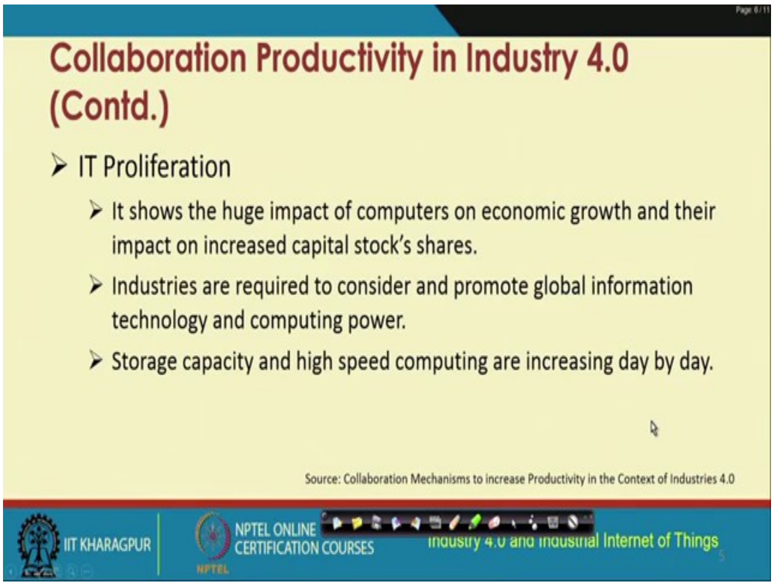


IT for IT proliferation. So, basically what has happened is as we know that computers, computational devices has a huge impact in our economic growth in the last few decades. And there has been increase in the capital stocks and shares across different companies worldwide. So, these industries worldwide are required to consider and promote global information technology, global information systems, with the help of this computing power. So, storage capacities have increased computational high speed computational capacities have increased and they are increasing even more day by day. So, this IT proliferation has basically helped in building the computational platform that will be required for coming up with the collaboration platform.

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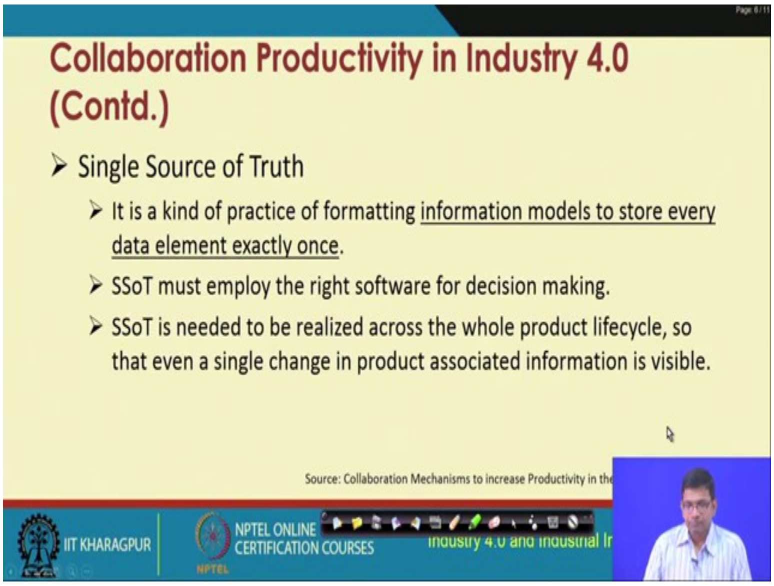


Single source of truth means we are talking about a single repository, where all the data are going to be stored. So, essentially we are talking about a data model and information model that will help in storing every data element exactly once. So, this single source of truth must employ the right software, at the right time, at the right place for right decision making. So, single source of truth is needed to be realized across the whole product life cycle, and this is very important.

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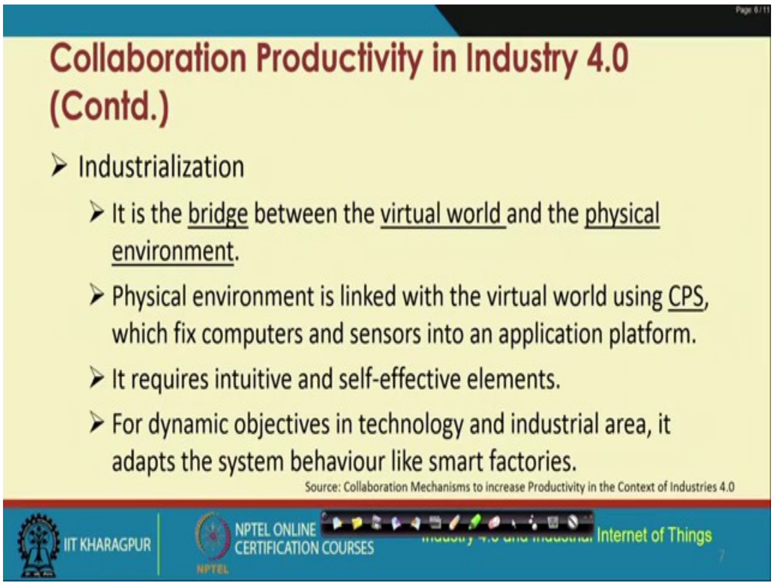

Industrialization. So, it is basically the bridging between the virtual world and the physical environment. So, the physical environment is linked with the virtual world using cyber physical systems which we talked about earlier. And these cyber physical systems are equipped with computers, sensors, actuators. So, these systems will require intuitive and self-effective elements to be adopted in them.

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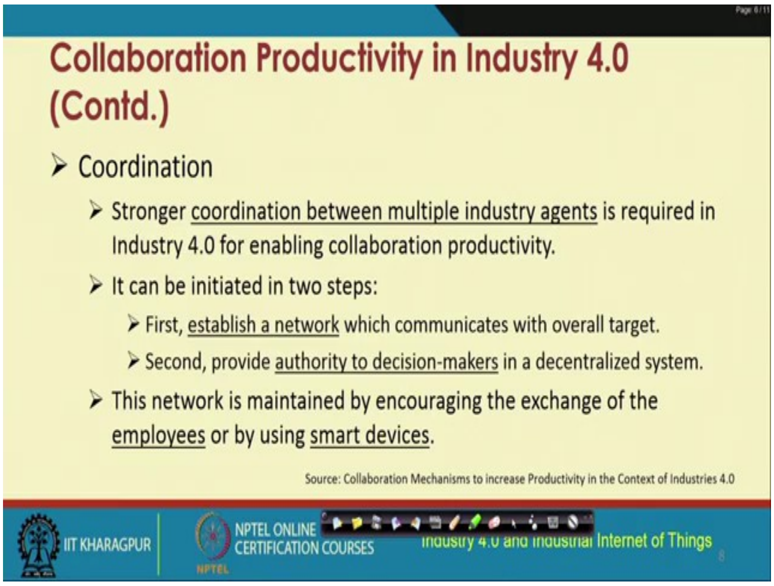


So, this is the industrialization aspect of it. And coordination is basically to ensure that there is stronger coordination between multiple industry agents in the same industry, across different industries, and so on, so that the collaboration productivity can be increased even further. Coordination can be initiated in two steps. In the first step, we can establish a network which communicates with the overall target, and in the second, providing authority to decision makers in a decentralized system.

So, this network we are talking about in the context of coordination is maintained by encouraging the exchange of employees or by using smart devices between different employees, because exchange, physical exchange, may not be required, if we equip your employees with different smart devices. This exchange of information can be maintained for stronger coordination between the employees of the same organization or across different organizations and so on.

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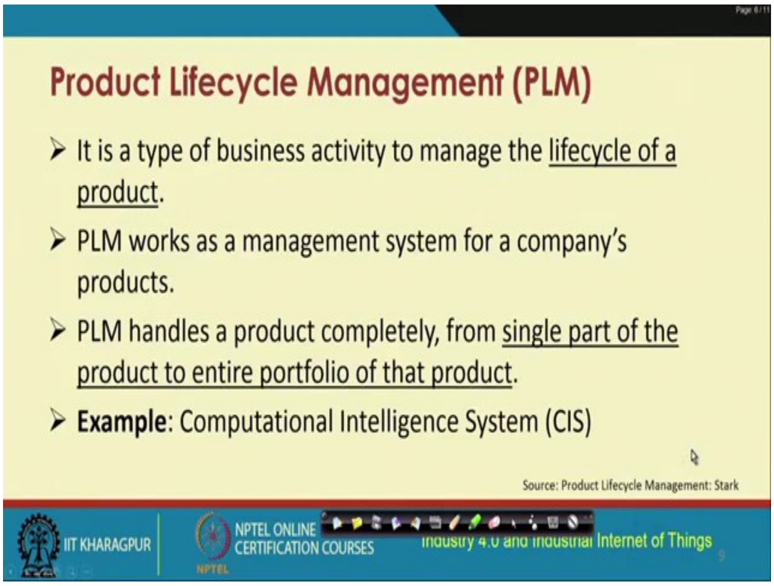


Now, let us try to understand the product lifecycle management aspect of it. So, product lifecycle management as this name suggests, this term suggests it is actually a widely used terminologies in the industry. So, it talks about the lifecycle of a product from ideation till deployment the entire lifecycle of a product is captured using these product life cycles.

So, this product lifecycle management works as a management system for a company's products. PLM handles a product completely from single part of the product to the entire portfolio of that product. Examples of product lifecycle management systems are basically, the CIS system, computational intelligent system, and there are many different other industry specific PLM systems that are widely used in the industries. And there are so basically these PLM systems are quite popular.

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The main goal of product lifecycle management is to maximize the product revenues, to decrease the product associated costs, and to increase the products value. So, obviously, as you can understand, these are very attractive features, which will be required to be implemented in order to move towards Industry 4.0, improving efficiency in the Industry 4.0, improving automation objectives in Industry 4.0.

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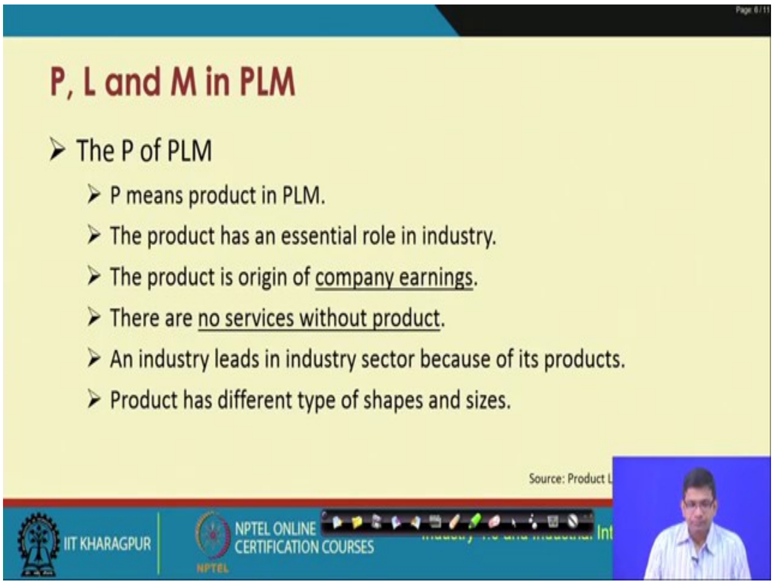


So, P, L, M, this P, P means product. So, the product is basically the central theme in the industry, everything is governed around products and processes. So, P corresponds to product, which is basically the central agent of consideration in PLM in the industries. So, the product is the origin of company earnings. So, this P is obviously, as I was telling you so far the most important component of product lifecycle management. And we can understand that if you do not have product, you do not have its services. So, every service is basically linked to that product.

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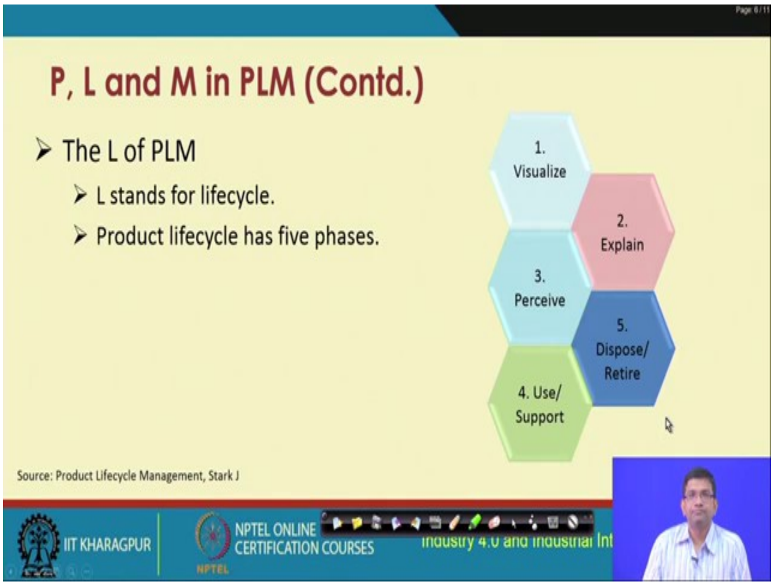


The L of product lifecycle management stands for lifecycle; L stands for lifecycle. And there are five different parts, five different phases in this product--lifecycle so in the lifecycle of PLM. So, one is basically visualization visualize explain perceive use and then dispose. So, visualize means ideation, ideation explaining the idea, perceiving the idea, realizing the idea, supporting the system, the product that is built, and then disposing or retiring the product, that is built. So, these are the five different parts, five different phases in the product lifecycle of any product lifecycle.

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Visualization as I was telling you corresponds to the ideation. People have different ideas regarding a product. So, they visualize this product to be built that is the ideation part. Next is the explanation this idea has to be transformed into some kind of a representation that is basically captured through the phase explanation phase. Perceiveness or perception is basically at the end of the previous phase, the product has to be built in its final form. And then use or support is basically the customer basically starts to use the product in the user support phase. And then once it is used, once it is no longer useful to the company, the product has to be retired.

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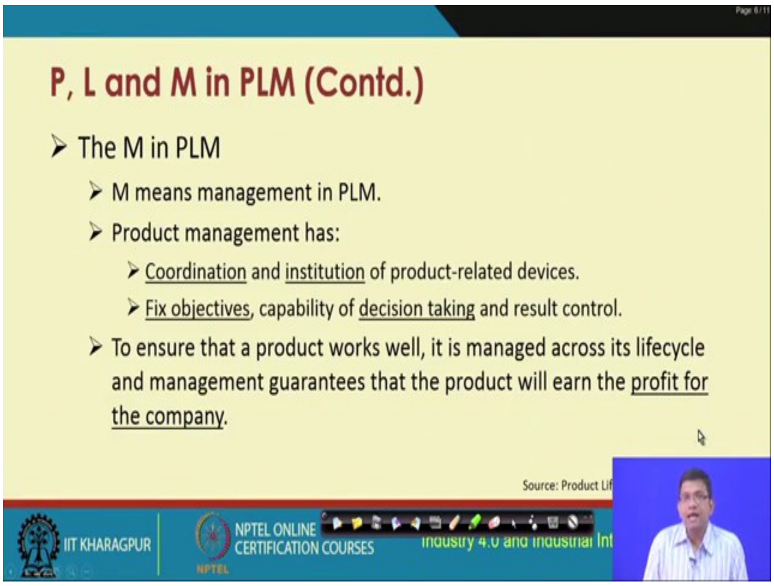

So, why we are talking about all of these things, we need to understand the different phase, the different phases of the lifecycle of any product. M in PLM means management. So, product lifecycle management, M stands for management.

Management, we are talking about product management over here, where the considerations of coordination and institution of product-related devices are important it is required to fix different objectives. And enforcing the capabilities of decision making, and taking result of the control, these are the different important considerations, in the management aspect of PLM. So, the whole idea in the management aspect of PLM is to ensure that a product works well, it is managed across its lifecycle and the management guarantees that the product will earn the profit for the company.

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In terms of Industry 4.0, it is required to improve efficiency, effectiveness, automation has to be poured in order to be able to achieve it. So, automation in the PLM is something that the industries will have to be striving for, with the help of different things such as computers alone embedded systems, cyber physical systems everything has to be taken together in order to improve upon this efficiency and effectiveness in the automation of PLM. So, this efficiency and effectiveness of PLM improves the market share and market size, with increasing revenue.

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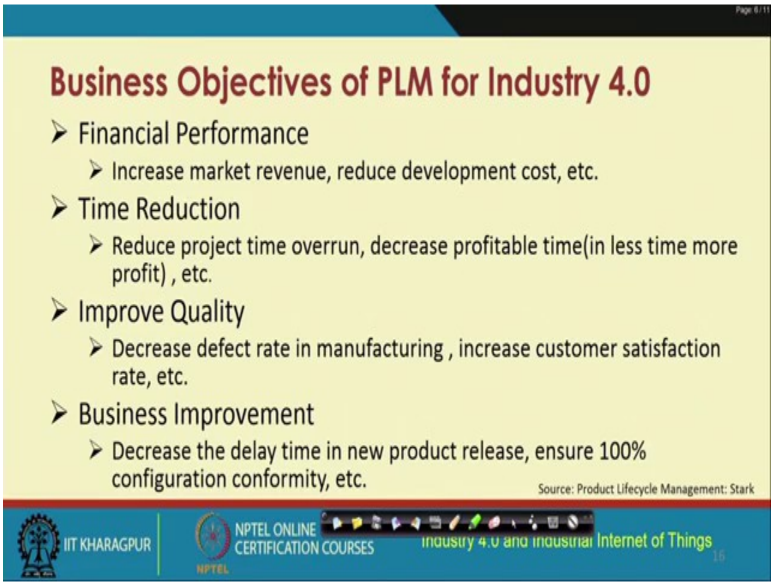


These are some of these business objectives of PLM for Industry 4.0, financial performance, which obviously talks about increasing the market share, increasing the market revenue, reducing the development cost. Time reduction basically, reducing the project time overrun, decreasing the profitable time; improving quality talks about decreasing, the defect rate that means the rate at in which, rate at which the manufacturing defects in these different products are going to be there.

So decreasing that rate improving the customer satisfaction and so on, these are basically improving quality aspect of the business objectives of PLM. And overall improvement of the business decreasing the delay time in product release ensuring 100 % configuration conformity, improving 100 % customer satisfaction, these are all the different business objectives of PLM for Industry 4.0.

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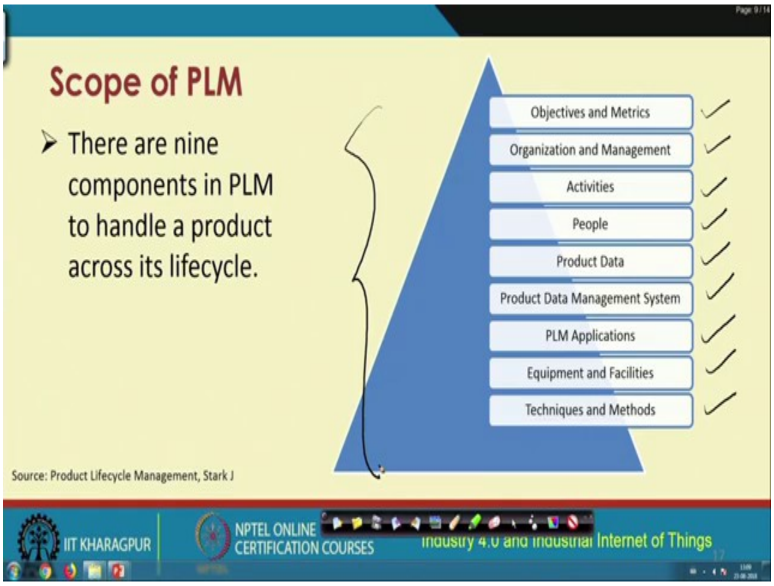


So, if we are talking about PLM, we need to understand few things. So, let us look at some of these different aspects.

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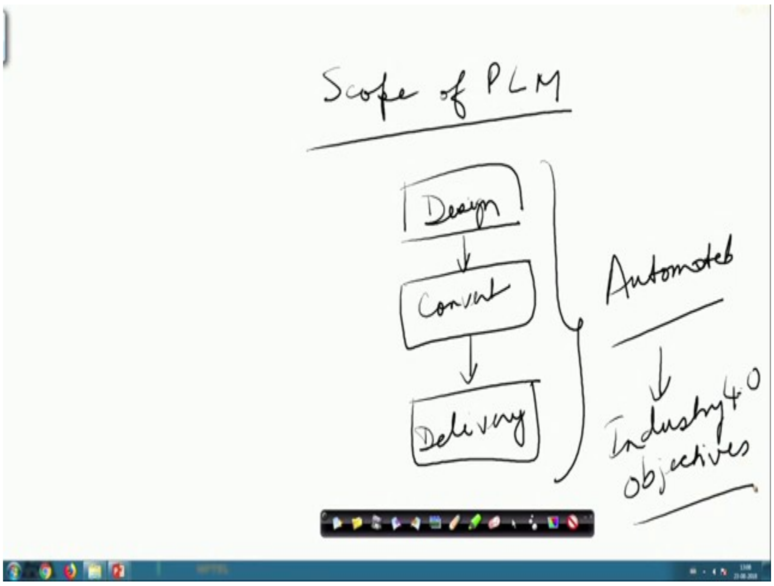


So, let us talk about the scope of PLM, in the context of Industry 4.0. So, first of all you need to design the product. Then this product has to be built in its final form conversion. Conversion of the design into the physical form of the product and then this product will be delivered. So, all of these, basically will have to be automated to the extent possible in order to comply with the Industry 4.0 objectives.

So, we will be going back what is the scope of PLM. So, there are nine components in PLM to handle a product across its lifecycle. And these are the different components of it. These are the different components objectives and matrix, organization and management, activities, people, product data, product data management system, different PLM applications, equipments and facilities, techniques, and methods. So, all of these different nine components will have to be handled in the lifecycle of a product in PLM.

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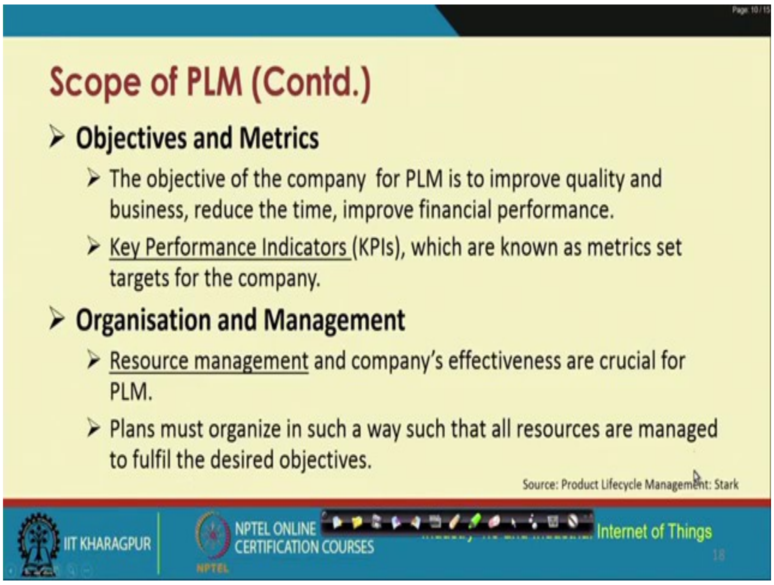


So, objectives and metrics, the objective of a company for PLM is to improve the quality and business, reduce the time, improve the financial performance. So, KPI is commonly known as KPIs key performance indicators are considered in the companies these are basically some kind of a metrics that are considered in the company. And these are targeted by the employees to be achieved, towards the development of a particular product.

The next thing is basically the organization and management. Here we are talking about resource management aspects. And the overall management of the different resources resource management means all kinds of resources. All kinds of resources including the product, the infrastructure, the human resources and all kinds of resources the management aspect of it should also be consideration alongside.

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Activities, there are many products product associated activities such as idea management, program management, new product development. People are involved to progress and maintain a product, example a business analyst, a cost accountant, so these are the different people aspects. And the product data it is a major asset, throughout the product lifecycle.

So, product will face problem if we provide false product data. So, product data means like you falsify some kind of a data. You say that the product is defect free, but let us say that there is some small or big defect, that exists in the product. So, this falsification should not be done. So, then the product itself will fail, and it will face problem in the market.

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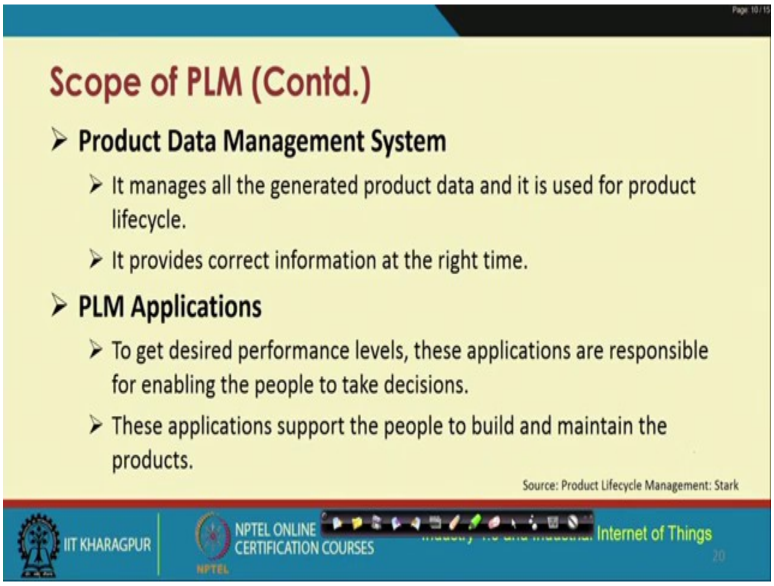


Product data management system. As this name suggests, it manages all the generated data and that is used for improving the life cycle product lifecycle overall. So, it provides correct information at the right time. PLM applications to get desired performance levels, different applications are required, which are responsible for enabling the people to take different decisions. These applications support the people to build and maintain these different products.

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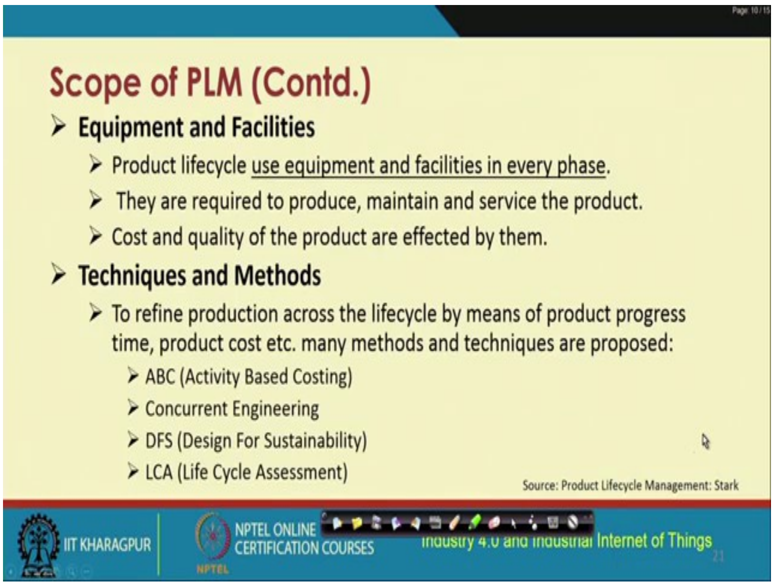

Equipment and facilities talking about the use of different equipments, use of different facilities, the use of different infrastructure, that are already existing in the industry and procuring the ones that are not already there in every phase of the PLM. Techniques and methods, to refine the production across the lifecycle, by means of product progress time, product cost, many methods and techniques can be used such as activity based costing, concurrent engineering, design for sustainability, and lifecycle assessment.

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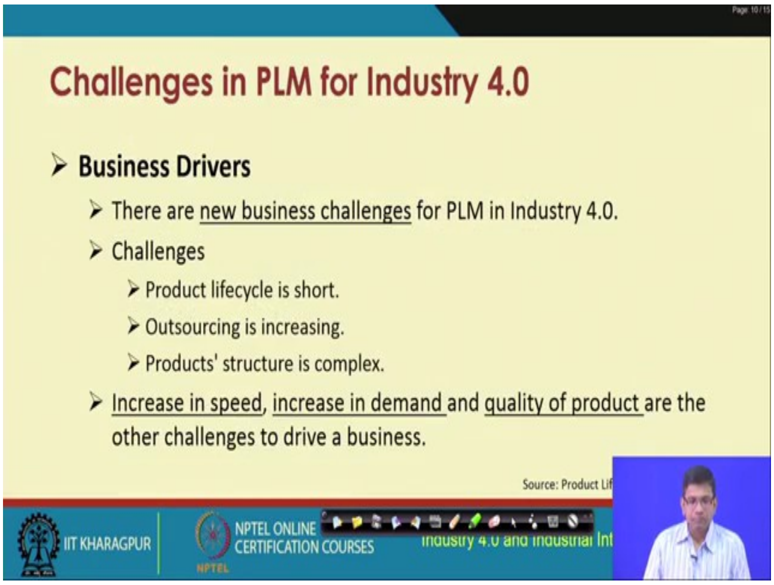


Business drivers there are many new business challenges if you have to adopt PLM for complying towards the objective of Industry 4.0 there are different business challenges such as reduced or shortened product lifecycle. Increased outsourcing in the new products in the context of Industry 4.0, and the products structure has become complex. So, think about IIoT systems, think about a CPS system, in Industry 4.0. We are talking about small sensor enable devices small actuator enabled devices.

So, the way these IoT systems are developed, it is a kind of different product lifecycle that is used for these IoT systems. So, the essentially what has happened is in IoT the product life cycle has reduced it has shortened, and a lot of things are basically lot of components are outsourced. And many of them are in sourced from different companies. So, basically this outsourcing and in sourcing in the context of IoT, and their use in Industry 4.0 has increased and consequently the structure of the product the building of the product, because there are so many different complex components in these different products IoT products that the product structure has also become complex.

So, these are some of these new business challenges for PLM in Industry 4.0 that will have to be kept in mind. Increase in speed, increase in demand, and quality of product are the other challenges to drive a particular business.

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Industrial requirement. Nowadays, we are not talking about physical presence of the different units, there could be virtual presence also. There could be geographically dispersed design teams supply chain itself has been made virtual to a large extent. And this could be further increased with the increase of adoption of these IoT systems. So, what is required is that the different industry components will have to collaborate with one another. So, net-centric technologies have increased in their use in PLM nowadays, and that has also not only improved not only increased the efficiency of the production process, but has also made it much more complex, in terms of development.

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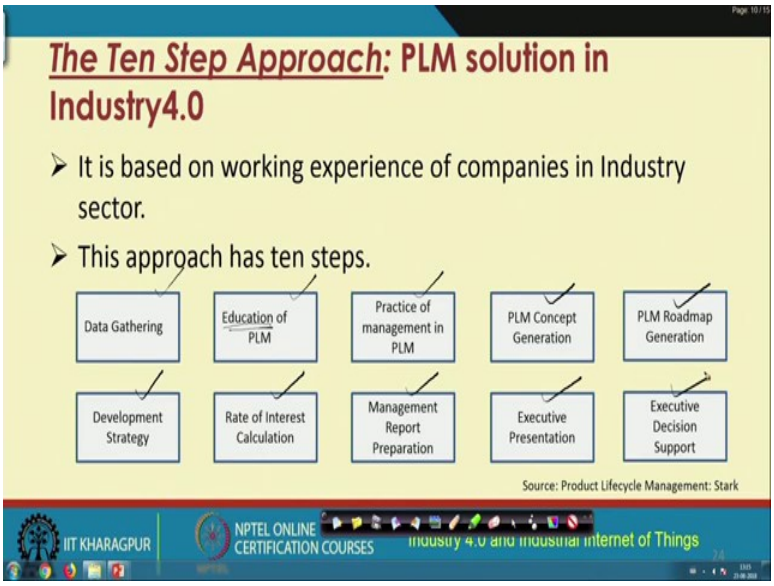


So, for Industry 4.0, these are the 10 step approaches that can be used for PLM. Number 1 data gathering education of PLM. So, education component is very important and is often neglected, but education and training is very important. Practice of management in PLM concept, PLM roadmap generation, development strategy, rate of interest calculation, management report preparation, executive preparation and executive decision support.

If you need to know in further more detail about each of these many of these are quite well understood, and I think most of them you can understand from these names alone. But if you need to understand in further more detail this is the source that can help you to understand in further more detail. So, you can go through this particular literature in order to understand these.

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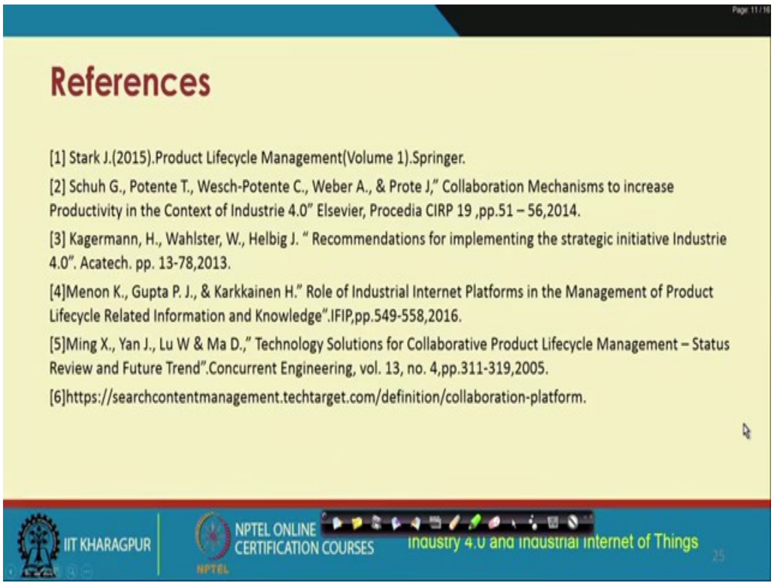


So, with this we come to an end of this lecture. So, collaboration platform product lifecycle management, their automation improvement in the context of IoT, IIoT, Industry 4.0 is very important. So, these are often overlooked, but should not be from our perspective and that is why we have included these things in this particular course on Industry 4.0 and IIoT.

Thank you.

**Introduction to Industry 4.0 and Industrial Internet of Things**
**Prof. Sudip Misra**
**Department of Computer Science and Engineering**
**Indian Institute of Technology, Kharagpur**

**Lecture – 13**
**Industry 4.0: Augmented Reality and Virtual Reality**

In this lecture we are going to get a brief overview of Augmented Reality and Virtual Reality in the context of a IIoT. So, augmented reality and virtual reality, they are popularly known as AR and VR, are quite important technologies, that have been adopted and are being adopted at present in different IIoT context, in the different industries. Because of different advantages that they offer, there they have some relationship between them they are interlinked, but they have some distinct differences.

So, in the next few minutes, we are going to understand the specific attributes of AR and VR and the different challenges, that are there in the adoption of AR and VR technologies in IIoT settings.

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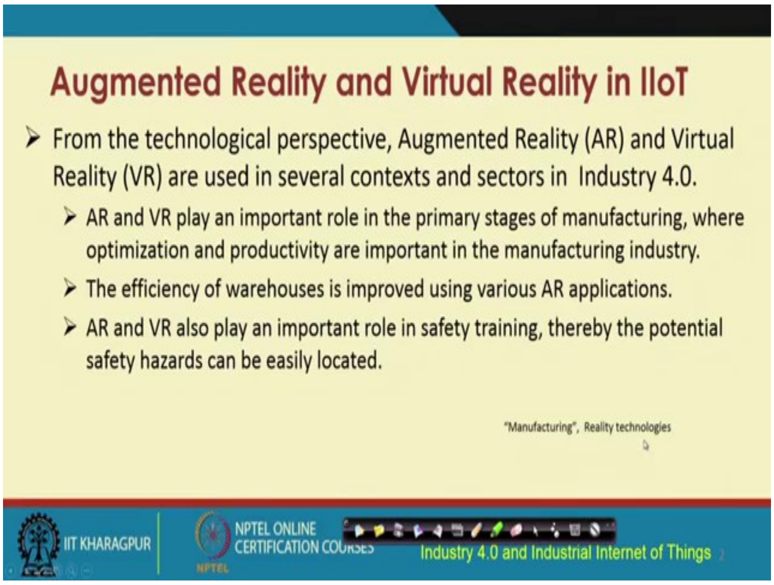


So, from a technological perspective, both AR and VR they can be used in different context, different industry sectors, they can be used and together they can help in improving Industry 4.0. So, they play a very important role in the primary stages of manufacturing, where optimization and productivity are important considerations. Because in any manufacturing industry it is not just the manufacturing of the product, optimization of the processes, improvement of the productivity, these are important considerations. The efficiency of warehouses is also very important and these can be improved using different AR applications. Both AR and VR are also important in safety scenarios.

So, for example, there are situations I will also talk about a scenario, where VR as well as AR can be used for training of industrial safety. So, we will talk about that in another lecture not in this lecture. So, I will showcase how AR VR can be used to improve the training of safety in industrial plants. So, these are very important technologies. So, that is the reason why I thought that a basic understanding about these technologies can help in improving the IIoT infrastructure in the industries.

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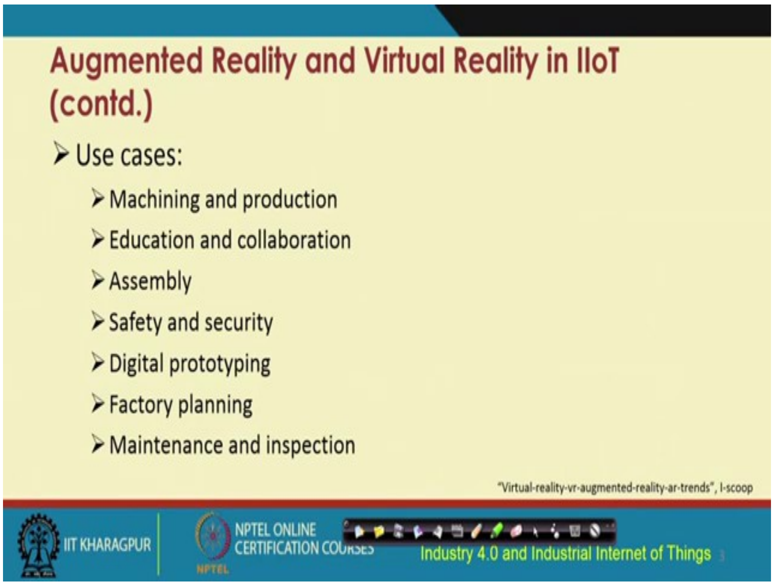


The different use cases that are served by AR and VR for IIoT are things like machining and production. These technologies AR VR can be used to improve the overall machining processes, production processes, and in education, training, collaboration, assembly line, safety security of different infrastructure in the industries. And digital prototyping, factory planning, maintenance and inspection, these are some of the different uses of these technologies in the IIoT settings. So, these are very important, but remember one thing that through this half an hour lecture, you are not going to learn about, how to use the AR and how to use VR.

So, here you are just going to learn about the different features of AR, different features of VR, how they can be used, where they can be used, where they cannot be used. So, these are the things that you are going to get an understanding about. You cannot learn through this half an hour lecture how to become a master of use of these technologies AR and VR. So, this is basically the overall, this is the overall scope of this particular lecture.

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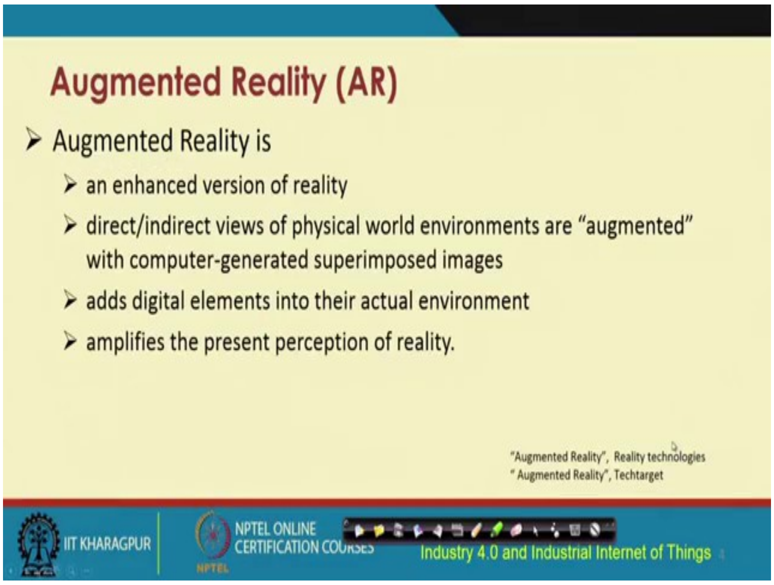


So, let us now try to understand what is AR. So, augmented reality basically, as this name suggests augmented. So, physical reality is augmented with certain information, typically, some computer generated digital images augmented with that kind of information to give a better feeling, better perception to the users, improve perception of the reality to the users.

So, it AR basically will improve the feeling of the reality, the physical reality of the world in which the user is operating. And that improved feeling as I just said can be offered with the help of computer generated technologies, typically different types of images, videos, etcetera. So, these digital elements are added to the actual environment and together we have an amplified environment, where the present perception of reality is improved this is what AR is all about.

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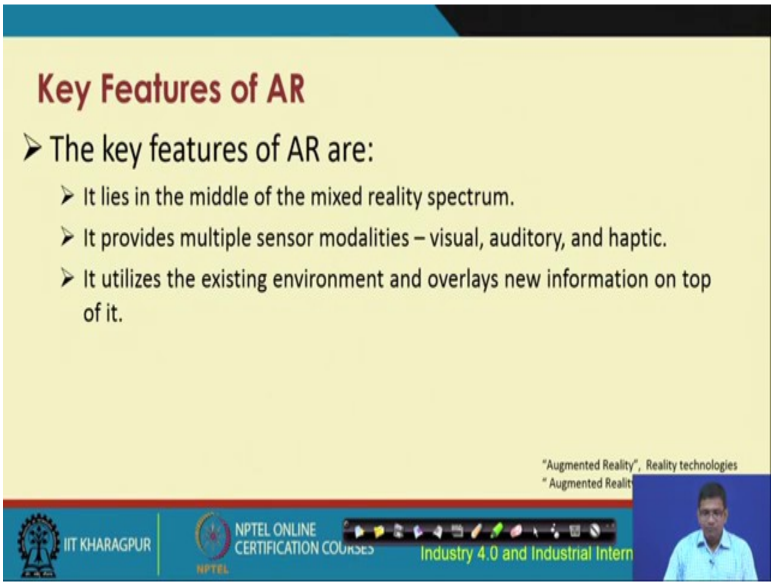


So, some of the key features of AR, it lies in the middle of the mixed reality spectrum. So, we are talking about different types of reality; we are talking about augmented reality, we are talking about virtual reality, we are talking about no reality at all, completely physical environment, we are talking about completely immersed kind of environment. So, AR is some kind of mixed reality kind of environment VR provides mixed reality environment.

So, it provides multiple sensor modalities, which can be visual, auditory or, haptic. Haptic means what? By touch, through touch, basically, you have different sensors which are added to the eye, to the ears, to the fingers, which can give the user an improved feeling. And these users could be any user and in the industrial settings in the IIoT settings we are talk talking about industry users typically. Let us say, a mechanic of a particular machine, an operator of a particular machine can be trained with AR, with the help of these different types of sensors, that I just mentioned visual, auditory, haptic sensors can be attached to that particular user or the mechanic or the operator of an industrial machine. And, different computer generated images can be shown and that basically will give a better perception of the physical environment in which that particular mechanic the operator is operating.

So, they will have improved augmented reality of the actual reality. So, that is going to be generated out of it. So, this is the whole advantage of the use of AR, in industry settings.

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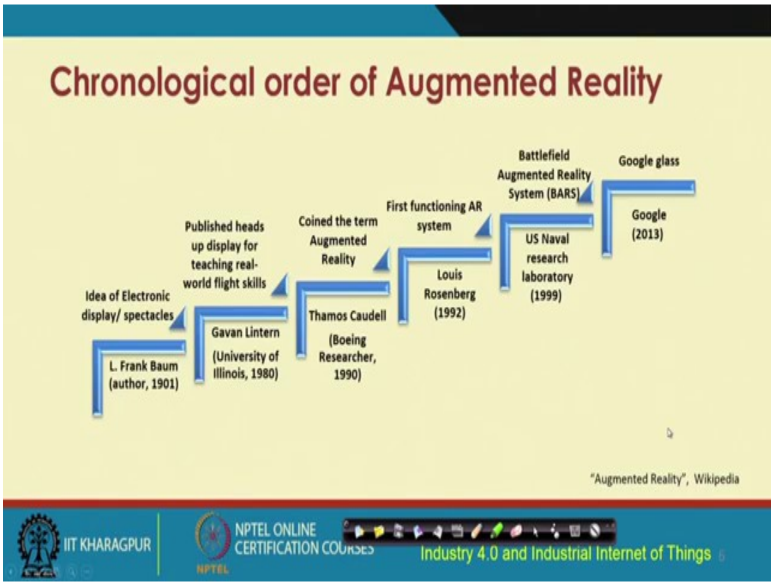


So, let us now go through the history a bit. So, AR has become very popular in the recent times, but it has been there since long starting from early 1900s. So, in 1901 the idea of electronic displays and spectacles came into being Frank Baum basically proposed this kind of idea use of this kind of thing. In 1980s, he published heads-up display for teaching real world five right skills we are done this publication of public publications of this kind of heads-up displays was made available by Lintern.

In the 1990s, Boeing researcher, Thamos Caudell coined the term augmented reality. In 1992, Louise Rosenberg was the first, he came up with the first functioning AR augmented reality system. In 1999, the US Naval Research laboratory came up with the BARS system, which is the battlefield augmented reality system. In 2013 Google came up with the Google glass, which is very popular and everybody knows about it at present.

So, this is basically the overall history of augmented reality. So, it has been there since the last century 1900, early 1900, till recently augmented reality in different forms was there, but now it has become much more popular, because of its use in different industry settings.

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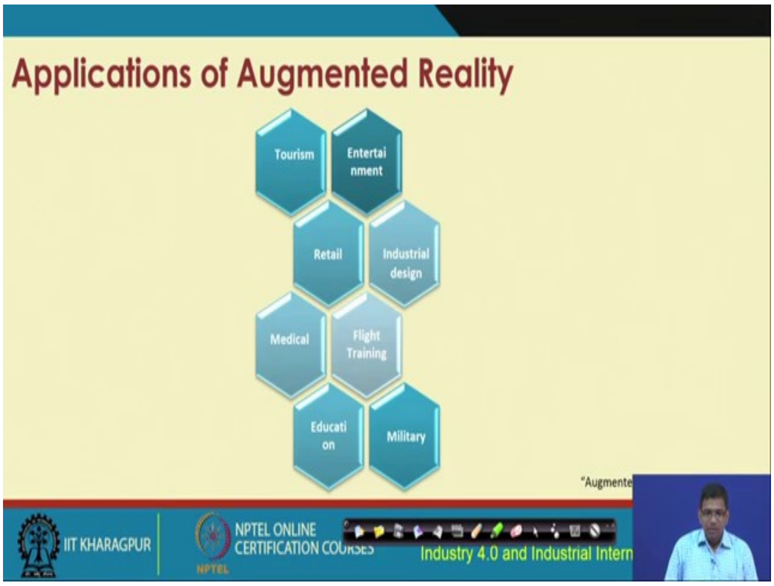


So, different applications of augmented reality in tourism, entertainment, retail, industrial design, medical environments, hospital settings, for instance, flight training, educational, military training and so, on augmented reality; reality has different applications.

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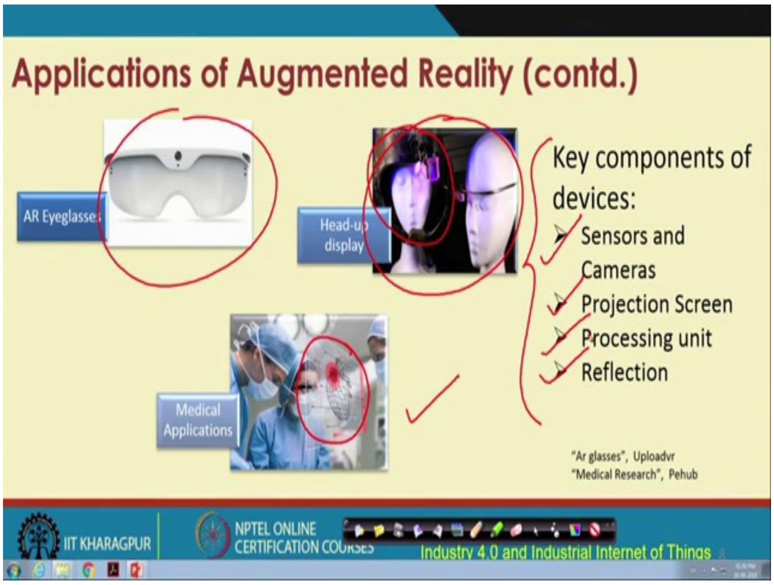


So, here in this particular picture, there are pictorially, the different augmented reality systems are shown. So, on the left hand side we have the augmented reality eyeglasses. This is the augmented reality eyeglass, this is the heads up display as you can see over here the individual is wearing it, the display unit heads-up display unit and then we also have like medical applications for instance as you can see over here the doctors are performing some kind of a heart surgery and can see using the display, the different aspects of the heart on upon which the surgery is being performed. So, these are some of the key components of these different devices, that are used for AR, there are sensors and cameras, projection screen, processing unit, reflection systems like mirrors etcetera.

So, these are some of the different components that are used for AR. So, let us do one thing, we will now try to some of the key features of how these AR systems work. So, what is important? We have these sensors.

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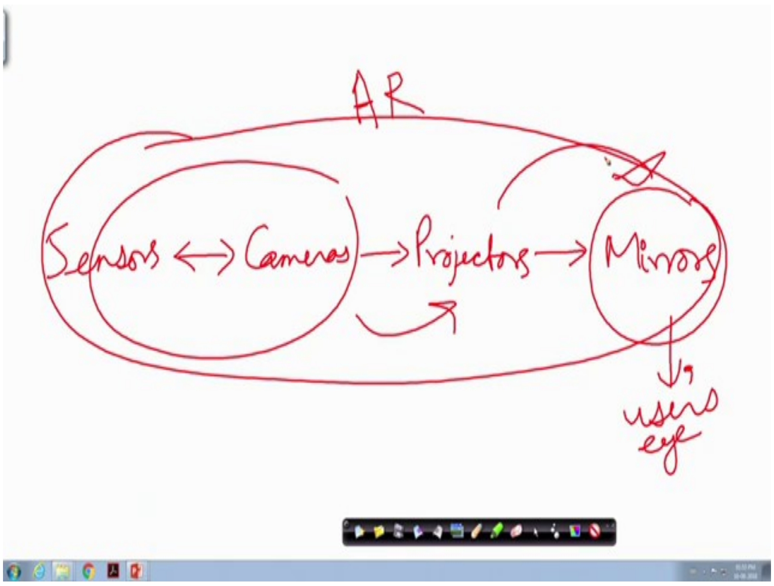


We have sensors; these sensors basically are the ones that gather real world information, then we have also the cameras and these cameras they scan the environment, they collect the data from the environment, from the surroundings. Then we have the projectors, basically, they project the information about the environment to somewhere and then we have the mirrors this is basically the reflection system. So, these are some of the different components of AR and how together the AR systems work. And these mirrors are very important because they can change the orientation based on how the users' eye changes its position.

So, these are the key aspects of AR and how it works. So, sensors collecting data, cameras also basically know projecting in the information collecting the information and then together the sensors, cameras, collecting this information and then sending it to the projectors, and this projector basically projects all this information and then you have this reflection system, which is the mirror. So, this is how the AR systems work holistically. But as I said at the outset that through this half an hour lecture you cannot become an expert of AR or VR, this is just to get a brief expository idea about how the systems work and what is in there.

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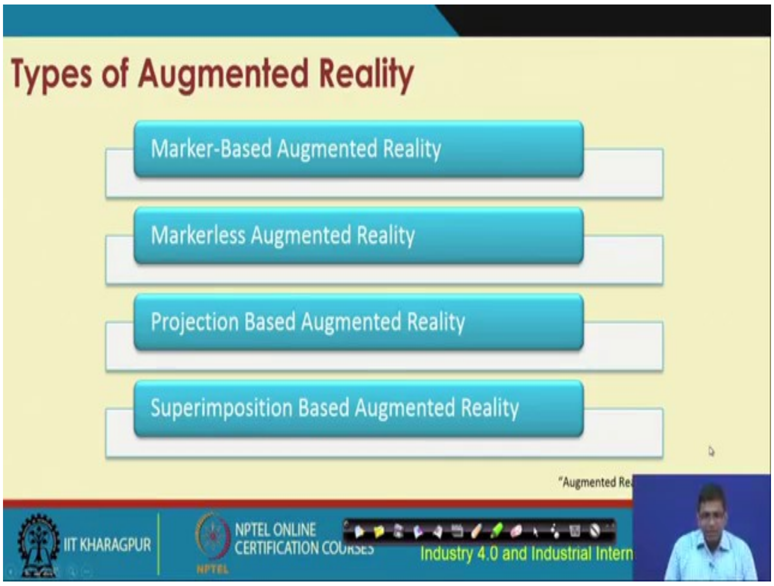


So, now let us look at the different types of augmented reality. We have marker-based augmented reality, marker-less augmented reality, projection based augmented reality, superimposition based augmented reality these are some of these different types of augmented reality.

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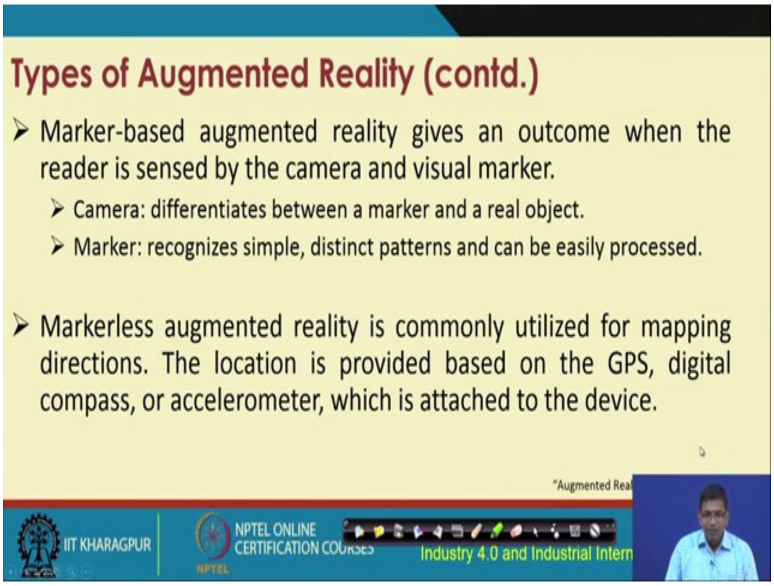


Marker-based augmented reality gives an outcome when the reader is sensed by the camera and the visual marker. So, there are two things one is the camera and the existence of marker. So, these markers basically will help in recognizing simple distinctive patterns, which can be easily processed and the camera is well understood what is the functioning of this camera.

The marker-less augmented reality unlike the previous one does not use any kind of marker and these commonly used things like GPS, digital compass or accelerometer, which basically help in offering information such as the location of a person or a device.

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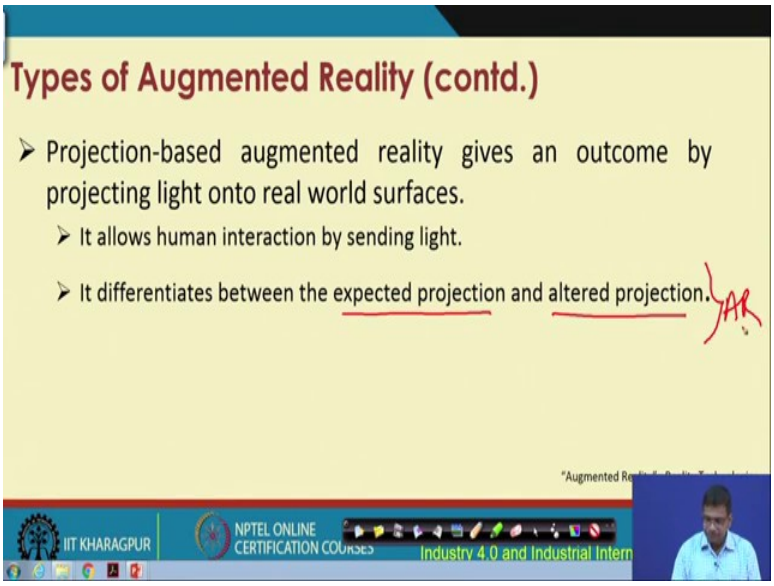


Then we have the prediction based augmented reality, that gives an outcome by projecting light onto the real world surfaces and it allows the human interaction by sending light. And it differentiates between the expected position projection and the altered projection expected and the altered.

So, this is these are very important things these are very important things in expectation and altered projection, this differentiation is very important and is key to AR.

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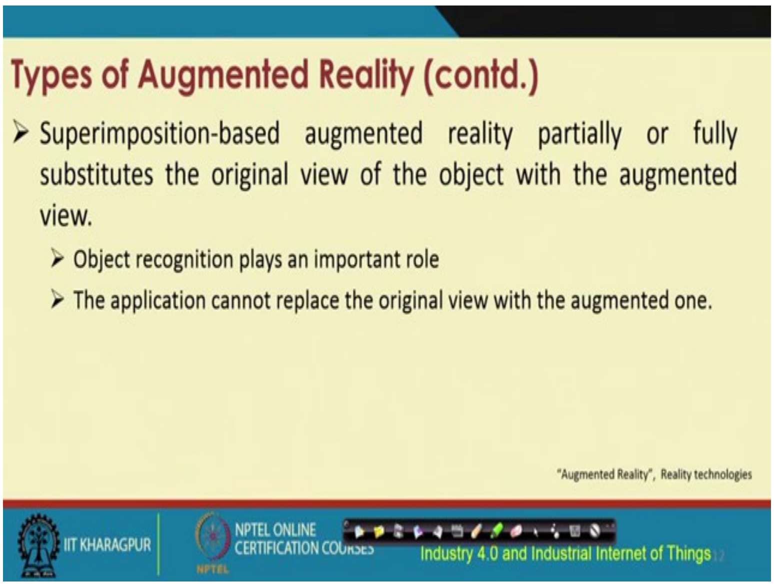

Then we have the superimposition based augmented reality, which partially or, fully substitutes the original view of the object with the augmented view. Here object recognition basically plays an important role and the application cannot replace the original view with the augmented one in this kind of superimposition based augmented reality.

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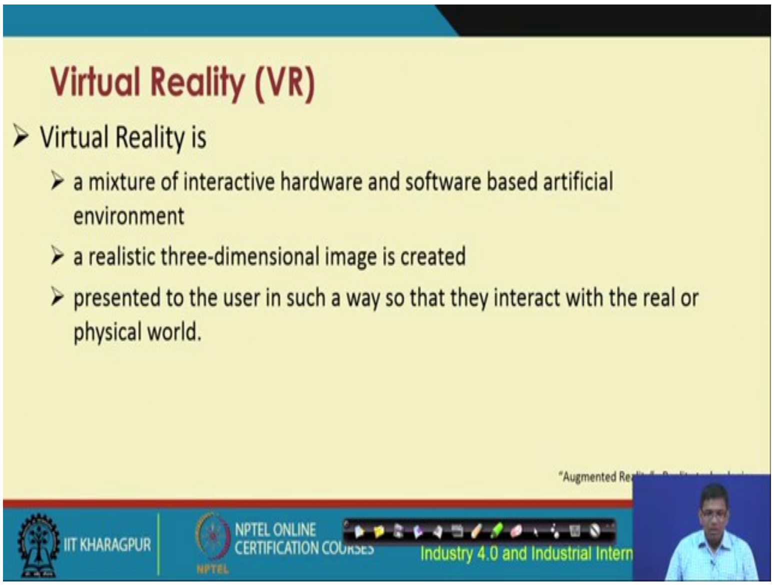


So, these are some of the highlights of AR and how it works at a very high level, what are the different components of it.

Now, let us look at what is VR and later on, after we have gone through the different highlights of VR, we will see that how AR and VR they compare between each other, what are the similarities between AR and VR and what are the differences. So, VR is a mixture of interactive hardware- and software-based artificial environment.

So, it is an interactive hardware unlike the previous one, here it is interactive and it offers a three dimensional image. A realistic three-dimensional image is created and the user in VR feels that the user is actually present in the physical world, which is being simulated, but is actually not being present. So, it is a virtual environment that is immolated, but the user feels that, the user is acting in the actual physical environment. So, it is a virtual immersion kind of experience that the user gets.

So, this information to the user is presented in such a way that the user feels that the user is operating is acting in the real world or physical world.

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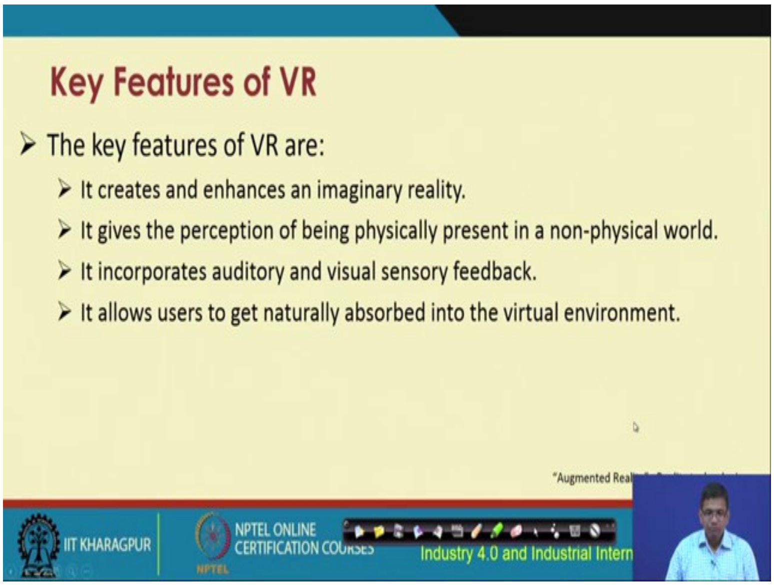


So, the key features of VR are, that it creates and enhances an imaginary reality, this is very important. It is something that is not real in fact, but is a virtual reality, imaginary reality. Then we have it gives the perception of being physically present in a non physical world, this is also very important. It is actually not a physical world, it is an emulated one, a virtual one, but the user feels that user is interacting with the physical world, which is being immulated.

So, it incorporates auditory and visual sensory feedback all kinds of sensors are used in this case also auditory, visual, touch, haptic interfaces are also used. So, user can hold devices and feel that actually the user is holding the device; for example, a user might feel that the user is holding the steering wheel of a car, but the actually its a virtual environment and in immulated environment, there are certain sensors which will give the feeling to the user that the user is holding a particular steering wheel of the car, but actually the user is not feeling. I mean not actually holding the user is not actually holding the steering wheel and he is not driving the car.

So, I hope that this basically makes it clearer to you how it is going to work, not I mean not the technical details of it, but an overall impression about how VR works. So, it allows the users to get naturally absorbed into the virtual environment. So, this is also very important in VR.

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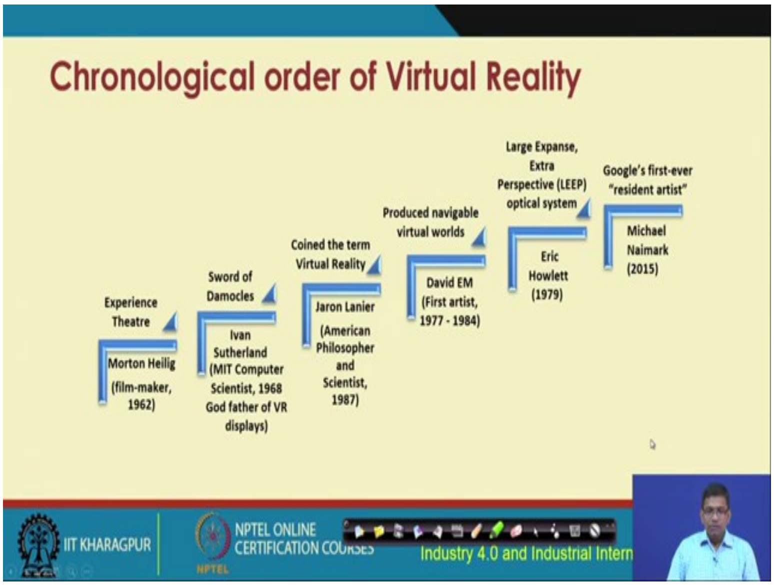


So, in terms of the chronological order of virtual reality, how it has evolved over the years. So, in around 1960s early 1960s the filmmaker Morton Heilig he created an experience theater. So that basically started the works, the initial works on virtual reality, then the Sword of Damocles was created by an MIT computer scientist in 1968 and he is considered sort of like a father of virtual reality displays, then in 1987, Lanier and American philosopher and scientist, coined the term virtual reality.

So, actually the virtual reality the popularity of virtual reality started with this term in 1987, the virtual reality term started in the 1987 and then David EM was the first artist, who died in 1984, he produced the navigable virtual worlds. And Eric Howlett, in 1979 created the leap system, which is the large expense, extra perspective, optical system, and in 2015, Google created the first ever resident artist system and that is a quite popular system, it is a virtual reality system. So, the Google glass we have talked about earlier in the context of AR and Google's in this system the resident artist system is another system which is an example of the virtual reality system. These are quite popular systems in terms of AR and VR being used in our society.

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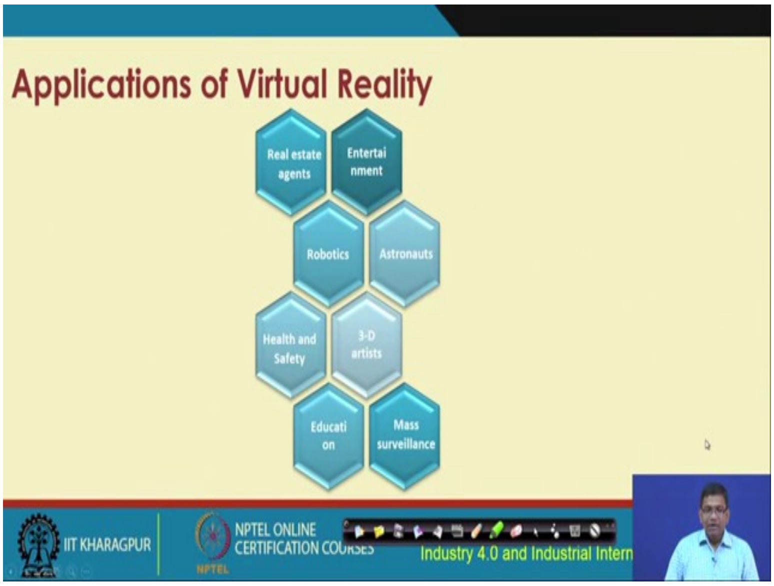


So, there are different applications of VR in terms of used by real estate agents, entertainment industries, robotics, astronauts; astronauts use VR a lot because even before and a space craft is sent to the in the space, the astronauts are trained in the virtual environments, using VR systems, the astronauts are trained similarly for the flight pilots, as well. Fight pilots are also often trained in the using virtual reality systems. And in health and safety healthcare industries VR are used. So, doctors are trained before actually performing a life critical surgery, the doctor can try to practice that surgery in the VR environment. In educational environments it is used by 3D artists, VR are used for mass surveillance also VR has found applications.

So, before going any further, let me just try to show you how overall how these VR systems are going to operate.

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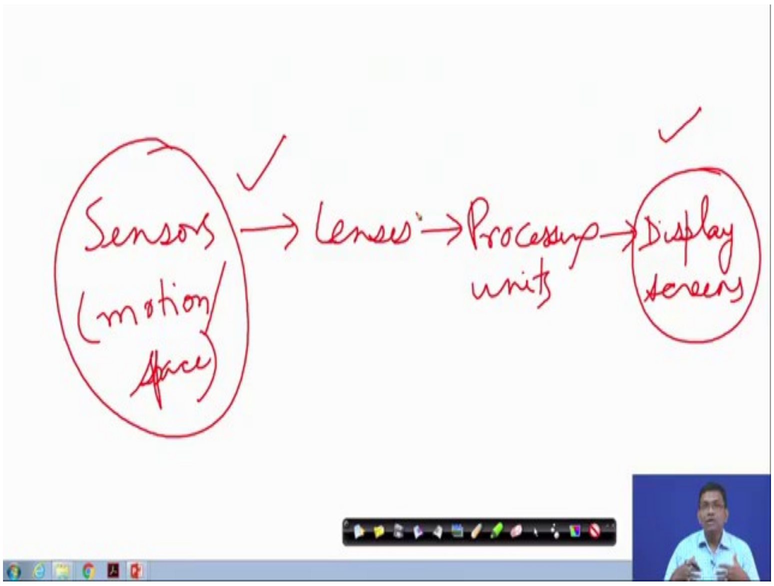


So, here also we have these different sensors here also like before we have different sensors. These sensors can detect the motion the direction in space, motion, space, the position in space, all these things can be detected using these sensors and there could be different types of sensors that would be used. So, then you also have different lenses, which could be used to capture and reshape the image of each eye. Then we have the processing units, which basically will process the data that is captured, then we have finally, the display screens, which basically give the user the feeling of being used in the physical world.

So, these displays are very important. So, these are the overall the different components of a VR system some of the different components, and these sensors are very crucial different types of sensors are used. These sensors, the display system, these are very important and of course, the lenses the processing units processing units are very important and you need to have high end processing units high end processing units are typically used in these VR systems. Because otherwise that feeling will not come if there is a delay between performing a certain action and actually getting the experience the perception if there is a delay, then this VR system is not going to be much useful.

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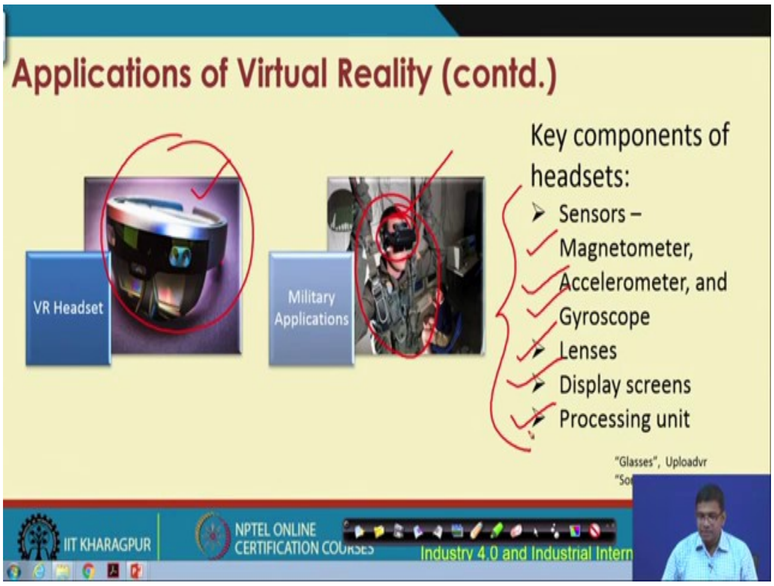


So, I was telling you about the different applications of virtual reality earlier. So, virtual reality, here we can see few pictures, this is a VR headset that you can see. Here as you can see over here virtual reality sets are being used by a military person to get trained with some combat operation or something very similar. So, there are different components of these headsets are very important. So, these are very important and there are different components of these headsets like different types of sensors, like magnetometers, accelerometer, gyroscope, the different lenses, display screens processing unit, all these as I was telling you earlier these are the important components of a VR system.

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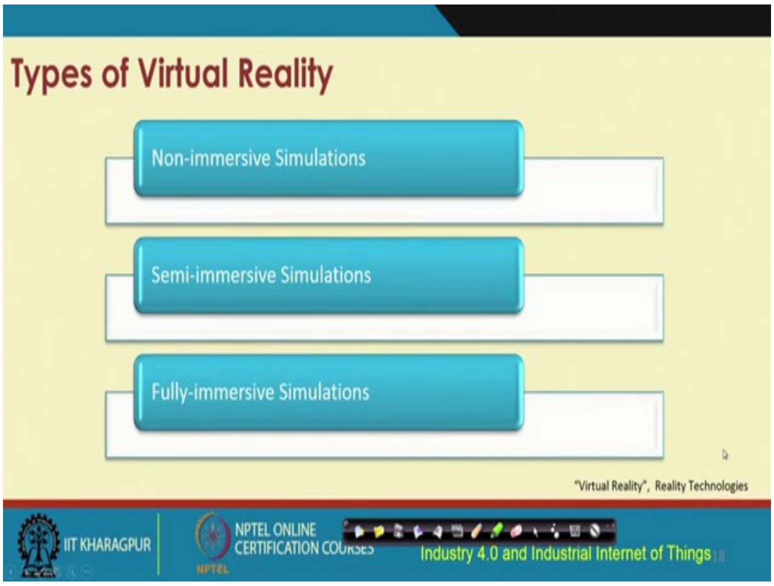


Different types of virtual reality; one is non-immersive simulation, semi-immersive simulation, fully-immersive simulation these are different types of virtual reality environments.

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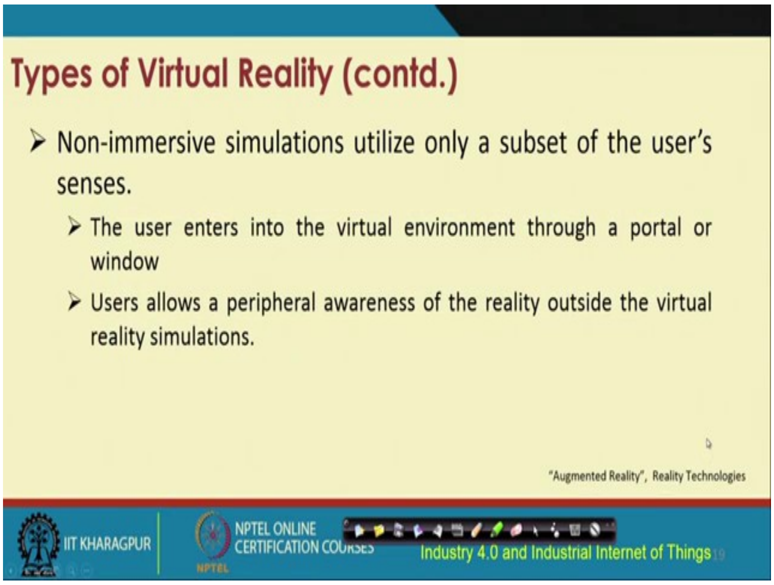


Non-immersive, as these name suggests, the user enters into the virtual environment through a portal or, window and this basically allows the users to have a peripheral awareness of the reality outside the virtual reality simulations. So, this name, as it suggests, non-immersive simulation, basically, utilize only a subset of the user senses not all of it as a non-immersive. But only a subset of the user senses are used in this kind of simulated platforms, non-immersive simulated platforms.

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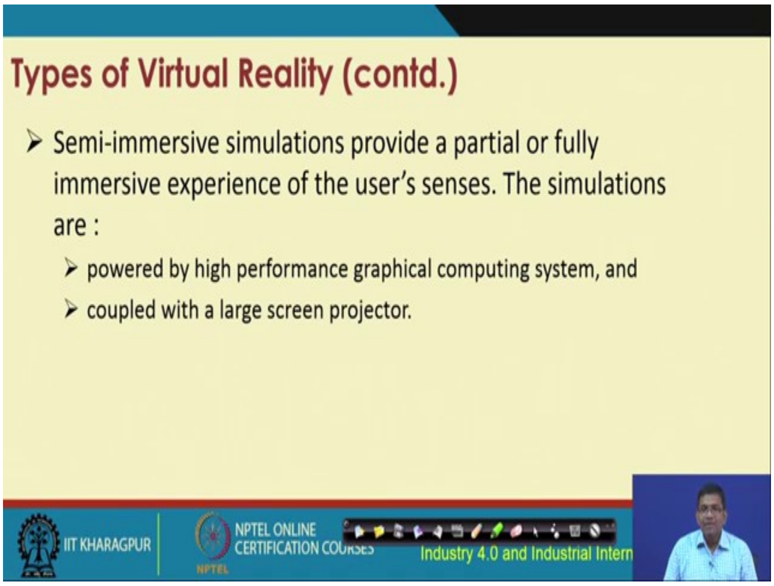


Semi-immersive again partly it is not like the non-immersive, but here partly partially or fully-immersive experience, is gathered by the users, through these different sensors and the users use of these different sensors and the senses sensing up through these different sensors, this is what is done in this non semi-immersive simulations. And here basically these are powered by high performance graphical computing systems, coupled with large screen projectors these are some of the things that are used for semi-immersive platforms.

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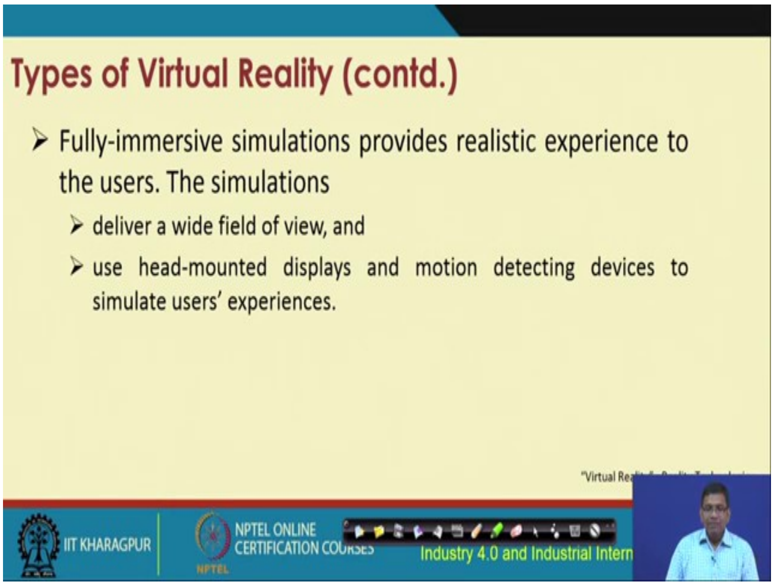


Fully-immersive is high end basically. Here you have complete immersive experience; complete realistic experience is offered through some simulations to the users, and these simulations offer a delivery of a wide field of view, using different head-mounted displays, motion detecting devices.

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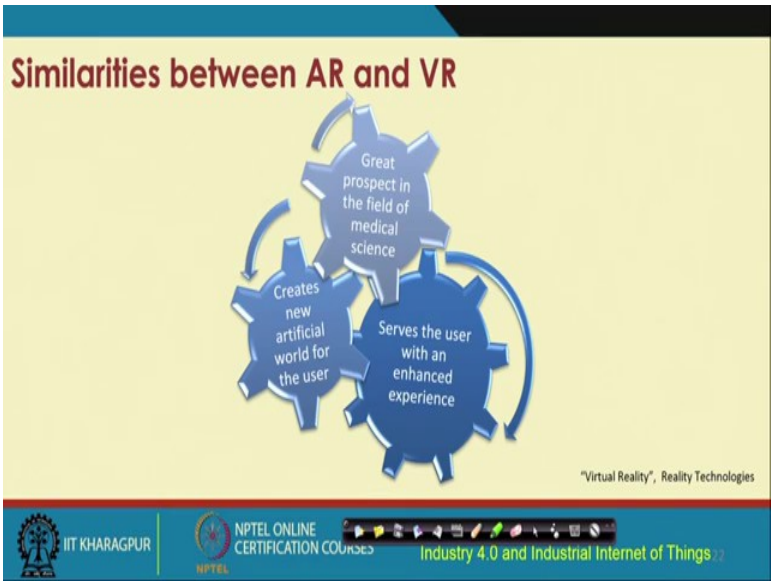


So, let us now having understood AR and VR so far, let us now try to understand the similarities between AR and VR. So, there are many different similarities they are very similar. So, both of these they create new artificial world for the users, both of these technologies can help create this artificial world. These serve the user with enhanced experiences that is also very similar, there is great prospect in the field of each of these AR and VR in fields like medical science, in astronomy, in flight simulations. There is lot of similarity I mean there is lot of use of AR and VR technologies in these different types of application domains.

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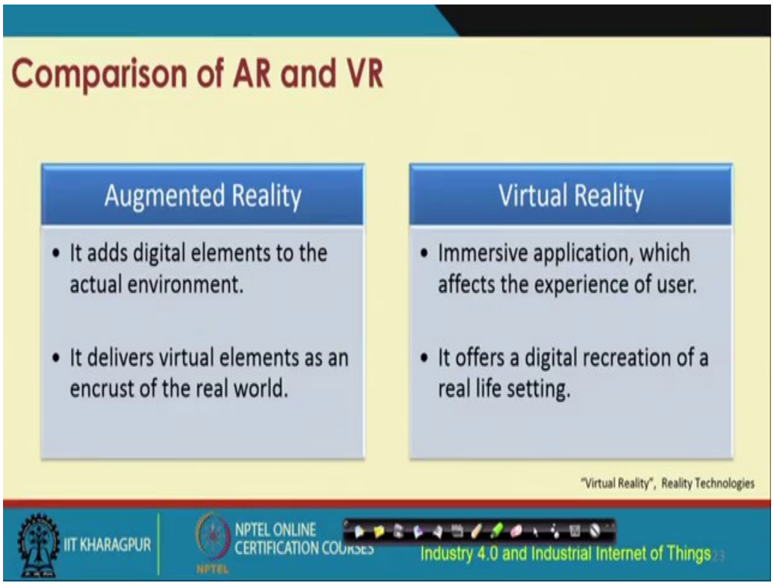


So, this is how these technologies compare augmented reality and virtual reality. Augmented reality adds digital elements to the actual environment. It delivers virtual elements as an encrust of the real world and virtual reality it offers immersive application. It is unlike in the case of augmented reality, what is happening is the physical world is augmented with certain high end ICT features, so that the user gets some kind of improved experience, in improved perception of the reality.

And in virtual reality on the other hand complete or partly partial or complete immersive experience is obtained by the user. So, user feels that the user is there and he is operating completely immersed or partially immersed in the physical environment, but actually it is not a physical environment, it is a virtual environment, in which the user is operating, but the user feels that the user is operating in the real physical world, which is not correct which is not the real one, but a simulated one.

So, it offers a digital recreation of the real-life setting, which one the virtual reality platforms.

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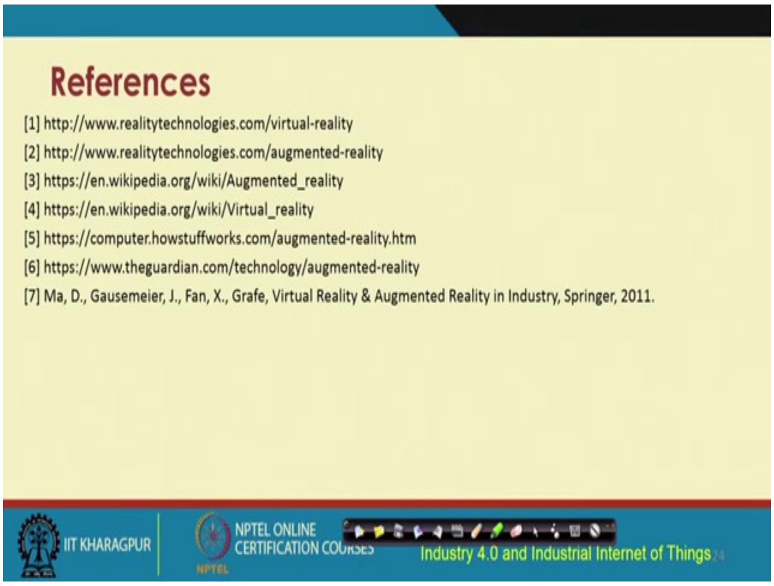


So, here are some of the references that one can go through. So, here I have given you some of the web references, but there are many books on AR and VR, there are many research papers on AR and VR, but I think for this course that, going through in detail of each of these technologies is necessary, it is not easy to understand each of them in detail unless you want to really get an in-depth understanding though about AR and VR.

But then again this will not be right course for you to get the complete understand about AR and VR, you need to register for some other online course on AR and VR. And so, this understanding about the different features of AR and VR systems, the different advantages the different aspects of it, this is sufficient for the industry persons, the learners, to know about how these things can be used in an industry setting to create an IIoT platform in their respective industries. So, with this we will come to an end.

Thank you.

**Introduction to Industry 4.0 and Industrial Internet of Things**
**Prof. Sudip Misra**
**Department of Computer Science and Engineering**
**Indian Institute of Engineering, Kharagpur**

**Lecture – 14**
**Industry 4.0: Artificial Intelligence**

In this lecture, we are going to go through some of the basic concepts of Artificial Intelligence in Industry 4.0. So, at present all of you must have heard about the hype of AI: Artificial Intelligence and its use in the industries and everywhere else, in fact, AI has become very attractive in the present times and it finds different applications in different domains industries inclusive. So, towards fulfilling the objectives of an Industry 4.0, it is envisaged that artificial intelligence will play a big role.

So, let us try to understand the basic concepts behind AI and how it can be used to improve the overall efficiency and address different challenging issues in the industrial sector. So, when we talk about artificial intelligence, what comes to our mind, it is some form of intelligence, we are talking about an artificial form of it. You must have heard about different things like a robot playing soccer, robo-soccer, robot playing soccer. Then you must have heard about the driverless cars, which has also become very popular in the last few years, the driverless cars.

These are all examples of use of AI techniques to solve different challenging problems, which otherwise are difficult to solve. But, it is not just robot playing soccer, it is not just the driverless cars where, AI has found application. AI finds the application in different domains in for credit card fraud detection AI could be used for designing a computer, which can play the game of chess. And, this is something that has happened since last few decades; a lot of people have taken a lot of interest in the applications of AI in games.

In the industries also for making the industrial processes much more efficient, to solve different problems, which manually was difficult to be solved AI and different other applications have found interest in the industries.

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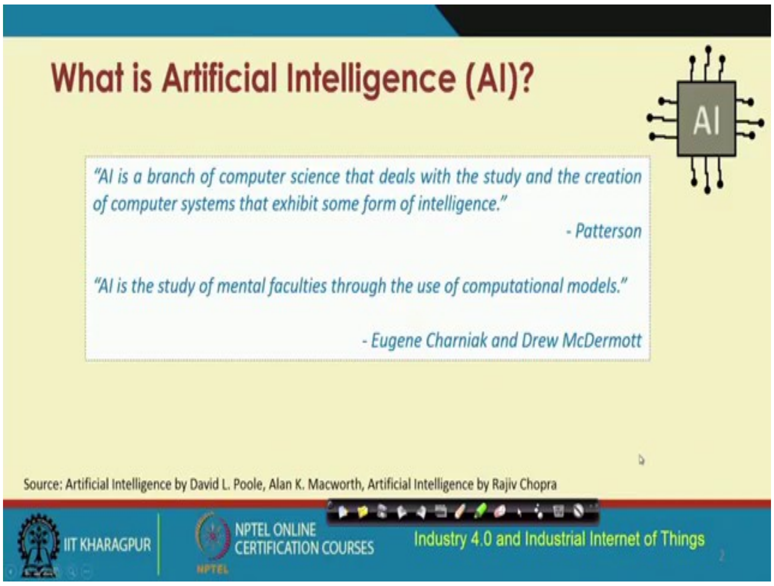


So, what is AI? Artificial Intelligence so, there are different viewpoints of what AI is. So, it is quite broadly scoped and there are multiple definitions to describe what artificial intelligence is, as per one of the definitions by Patterson; AI is a branch of computer science that deals with the study and the creation of computer systems that exhibit some form of intelligence. So, we are talking about computer systems exhibiting some form of intelligence which is very similar to the natural intelligence of human beings. So, striving to build systems which can try to intelligently think and behave like human beings is what one of the definitions of artificial intelligence says.

Another viewpoint as I told you that there are many different viewpoints of what AI is; another viewpoint is how we can use how we can use the different computational models to improve the mental faculties of humans is what again AI can do. So, that is another scope of AI. So, like this there are different viewpoints of what AI is. So, the lateral definition is basically proposed by Eugene Charniak and Drew McDermott.

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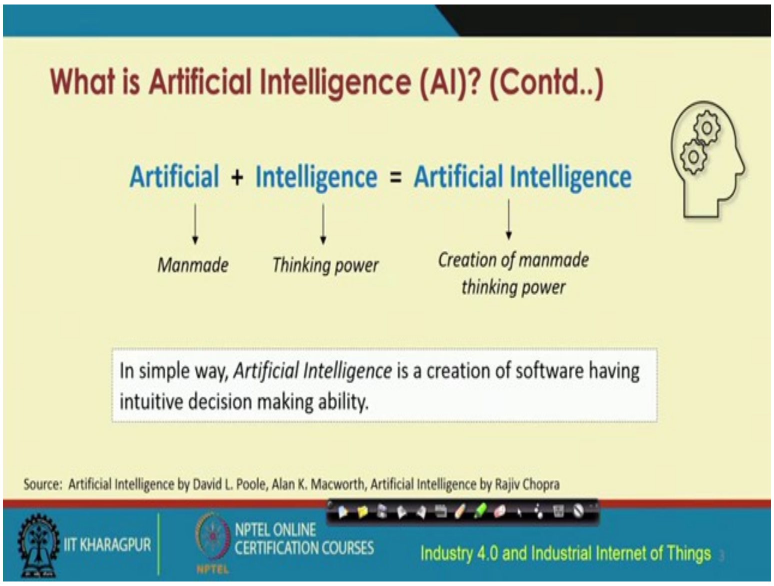


So, we are talking about artificial, which is manmade and integrating with the intelligence, which is basically the thinking power and together achieving a system, the development of the system an AI based system Artificial Intelligence system, which is a creation of man-made thinking power. So, in simplistic form AI is a creation of software, having intuitive decision making capability. So, remember one thing that AI systems are typically software-based, but in industrial sector or, many other domains they these AI-based software will have to work on some kind of hardware. So, you cannot, basically, leave hardware completely separated when you are talking about AI systems holistically.

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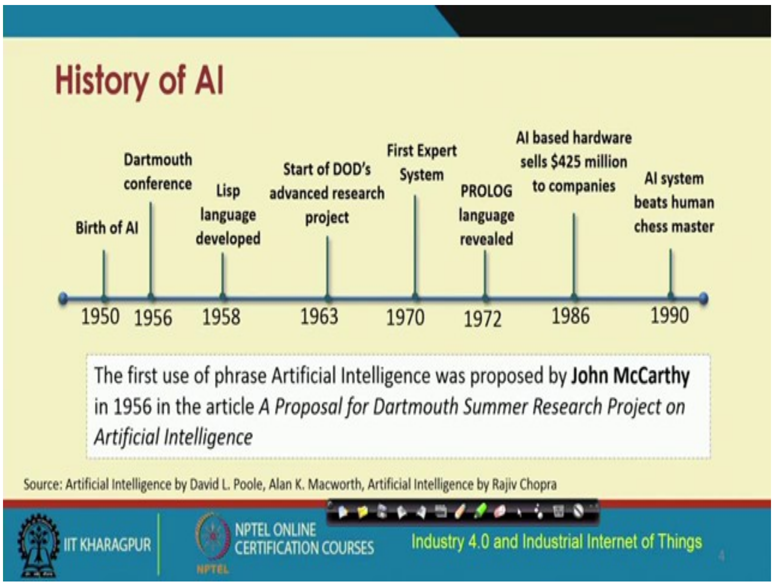

If you look at the origin of AI, AI in the recent times have found lot of popularity in our country and globally, but AI has been there since long starting from the 1950s AI has been in existence. Then in, earlier there used to be different theoretical research works on AI. There have been different languages that have been proposed for use with AI like Lisp, PROLOG. Then, in the 1970s the concept of expert systems came into being. Expert systems are basically the ones where based on certain pre-existing knowledge the systems are going to perform better in the future.

So, expert systems came into being, then in the 1990s, somewhere in the middle of 1990s, if you recall the Deep Blue became very popular. IBM came up with their computer, the Deep Blue, which is a AI based system, which can play chess. So, if you recall its history now, that Deep Blue, basically defeated one of the greatest chess players long time back. So, the computer, that was when an artificial system was able to supersede the brain of a human being and an expert brain, an expert chess player was defeated by Deep Blue in 1990s and that is when the applications of AI became popular in the domain of games and chess, particularly.

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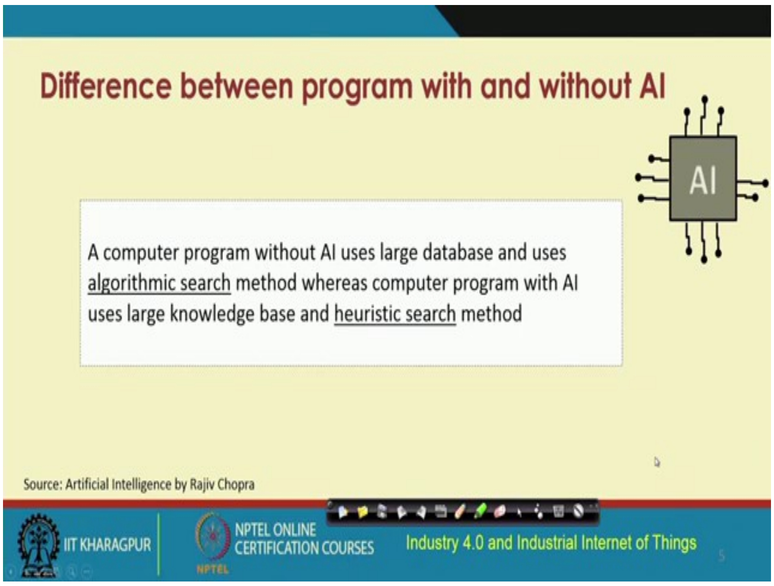


So, what is the difference between a program, which uses AI. So, a computer program without AI uses large databases and algorithmic search method, whereas, a computer program with AI uses large knowledge base and heuristic search method. So, it is algorithmic search versus heuristic-search method.

Algorithmic search basically follows certain well-defined procedures in order to come up with some optimized solution whereas, heuristic search as this name suggests; heuristic search is popular in AI. Because, many of these AI-based problems are not easy to solve. The search space is huge, many of the AI problems is huge. So, where you cannot come up with some efficient solution using the traditional methods of search like the algorithmic search methods.

So, heuristic search basically talks about heuristics or rules of thumb being used to come up with solutions which will be good enough to solve certain problems at a certain point of time. So, these are the heuristic search methods; heuristics search methods are quite popular search methods in the domain of AI. And, heuristic search methods have found lot of use in the applications of AI in games in different games chess inclusive.

So, actually what happens is why the AI is why the search method heuristic search methods are very popular in AI is, because think about computer games, things about chess the game of chess. So, sometimes the input space is so, broad and if you do not use you cannot use the traditional search methods. So, you have to use some heuristic methods to come up with certain solutions, which will perform superior at certain point of time under certain conditions. So, heuristic search methods are quite popular in AI and AI for games.

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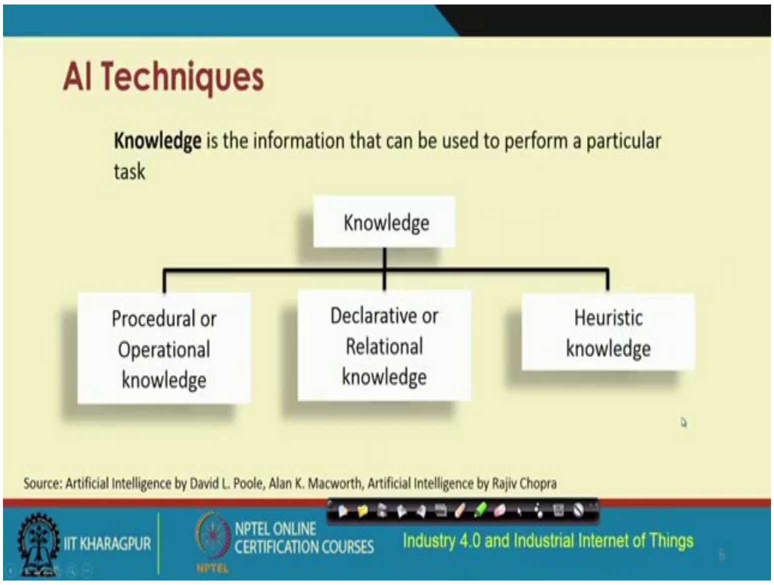

So, AI is heavily based on the concept of knowledge. So, we are talking about several pieces of data can lead to information and then information can build help in building knowledge. So, knowledge is that information that can be used to perform a particular task. So, there are different forms of knowledge particularly in the context of AI. There is procedural or, operational knowledge, which basically talks about the procedures that will have to be adopted in order to; the knowledge about certain procedures, that will have to be adopted in order to come up with a particular problem.

So for example, a quadratic expression or quadratic equation. So, the procedures that will have to be followed in order to solve it that is procedural knowledge, declarative or, relational knowledge, this is also known as descriptive knowledge. So, here basically we are talking about the knowledge, the description of a certain thing, an object an event or something alike the knowledge about it; storing such kind of knowledge is important. And, that kind of knowledge will be used whether it is procedural, declarative or, heuristic, that kind of knowledge is going to be used to make the next move or, to improve the processes in the industries. The way things are happening based on certain existing knowledge you can try to improve upon the processes in the future and so on.

So, that is where this concept of knowledge and AI comes in applicable in the context of industries and industrial processes. Heuristic knowledge is basically these different heuristics that will or the rules of thumb that will have to be used in order to address certain problems, certain challenges at different points of time that is heuristic knowledge.

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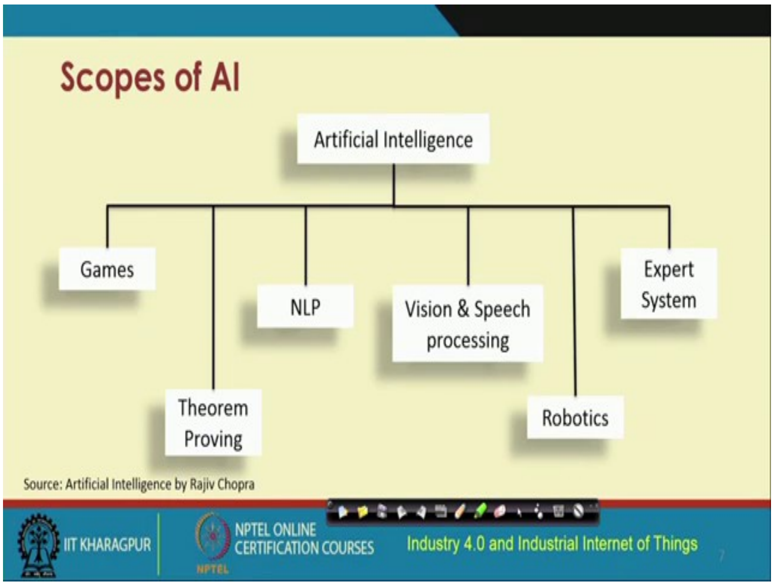


Now, let us talk about the scope of AI. Artificial Intelligence has found use in diverse fields. In games we have already talked about, in chess game, in soccer games, in different other games, AI has found applications. In theory improving, NLP is basically Natural Language Processing. So, AI in NLP means what that you are trying to come up with some rules, which can make the computer understand not the computers language, but the way the natural languages like English, French, with which humans are conversant to communicate with one another.

So, that is NLP, then AI has also found use in vision computer vision, speech processing. Computer vision is basically trying to enable a computer to see around, to see around, to feel what is around it and so on. Speech processing, on the other hand, is enabling a computer to understand, the way humans speak, what the humans are speaking. Not just the text, but the speech of the human beings can be understood typically in real-time or, may not be real-time as well. So, if you are speaking in English, the speech processing would help the computers to understand what the humans are talking about in their own language.

Then comes robotics AI in robotics, robot performing different actions, robot making different moves, in a particular terrain, performing different moves, taking different trajectories. So, the in AI in robotics is very important and in expert systems. Building expert systems, which are basically in knowledge intensive systems, based on the knowledge base, that is resident in these systems, these systems can provide expert advice; expert advice to users about what should be done next or what should be done in the future.

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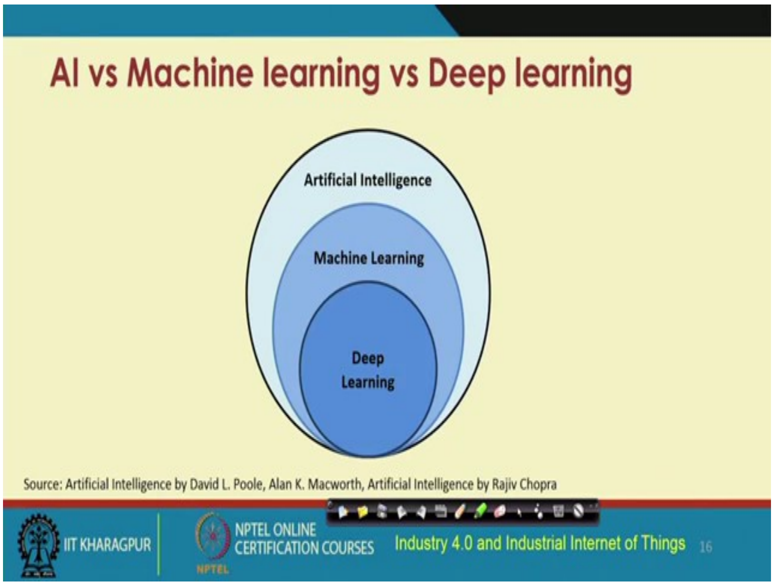


So, artificial intelligence is very important, it has become very popular. Artificial Intelligence, ML: Machine Learning, Deep Learning these things have become very popular in the recent years. So, Artificial Intelligence, ML, DL, these are linked to each other. All the people are talking about machine learning, deep learning, artificial intelligence, but there is a linkage and this is this figure in front of you shows what is the scope of each of these.

Machine learning or deep learning are basically branches of artificial intelligence, but then they are in artificial intelligence beyond learning there are different issues. Issues of search, classification, these that it sends means there are a lot of, lot of different issues are there beyond learning in AI. So, this is how these three recently popular technologies have become or what is what is what is there scope. So, that is what is defined.

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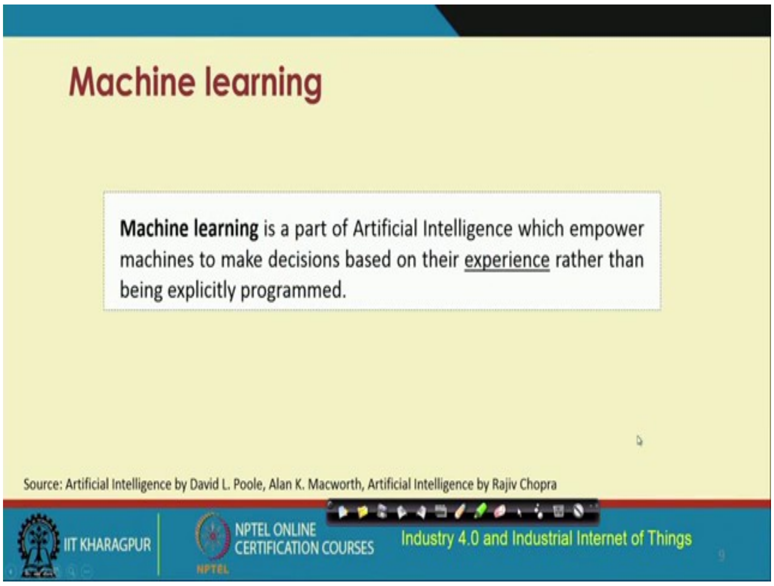


So, what is machine learning? So, machine learning is a part of AI which empowers the machines to make decisions based on their experience rather than being explicitly programmed. So, in the computer basic computer programming or fundamental computer courses in any B.Tech program or whatever; what the students are taught typically is to make to explicitly program certain steps, which the computer are going to take in order to solve a problem. In machine learning, we are talking about some kind of a software or a program, which based on the experience, previous experience, past experience will take actions, better actions in the future. So, with time better and better actions based on the past experience will be taken.

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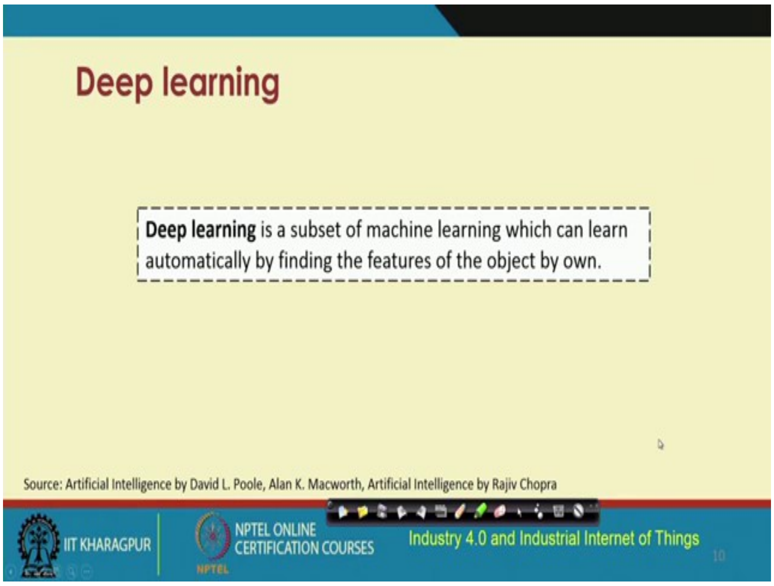


Deep learning, basically, is a subset of machine learning, which can learn automatically by finding the features of the object on its own. So, what is so, deep learning is basically where some deep computational structures are used to come up with some efficient algorithms, which can do certain things much more efficiently with grater greater accuracy; efficiency in terms of accuracy, typically. So, better accuracy in a better manner will be done things will be done by deep learning.

So, it is not like deep learning is the only solution, deep learning has its own application domains. There are other non-deep learning, the traditional machine learning schemes, which are also advantageous in certain contexts. It is not the deep learning is the solution in machine learning, it is not like that. So, you can use deep learning or non-deep learning methods to solve certain learning problems depending on the certain requirements that are there.

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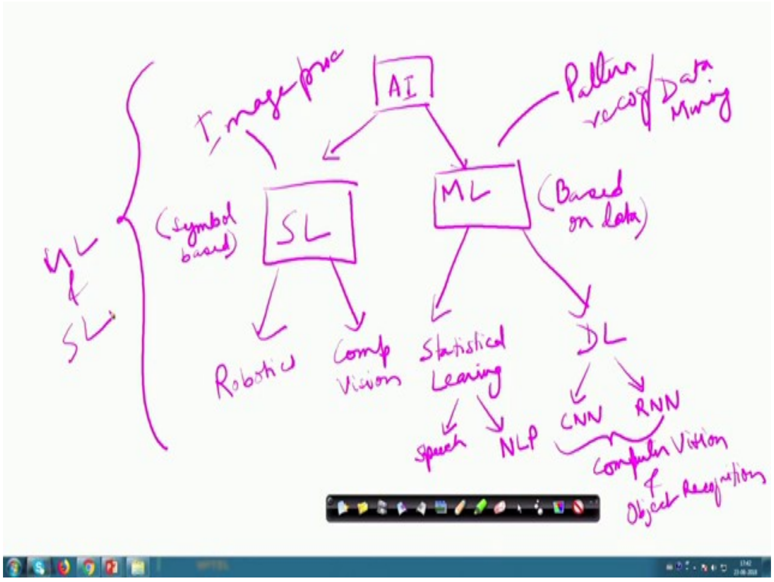


Now, let me talk about an interesting thing. So, we need to understand the, the difference between the different AI techniques. So, AI we have talked about machine learning, there is also something called Symbolic Learning. So whereas, machine learning is based on data; symbolic learning is symbol based.

So, applications of this thing good applications would be in pattern recognition, machine learning has lot of applications in pattern recognition, data mining, and here symbolic learning has lot of applications in for example, image processing, image processing. So, symbolic learning, basically, we are talking about applications in computer vision, then, robotics and this can be machine learning, can be of different types; we have already talked about deep learning.

But, it could be also the traditional statistical learning. So, statistical learning has applications in natural language processing, has applications in speech recognition. Deep learning can be of different types: convolutional neural network is one, a recurrent neural networks is another. Each of these can be used to address again different problems of computer, vision, and also object recognition.

So, this is basically the scope of artificial intelligence and the different forms of not the scope of artificial intelligence, entirely, but in the context of learning.

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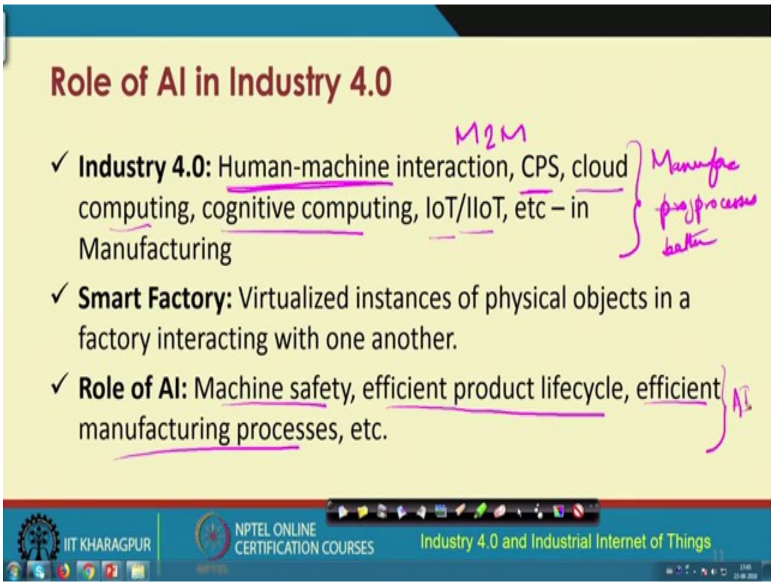


Let us now go back and talk about, we have understood more or less the scope of AI, the different applications of it, its importance in the context of industries and different other application domains like games, computer vision, robotics, but let us now try to understand in little bit further depth. So, that we will be able to realize that why AI is popular in building systems, which can help achieve the objectives of Industry 4.0.

So, in Industry 4.0 we have talked a lot in the previous lectures about Industry 4.0 and its scope, but what is Industry 4.0? In Industry 4.0 we are talking about few things, first of all human machine interaction. This is very critical, humans and machines interacting. We also in Industry 4.0, we are also talking about in certain cases machine to machine communication. One machine directly talking to another machine without any human intervention, machine to machine communication. Cyber physical systems we have talked a lot in a previous lecture also associated technologies such as cloud computing, cognitive computing, IoT or IIoT; all of these can help in making manufacturing processes better.

So, that is Industry 4.0. Now, smart factory smart factory is another one which is talked a lot in the context of Industry 4.0, smart factory. So, basically this smart factory what it does is these factory, machines in the factories, the physical objects that are there in the factory, which interact with one another. The virtual instances of them would be created and those virtual instances would be made to talk to one another. This physical world and the virtual world, instantiation of the physical into the virtual space and making the physical objects and consequently the virtual ones talk to one another is what is done in the context of smart factories in Industry 4.0.

So; obviously, things like machine safety, efficient products lifecycle, efficient manufacturing processes, these could be achieved with the help of AI. And, these are required for making smart factories which in turn will help achieve in building Industry 4.0 compliant industries.

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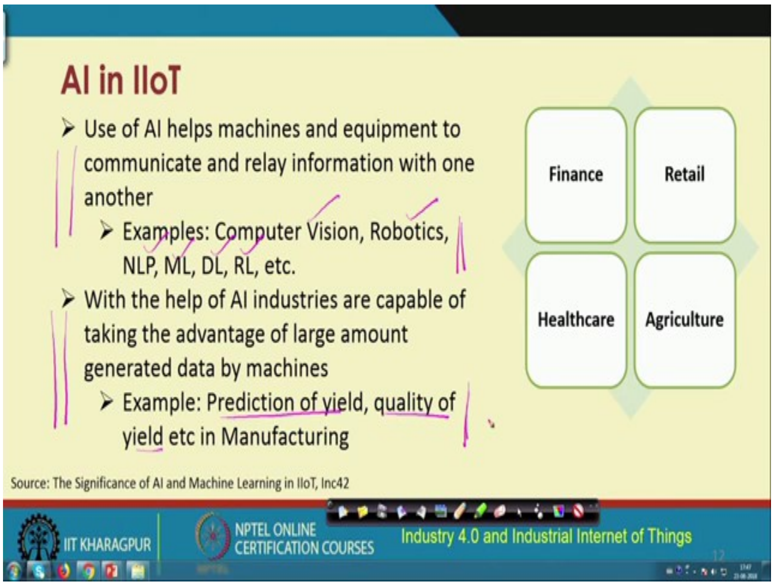


So, IIoT, IoT in general and Industrial IoT, these are the ones, which essentially will help achieve the objectives of Industry 4.0. AI can be used in along with IoT, along with IIoT and also to transform these systems into efficient systems; IoT and IIoT systems efficient using AI. So, basically, use of AI helps the machines and equipments to communicate and relay information with one another. And, this thing can be used in different industry sectors, finance, retail, healthcare, agriculture. And, you name it and it is possible to use AI in order to help these machines and these equipments communicate and relay information with one another much more efficiently.

For this specifically you could use computer vision, robotics, NLP, ML, DL, RL all of these things that we have talked about so far you could use them. So, with the help of AI in industries, in the industries are capable of taking the advantage of large amount of data that is generated by the machines to do something better. So, one aspect is to improve upon the communication, automation, relay, etcetera, etcetera using AI. The other one is that once you have used IoT and IIoT, in the industries; what is happening is these sensors actuators, etcetera from these IoT devices are going to throw in lot of data.

So, that data we will have to be analyzed and one can take advantage of the past data. The experience that is generated from this previous historical data to make things much more efficient, to make processes efficient in the future. Examples would be for prediction of yield, quality of yield, prediction of the quality of yield, in manufacturing. So, these are different examples of use of AI. AI for improving the automation, communication, delay of information etcetera and for improving the prediction processes in terms of quantity of yield, quality of yield etcetera in the manufacturing industries.

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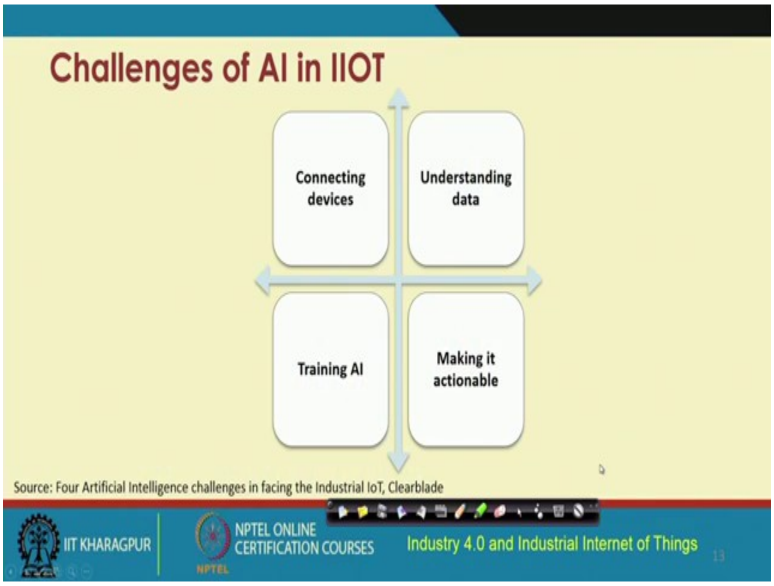


So, there are different challenges of AI in IIoT. Connecting different devices, understanding the data, training the data, making it accessible, making the machines or whatever actionable these are all different challenges of use of AI in IIoT. So, I do not need to explain each of these, but only thing that I would like to highlight is the training. Training is very important because, you are using past data, which you will be using to train the machines to do something better in the future that is one type of learning in fact, in AI that is one type of learning. So, there are different types of learning. This is one type of learning that using the training data set.

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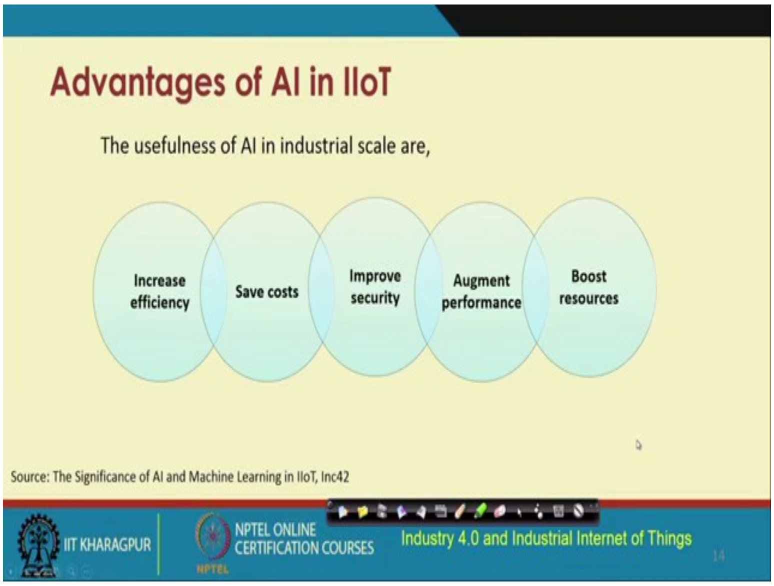


So, there are different advantages of AI in IIoT. The usefulness of AI in the industry scale are to increase the efficiency, save costs, improve security, augment performance and boost up resources in the industries; resources of all kind as I said in a previous context in a previous lecture before. So, boosting up all kinds of resources, all kinds of tangible, non-tangible human resources. So, all kinds of resources could be boosted up, with the help of use of AI in the industrial scale.

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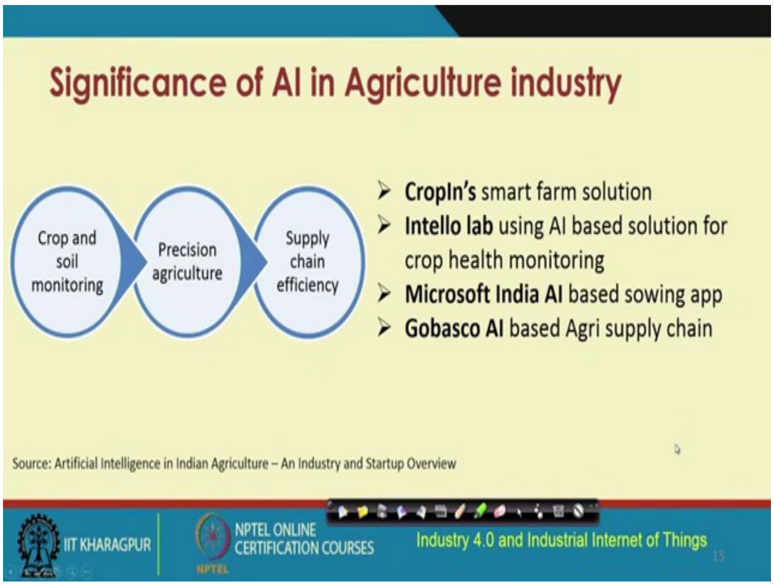

So, AI has found use in different industries. In the agriculture industry, AI could be used for crop and soil monitoring, for precision agriculture. Precision agriculture means like coming up with precise predictions about certain things, precise predictions about certain things. For example, when do you need in the agricultural field, when do you need precisely to irrigate the field, to put fertilizers in the field, and exactly the area, where the fertilizers will have to be applied.

What fertilizers exactly would be required, not that you put in any kind of fertilizer it will be. So, all these predictions, precisions, in agriculture could be achieved with the help of use of AI. Supply chain efficiency also can be improved in supply chain in the context of agriculture and food could also be made much more efficient with the help of AI.

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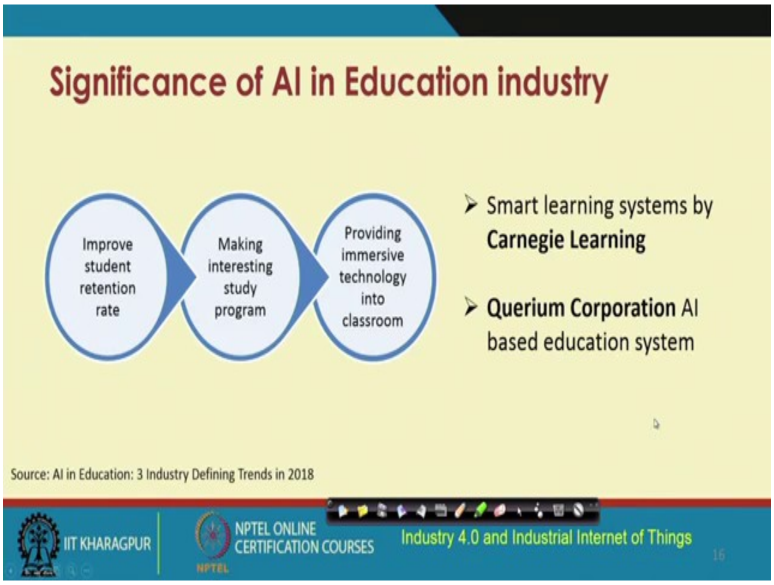


So, that is the AI in agriculture, AI could be used in education industry, to improve the student retention rate for making interesting study programs and for providing immersive technology into the classroom. So, already there are different existing systems which use AI in the education sector. So for example, the smart learning systems by Carnegie Learning, then Querium Corporation AI based education system. Like this, there are many different types of AI based systems in education sector that are available for use.

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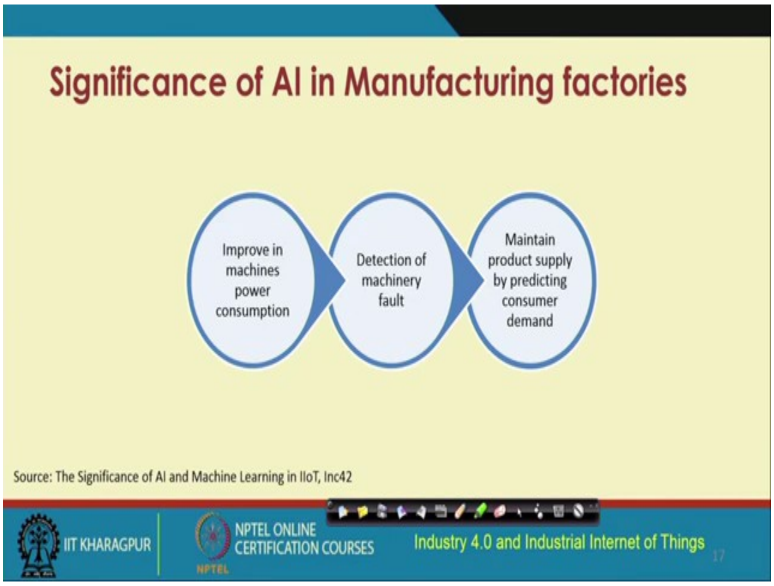


So, in the manufacturing factors sector, manufacturing industries AI could be used to improve machines power consumption, detection of machinery fault, maintaining product supply by predicting consumer demand. So, these are the different applications of AI in manufacturing.

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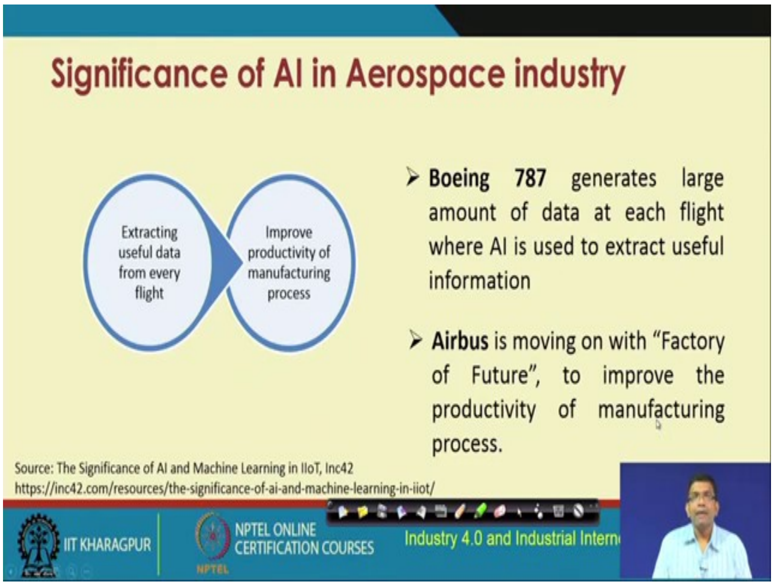


AI in the aerospace industry extracting useful data from every day of flight, improving productivity of manufacturing processes. All these top aircraft manufacturers like Boeing, Airbus, they use AI heavily in their processes.

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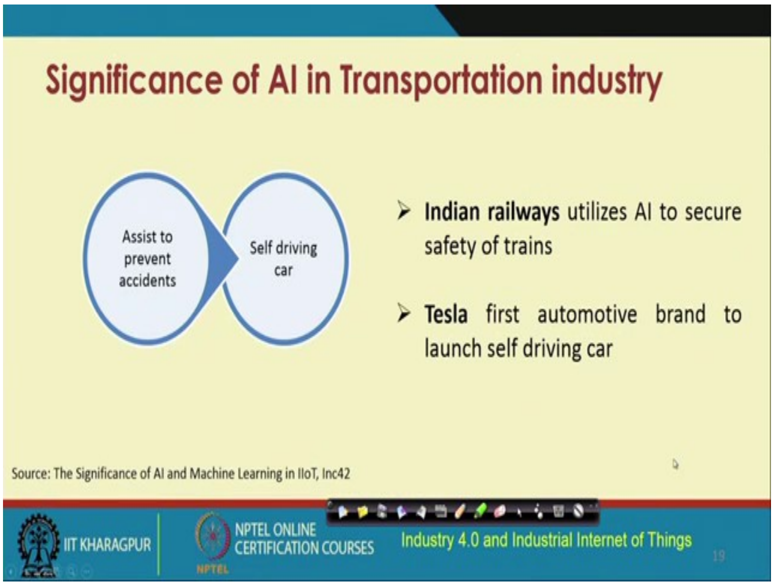


So, in the case of rail transportation or automotive transportation, etcetera AI is also used, self-driving car is something that I mentioned at the outset. Like this assisting drivers to prevent accidents these are all different applications; these are some of the different applications of use of AI in transportation industry.

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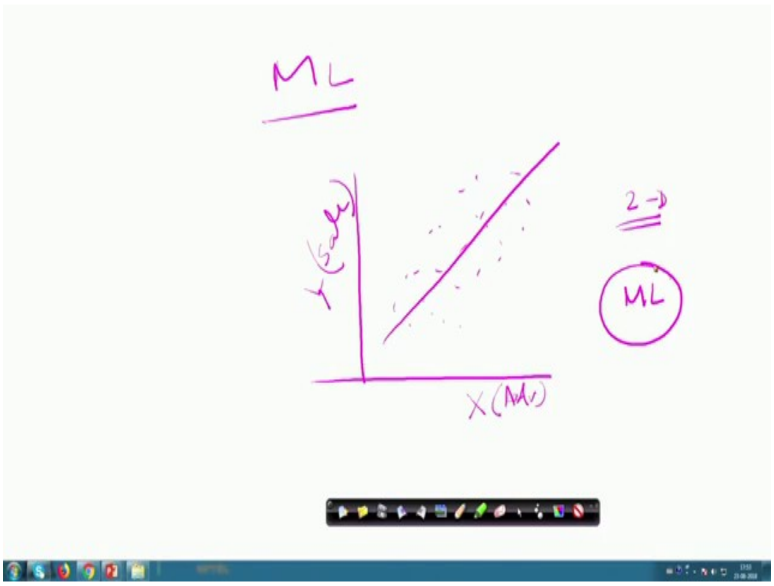


So, one last thing before we get into the references, one last thing that I would like to highlight about machine learning is that machine learning can help do something else as well. So, if you are talking about something X let us say some parameter advertisement let us say and let us say that this is the sale, the Y-axis. So, you can have different data which could be plotted and then you can have some kind of a regression fitting or some correlation study etcetera. So, if you are talking about this kind of thing, the humans are very good in doing things because it is a 2-dimensional thing and we know different ways of curve fitting. So, handling correlation regression in 2-dimension.

Think about the same problem, if you are increasing the number of dimensions. So, if you are increasing the number of dimensions and doing something very similar using the human expertise and human eye, human intelligence, human brain, that is difficult. So, the computers can do it and in fact, more specifically machine learning can help you achieve these different types of correlation, curve fitting, in multiple spaces having multiple dimensions, at the same time. So, this is also another application of machine learning and how humans and machines can perform better than humans, in these contexts.

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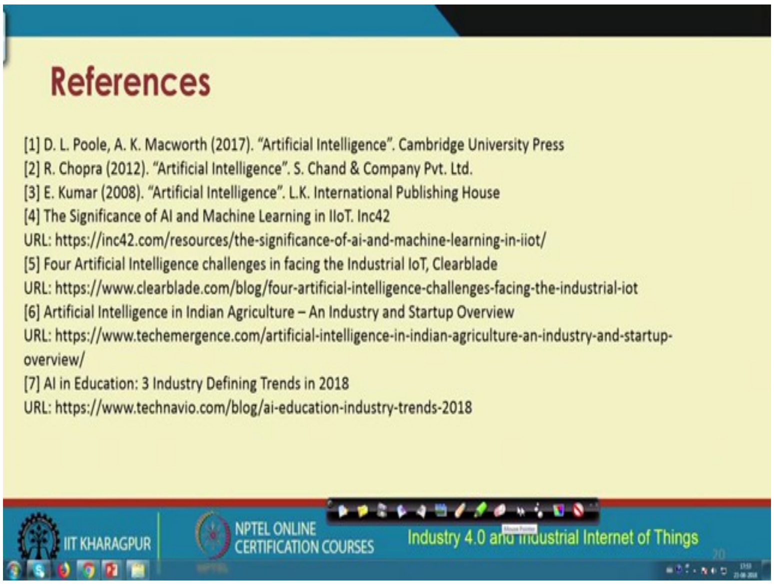


So, let us now, go back and look at these things. So, these are some of these references that are there. So, the references for AI, ML, DL, its huge these are some of the ones that, if you are interested to know little bit more, in depth, you could, but mind you that through this course you cannot become an expert of artificial intelligence. Artificial intelligence are semester long courses themselves and all you need to do in this course is just to get yourself exposed to the different concepts and which is what I have done. But, then if you need to actually implement AI-based techniques to solve certain problems, you have to take separate semester long courses in AI, ML, DL. So, with this we come to an end.

Thank you.

**Introduction to Industry 4.0 and Industrial Internet of Things**

**Prof. Sudip Misra**
**Department of Computer Science and Engineering**
**Indian Institute of Technology, Kharagpur**

**Lecture – 15**
**Industry 4.0: Big Data and Advanced Analysis**

In Industry 4.0, we are talking about use of IoT, IIoT, Industrial IoT, which essentially are heavily based on the use of different sensors and actuators. So, these sensors typically sense lot of different data and this data are sent continuously after they are being sensed. So, this data will have to be processed. So, what kind of data we are talking about? So, this kind of data in the context of IoT, IIoT, Industry 4.0, exhibit the behavior of something known as big data. So, we have to analyze the big and the traditional forms of data, to gather meaning out of it.

So, when we talk about this analysis whatever we talked in the context of machine learning in AI those kind of methodologies are also applicable over here. So, analytics, statistical analytics, machine learning-based analytics, use of different methods of neural networks, SVM, all of these could be used to analyze the data, in addition to the statistical methods, the multivariate statistical methods that we are all familiar with. So, those could also be used to analyze the data. So, what is important is that you try to gain meaning out of the data that you receive from these IoT devices in IIoT.

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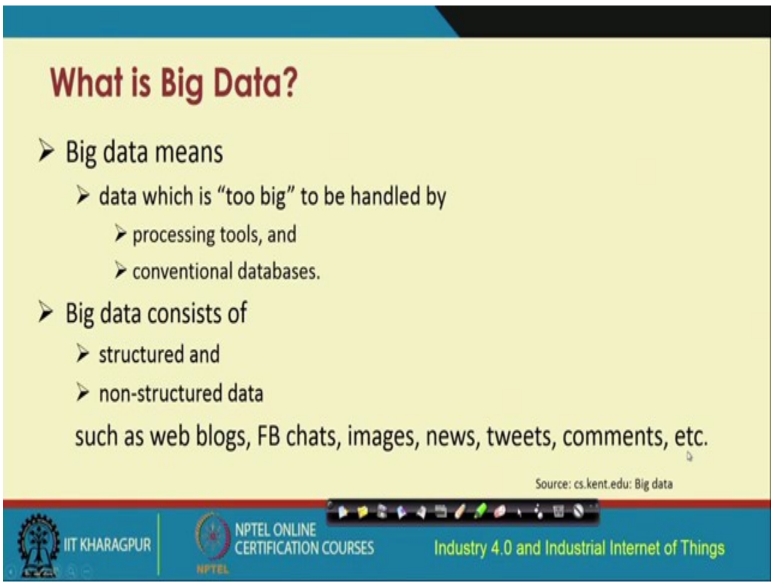

So, what is big data? So, data which is too big to be handled by processing tools and conventional databases, conventional processing tools. So, big data are typically the ones which exhibit the properties of non-structured data, but they could also have structure data. Structure data means what? Structure data are the ones, which could be stored in the form of tables in different databases; for example, relational tables. So, for example, databases like MySQL, Oracle, they use relational tables.

So, you can store those data in these relational tables in the form of these tables you can store this data so that is structured way of storing the data. And not that all kinds of data could be stored in the form of tables. So, certain data for example, Web blogs, Facebook chats, images, the newspaper blogs. So, all of these will exhibit non-structured behavior of data and they cannot be used, they cannot be stored in relational tables in the traditional form. So, these are like big data, non-structured as well as structured data, which will have to be handled in certain ways.

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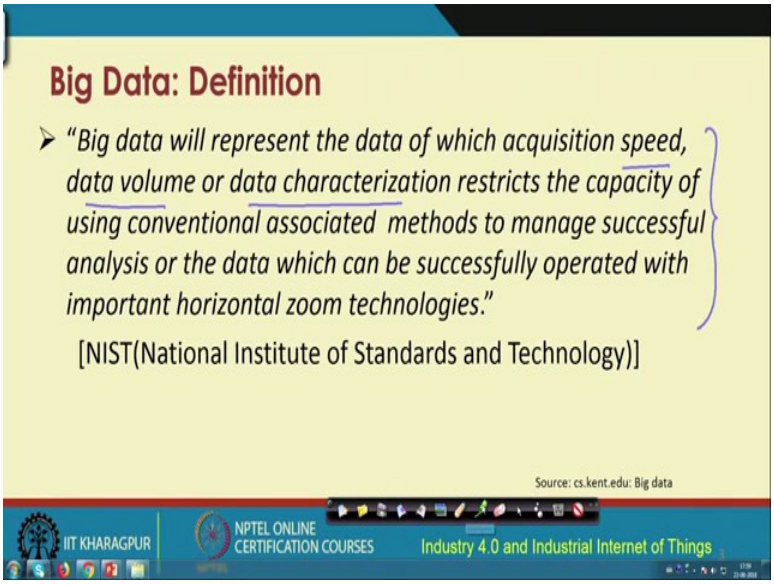


So, let us look at some of the key attributes of big data. We are talking about representation of data, which acquisition speed the data volume, data characterization, restricts the capacity of using conventional associative methods to manage successfully; the analysis or the data, which can be successfully operated with important horizontal zoom technologies. This is as per one of these definitions of big data.

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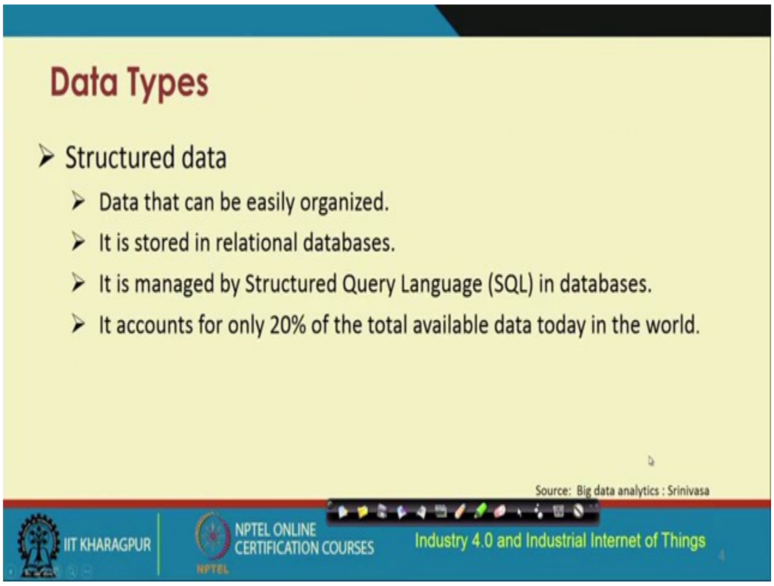


So, I was telling you that in the context of IoT, IIoT, we will get both structured data as well as unstructured data. So, structured data as I was mentioning before are the ones, which can be stored easily in an organized fashion in typically relational tables. So, if you are able to store this data in the form of tables, so you can use a language like SQL, Structured Query Language to query these tables to access the data, that are stored in them.

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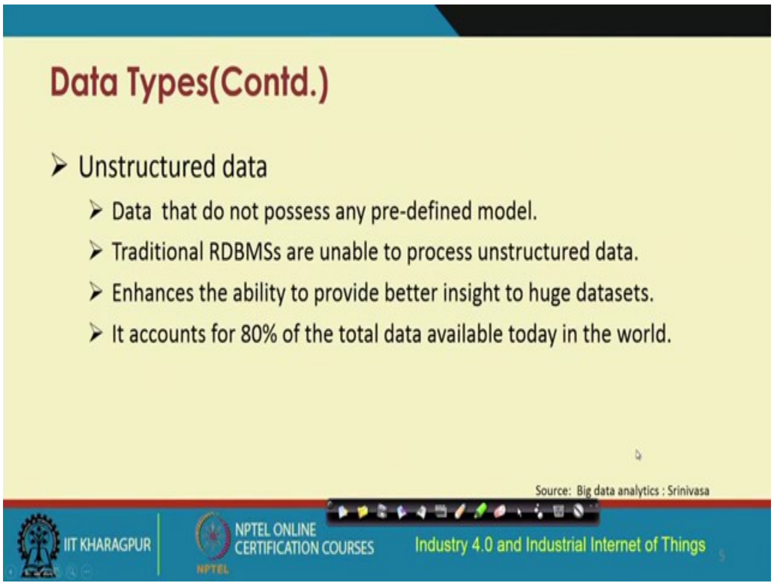

However, if you are talking about unstructured data you cannot store this data in the form of RDBMS tables and there is no predefined data model that could be used to analyze this data. So, basically most of the data that we encountered in the present-day world, would be unstructured. So, you cannot use the traditional database techniques that you are already familiar with in order to analyze this kind of data. And at the same time not only that these data are unstructured, but also this data come in huge volumes, so you are talking about huge datasets that will have to be stored in certain way.

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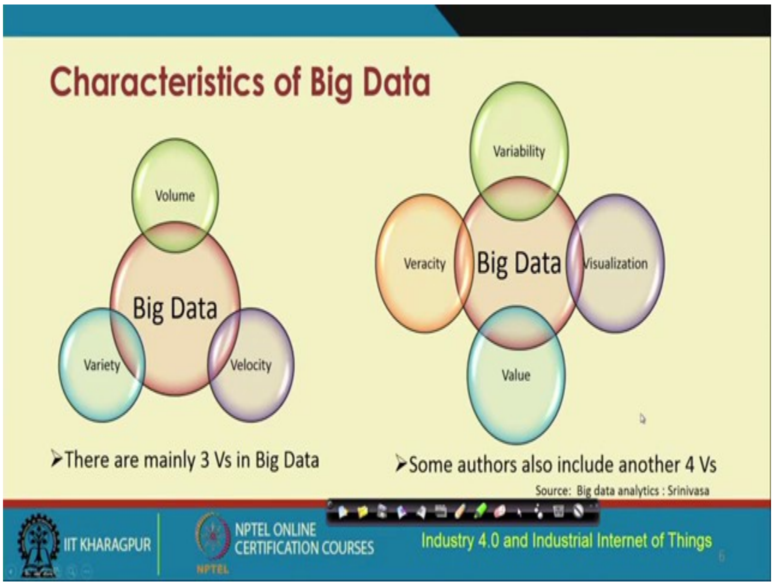


So, these are some of these characteristics of big data we are talking about volume, variety and velocity. So, these are the main 3 V's of defining big data. Data which is large in volume which exhibits variety and which arrives at high velocities at the processing server or processing agent. These kind of data traditionally were termed as big data, but as researchers what with big data more and more they also included few more different other aspects; other aspects other V's in fact. So, other V's like variability, visualization, value, veracity, so these are 4 additional V's that will also characterize big data. So, traditional 3 V's plus the 4 V's, 7 V's would be used to characterize big data.

So, let us try to understand these in little bit more detail. So, let us talk about the 3 V's first volume, so volume, velocity, variety.

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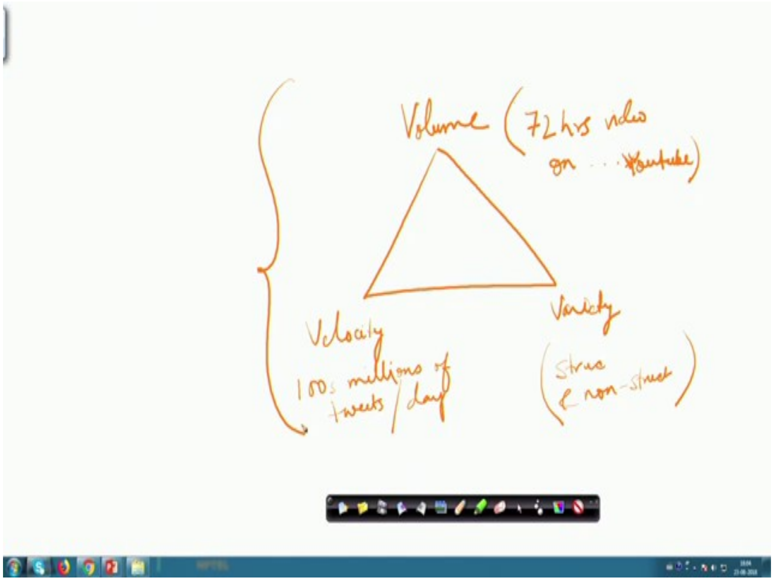


So, these 3 V's let us consider. So, what is this volume? This volume is large volumes of data we are topically talking about. For example, some 72 hours of video on some server such as let us say YouTube; let us just take for example, it could be anything. This is huge kind of data and huge in volume. Then if you are talking about velocity, if you talk about twitter for example, or similar kind of other platforms we are talking about some 100s of millions of tweets, on average per day. So, as you can understand that handling this kind of velocity of data is very important.

And then variety and this variety could be you can have both structured as well as non-structured data. So, variety of data for example, image data, text data, then video data, all coming together at the same time, that is variety. So, in big data context, we are typically talking about data, which is coming you can think of it as a pipe, some kind of a pipe through which data are coming continuously, huge volumes of data are coming at high velocities and this data the composition of this data are all very varied, text, image video and differ different types. So, all these data coming at the same time, handling this kind of data, using conventional data warehousing, database techniques, etcetera, it is not possible. So, people are talking about how you can have newer methodologies, newer tools in order to address this kind of data. So, let us just go back to what we were discussing in the slides.

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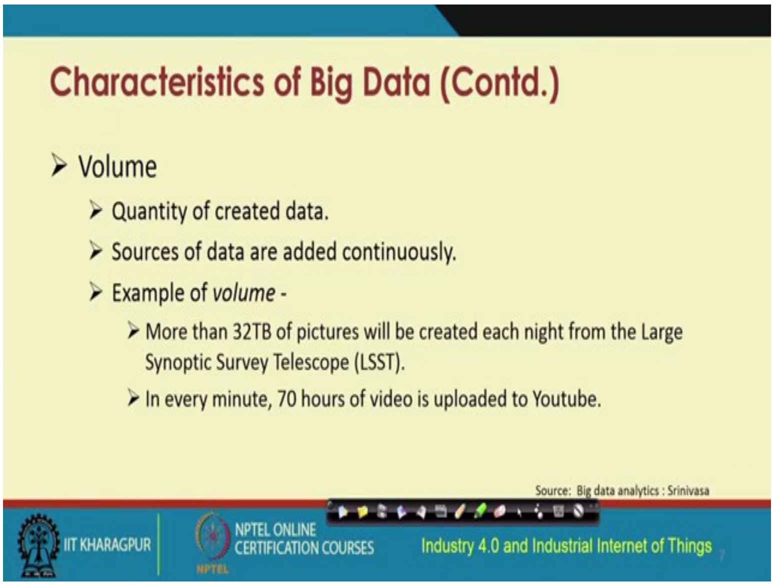


So, we are talking about huge volumes of data, we are talking about data not just in gigabytes and terabytes, we are talking about petabytes, hexabytes and so on of data, how do you store, that kind of data that is very important.

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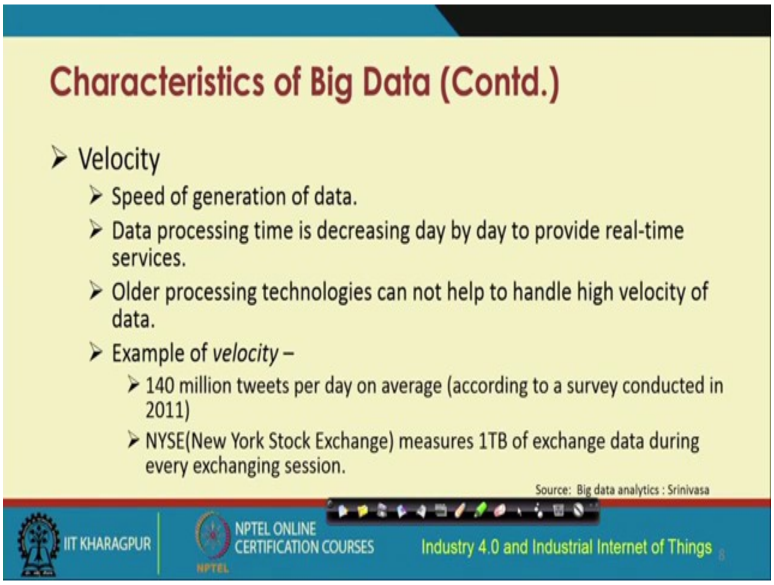


Velocity, speed of generation, 100s of millions of tweets per day on average that is huge velocity of data coming in, data getting generated. So, if the data is getting generated you have to handle the data and this is a high velocity data that is coming in and that has to be handled.

On the other hand, stock exchanges like New York stock exchange. So, they handle large volumes of data coming in high speeds. So, many exchanges, financial exchanges are carried on in the stock exchanges, so the speed is also very important of this kind of data.

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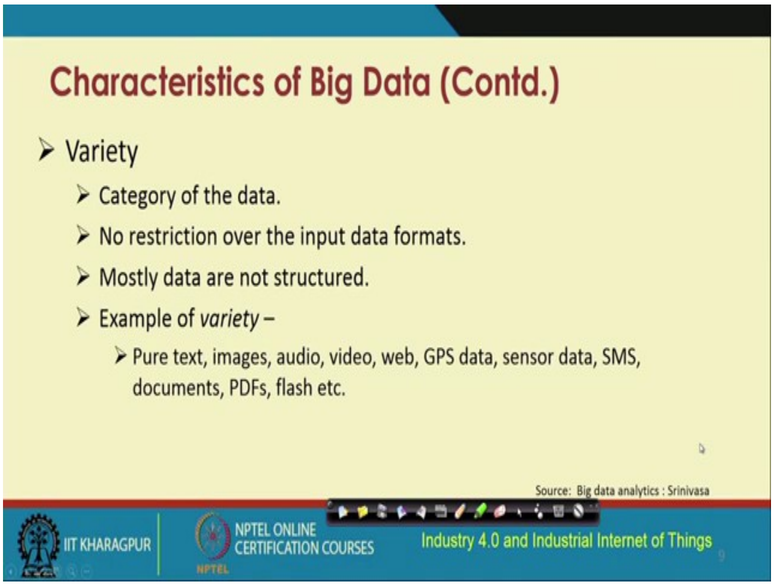


Variety, we are talking about different varieties of data--text, image, audio, video etcetera, etcetera all different types of data without any restriction about the data format.

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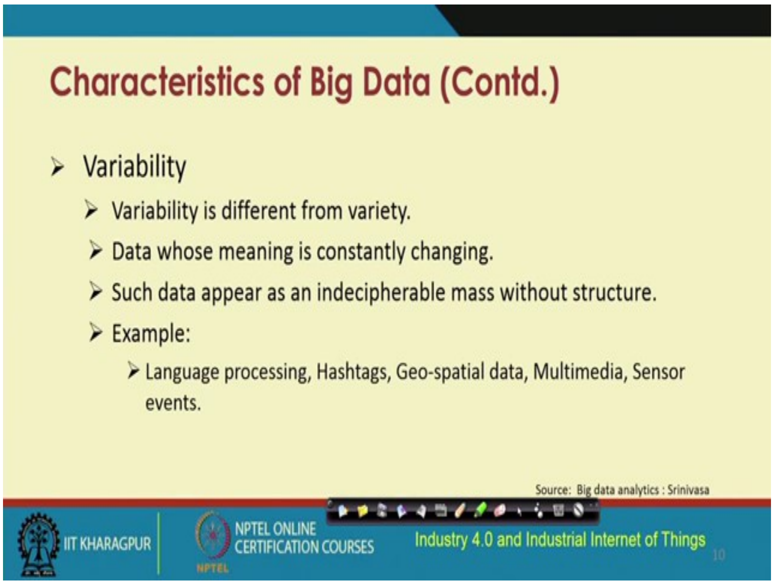

Variability, so here we are talking about it is different from variety. Here we are talking about the data whose meaning is constantly changing. So, example would be language processing, hash tags, geo-spatial data, multimedia data, sensor data, etcetera.

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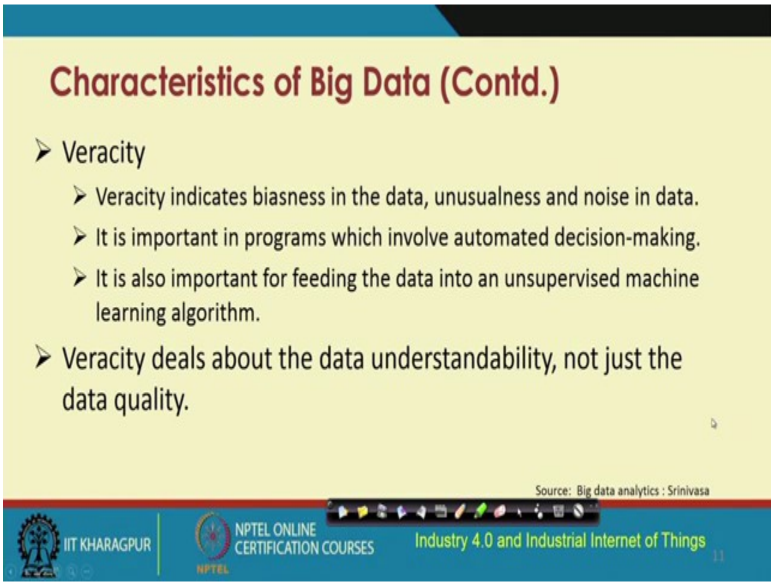


Veracity indicates the biasness in the data and it talks about the unusualness and noise in the data. So, it is important in programs, which involve automated decision-making. Veracity deals with the understandability of the data and not just the quality of the data, understanding the data is important in this thing; understanding the data is important in velocity.

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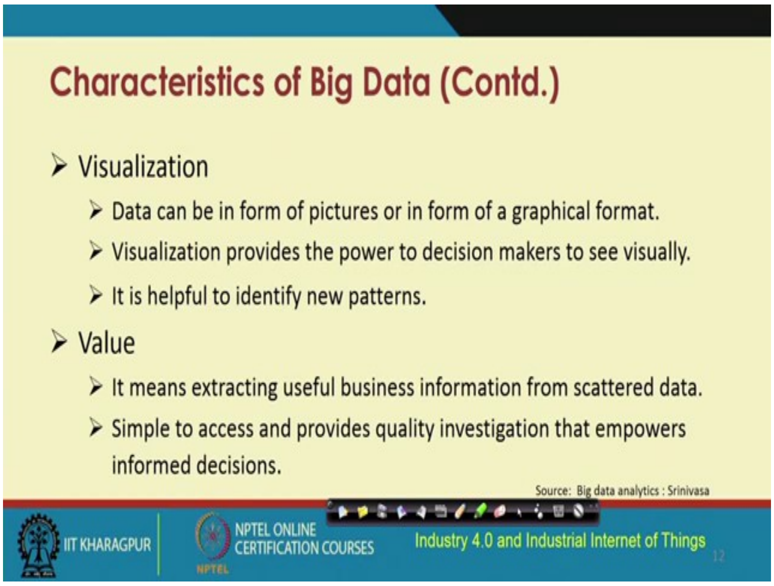


Visualization: visualization we are talking about in what form the data will have to be visualized, in graphical form, in textual form, what are the different patterns that can be visually identified. So, all these different character characteristics of this data the visualization of the data is important. And value, which is basically extracting some business information from the scattered data. So, this is basically the value attribute of big data.

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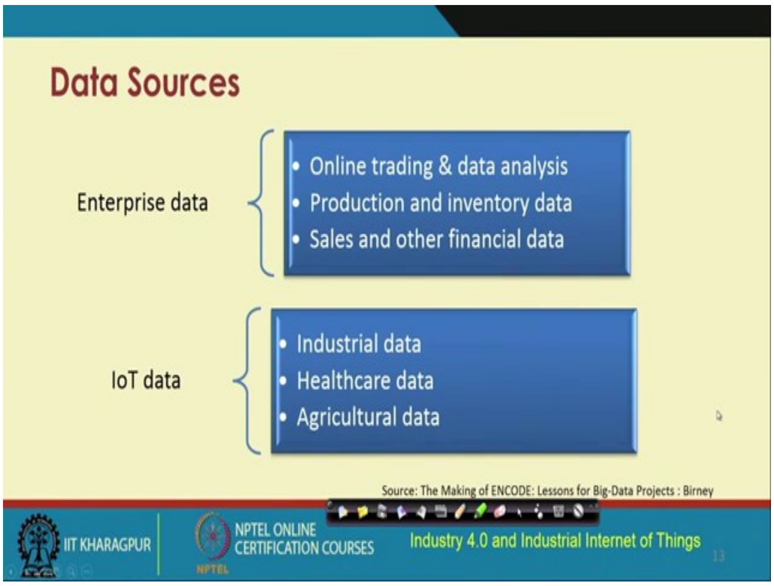

So, what are the sources of data? Enterprise data can be generated from online trading, data analysis, production inventory data, sales and different other financial data. These are some of the examples of enterprise data. IoT data like industrial data, healthcare data, agricultural data, and so on.

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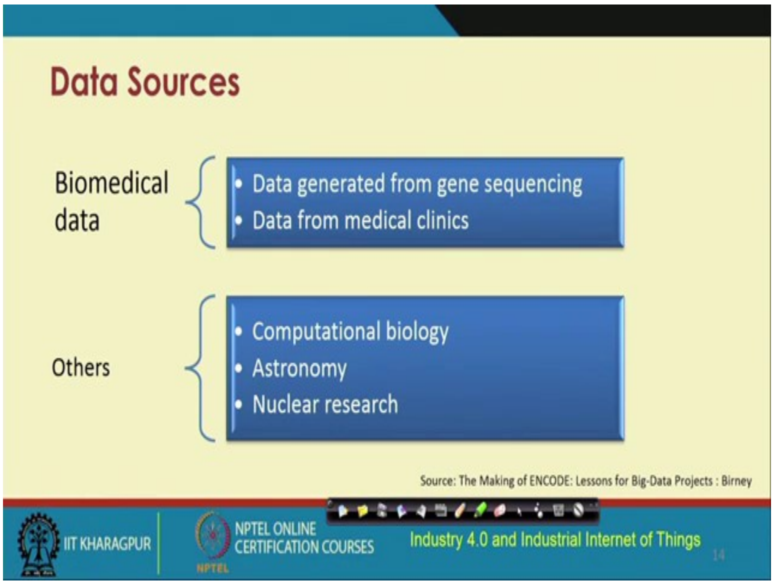


Biomedical data, data that are generated from gene sequencing, from medical clinics. And other data such as computational biology data, astronomy data, nuclear research data, these are the different sources of data. Astronomy, so some of these telescopes have been planted in certain parts of the world to look at the sky continuously, round the clock 365 days, a year, these are scanning the sky. And so as you can understand continuously in the, so much of data are coming from these telescopes. So, these kind of data will have to be handled; these are data which come in huge volumes. So, these are some of the sources of data.

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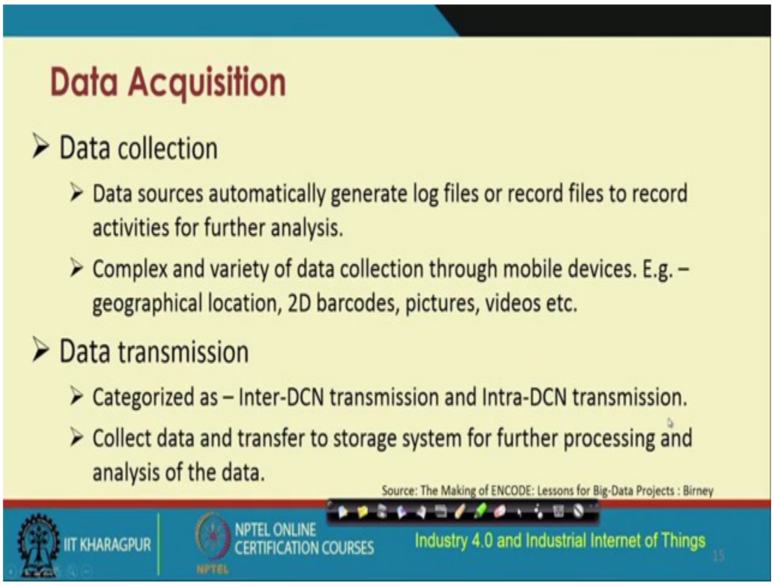


But in the context of industries similarly these machines, cyber physical systems machines continuously do by virtue of their continuous operation interaction and so on they are generating data, which typically is a combination of structured and unstructured or non-structured data. And these will have to be handled using these different analytical techniques for big data, data collection. So, you have to collect the data. So, the sources could be from log files, record files, from sensors, from different other sources like RFID devices and these could be coming from different sources.

Data transmission is then important. We are talking about data inter DCN transmission and intra DCN transmission. What is this DCN? DCN is basically data center network. Within a data center network of data center; that means, different servers interconnected with each other in a data center within that the transmission of the data and then from one data center to another data center, inter-data center network transmission, that is another type of transmission.

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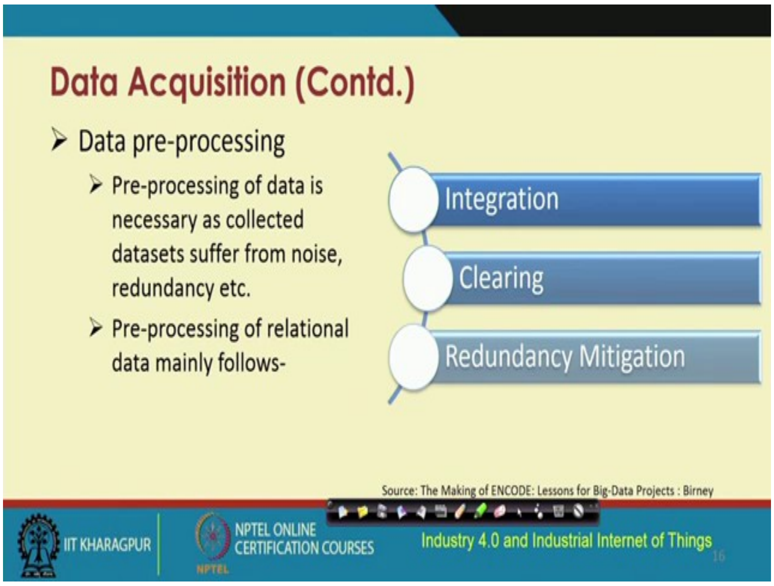


Then the data will have to be processed. But before that it has to be pre-processed. The data will have to be pre-processed to remove noise redundancy, inconsistency. And this pre-processing of relational data mainly follows integration, clearing, and redundancy mitigation.

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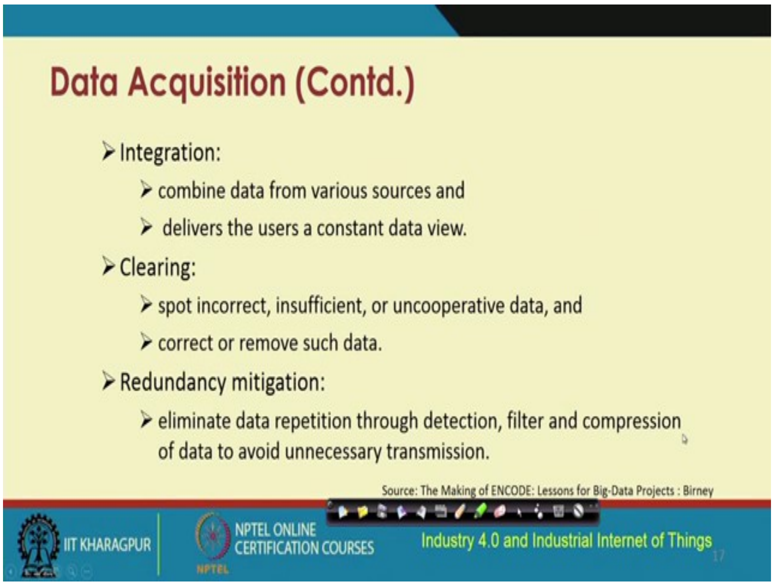


Integration is basically combining the data from various sources and delivering the users a constant data value. Clearing is spot, if there is something that is spotted to be incorrect, insufficient or uncooperative, then that kind of data will have to be spotted, corrected or they have to be removed. Redundancy mitigation--if there is any redundancy in the data there has to be filters in place which will in remove the repetition of such kind of unnecessary data from being transmitted, because the bandwidth is also very limited. So, you do not want to transmit, redundant data unnecessarily.

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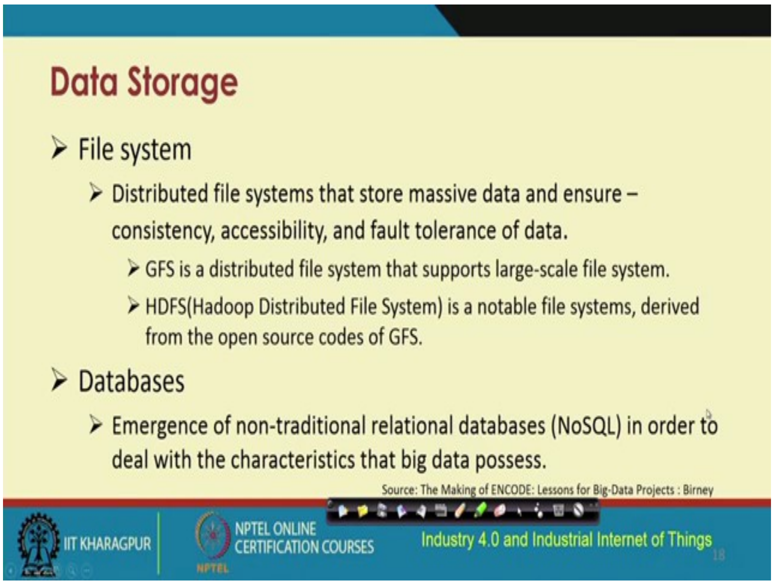


Data storage is important here we are talking about how the file systems would be for storing the big data. So, GFS is a distributed file system that helps in supporting in the storing, storage of large scale files. Another one is HDFS, HDFS is basically something that is followed in the Hadoop technology, Hadoop system, which is quite popular for use with storage of data, in the big data context. So, HDFS file system is a notable file system derived from the open source course of GFS. So, GFS and HDFS our file systems that are quite popular for use in different contexts of big data.

Databases, databases of different types non-traditional database wearing non-traditional relational database, like NoSQL language is there; like SQL, SQL is for the traditional relational databases use with querying this traditional relational databases and for non-relational databases. NoSQL query language could be used.

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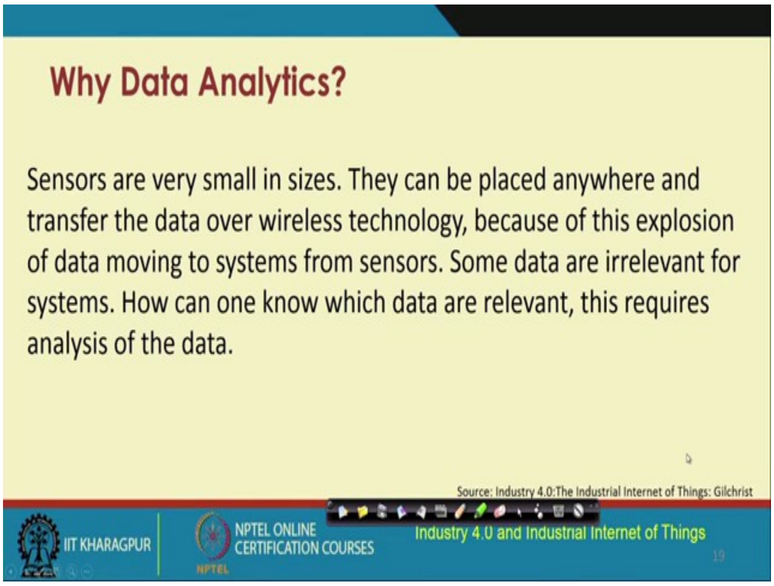


So, why do you need data analytics? So, in the context of IoT, IIoT, Industry 4.0 in general sensors that are used are very small in size, and they can be placed anywhere and these data from the sensors can be transferred over some networks, typically, wireless in nature. Because of this expression of data moving to systems from systems would be using these different sensors and the data will be moving from one sensor to another.

So, some data are irrelevant for systems. So, how can one know which data are relevant and which are not, so that is why this data will have to be analyzed. And also, there is one more point to it that once you have analyzed, the data you can perform certain actuation on the system, on the physical system, on the physical environment. So, those equations can be performed, based on the results of analysis of the data that is obtained.

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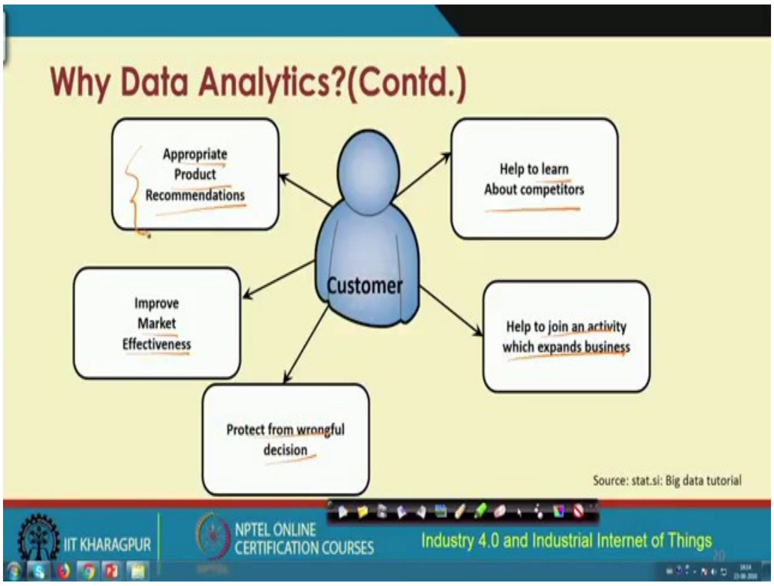


So, analytics is very important. For a customer, analytics will help the customer to learn about competitors, learn about competitors, help the customer to join and activity, which expands business. For the customer to protect from wrongful decisions, improve market effectiveness, and picking appropriate product recommendations, making appropriate product recommendations.

For example, if you are getting into Amazon or eBay or something you must have observed or even like Flipkart, etcetera they use recommender systems a lot. So, recommender systems basically what they do these are also AI based systems. They analyze the data using certain techniques maybe, machine learning or whatever and they will be making recommendations or suggestions to the user about what they could do next. So, these are the recommender systems.

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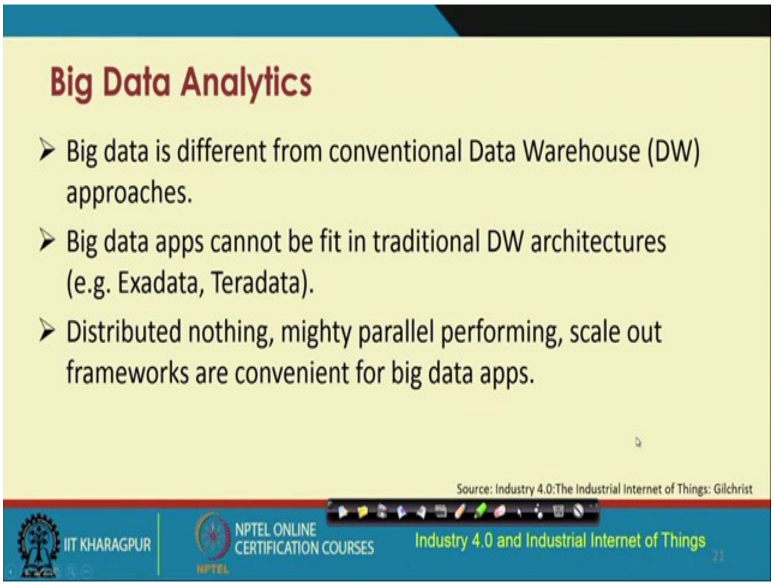


Big data analytics talks about a different way of handling data from the conventional way, data are handled in databases and data warehouses. Big data apps cannot be fit in traditional applications, cannot be fit big data applications cannot be fit in traditional data warehouse architectures because here we are talking about large volumes of data, Exadata, Teradata.

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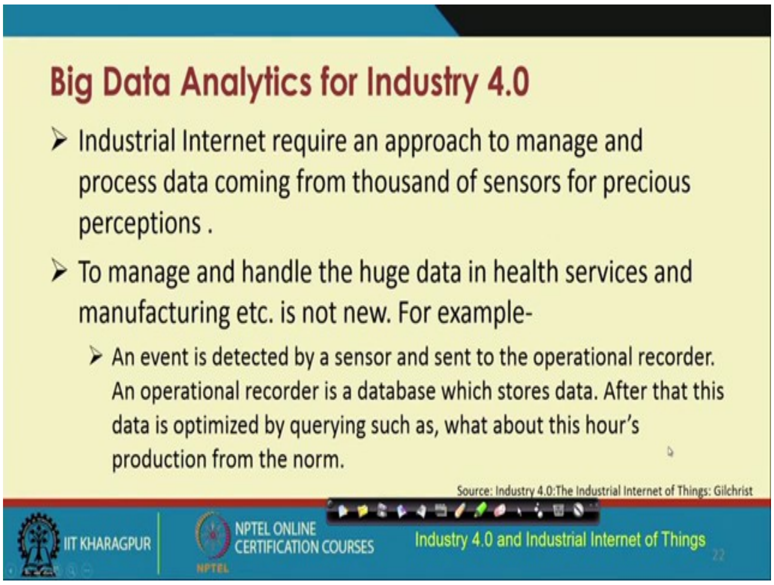


For Industry 4.0, we are talking about use of internet, industrial internet, which require an approach to manage and process data coming from thousands of sensors for perceptions. To manage and handle this huge data in health services manufacturing other industries agriculture inclusive, is not new. For example, an event is detected by a sensor and sent to the operational recorder and an operational recorder in it is a database, which stores the data. And after that this data is optimized by querying the system about something like, what about this hour's production from the norm from the normal. So, this kind of queries could be made from the data. So, that is where this big data analytics could be used in the context of Industry 4.0.

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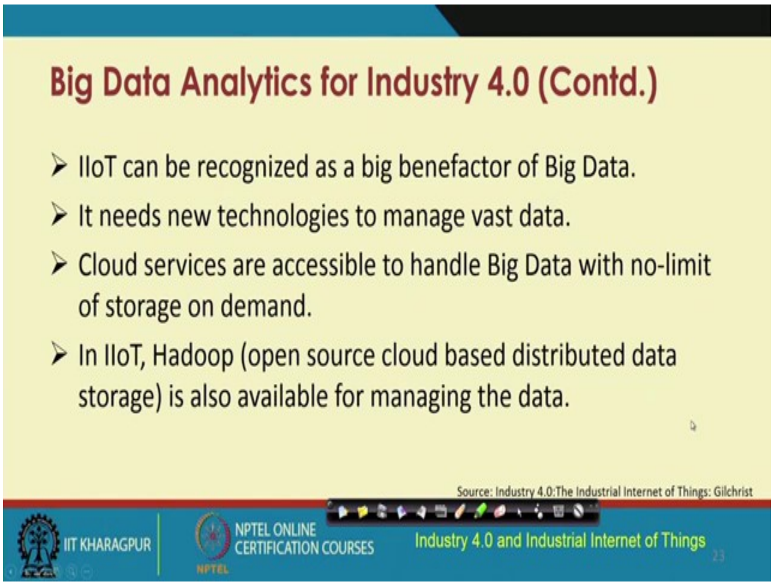


So, IIoT can be recognized as a big benefactor or big data. It needs new technologies to manage first data. Cloud can come to the help, because cloud can help in storing the data and also processing the data, because there is as such virtually there is no limit on the storage because if everything the storage is also obtained on demand. So, in IIoT for helping in the management of the data technologies such as Hadoop, which is an open source cloud based distributed data storage platform, cloud can be used for the analysis of this kind of data, which is big data. So, Hadoop is quite popular in the context of big data analytics.

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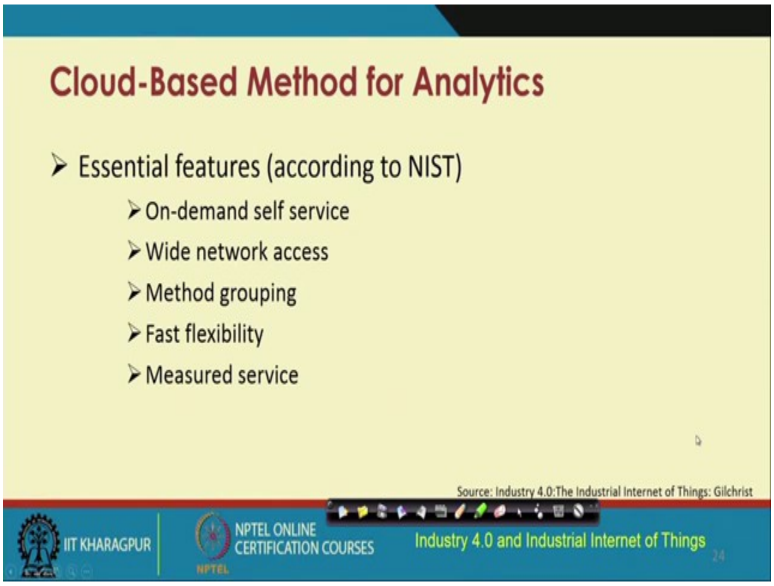


So, cloud-based methods for analytics would be; so first of all, cloud could be used for handling data big data, more specifically. So, there are different features of these on demand self-service, cloud basically helps in getting through a self-service kind of mechanism computational resources on-demand based on what the user requires. So, the scalability is also much better.

So, this is basically in a cloud offers wide network access, it offers the capability of grouping different methods, faster flexibility, and offering measured service. Measured service means based on the units of usage of cloud, the user is going to be charged accordingly.

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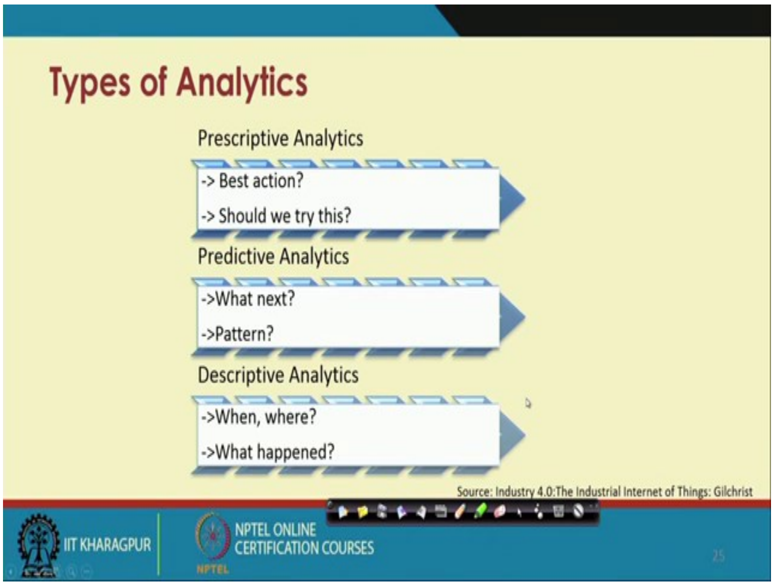


So, there are different types of analytics--prescriptive analytics, predictive analytics, and descriptive analytics. And prescriptive analytics talks about what is the best action, should we try this and so on. Predictive analytics talks about what is next, what is the pattern that is there. And descriptive analytics is when, where, etcetera what happened, these are all descriptive analytics. Predictive, prescriptive, and descriptive analytics are different forms of analytics.

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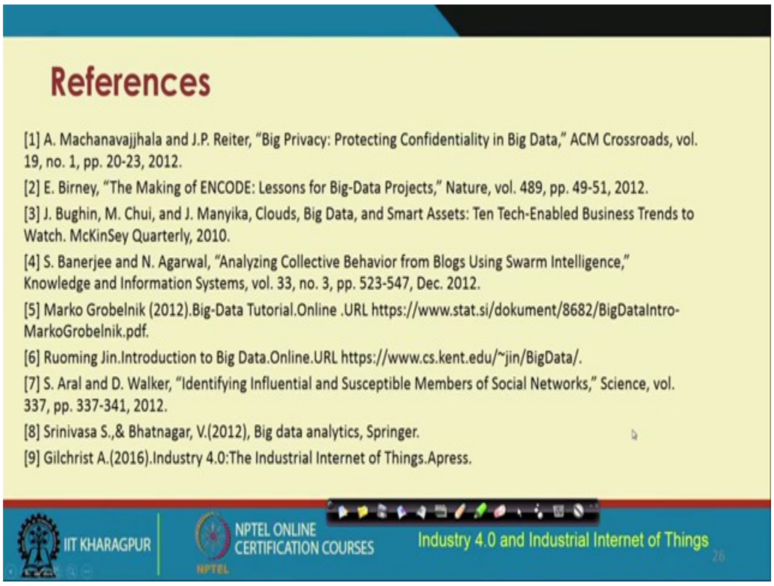

So, these are some of the references on big data and analytics. So, if you are interested you could go through any of these references, but there are huge number of references on big data and analytics at present and you could go even beyond these lists of references that are there for you.

So, with this we come to an end of analytics. Remember one thing that artificial intelligence, analytics etcetera these are not fields which are separate and are different from Industry 4.0 and IIoT. Without these enabling technologies, like the other technologies, you cannot basically survive to build IoT systems, IIoT systems or to achieve the vision of Industry 4.0. So, these are very important technologies for an analysis of the data, which could be used for analysis of the data, in the big data context in Industry 4.0.

Thank you.

**Introduction to Industry 4.0 and Industrial Internet of Things**
**Prof. Sudip Misra**
**Department of Computer Science and Engineering**
**Indian Institute of Technology, Kharagpur**

**Lecture – 16**
**Industry 4.0: Cybersecurity**

In this lecture, we will talk about Cybersecurity, which is a very important topic. In fact, a topic, which is of utmost concern in IoT, in general and IIoT, as well for the industries. In the context of Industry 4.0 whatever we have talked about so far, all these things would be meaningful, if people are not much concerned about the security of their systems, the physical systems, the cyber physical systems, and also the security of the data. The overall data that is collected and transmitted through the system has to be secured, the privacy of the data has to be maintained, it has to be the data, that is received from one person, it has to be trustworthy and so on. So, like this there are different allied issues as well when it comes to Cybersecurity.

Security, privacy, trust these are all interlinked entities and these are of utmost concern in the context of any system, and definitely for any internet-based system and low-powered resource constraint systems IoT, IIoT, and so on. So, that is why in the context of Industry 4.0 we need to understand the basic concepts of Cybersecurity, what are the different elements of it, and some of the different types of threats that are there in terms of securing the cyber physical systems in the industries. So, we will look at each of these in detail now.

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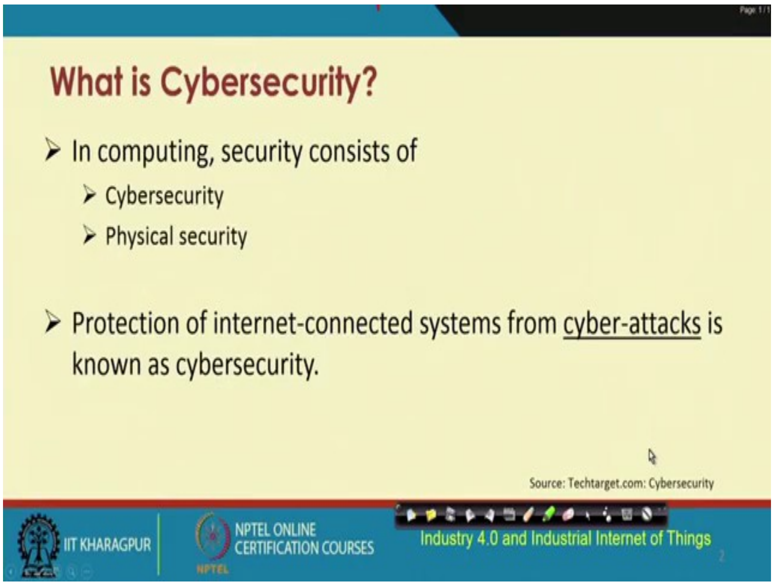


So, what is Cybersecurity? It is basically the security of the cyber infrastructure that is there. Basically in computing what is there is we are talking about not only the cyberspace in computing, we talk about the computing infrastructure, which includes hardware, software etc. Not only the security of the cyber infrastructure, but also the physical security, the physical security of the computing machines, the non-computing machines, and so on. So, other all kinds of machines the physical security of the machines on which the cyber infrastructure operate.

So, we are concerned about two things, one is the Cybersecurity and the physical security these are the two different things that we are primarily concerned about in the context of security.

So, protecting against what? Protecting against different attacks. Attacks will be performed by entities, which want to harm the infrastructure. In the context of industrial IoT, the fundamental premise is that the machines the systems are all interconnected. So, if they are all interconnected we have an internetwork, and we are talking about the potential of different intruders getting into the system and trying to launch some kind of attack to harm the system, the way it is operating, the different data that are being transmitted, stealing the data, overall harming the network, the hardware, the software and the physical machines themselves. So, these are all the different aspects of Cybersecurity in an internet connected world.

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So, when we are talking about Cybersecurity we need to talk about how to protect the hardware, software and the data. So, what happens is that in the case of a cyber physical system enterprises use Cybersecurity and physical security simultaneously against unofficial access to data centers.

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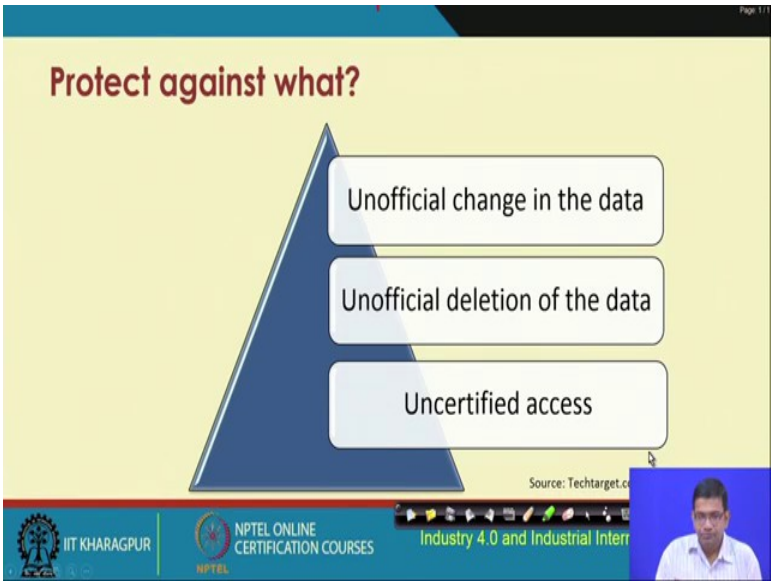


So, what should we protect and it is protection against what? So, protection against unauthorized, unofficial change in the data; unauthorized on unofficial deletion of the data and uncertified access. So, these are the 3 different things against which the protections will have to be made.

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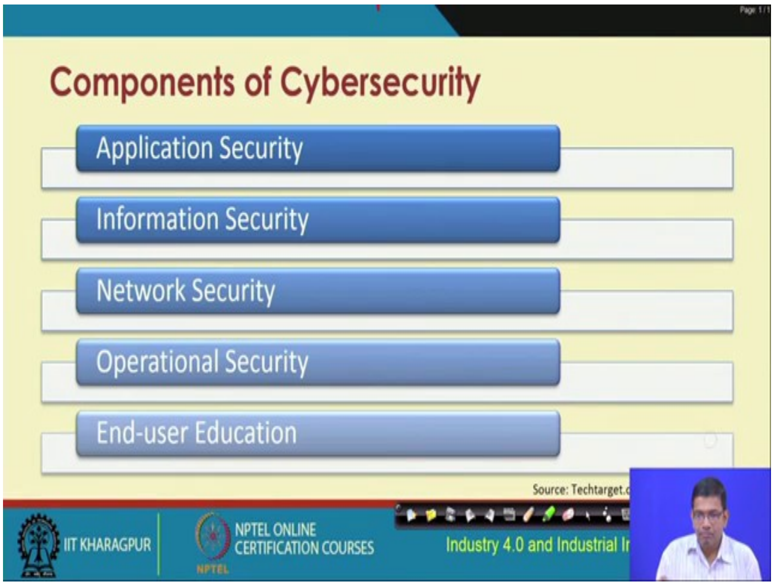


Let us now get into understanding and going back into the understanding about how in general the IIoT systems or IoT systems in general work. And this is something that we have already discussed in significant detailed in the past.

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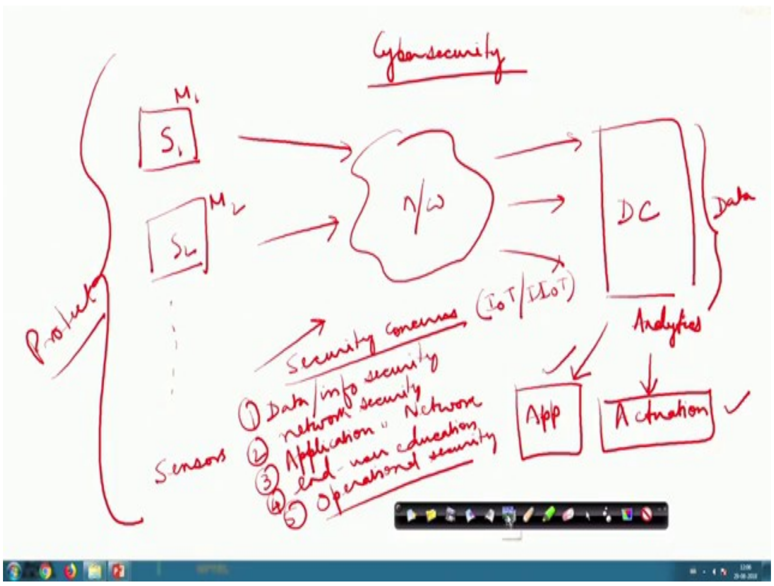


So, what we have? We have different physical systems on which there is some kind of sensor that is deployed. So, we have a machine 1, which has some sensor. Let us say, a machine 2, which has some other sensor and likewise, we have different machines, which have one or more sensors. Here I have drawn a single sensor per machine, but it is also possible that a machine would have multiple different sensors.

So, these sensors what they do? We have seen this before, through some kind of a network, these machines are going to send the data to some other infrastructure. This is where we will have some data center or, some server or, something like that, which will get access to the data, which will acquire the data, and we will run different analytics on it. This is typically what is done. And based on the analytics we have also seen that some kind of actuation may be required to be implemented. So, this is typically how any IoT system and IIoT system, at a very high level, is going to work.

So, what are the different layers over here? We have sensors, which will sense the environment in the physical environment, in which they operate, collect the data pass it, through some network. Then this data is being sent through the network, will have to be analyzed and some actuation may be required over here. And actuation may be there or, even what might so happen is the data would be the analysis of the data, in some kind of application software.

So, now we know if we are talking about Cybersecurity. These are the things that we need to keep in mind. We have to holistically, we need to protect we need to protect this system from unauthorized, unintended access and potential harm to the system. So, how do we do it? One thing is that the data that is received from these sensors, we can we have to protect it. So, we have what? We have data or information security. Then we have to do what, this is number 1. Number 2 would be the finally, the data will have to be sent through the network. So, we need to have network or inter-network security we also need to ensure that these applications that are running on the system like these ones these also will we will need to be protected. So, we are talking about application security.

There are few other types of security concerns that will have to be there. So, the users, the end users, who are using the system or are different actors taking part in the system they will also need to be educated enough to use the system properly, and that there are some potential issues with security of the system of the infrastructure of the data and so on. We are talking about, end user education for security. Finally, overall the operations that are being carried on security of the operation, so operational security. So, we have these as the different security concerns in the context of IoT or IIoT. These are the main components of Cybersecurity, application security, information security, data security, information or data security, network security, operational security, and end-user education.

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Application security basically ensures that you are protecting the different applications from outsider threats. So, basically some software, hardware and procedural methods could be used for this particular protection.

So, what is required is to have some kind of protection that means some kind of countermeasures at the software level as well as at the hardware level. Software level, one could use different application firewalls for this particular protection. At the hardware level, countermeasures could be used, some kind of proxy or router or similar kind of device, which will have the protection against this kind of outsider threats. So, these are the different measures that could be taken.

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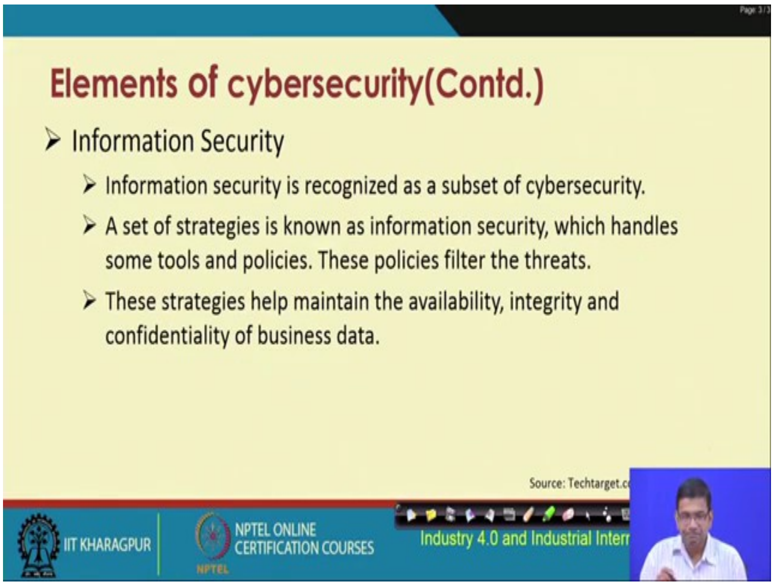


Information security, is basically recognized, as a subset of Cybersecurity, where we are talking about a set of strategies that should be adopted, which will have some policies associated with it, and some tools. And these policies, the tools also are supposed to filter the different threats, based on certain rules. As a consequence, implementation of all these different policies rules we are going to have, we will maintain the availability, the integrity, and the confidentiality of the data, and this is very paramount. So, information security, protecting, the availability, integrity, and confidentiality of the data, in the context of businesses and industries is very important.

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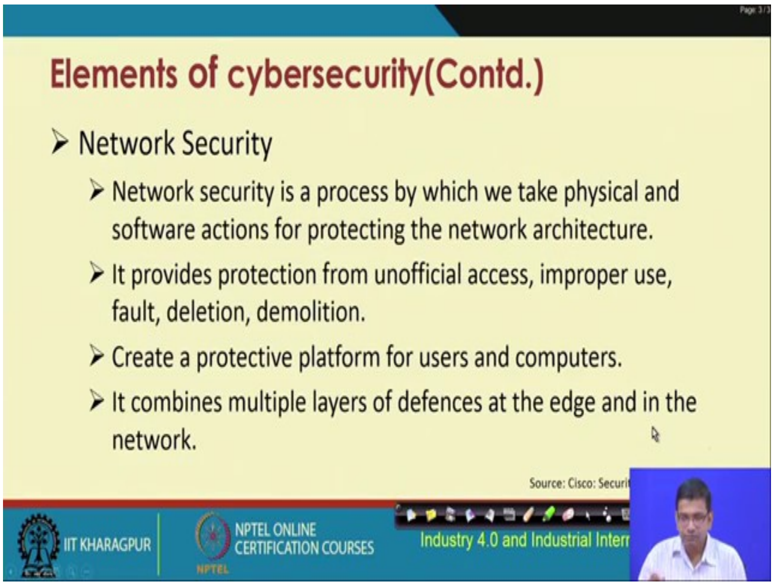

Network security as the name says we have to protect our network from unauthorized access. So, basically the physical and software actions that would be required for protecting the network architecture those processes will have to be laid down.

Network security would provide protection from unauthorized access, improper use, fault, deletion, demolition, and so on. So, it is a protective platform, it is a protective platform that will have to be created on top of the basic network, for protecting from unauthorized users, protecting from damage unauthorized access, and damage to the existing infrastructure like computers and so on. So, network, basically is a vulnerable point through which potential attackers can get in and launch different attacks.

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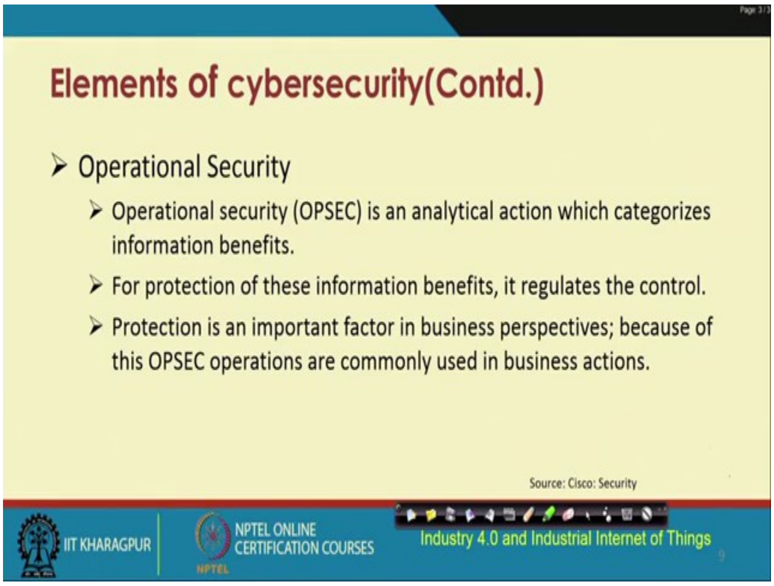


Operation security is an analytical action, which categorizes the information benefits and for protection of these information benefits, it regulates the control. So, protection is an important factor in business perspective, because of the operational security operations the business actions are going to be protected.

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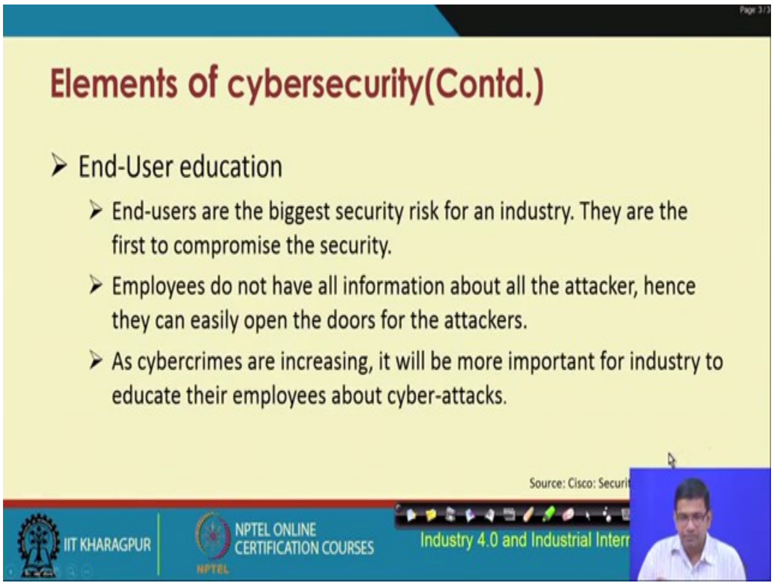


End-user education, end users are the biggest security risks for an industry. They are the first to be compromised in terms of security. So, employees and the end-users, typically, do not have all types of idea about the information threats and threats to the infrastructure. So, these end-users can be the vulnerable points in terms of security. They will have to be educated enough so that unintentionally they do not open the doors for the attackers. And as cyber-crimes are increasing it is more important for the industry to educate their employees about potential cyber attacks.

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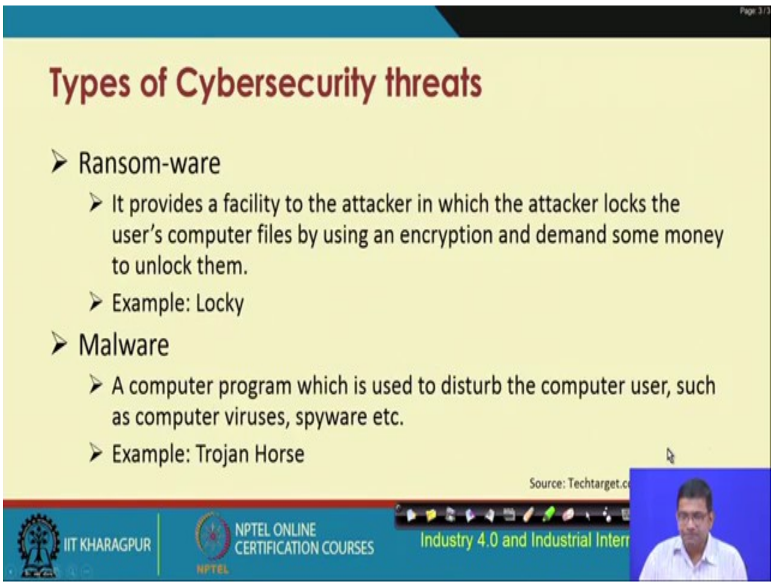

So, what are the different types of Cybersecurity threats? Cybersecurity threats are varied, they are of different types and understanding all of them is a herculean task, by itself.

So, ransom-ware is a very common, common type of attacker. It provides a facility to the attacker in which the attacker locks the user's computer files, by using an encryption and the attacker will demand some money in order for them to lock the system to be further used by the legitimate users. They will lock the system from being used. One of the examples of this type of attack is the Locky, a ransom-ware type of attack.

Malware, and as this name suggests it is a computer program, which is used to disturb the computer user such as different computer viruses, spyware and so on. And spyware computer viruses we are already familiar with like Trojan Horse. So, these are the ones that basically they disrupt the normal operation of the computers and the cyber infrastructure, and they will not basically protect or they may not disturb completely, they may not disrupt the functioning of the system completely, but at certain operations, certain procedures, certain processes, might be disrupted and that will basically disturb the regular user from performing their legitimate tasks.

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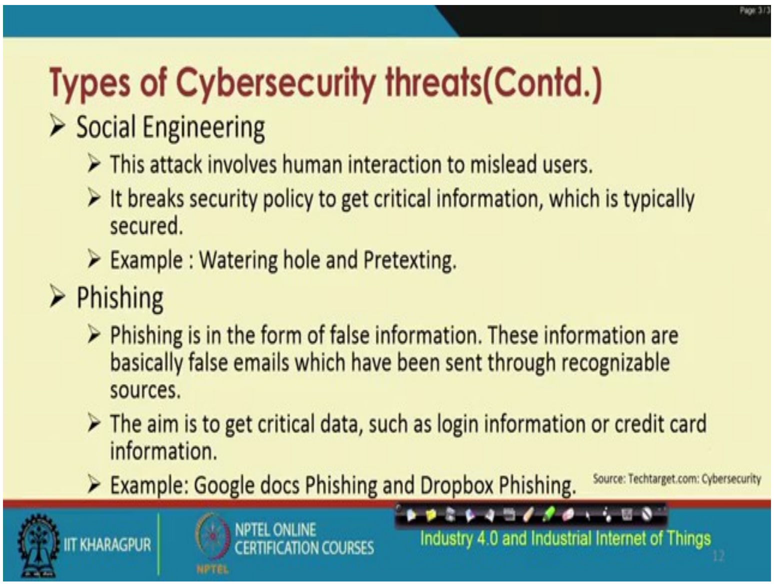


Social engineering, this attack involves human interaction to mislead the users. Social engineering breaks the security policy to get critical information, which is typically already secured. So, security policies are basically broken in this kind of social engineering Cybersecurity attack. So, examples are watering hole and pretexting.

Phishing is a form of attack, where false information is sent, and these information are basically in the form of sending false emails, which have been sent through recognizable sources and the aim is to get critical data such as login information or credit card information. So, phishing attacks, who are already in the emails, which are basically phishing attacks, which will ask you for credit card information, the login information saying that the email account is going to be invalid after a few days. These kind of attacks are going to be made and will basically, if somebody is not already educated about the potential threats from these kind of attacks, the user would supply the credit card information that is requested or supply the username and password to the attacker unintentionally and that way they will lose access to their system.

So, example of this thing is Google docs phishing and Dropbox phishing attacks and they are like these different types of other phishing attacks that are possible on different systems.

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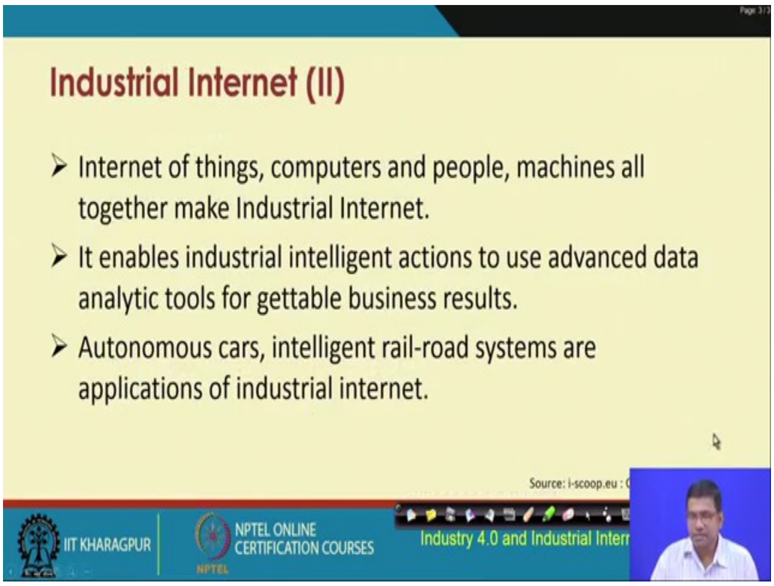


Now, let us go back to the industrial internet. So, when we are talking about industrial internet, we are talking about typically use of different things sensors, actuators, internet of things. So, internet of things computers, people, machines all together are different participate participants in the development of the industrial internet. The industrial internet enables the industrial intelligent actions to use advanced data analytic tools for getting desired business results. Examples of industrial internet are basically outcomes such as having autonomous cars, and intelligent railroad systems.

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So, for IIoT securities security issues are important and securing the standards for securing the systems are required to be designed. So, industries will need to use diverse systems and equipment but everything will be integrated on the smart factory platform.

When we are talking about industries certain things are legacy, which have been there for decades in the industry whereas, certain systems might be the recent ones, which have already been built to be secured. So, legacy systems particularly should be taken seriously in the in the in the process of implementation because these systems might be the points of vulnerability for launching different attacks, for the attackers to get into the system the legacy systems could be the ones, which could be the vulnerable points because those days earlier days security was not well understood systems were designed not to be always secured and so on.

So, there are some potential possibilities of leaving some points in those systems, which basically the attackers can launch the attacks. So, every week line in the production system, in the industrial process puts the whole factory at risk. So, living security at the hands of the individual IIoT implementers is consequently dangerous.

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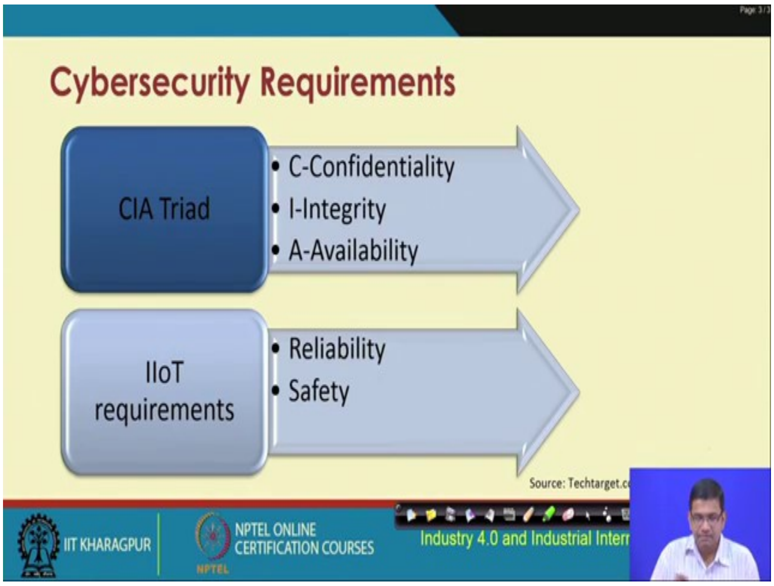


So, what are the Cybersecurity requirements in the context of a IIoT and Industry 4.0? The first one is the fundamental one, which is not only applicable for IIoT but for any computing system, this is known as the CIA Triad, C stands for confidentiality, I stands for integrity and A stands for availability. And the second set of requirements are basically the IIoT specific requirements, which talk about reliability and safety.

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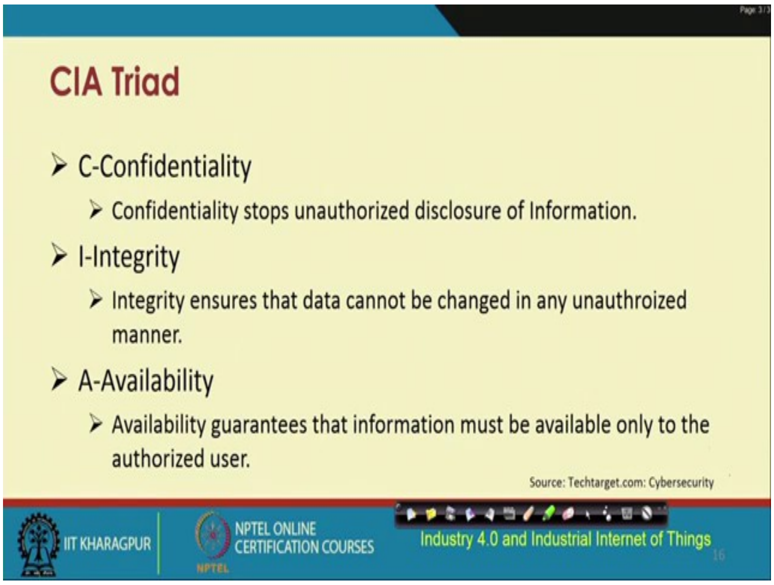


So, confidentiality in the CIA Triad stops from unauthorized disclosure of information. I stands for integrity, which ensures that the data cannot be changed in any unauthorized manner and A stands for availability, which guarantees that the information must be available only to the authorized user.

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In the context of IIoT, these are some of the challenges with respect to provisioning Cybersecurity. So, basically when we are talking about industries, we are talking about machines, where different sensors, actuators are all deployed and these nodes are all inter-network, they are all interconnected.

So, basically if you need to have such a kind of system getting some kind of a transformation that the industries will have to go through to transform from the physical systems the standalone physical systems, without these kind of infrastructure, that has been existing for years, and transforming into something that is smarter, connected machines with sensors, actuators. So, this transformation will have to take place. When this transformation is going to take place, you have to take into account all these different points of vulnerability, that can be potentially introduced through this transformation process.

So, when we talk about transformation capabilities such as manufacturing, logistics, shipping, healthcare and industries these will have to be taken in the into consideration differentially, differently in the context of industrial internet. So, what might happen is one might incur data breaches, which increases different types of cyber crimes and cyber threats because there are different types of attacks, that are possible.

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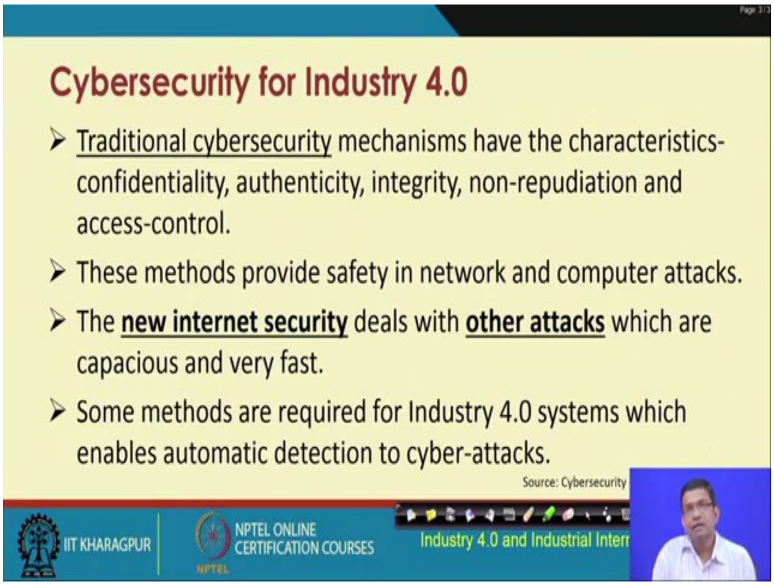


Cybersecurity for Industry 4.0, which will need to be taken into consideration like that confidentiality, authenticity, integration, non-repudiation, and access-control.

We are gradually trying to make our machines and different devices in the industry smarter. So, we are introducing computers networks into our systems. So, there are some new internet security issues, that will have to be identified through this introduction and transformation process. These new security issues will have to be identified and the potential attacks that can come in we will also have to be analyzed, identified and resolved. So, different methods we will have to be devised for handling the different security issues, security threats, in the context of industry 4.0.

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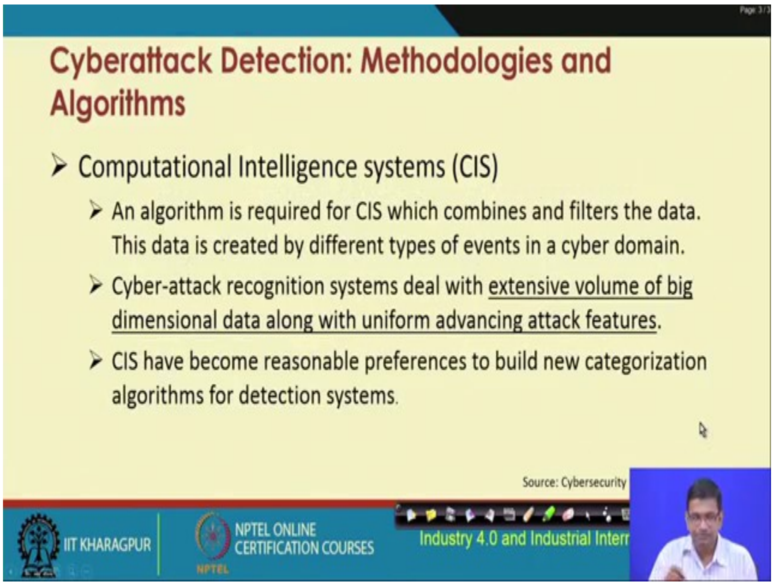


Different methodologies have been proposed, different algorithms are there, one of which is for cyberattack detection. A computational intelligent system platform, which can predict if there is some kind of attack that is going to come in the future. Basically this platform implements an algorithm that is required, which combines and filters the data, and collected, will be analyzed to identify, whether there is a potential threat, that can come in the future. So, this is the CIA system that and this is how it performs.

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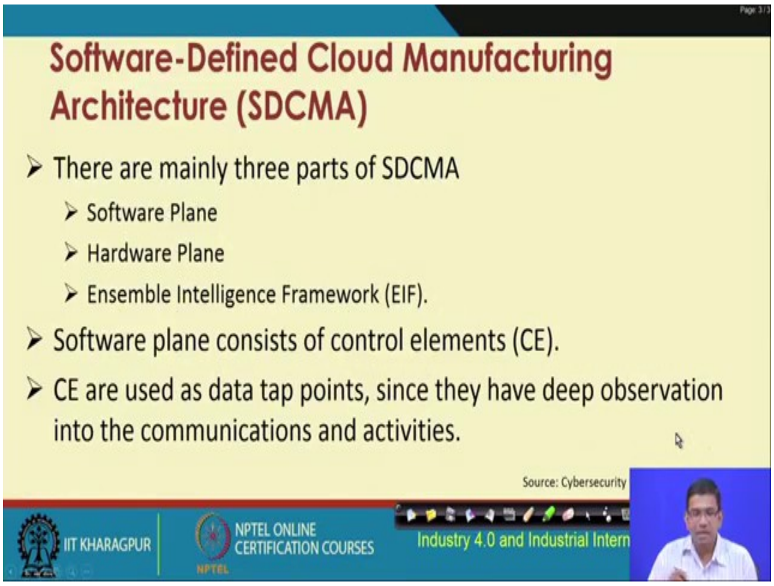

And another one is the software defined cloud manufacturing architecture. In this basically you have 3 parts of the system one is the software plane, second is the hardware plane and the third is the ensemble in intelligence framework the EIF.

The software plane basically consists of different control elements in the CEs, and each of these CEs is used as the data tap points, since they have deep observation into the communication and activities.

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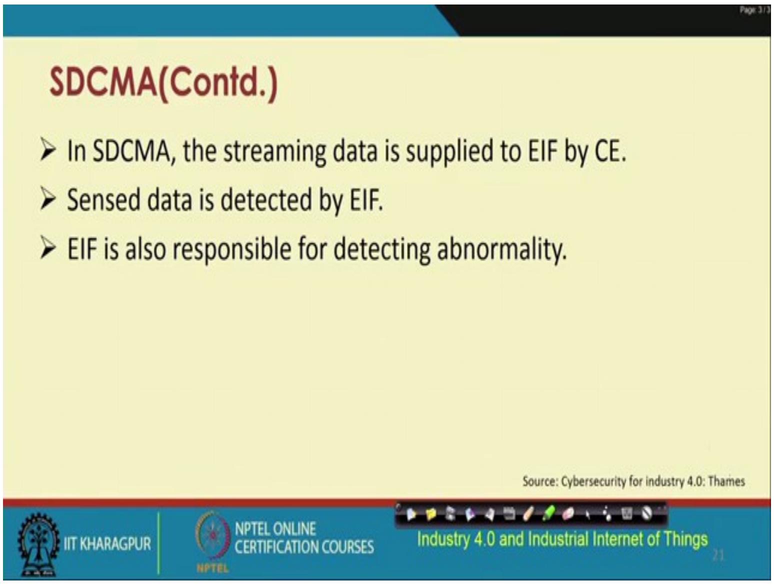


In SDCMA, the streaming data is supplied to the EIF by the CE, and the sense data is detected by the EIF, and this EIF is also responsible for detecting the abnormality.

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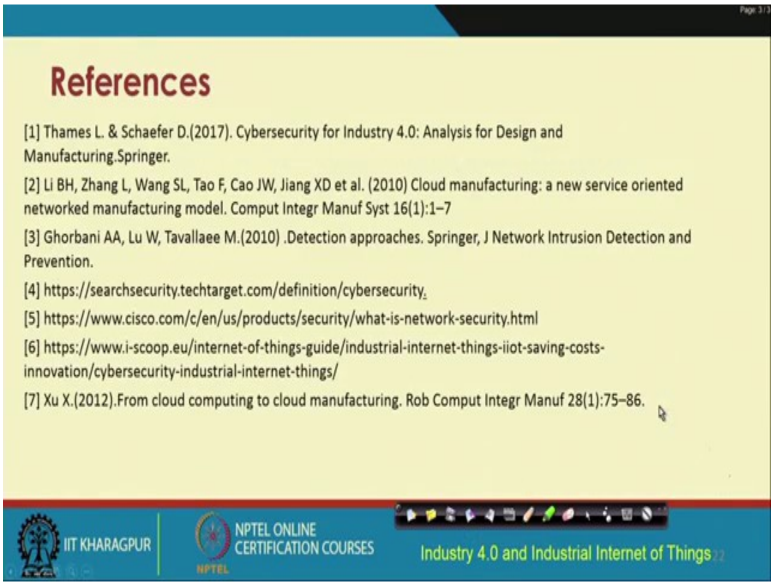


So, with this we come to an end of this lecture. So, what we have done is we have understood the essence that why Cybersecurity is important, the essence of it we have understood, the different elements of Cybersecurity, the possible types of attacks that might be launched on these IoT and IIoT platforms in Industry 4.0. And if you are interested to know more in-depth of these things, these are some of the references that is given in front of you and you can go through them. There are many different other references that can also be obtained through some kind of search. You will be able to get the other differences talking about different issues, different solutions and so on.

So, Cybersecurity, security for IoT security, for IIoT or nowadays, and lot of research are going on these topics. So, if you are indeed interested to deep down into each of these issues you have to basically go through these different literatures that are available and if you are also interested if you are a security researcher, you might be interested to implement them. So, for that also you need to go through these different literatures in these differences and outside in more detail.

With this we come to an end.

Thank you.

**Introduction to Industry 4.0 and Industrial Internet of Things**
**Prof. Sudip Misra**
**Department of Computer Science and Engineering**
**Indian Institute of Technology, Kharagpur**

**Lecture - 17**
**Basis of Industrial IOT: Introduction**

In this lecture, and few others to follow, we will be going through some of the basic concepts of industrial IoT or IIoT. In this lecture, specifically, we will go through some of the introductory motivating concepts, behind industrial IoT and how we can have a basic setup of industrial IoT in the lab scale. So, we will go through these different concepts to motivate why Industrial IoT is required.

So, at the outset let us consider different industrial application domains. Domains such as manufacturing industries, agriculture, mining, transportation and logistics, healthcare, and so on. So, there are different application domains and accordingly there are lot of industries, who cater to these different domains.

So, they have their own different industrial processes and we have gone through the basic concepts of different industrial processes and how these processes can be improved with the help of IoT in the previous lecture. So, what needs to be done is we need to really understand that how industrial IoT solutions can help in improving the overall efficiency of these different processes.

So, at the outset let us consider a few examples. Examples of let us say to start with mining industry in different mines. For example, coal mines there are different processes, that are there, mining processes that are there, which can monitor and prevent different events from happening.

So, for example, it is quite common in coal mines to monitor the gases the different gases that are formed in the mining process. For example, there are different gases such as methane different other gases. For example, carbon dioxide, carbon monoxide, and many others, which are basically formed in the underground mines in the mining process. So, these gases we will have to be detected and it is very important to detect these gases, because many of these gases can pose as hazards, because for example, methane. Methane is a highly inflammable gas, as most of you already know carbon dioxide or carbon monoxide can also cause fatalities. So, these gases are very harmful gases like this there are different other gases that are there. We need to it is very important to it to ensure that in the mining process in an in coal mines particularly to monitor continuously monitor the level or the concentration of each of these gases that are being produced.

So, gas monitoring under in the underground mines continuously in real time is very important and accordingly if the concentration of a very harmful gas has increased beyond a certain threshold or a limit, then it is very important to generate alerts for the mineworkers or at the control centre and accordingly take steps such as evacuate the mine workers or whoever is there underground. So, that is one application like this there are different other applications in underground mines for example, strata, a fall monitoring. So, let us say that you are mining the coal out and the strata or the roof above the area from where the mining has been conducted that might collapse. So, that monitoring of that roof above the extracted portion is very important. So, the roof might collapse and cause a hazard to the mining workers. So, like this there are different other applications also. So, all these things for doing all of these things it is very important to use these different technologies like IIoT or Industrial IoT. So, Industrial IoT applications for gas monitoring underground mines is very important application.

So, over here in the classroom itself.

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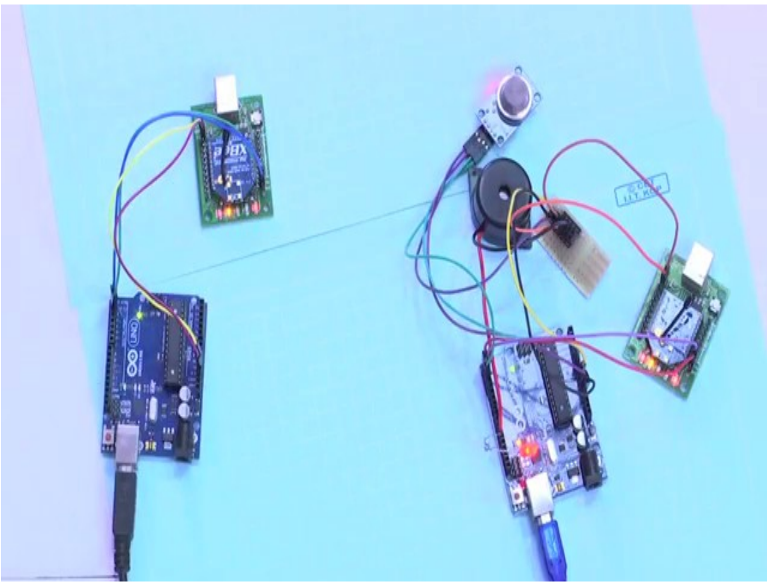

Let us look at a very simple application of gas monitoring, using different sensors and IIoT technologies. So, at the outset let me just tell you one more thing that. So, when we talk about a IIoT. So, Industrial IoT means its kind of a specific type of application of IoT for addressing the different industrial issues.

So, here I am talking about mining industry, gas monitoring, and so on for another industry there are different other issues, but at the core of all of these it is about sensing, actuation, networking, connectivity, processing and so on. Let us look at one very small kind of application of gas monitoring. This is a gas sensor which can detect few gases.

So, this sensor can help you in doing it then we have an actuator, which is a buzzer. We have kept this buzzer, because we want to show that if the concentration of the gases is increased, then the sensor is going to pick it up and this buzzer is going to buzz showing the actual concentration of the gas, the LPG gas, but it could be any other gas as well it has increased.

So, this is the one which will do it and then we have. So, this sensing is done over here by this sensor and in then this sensor sends this data and some processing is done over here by this microcontroller unit that we have and thereafter this data is sent from one site to another site. So, let us say that this is one site and this is another site. So, this is sent from one site to another site and for this we have two different communication modules over here this is one and this is another.

Let us say that, this is the sender and this is the receiver. This receiver unit is going to sense, going to collect all these data that are sent by the sender unit, connected to the sensor and that will be picked up over here at the receiver and from there it is going to be sent to the control center.

So, this is going to be sent to the control center from where the monitoring of the gases are going to be done. Let us take a look at this example. So, let us say that we bring some concentration of LPG gas over here as you can see that it has alerted. So, the sound came. So, this buzzer has buzzed.

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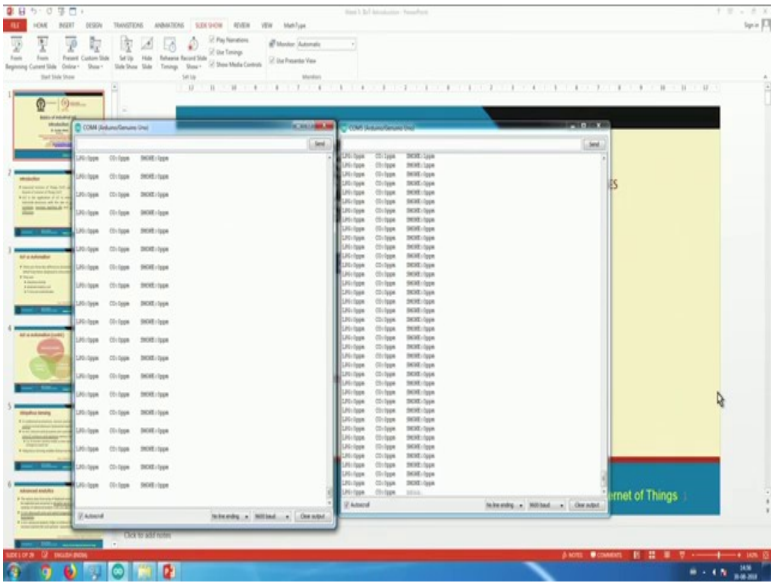

So, if we look at this data this is basically the sender as you can see over here detected some smoke or whatever some gases some carbon monoxide gas was detected and then it is sending it and the receiver is receiving over here.

So, this is basically the receiver over here as you can see it is showing that it had received these. So, over here as you can see on the top. So, we can try it out once again. So, you can see that this is the sender, which is showing that some gases have been detected and this is the receiver, which is also receiving those values. Let us assume that this is the control center from where this concentration of these gases are being detected and this is how this monitoring can be done. This is a very simple kind of application showing how gas monitoring can be done not only in mining industries, but also in other industries as any other chemical industry or whatever where gas monitoring is also very important, like the gas monitoring application for underground mines. Let us consider another application of IIoT. Let us consider the healthcare industry, for example, in hospitals, there are different patients, health care professionals such as doctors, nurses. It is often very much important to monitor the condition of the patients continuously in real time and so on.

So, with the existing technology the traditional technology it is difficult, because traditionally what has to happen is the doctors and nurses or other healthcare professionals we will have to periodically visit the patient. Then monitor the health of the patient that is one. Better than that is, at the word site of the patient there might be some different medical devices which might be also equipped with different sensors, but those sensors are standalone sensors, they are typically not connected sensors and all they can do is they can give the they can show the value the physiological parameter value that is being monitored for the patient.

So, with the advent of IIoT and IoT, in general, it is now possible to continuously monitor the health condition of the patient. So, over here like the previous example, I am now going to show you two very fundamental sensors that can be used for monitoring the health of the patient.

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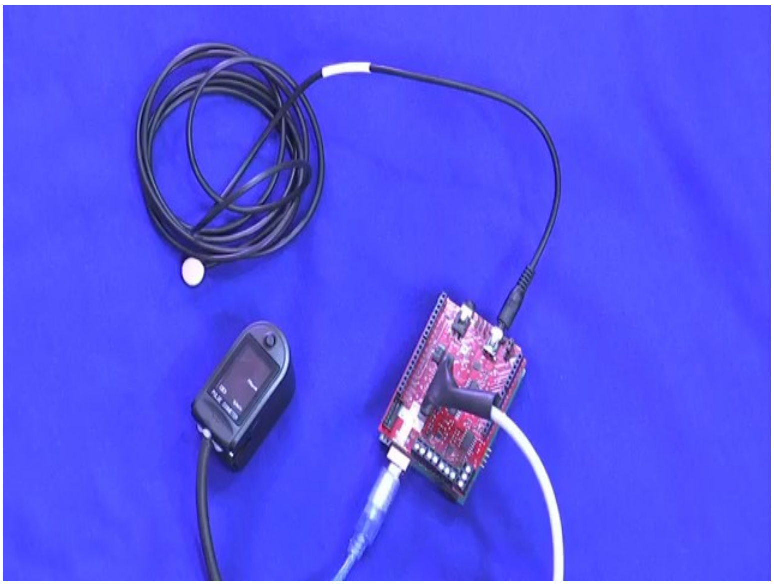

Here what you see this is the temperature sensor this is the body temperature sensor that is there and this is something known as the pulse oximeter. So, pulse oximeter, basically measures the oxygen saturation in the blood of the patient, as well as the pulse rate.

These two sensors have this picked up, you can use different other physiological monitoring sensors to monitor the condition of the patients and the advantages is, as I was telling you that autonomously in real-time continuously the condition of the patients can be monitored and alerts can be generated for the doctors, if there is some criticality in the health condition of the patient.

So, now you can understand that this is a very useful tool that can help you achieve it. So, how it is done in this case? So, this body temperature sensor let us say that, it is fitted with a patient. I have just pressed it to show the body temperature.

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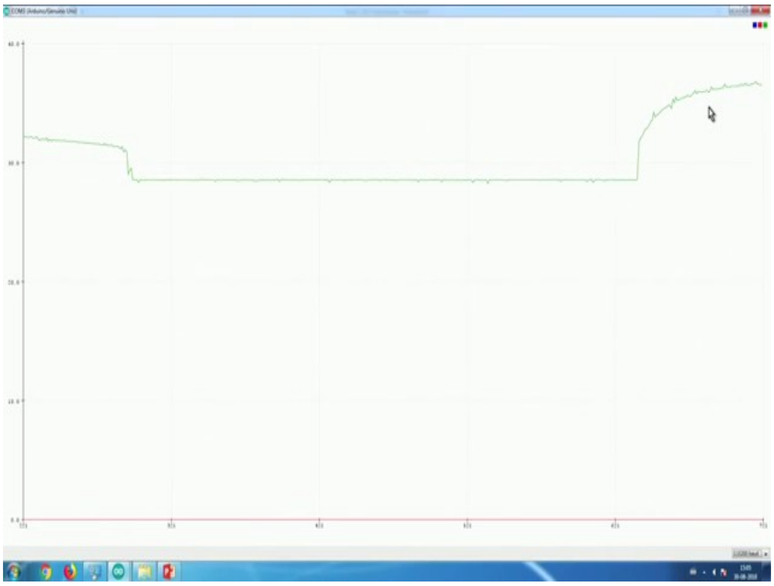

So, what I have over here as you can see on the screen as you can see over here the temperature value it is increasing. This is the temperature reading, this is continuously increasing and let us say that, this is at the doctors panel for one patient or for many patients also this thing can be extended and can be scaled up to monitor the health condition of different other patients. So, this is the temperature plot and likewise this pulse oximeter that is there.

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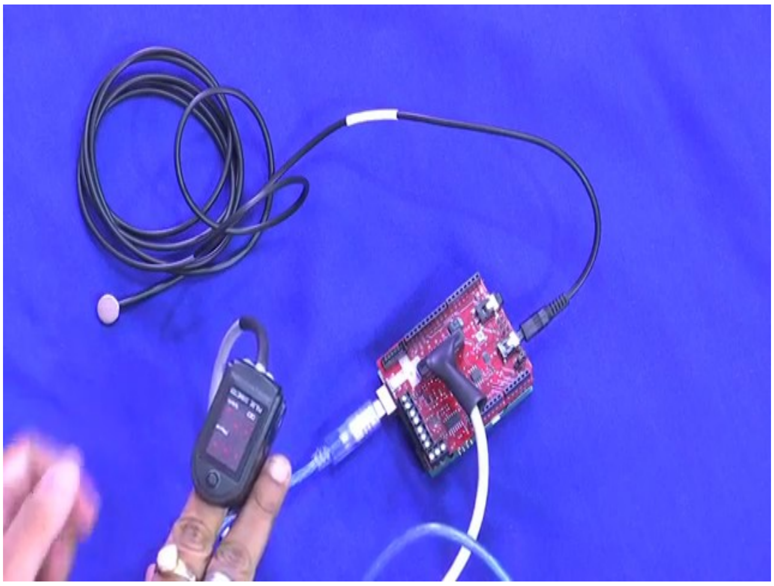

I could use it to show you that, a patient could be fitted with it like this.

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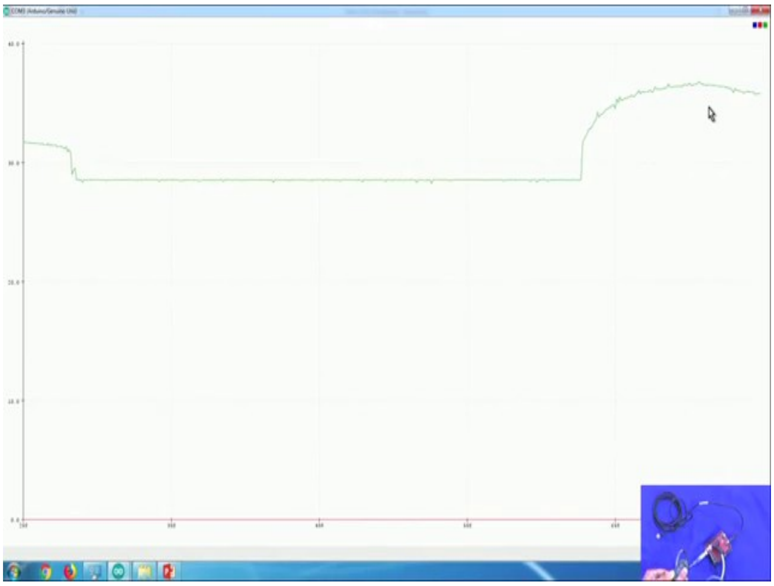

Then on the screen I should be able to get the value of two things. So, I have now put the pulse oximeter sensor put my finger into it and I just told you that the pulse oximeter sensor helps in measuring two things, one is the oxygen saturation in the blood and the other one is the pulse rate.

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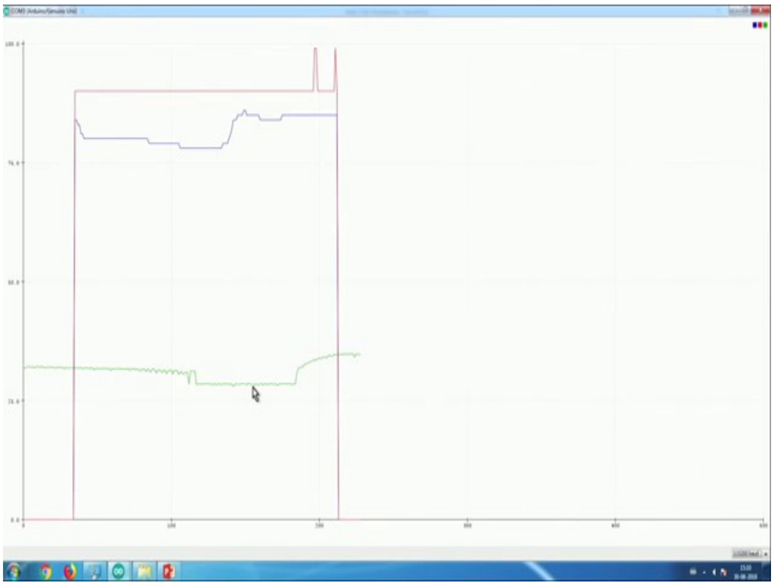

So, now looking at the control view.

So, as we can see over here, this is the blue one is basically the heart rate and this is the oxygen saturation in the blood and as you can see over here these two values are gradually getting plotted over time, this temperature value is still low, because I just left it out, but I could be again putting it on my finger for measuring the temperature and the temperature value the body temperature value is increasing.

So, this is an application of different healthcare physiological monitoring sensors, which can be used in the health care centers such as hospitals, for continuously monitoring the health condition of different patient by the doctors and nurses.

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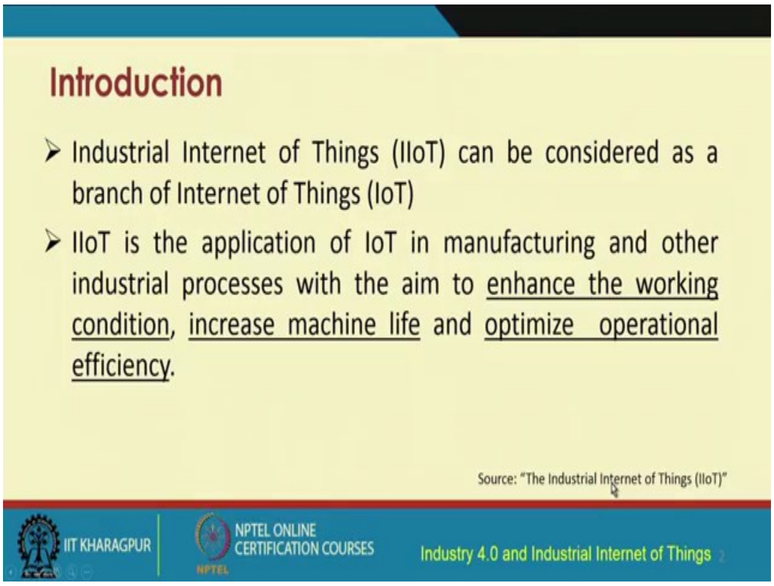


Let us and look at the details of Industrial IoT. So, as I told you at the outset that Industrial IoT is about the use of Internet of Things for serving different industrial applications. So, industrial applications could be many such as manufacturing, agriculture, and healthcare.

And so, basically IoT for industrial applications is what IIoT talks about and the overall idea is to use this IIoT for increasing or enhancing the working condition in the industries such as the safety, safety of the workers in the industry, the ergonomic conditions in the industry and so, on safety ergonomic issues and. So, on increasing the machine life, optimizing the operational efficiency, and many others. There are many different uses of Industrial IoT.

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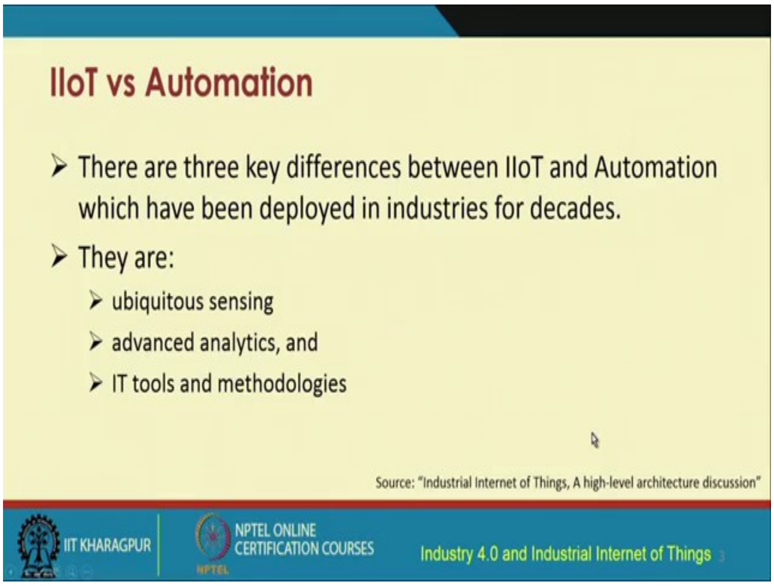


So, IIoT and its primitive have been there before as well and in this new context that IIoT become more interesting. IIoT is primitive is that automation that has been there since long in the industry, since decades, it has been there industries have been using automation, since long. These are the key differences between IIoT and Automation. These differences are with respect to three different parameters with respect to sensing, with respect to analytics, and these IT tools and methodologies that are being used.

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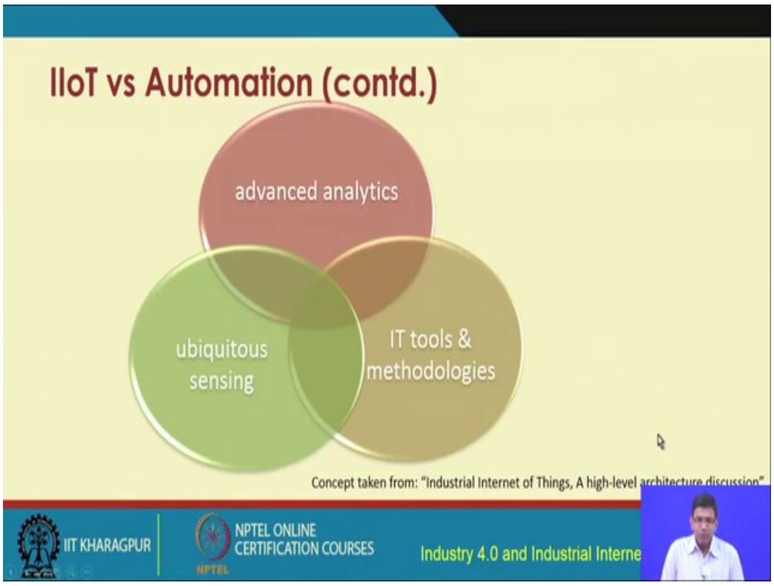

So, let us take up one by one each of these. So, these differences with respect to sensing analytics and methodologies are with they have their own different facets.

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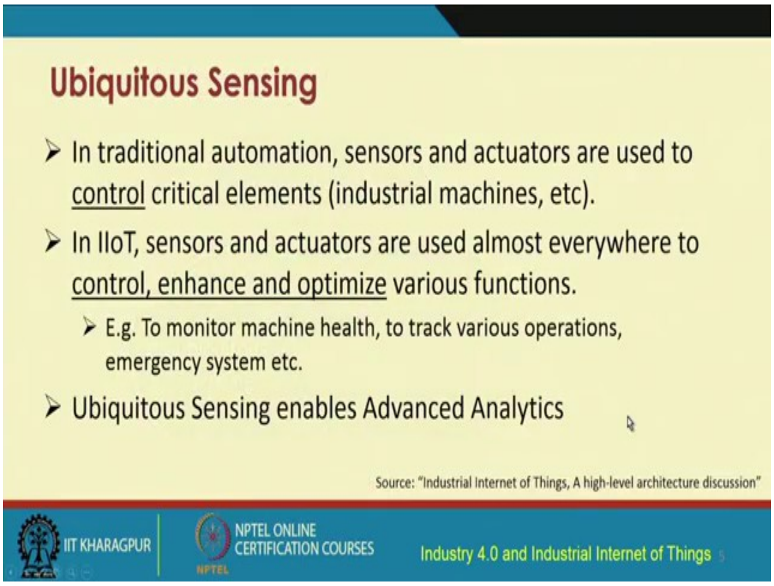


So, let us start with the ubiquitous sensing first. So, in traditional automation before IIoT became popular, sensors and actuators have been used to monitor the condition of the machines these have been there and it is not new. Different sensors are used to monitor the critical elements such as whether a particular component of a machine is functioning properly or not.

And if it is not or even if it is to actuate certain other components and that has been there it is not new, then in IIoT sensors and actuators have been also used everywhere to control, enhance, and optimize various functions. Those things have been there since long, but what has been what has come up to be new is to be able to monitor the condition of different machines at the same time and having each of these machines share the data between themselves and to some central point is something that is newer. So, this whole packaging is new.

So, this ubiquitous sensing is useless basically in the IIoT context, if we are not taking advantage of the data and running some advanced analytics on top.

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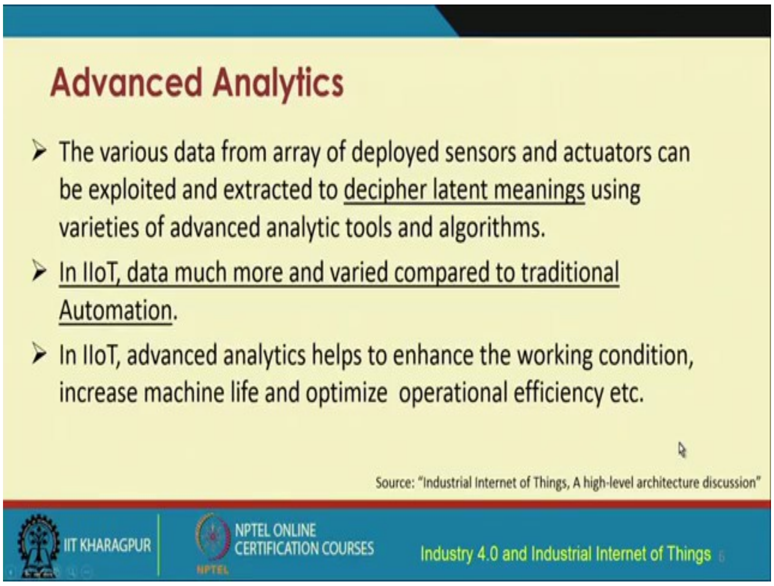


Now, with respect to analytics in a standalone fashion have been there, but in the context of IIoT, we are talking about, a large volume of data coming from different machines in the same industry and different other industries and locations. And then getting a holistic view of it and all these things are possible due to this connectivity issue, that I told you the earlier.

So, because of this connectivity between these different machines, different locations. This volume of data and running different analytics intelligently to decipher the latent meaning of these different activities that are being carried on and the condition of these different machines, that are operating in the industry, this is possible now.

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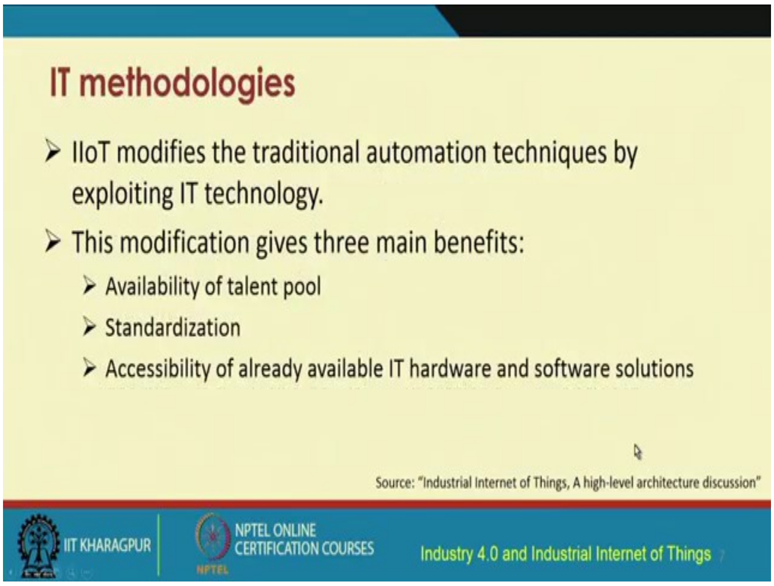


With respect to these IT methodologies, automation is solely dependent on IT and this has been there again since long. IIoT basically modifies the traditional automation techniques by exploiting the IT technology and particularly with respect to the networking aspect, the communication and networking.

This modification gives three main benefits availability of talent pool, standardization, and accessibility of already available IT hardware and software solution in all these industries, and as I told you these IT hardware and software has been there since long and we are not talking about anything new now, but this connectivity is new.

Connectivity issue and scaling up earlier everything was die being done individually in these machines in a standalone fashion now we are talking about this overall networked, networking among these machines, among these IT infrastructure, with the help of packaging, with sensors, actuators and that is what has become the newer concept in the context of a IIoT and it is automation, the traditional automation plus network, sensing actuation, and decision making and I would define IIoT to be this way.

IIoT is the traditional automation with the help of standalone computers, computing devices and plus added to that sensing, actuation, and decision making, in a connected manner.

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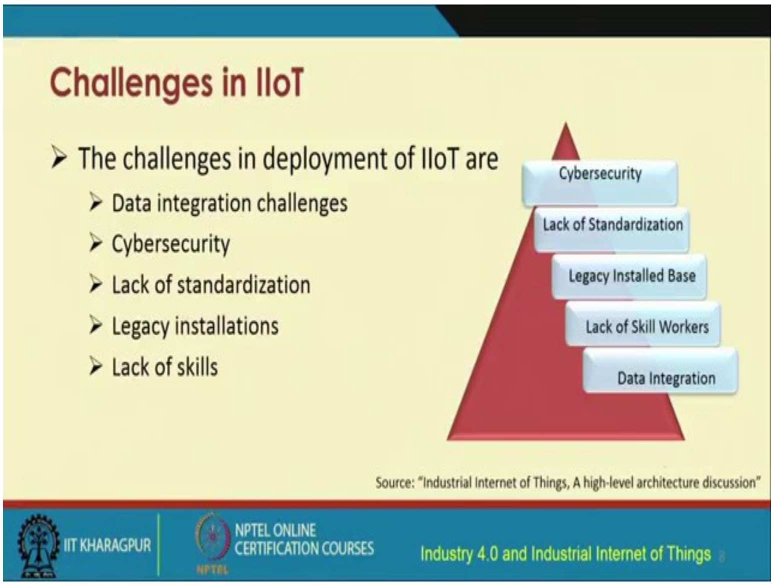


So, there are different challenges in the deployment of IIoT. There are data integration challenges. So, we are talking about large number of machines. These different machines have their own heterogeneity in place, heterogeneous data and integration of these varied types of data coming in high volumes and large different types of varieties.

These the integration of such data is a huge challenge, in the IIoT context, and this was not there earlier when the traditional automation was there in the industrial plants. Cyber security we have talked about it earlier in the context of Industry 4.0. So, cyber security is very important because now we are talking about a very connected world, where a world where different machines are connected between themselves and machines to people, machines to humans, humans to humans, and so on.

So, much of connectivity is there that it is quite likely that we are going to introduce some vulnerabilities in the overall network and making it possible for different types of attacks, newer types of attacks to be launched. The third one is lack of standardization in IoT, in IIoT, and so on. There are no there is no single standard that governs IIoT that governs IoT, there is no single standard. There is lack of standard. There are some standardization efforts disparate wants that are going on globally, but there is no single standard.

So, this basically is also a huge challenge in the context of IIoT. The next one is legacy installations when we talk about industries. Industries have huge legacy machine base and these machines have been operating successfully since decades, now with the incorporation of IIoT what is going to happen is you have to have support for these newer technologies and newer machines being procured, with the installed new technologies supporting IIoT and also having that integrate with the legacy installations.

And the last challenge is basically, the lack of skills, this is a new technology, holistically all the bits and pieces have been there, and we still do not have enough skilled manpower in these different industries, who want to adopt this new technology of IIoT.

So, because of this lack of skilled manpower, there are different problems that are possible. It is possible that without the lack of skills, vulnerabilities might be put in into the system, and which might attract different attackers who can launch different attacks and cause harm to the overall system thereby resulting in loss to the business, who adopted this IIoT technology.

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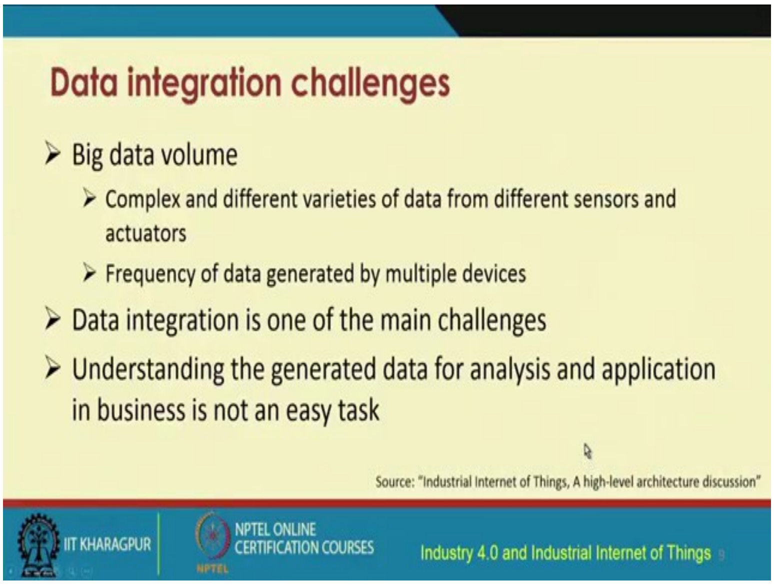


There are data integration challenges with respect to the volume of data, that is coming in, we are talking about the complexity of the data, the variety of data, that is coming in, a huge volume, in large velocities continuously these data coming from these different sensors and actuators. So, to manage this data, to analyze this data is a very herculean task. So, that is why this adoption of IIoT is also very non-trivial.

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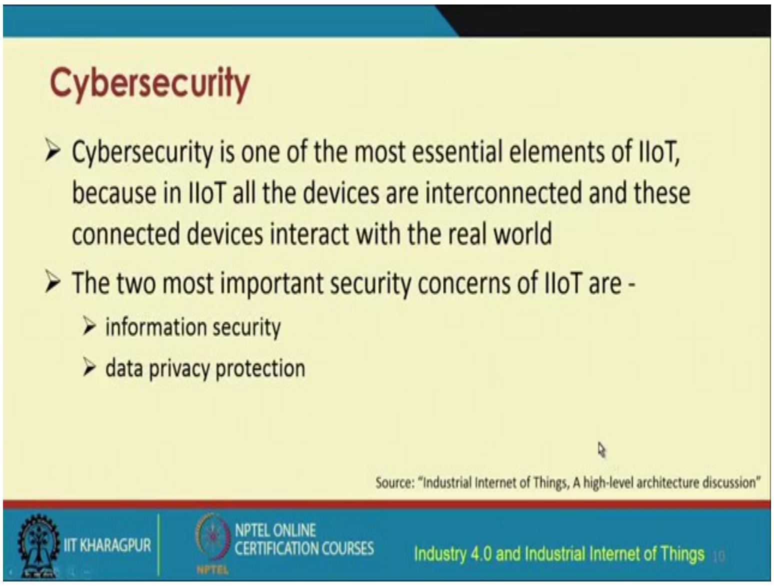


Cybersecurity is something that I have already told you, we are talking about a well connected internet worked world of different devices, machines working in the industry and once we have set up this network, it is quite possible that we will introduce different security issues. Issues of vulnerability, introducing different security issues and attracting different types of attackers, this is quite possible, and the other very related issue to the cyber security or information security or system secure, is the privacy issue.

So, here we are talking about collecting lot of data autonomously from these different machines. So, it is quite possible that one would be concerned about the privacy of the individuals working in these different factories. The privacy of the data that is collected from these individual machines autonomously. So, the privacy of the machines, individuals working in the industry, this also becomes a very important concern along with information and system security.

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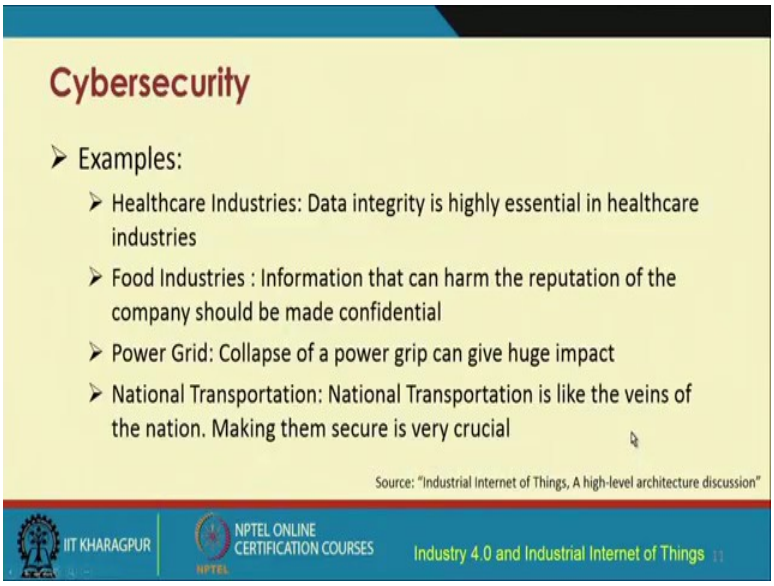


So, for example, in the healthcare industry data integrity is highly essential.

So, nobody should be able to tamper with the data, actual patient data, that is being collected. So, obviously, in healthcare industry from this particular viewpoint security is very important. In food industries also if somebody plays around with the data that kind of attack can harm the reputation of the company and that kind of data should be made secured, should be made confidential. In the power sector like power grids. It is very easy for one to have a grip of the power system and cause a huge impact like having a launching some kind of attack which is going to bring the system down and having a large downtime.

So, these kinds of attacks are possible. Similarly, in transportation as well transportation typically highway transportation is sort of the vein of any nation. So, securing this turns into the IIoT infrastructure in this transportation domain is also very crucial.

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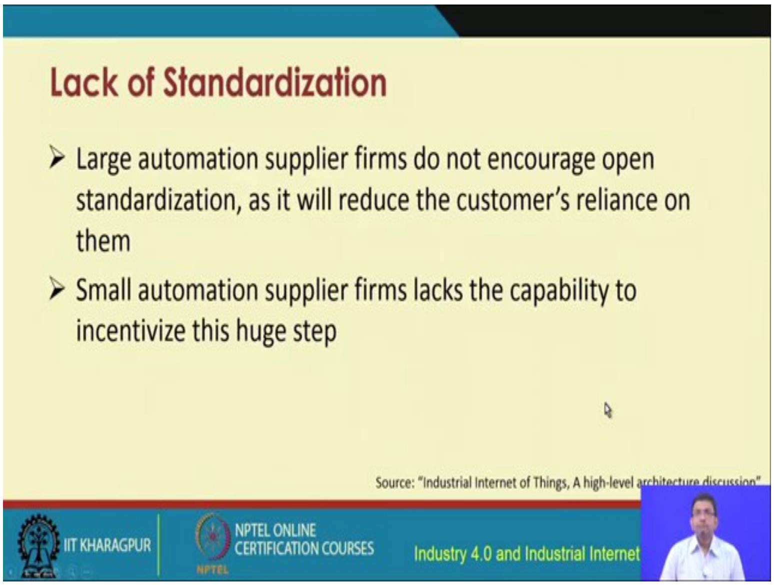


So, there is lack of standardization, as I was telling you earlier. So, the large automation suppliers firms do not encourage open standardization.

So, they will need they would encourage to have their own different, customized solutions and that also has an age in terms of business profits and so on. And this whole issue of standardization will reduce the customers reliance on these different equipments that are collected. So, small automation supplier firms basically lack the capability to incentivize this huge step.

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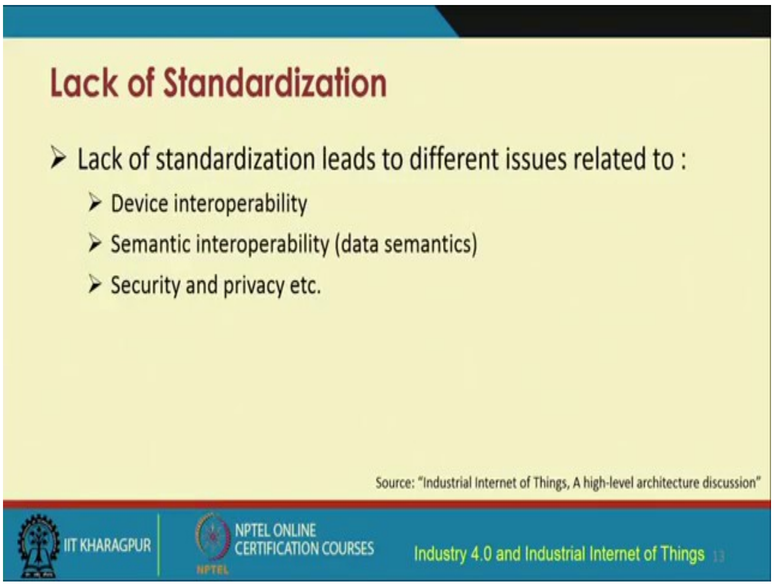

Lack of standardization leads to different issues related to device interoperability, semantic interoperability, device interoperability is understood. So, different machines supporting different IoT devices they need to talk to each other all and they have been made by different vendors.

So, device level interoperability is understood, but what is the semantic interoperability that we are talking about. Semantics means, meaning. So, these different devices talking different languages they should be able to talk to each other meaningfully, they should be able to understand what they are talking about. So, that is the semantic interoperability and; security and privacy issues and the standardization concerns are also very important, in this context.

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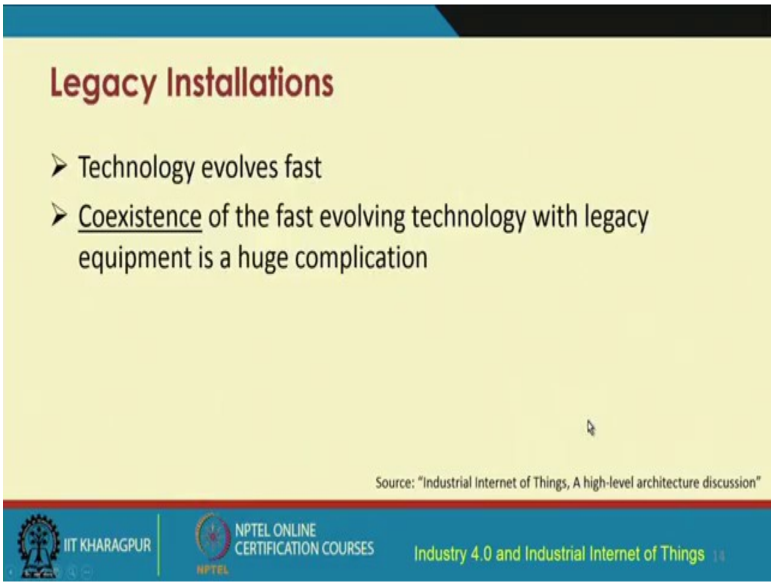


Legacy installations are a very crucial aspect to be considered. Technology is evolving fast, there are technologies in the industries that have been therefore, decades there are certain technologies that have there are more advanced than those legacy wants and there are some very new technologies that are adopted.

So, all these technologies should be adopted, the newer ones with that legacy ones should be all integrated together leave it without leaving any kind of vulnerability in the whole integrated system.

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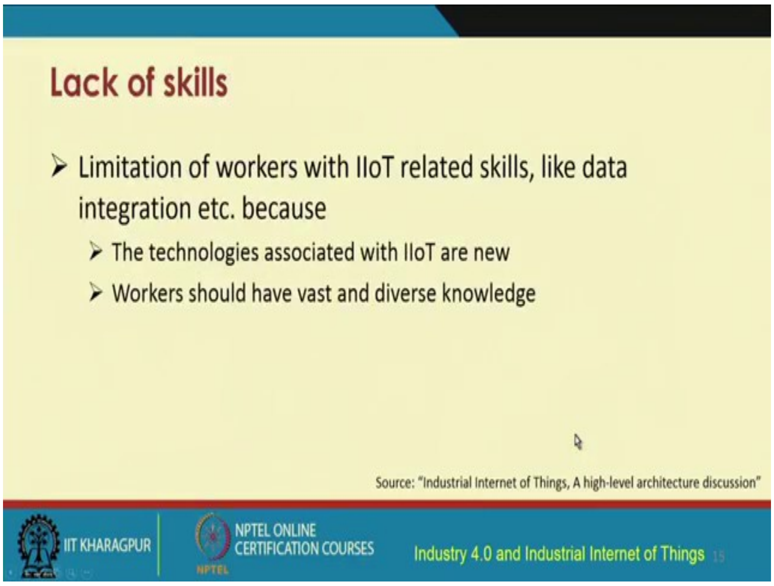


Lack of skills about a world of IIoT, it is a new technology. So, new technology means we have limitation of workers with IIoT related skills like data integration etcetera because these technologies are associated with IIoT and these new associated technologies these technologies are new in nature.

So, workers should have fast and diverse knowledge about these technologies.

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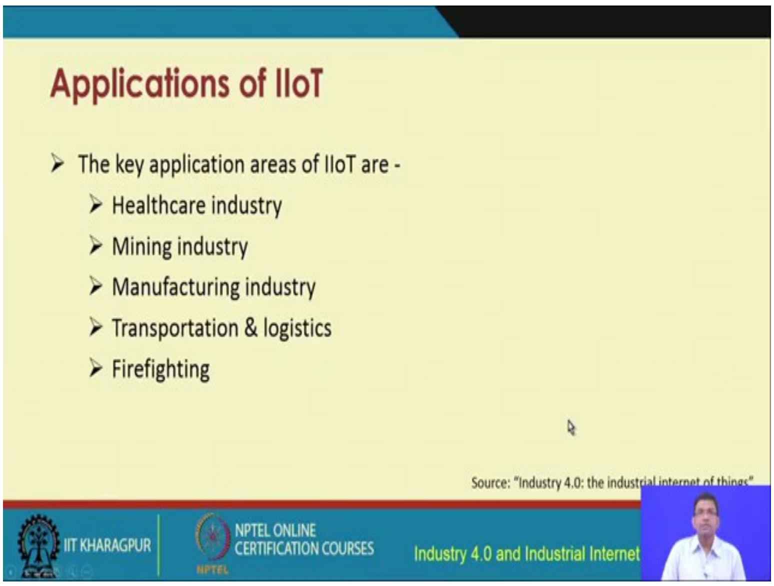

So, earlier at the very outset about the different applications of IIoT are in the healthcare industry, mining industry, manufacturing industry, transportation and logistics, firefighting, sewerage, smart cities and so on.

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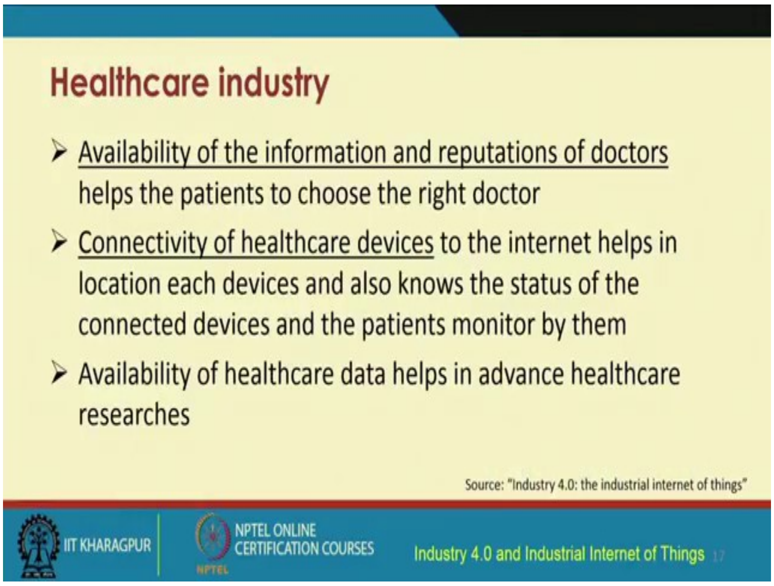


So, in the health care industry availability of the information and repetition of doctors helps the patients to choose the right doctor. Connectivity of healthcare devices to the internet will basically help you in doing it and this is what we had seen in a very small scale and application of IIoT in the healthcare industry.

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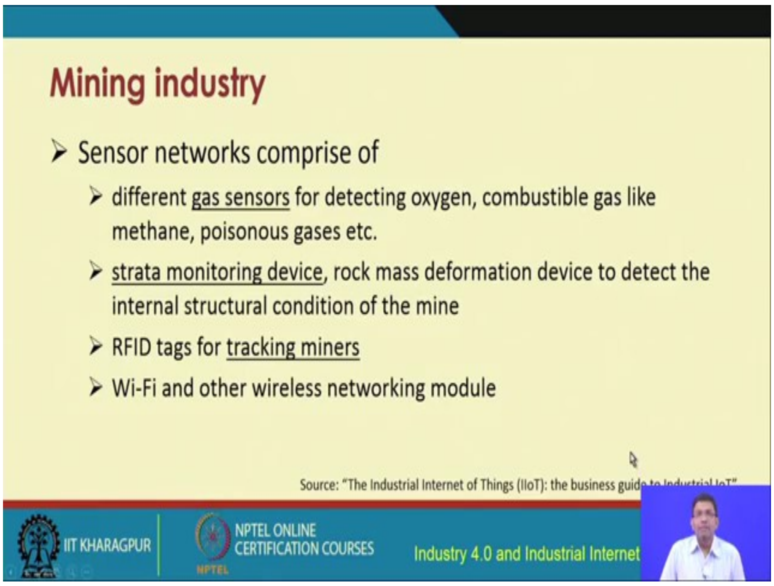

So, at the very outset I had given you the example of this temperature sensor and pulse oximeter sensor being used and through a connected network this data is sent to the control center for further evaluation, monitoring, and so on.

So, that is basically a very rudimentary form of application of IIoT in the healthcare industry. The mining industry also gas monitoring and the example that I had shown you at the very beginning gas monitoring in coal mines monitoring the level of what the concentration of poisonous gases like methane and carbon monoxide. So, this can be possible with the help of a IIoT-based technologies.

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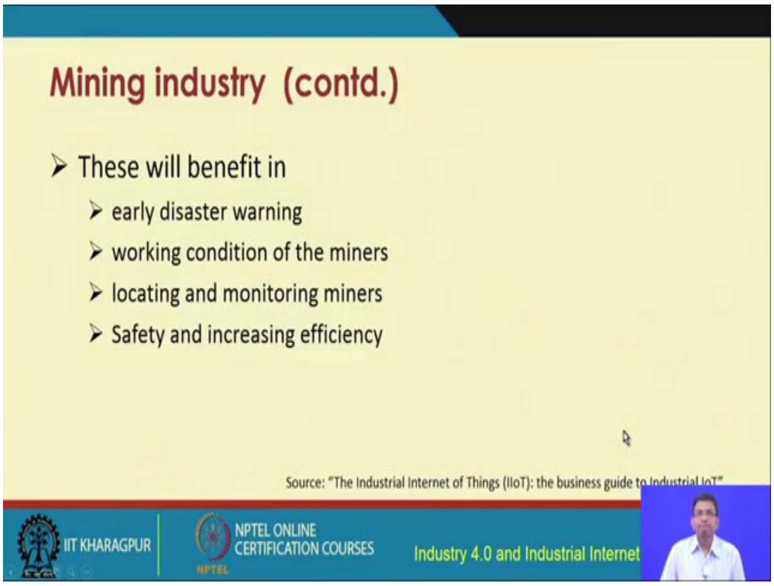


So, the adoption of IIoT technologies in the mining industry we will benefit in terms of having early with disaster warning, working condition of the miners can be monitored in real time continuously, and so on.

Locating and monitoring the miners during normal times and during emergency situations let us say if there is a mine fire locating and monitoring the miners is a very important problem and IIoT can help in doing. So, in an efficient manner safety and increasing efficiency in the mining industry is another benefit that will come out from the adoption of IIoT.

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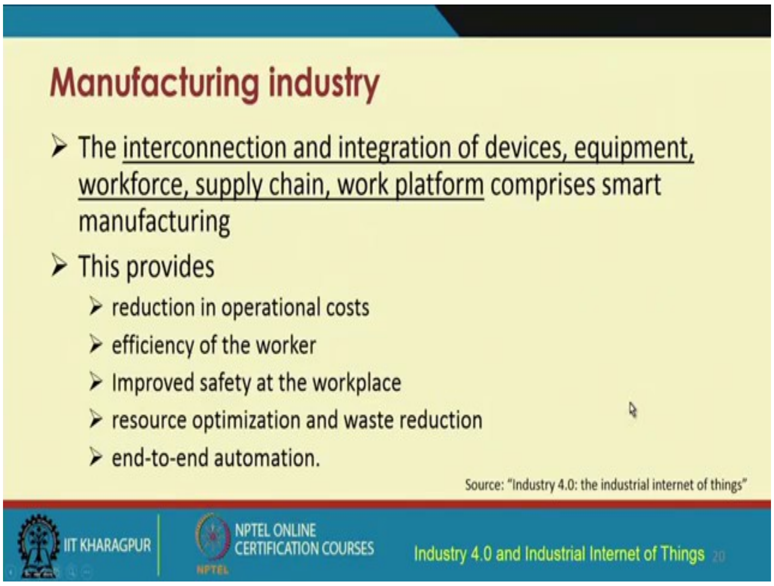


In the manufacturing industry, an interconnection and integration of different devices, different machines, equipments, workforce, supply chain, work platform.

So, together the integration of all of these things would make a smart manufacturing platform that will provide reduction in operational costs, efficiency of the workers can be improved, improved safety at the workplace, resource optimization, waste reduction in the industries, and end-to-end automation, these are all the different benefits of interconnection and integration of all these devices in IIoT, in the manufacturing industry.

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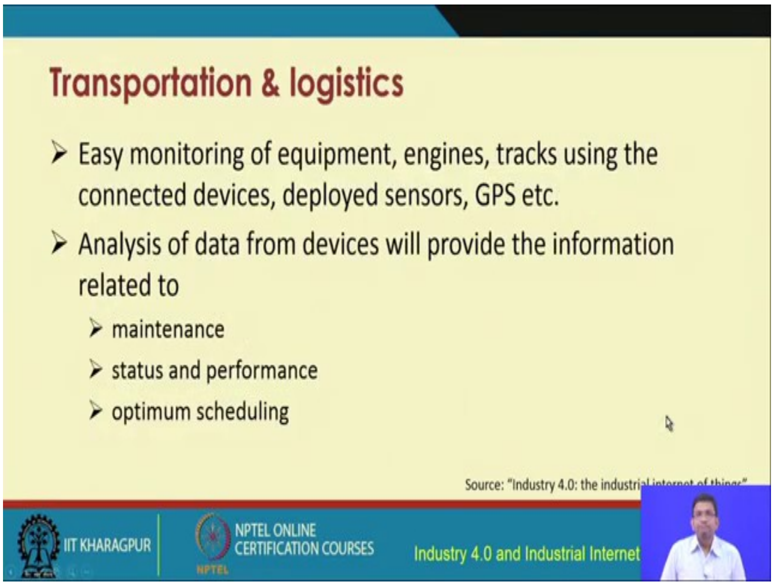


Transportation and logistics likewise it is possible to easily monitor the equipments, engines, tracking using the connected devices, deployed sensors, gps. So, this kind of tracking devices, tracking sensors and can be used to track for example, where the different trucks are in a particular logistic application. The trucks that are there on the highway at which position these different trucks are how much time they are resting on the highway and whether they are having adequate sleep or not their drivers of these different vehicles whether they are having adequate sleep or not and whether the condition of these trucks.

This is a just an example that, the condition of the trucks whether these conditions are good enough for carrying on further or there is some kind of maintenance activity that will need to be carried on, like this is the scheduling optimum, scheduling of these different vehicles could also be performed with the help of IIoT technologies.

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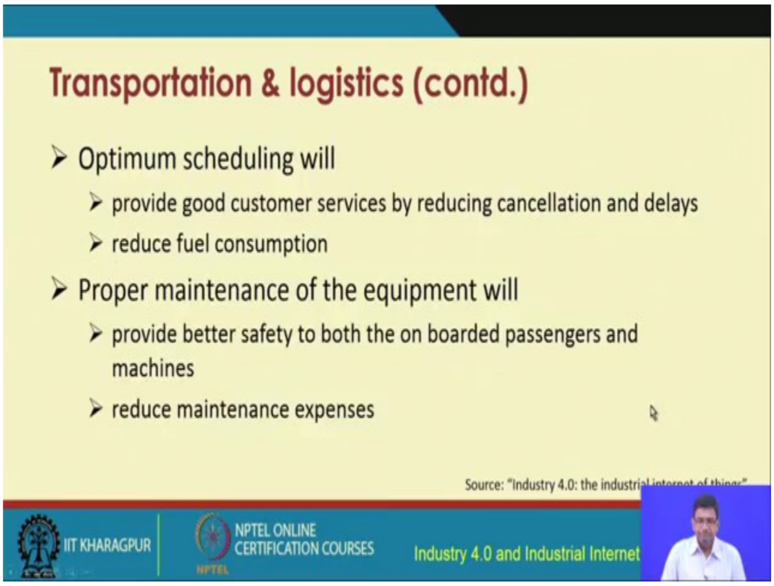


So, optimum scheduling we will provide good customer services by reducing cancellations and delays and reduce overall fuel consumption. So, proper maintenance of the equipment, we will provide improved safety to both the onboard passengers and the machines and thereby reducing the maintenance expenses.

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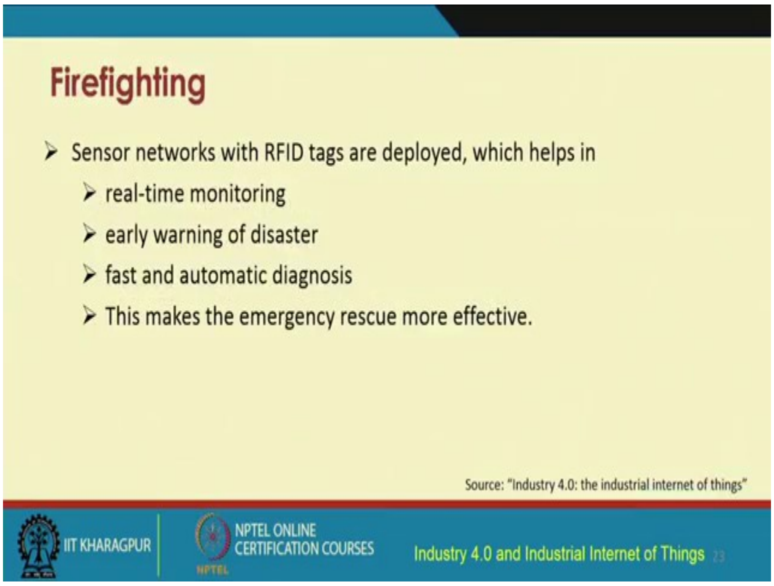


Firefighting also attracts lot of use of different IIoT technologies sensor networks. With RFID tags, real-time monitoring of fires in the industrial workspace or even in different other areas such as different buildings, in homes and so on, and early warning of different incoming deserters can also be possible. With the help of the use of IIoT in the firefighting application domain.

The last thing is the automatic and fast diagnosis of these different faults, that can happen, can also be performed efficiently and promptly, with the help of the use of IIoT technologies.

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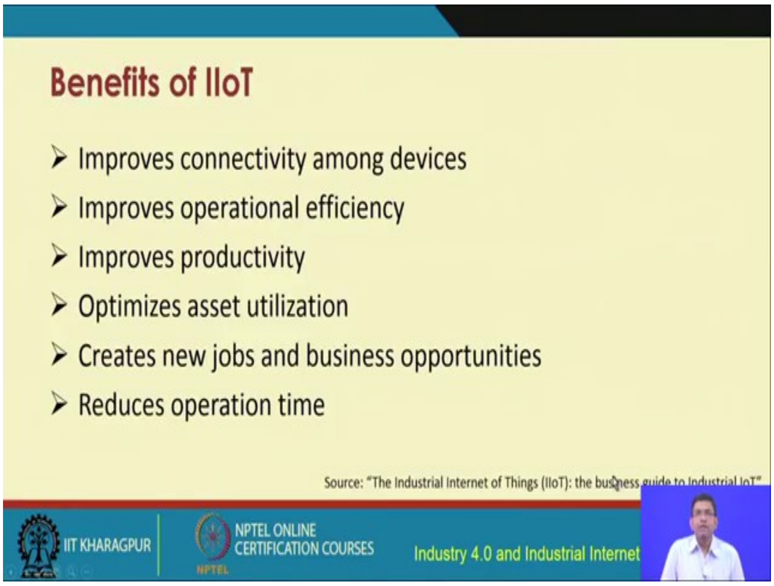


So, these are different benefits of IIoT improving connectivity among devices, improving operational efficiency, improving productivity, optimizing asset utilization, creating new jobs and business opportunities, and reducing operation time, these are the different benefits of the adoption of IIoT technologies in the industry.

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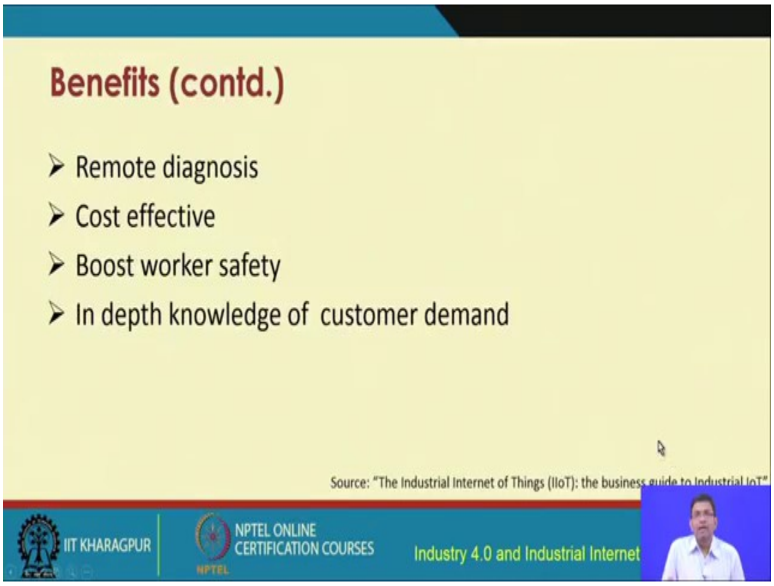


So, there are different other benefits as well remote diagnosis then remote diagnosis of what? Remote diagnosis of machines, cost effectiveness, boosting workers' safety and this is worker safety ergonomic issues. IIoT technologies have found lot of applications there are new number of different projects that are running on worldwide to improve IIoT to improve worker safety in the industries, with the adoption of these different IIoT technologies.

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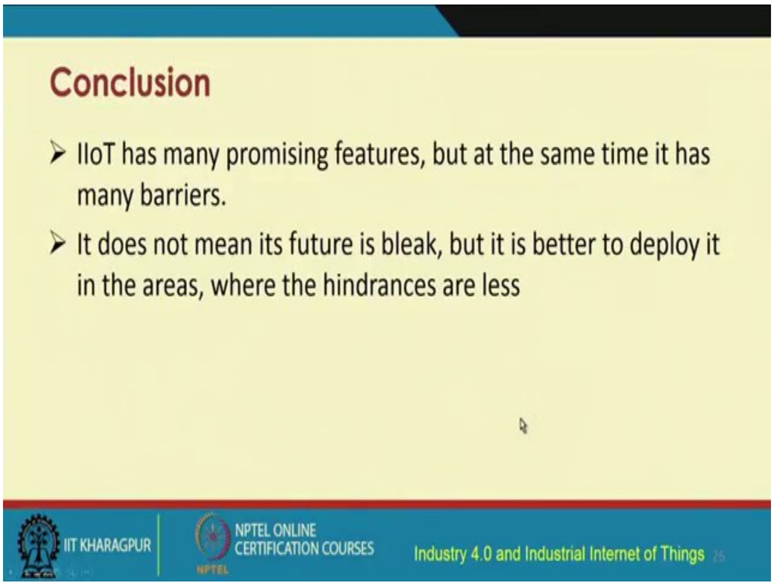

So, to conclude IIoT is a very promising technology, which has different attractive features, but at the same time there are many barriers that will have to be crossed, and it does not mean in the future. These barriers are many different challenges to be overcome. It does not mean that the future of IIoT. In fact, the adoption of IIoT is increasing day by day continuously in all industries in India and throughout the world.

And so, basically it is gradually, every day the adoption of IIoT technologies is increasing and it is quite expected that in the future it is going to increase even further and we would be able to see a very well connected world, where different industries are connected, advanced analytics are being carried on to get to mind in lot of data to get lot of insight about the different aspects, that these different industries are addressing.

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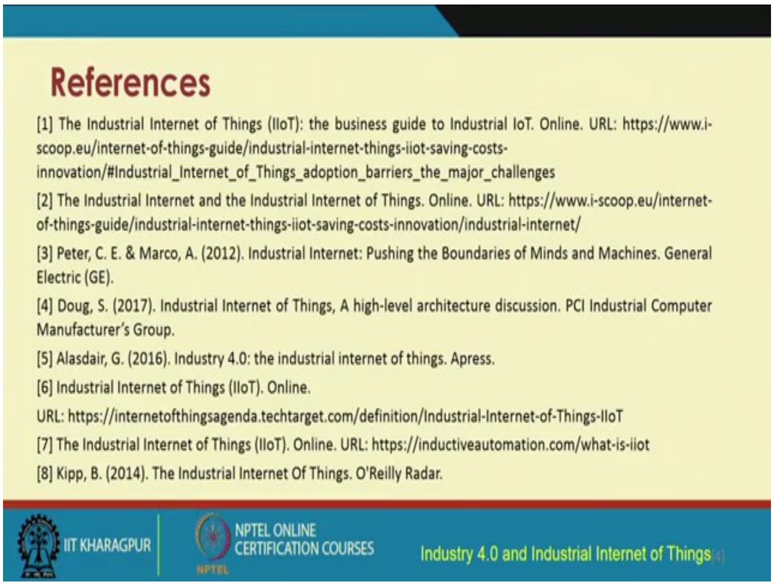


So, these are some of these references for you to go through if you are interested to dig further into these basic issues and with this we come to an end.

Thank you.

**Introduction to Industry 4.0 and Industrial Internet of Things**
**Prof. Sudip Misra**
**Department of Computer Science and Engineering**
**Indian Institutes of Technology, Kharagpur**

**Lecture – 18**
**Basics of Industrial IOT: Industrial Internet Systems**

In this lecture, we will go through some of the basics of Industrial Internet Systems. So, industrial internet systems is something, that has also become very popular, in the recent years, along with Industrial IoT. So, basically these two efforts although are quite similar in nature their origin is bit different.

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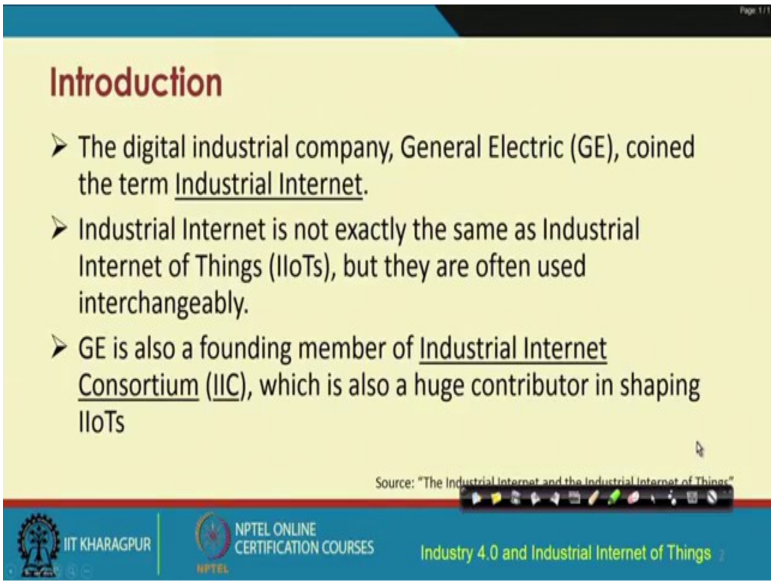


So, industrial internet the origin is basically linked to the digital industrial company, General Electric, who coined this term industrial internet. And it is not exactly like the industrial IoT that we discussed in the previous lecture, but is often commonly used interchangeably by people in the industries.

So, General Electric along with few other members founded the industrial internet consortium IIC and this consortium is the body, which is largely the main player for shaping up this industrial internet for the future.

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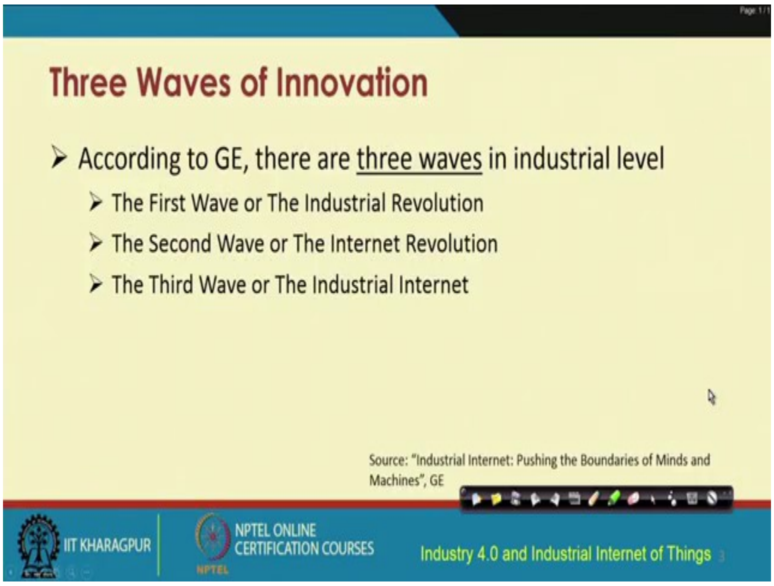


There are three waves of innovation that have gone through in the industrial level. The first wave was the industrial revolution, in the second wave was the internet revolution. And the third wave, in the industries is this industrial internet and this is as per the company general electric, this is how they have visualized the revolution in the industrial sector over the last large number of years that industries have passed through.

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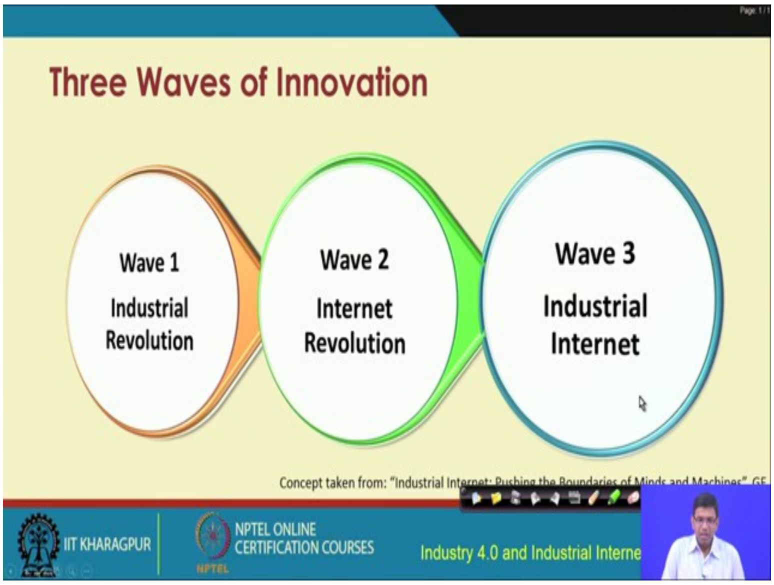


These are basically pictorially shown over here, wave one was the industrial revolution, wave two is the internet revolution, and wave three is the industrial internet.

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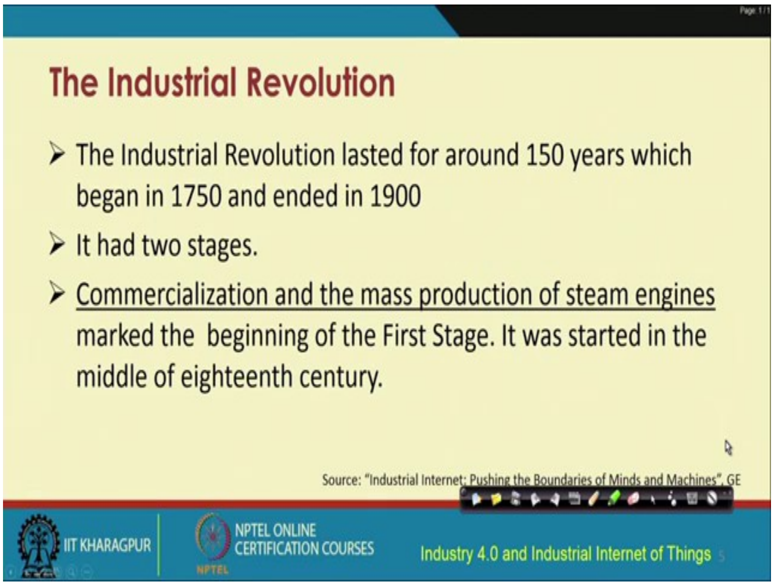


So, the industrial revolution happened more than 150 years back, in the 1970s it started, and ended in the early 1900. So, that was the industrial revolution. It had two stages--the first stage was the commercialization and the mass production of steam engines. So, that was the first stage and that started in the middle of the 18th century.

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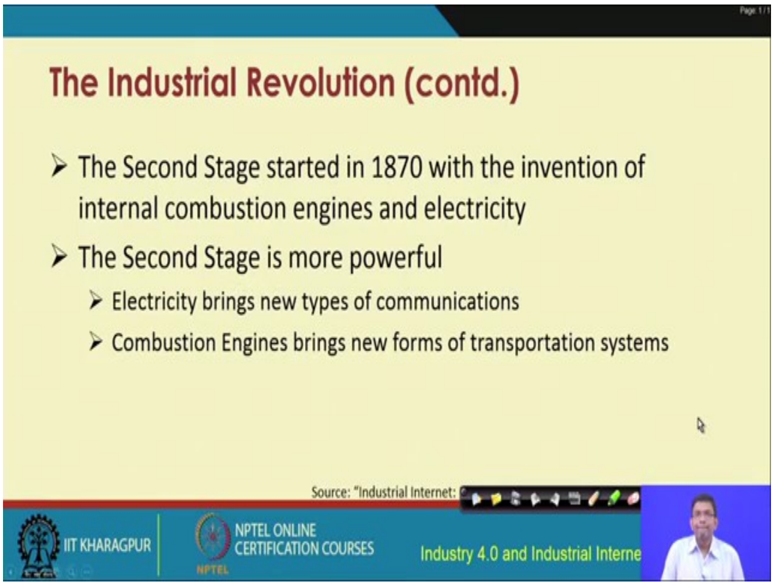


In the second stage, basically started in 1870, and with the invention of the IC engines, the internal combustion engines and electricity.

So, the starting of the invention of IC engines, basically led to lot of development in the transportation sector. So, basically all these different engines the petrol engines, the diesel engines, that these different vehicles use are a result of the invention of these IC engines. Electricity also bring brought in lot of different types of advancements; advancements in terms of different types of communications, communication between different people communication, between different machines, and between machine and people. So, all these different things have been possible with the help of the advent of electricity.

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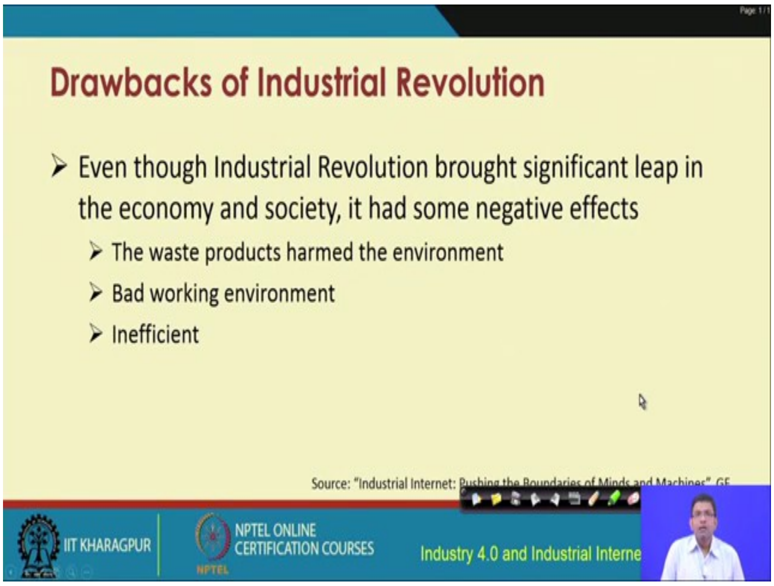


The drawbacks of industrial revolution was that even though industrial revolution was a significant leap in the growth of economy, in the growth of society, and so, on there were different negative aspects. Negative aspects for example, the increase in industrialization, increased the amount of waste products in the society, and these have lot of adverse effects on the environment. Second adverse or, negative effect of industrial revolution was the increase in the bad working environment of the workers. Third is the inefficiency.

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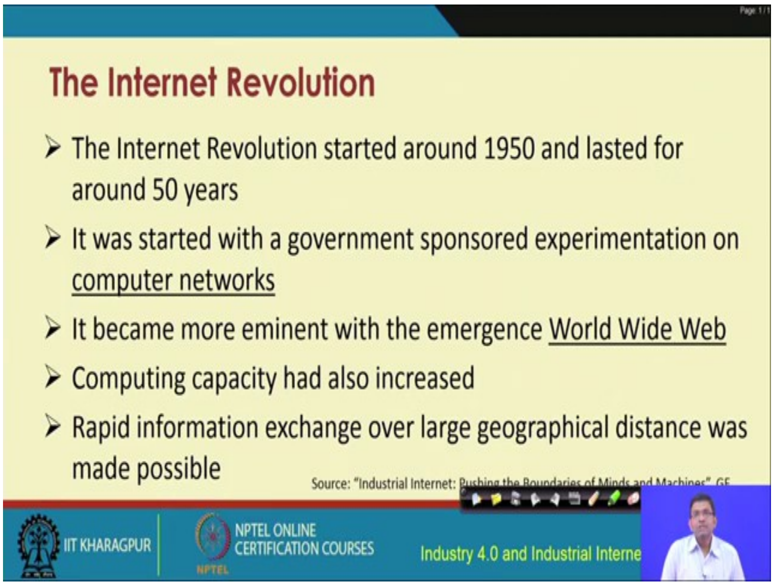


So, these are the different drawbacks of industrial revolution, the industrial revolution was followed by the internet revolution, which started around the nineteen 50s and continued for more than 50 years. So, this internet revolution started with a government sponsored project to build a network of different computers, but in the early days the computers used to be very big in size, these computers were not portable. So, this government sponsored project enabled to prove the concept that from one computer, it is possible to send data to another computer. Now, the question is that how we can use it for increasing the productivity in the industries.

So, basically what we are think I mean what has happened is these different machinery in the industries would be connected to different computers and through this connectivity, what it would be possible is to monitor the condition of these machines in a much more efficient manner than before. So, this computer networks the concept was proven, then came the emergence of the world wide web, and now we can see that the world wide web is something, that is popularly used by everybody in the society and also in the industries particularly all industries have lot of use of internet lot of use of world wide web and so on.

So, computing capacity had also increased over the years, we have small sized computers that have the same power like the computers that were there several decades back. This computing capacity has increased and these computers have also became become portable. So, because of this portability the internet has also become very popular, everybody now owns a computer, these computers are very high performing than what is to exist several decades back, and also because these are portable now it is possible portable and cheap also these computers are very much cheap.

So, that is why the internet also became very popular and with the emergence of the World Wide Web, different internet-based or web-based applications have been developed for use in the different industrial sectors to improve the efficiency of the different industrial processes.

With the advent of the internet and the computer networks and so on, now it is possible to rapidly in to exchange information rapidly over large geographical distance and that was not possible earlier. So, now, it is possible that different industries would be connected to each other and they may not be geographically co-located. They might be geographically distant apart, but still they would be able to talk to each other.

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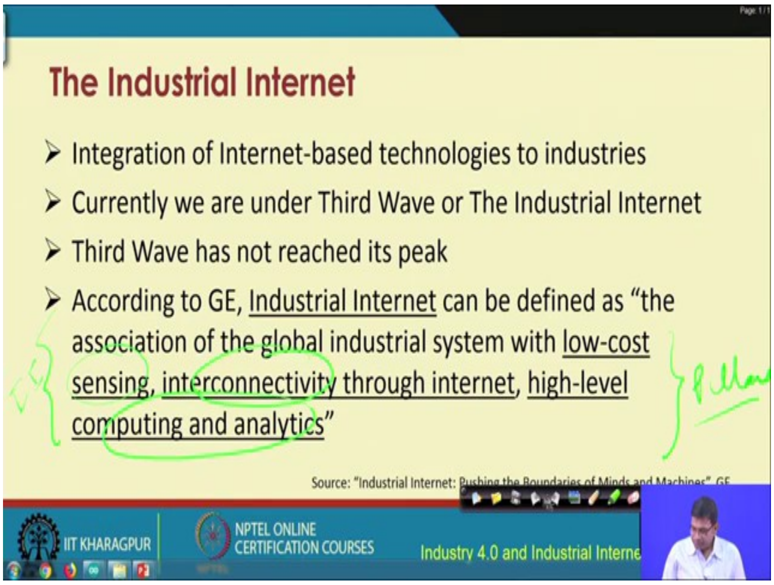


Then came the industrial internet and this is this new revolution that the world is currently going through, the industrial internet revolution, which is about integration of internet-based technologies to the internet to the industries. So, currently we are under the third wave or the industrial internet wave and it has not yet reached its peak.

According to GE, industrial internet can be defined as the association of the global industrial system, with low cost sensing, interconnectivity through internet, and high level computing, and analytics. So, as you can see over here we are talking about sensing, interconnectivity, and we are talking about computing and analytics. These are the three different pillars in the development and incorporation of industrial internet.

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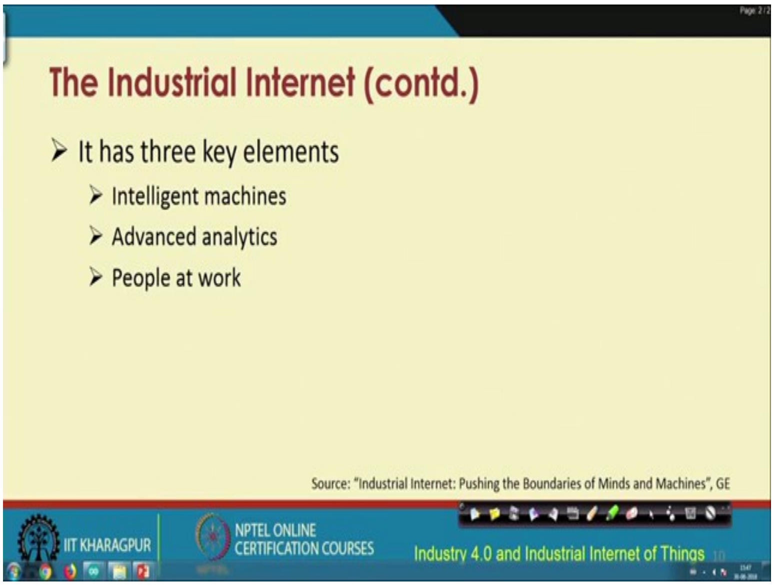


So, the industrial internet has three key elements, the first one is that intelligent machines. So, machines have been made much more intelligent, with the introduction of or integration of different computing elements into it. The second key element is advanced analytics, and the third one is we have people at work.

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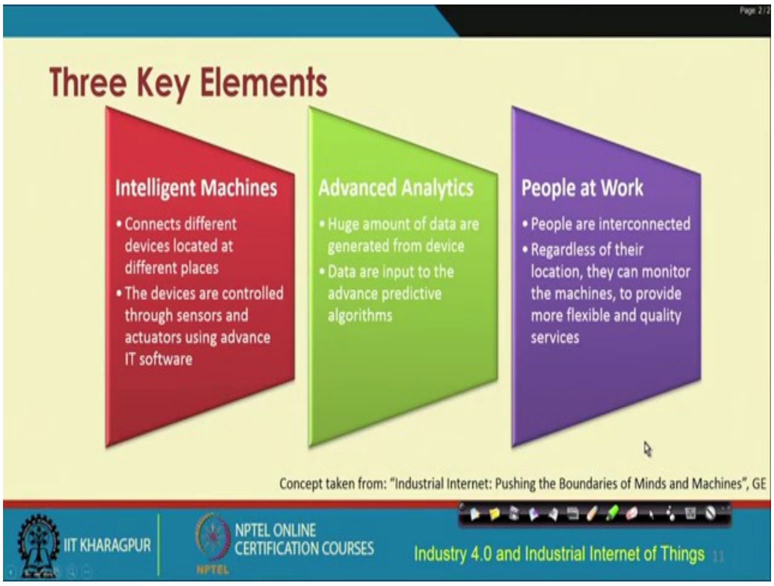


These are the three key elements intelligent machines that help connect different devices and different machines, which may not be co-located the devices are controlled through sensors actuators and using different other advanced IT hardware and software.

Advanced analytics here we are talking about handling huge amount of data, that are generated from these different devices the data are input to the advanced predictive algorithms, that are being proposed and many of these algorithms, have their base, have their origin in advanced statistics in advanced machine learning and artificial intelligence, people at work now it is possible that everybody is connected, interconnected with one another.

So, regardless of the location of where these different people are now it is possible that these different people, they can monitor the machines, which may not be located, where they are, but might be located distance apart, and it is now possible for people to monitor the condition of the machines to provide more flexibility and quality services to the industries. So, these are the three different key elements.

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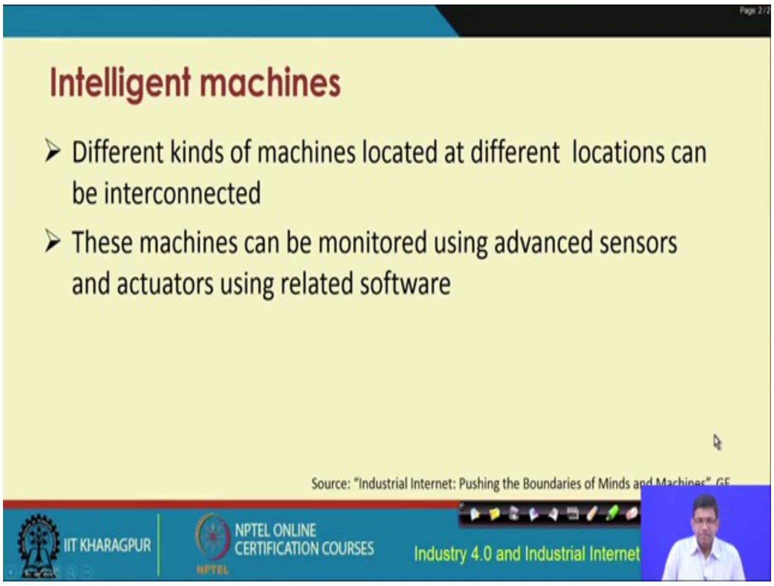


Intelligent machines, different kinds of machines, are located at different locations and they are interconnected, these machines can be monitored using advanced sensors and actuators and so, overall everything is connected using different software and hardware elements.

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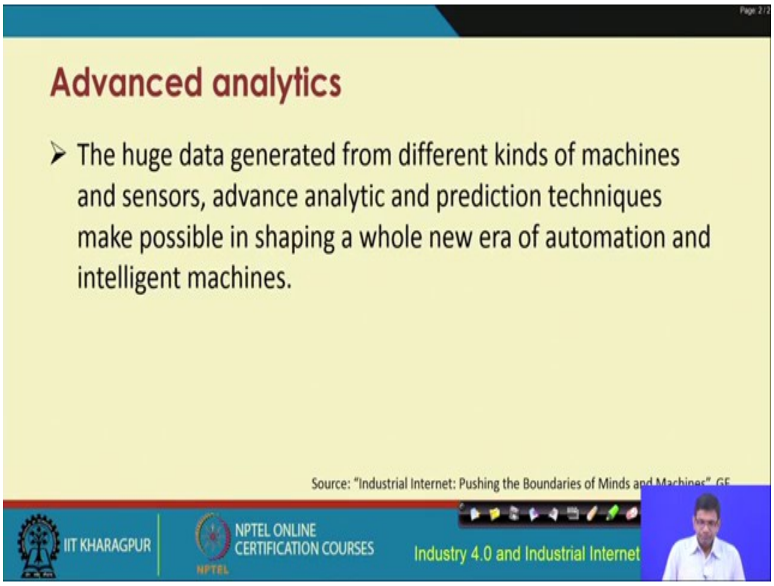


Advanced analytics, the huge data that are generated from different kinds of machines and sensors, these data can be analyzed with the help of advance statistical machine learning and AI techniques to make different predictions and, within with these predictions, basically, it is now possible to have intelligent machines being automated and this era of automation and intelligent machines that, we are talking about where advanced analytics can play a huge role.

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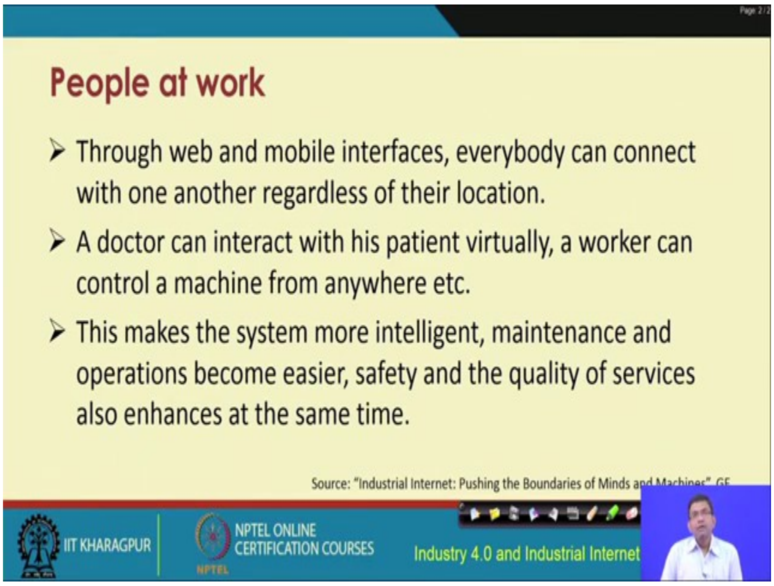


People at work. So, now it is possible through different collaborative platforms, such as web and mobile interface different people, they would be able to talk to one another they can remain connected to one another and irrespective of where they are located in the world they you can connect to one another.

So, basically a doctor can now interact with their patients virtually. A worker can control a machine from anywhere and, this makes the system much more intelligent and with the use of this technology, the industrial internet, it is possible to much more easily maintain and operate the different machines, and also to improve the overall workplace safety and quality of services that are offered by these different industries.

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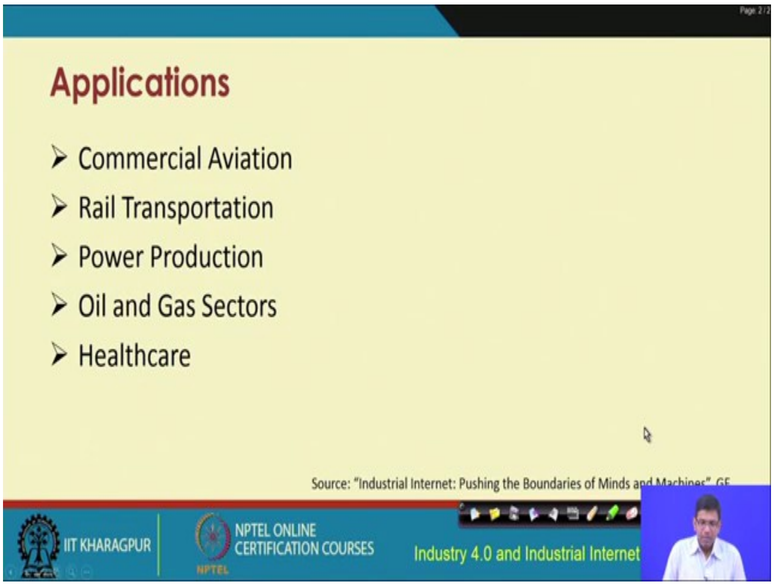


Different applications of the industrial internet commercial aviation, rail transportation, power production, oil and gas sectors, and healthcare.

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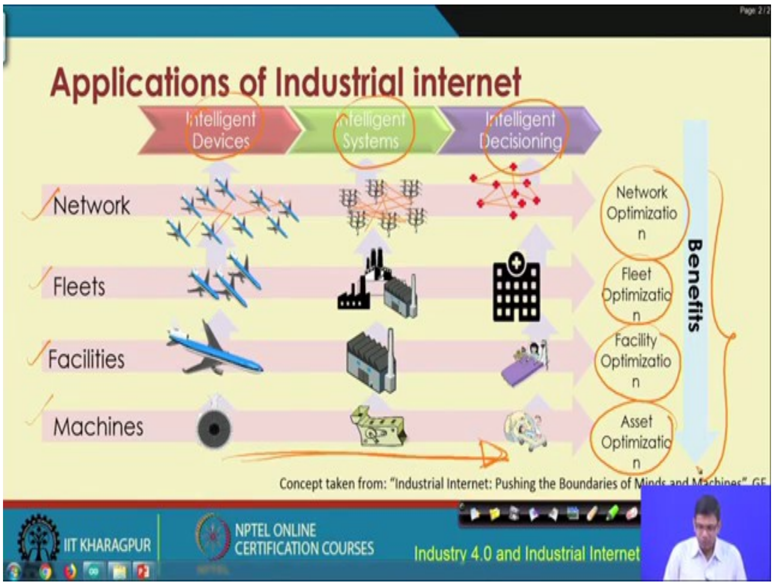


These are some of these different applications of the industrial internet.

We are talking about as you can see over here from machines. So, we are talking about machines, then facilities, fleet and network. So, and gradually as you can see over here we are moving to the world from regular intelligent machines to intelligent systems to ultimately intelligent decision making systems.

So, this is what and how we are gradually transforming ourselves. So, overall corresponding to this machines facilities fleet and network we are going to optimize at different levels, we are going to have asset optimization, facility optimization, fleet optimization, and network optimization and these are the different benefits of the use of industrial internet overall to improve, the industrial conditions, the industrial processes, the machinery, the monitoring, and the overall working condition, the safety of the different people, who are working in these different industries.

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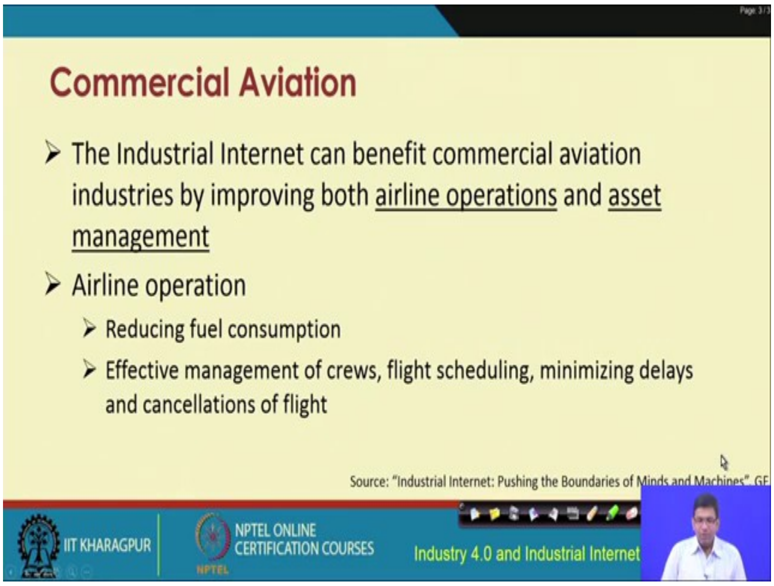


In terms of commercial aviation, the industrial internet, has benefited the commercial aviation industries by improving both airline operations and asset management. Now, in terms of airline operations, with the help of the industrial internet it is now possible, to reduce the overall fuel consumption, to effectively manage the crews, to schedule the flights effectively, minimize delays, and cancellations of different flights.

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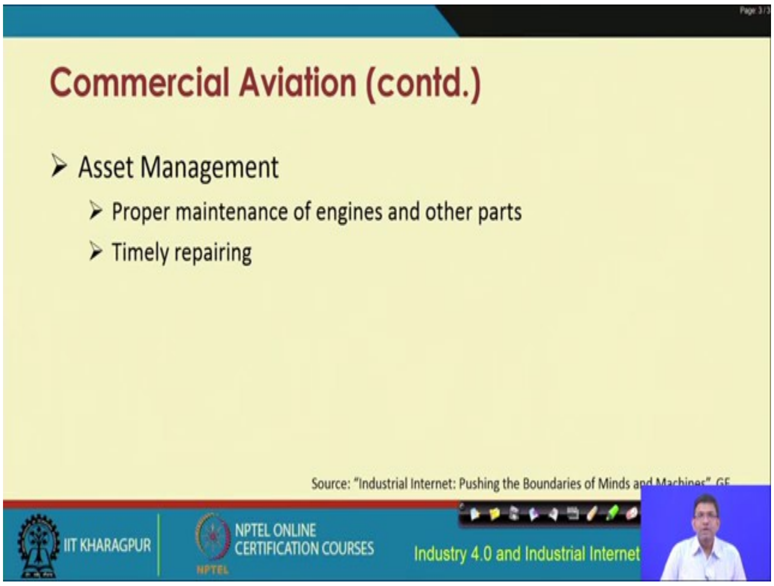


In terms of asset management, now it is possible to timely repair the different machines to properly maintain the engines and other parts of the different machinery.

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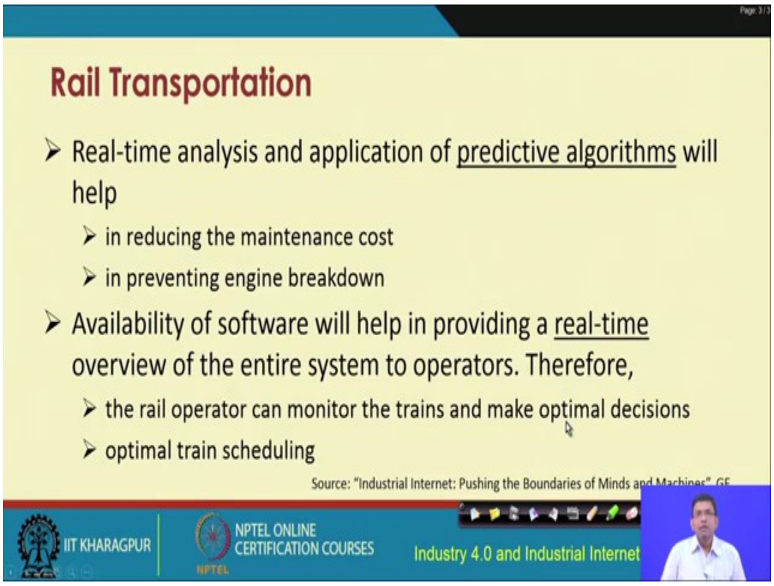


Rail transportation is now possible with the advent of the industrial internet to have real-time analytics and application of predictive algorithms. And that this will help in reducing the overall maintenance cost, and preventing different breakdown of different machinery parts, such as engines. Availability of software also helps in providing real time overview of the entire system to the operators.

So, with the help of software in a software can be developed to basically monitor the condition of the different machinery in real-time continuously. So, therefore, for example, the rail operator can maintain, and monitor the trains and their conditions, and make optimal decisions, it is also now possible to have optimal train scheduling with the use of different optimization techniques.

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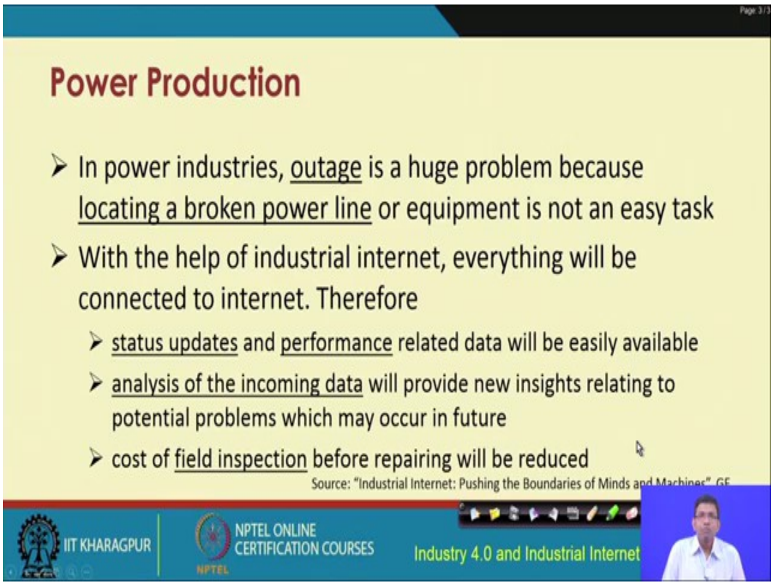


Power production in the power sector, as well power outage, is a huge problem and because of issue such as somewhere where the power cables are installed, the power line might be broken.

So, it is now important to locate the point where the power line is broken or where the equipment has gone down. So, with the help of the industrial internet, everything will be connected to the internet. And therefore, it is possible to get status updates and performance related data in real-time wherever this data can be made accessible. So, if it is through the internet, then, the data can be accessed from anywhere in the world. Analysis of the incoming data will provide new insights relating to potential problems which can occur in the future cost of field inspection before repairing will also get reduced with their option of the industrial internet.

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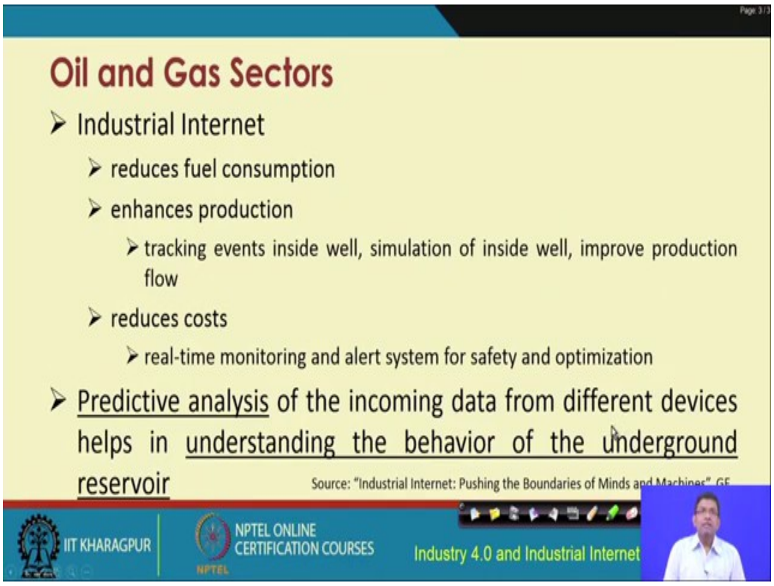


In the oil and gas sector the industrial internet can be used to reduce fuel consumption, enhancing productivity and reducing costs. So, different predictive analytics with the help of statistics machine learning artificial intelligence, as I said before can be used to analyze the incoming data from different devices and helping in improving the understanding of the behavior of the underground reservoir.

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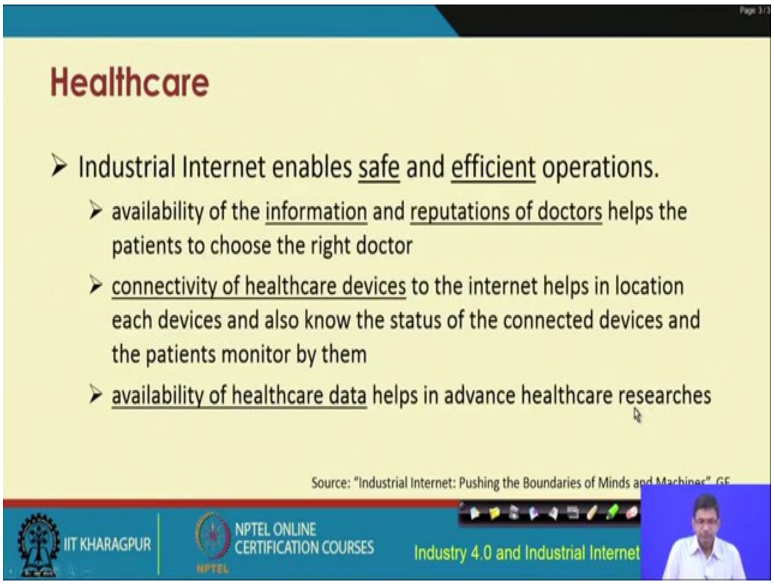


In the healthcare domain industrial internet enables safe and efficient operations, availability of the information, and reputation of different doctors, availabilities of stock of different medicines, availability of different healthcare machinery, and healthcare diagnostic platforms can help the patients to choose the right doctor, the right facility, the right hospital and in real-time.

So, the industrial internet revolution in the healthcare center is considered to be very crucial, connectivity of healthcare devices is also very important this connectivity basically helps, in what I was telling you earlier to send the data from one point to another. And it is now possible not only to send the data of different patients or whatever from one point to another, but also to help the patients to stay interconnected with one another to share the different information over this collaborative platform and so on. Availability of healthcare data also helps in advancing healthcare research.

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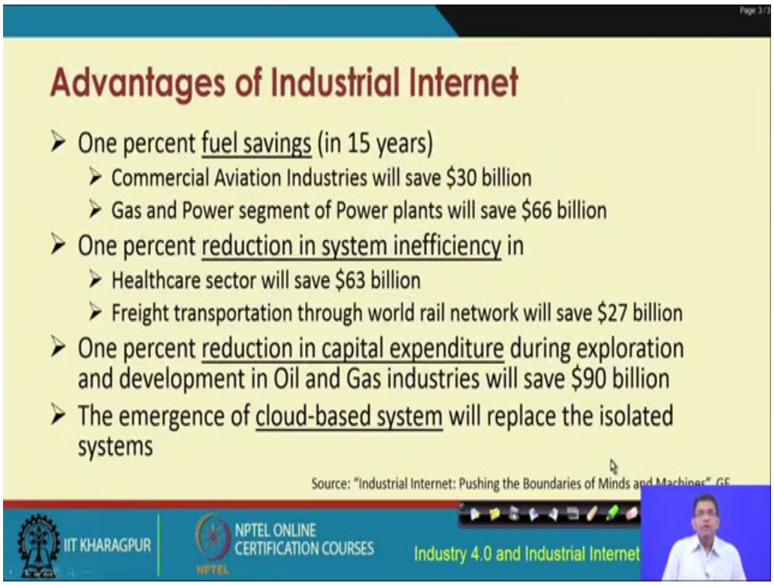


These are the different advantages of the industrial internet, with the adoption of industrial internet, it is now possible to save on fuel in, every 15 years. So, in every 15 years it is expected that the commercial aviation industries through the adoption of industrial internet, we will save over 30 billion dollars.

Gas and power segment of power plants will also save over 65 billion dollars 1 percent reduction in system inefficiency in healthcare center will save 63 billion dollars, freight transportation through world rail network will also save 27 billion dollars, one percent reduction in capital expenditure during exploration and development in oil and gas industries will save 90 billion dollars.

And the emergence of cloud based system will also improve upon what we have been able to achieve. So, far and this figures that we have seen so, far we would be able to improve even further by replacing the isolated systems with the help of cloud-based systems. So, cloud-based systems will help you to get access to the infrastructure that computing infrastructure, the software, hardware, whenever and wherever it is going to be required, in a much easier way, through the pay-per-use concept.

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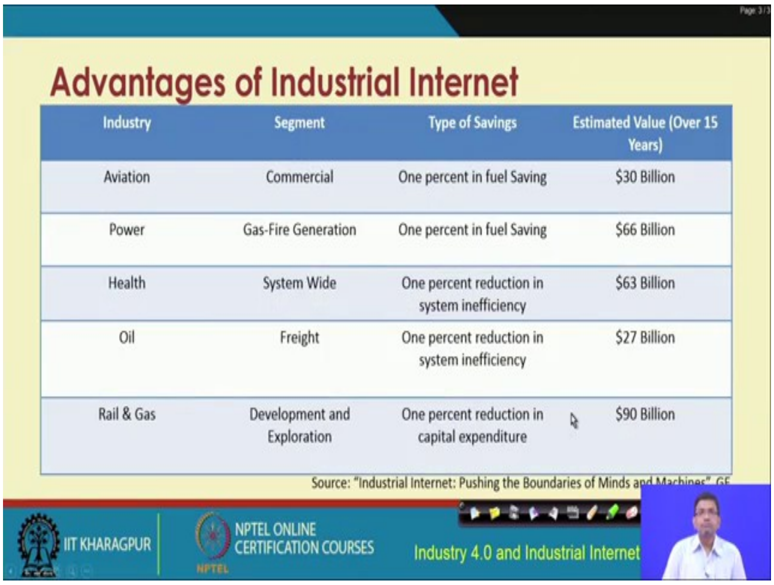


This is a summary of the advantages of the industrial internet, in different industrial domains aviation power health oil and rail and gas.

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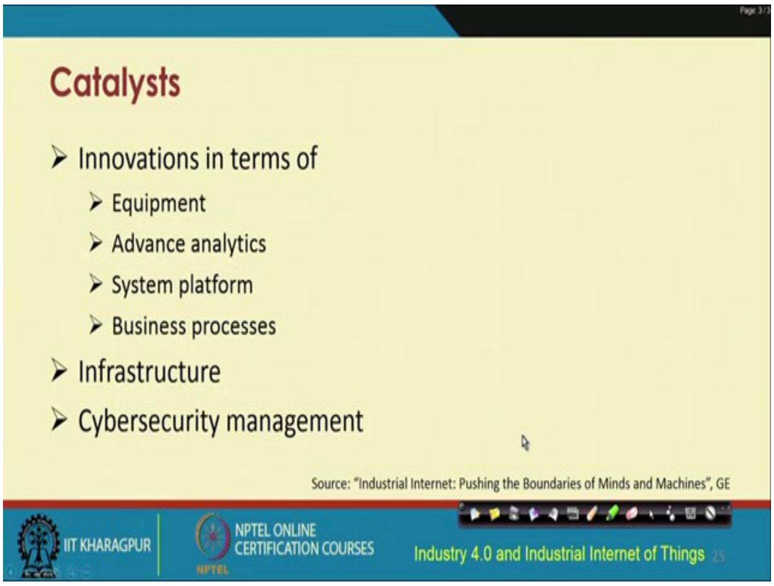


These are some of these catalysts which will work to promote the adoption of industrial internet, innovations in terms of equipment advanced analytics safety platform and business processes is number 1. Number 2 is infrastructure and number three is cyber security management and each of these we have already gone through, in much more detail in the previous lectures.

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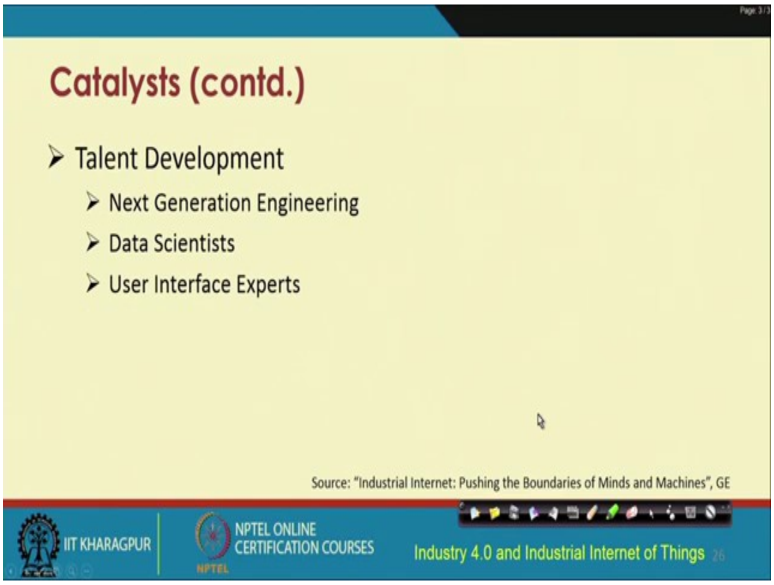


Talent development here we are talking about the use of different next generation engineering techniques, data scientific techniques, and user interface techniques to improve upon the talent man manpower, talented manpower, to improve upon their talent.

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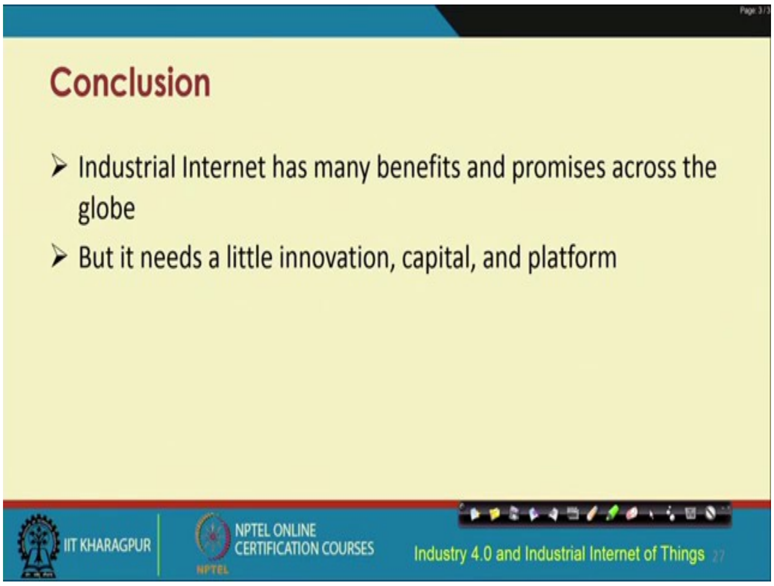


So, now to conclude industrial internet has many benefits and promises across the globe, it is industrial internet is now globally used it is quite popular, everybody is using it whether it is a small scale industry or a medium scale industry, or a large scale industry. Industrial internet and its different applications are finding different usefulness and one has to leap through this usefulness to improve upon the efficiency of the workplace of the processes of the machines in the industries even further.

But what is important also to have further innovation cutting down on the costs, further, through these innovative steps and adoption of different platforms and industrial internet platforms, through the adoption of all of these it is now possible to improve the overall efficiency and cutting down on the perform on, the reduced performance issues through the adoption of industrial internet.

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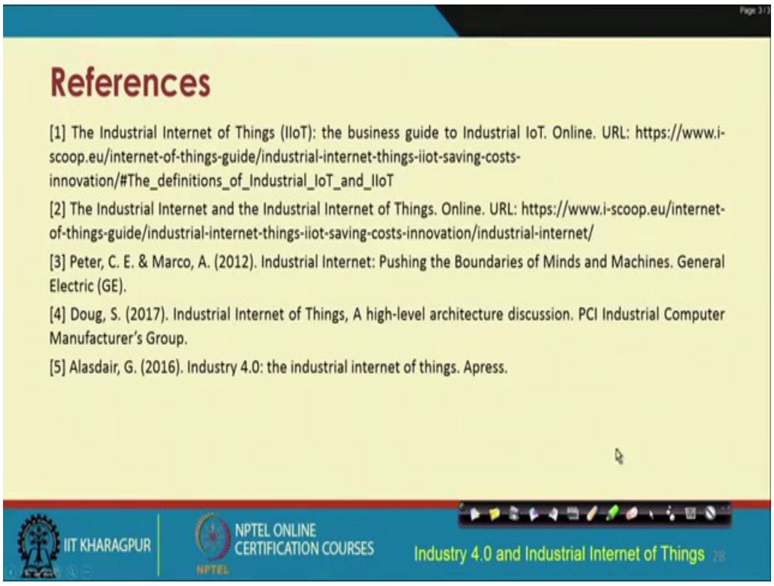


These are some of these references, and with this we come to an end, of this particular lecture on industrial internet, as we have seen in this particular lecture, industrial internet has lot of similarity with the industrial IoT, which again has also a lot of similarity with automation issues in the industry, but all of these even though are similar, they have their own distinct identity. The origin is also distinct and that is how these have also become very popular on their own standing.

Thank you.

**Introduction to Industry 4.0 and Industrial Internet of things**

**Prof. Sudip Misra**
**Department of Computer Science and Engineering**
**Indian Institute of Technology, Kharagpur**

**Lecture – 19**
**Basics of IIoT: Industrial Sensing & Actuation**

In the previous lectures, we have gone through the revolution of the industries, the industrial revolution, internet revolution, and at present the industrial internet revolution that the industries are going through. Now, we have also seen that parallel industrial IoT has become very popular. And when we are talking about whether it is the industrial internet or the industrial IoT. At the core, it is about sensing and actuation.

Sensing and actuation is very important and then comes issues of connectivity, communication, analytics, and so on. So, there are different sensors, when we talked about the introductory issues of different sensors, sensing and actuation. I have shown you different sensors that could be used for connecting with IoT. For Industrial IoT, there are certain specific requirements.

The sensors that are used in the industries are typically the ones, which have higher performance, are much more accurate, and are able to perform for longer durations of time. So, they are high grade, better performing, highly and normally scalable, and can work for longer durations of time. So, we need to now understand the specificfications of these different sensors and actuators being used in the industrial sector. So, industrial sensing and actuation is what we are going to cover in this particular lecture.

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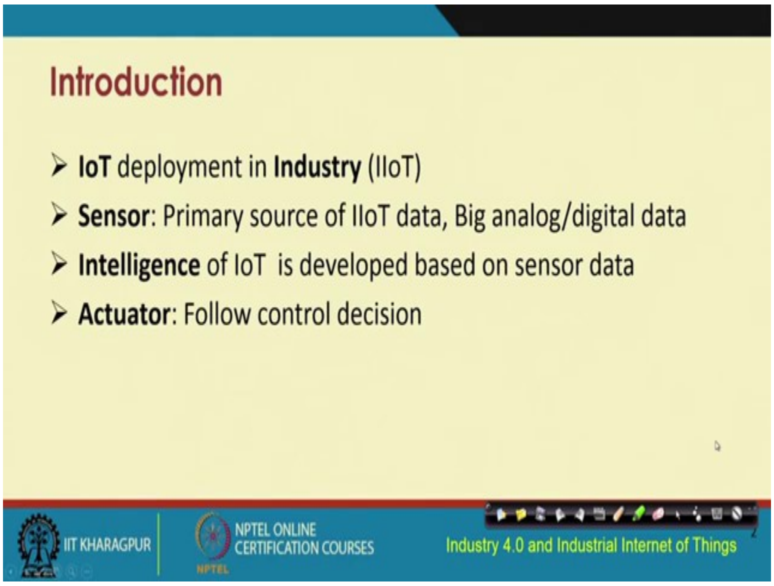


So, just as a recap when we are talking about IIoT, if we are talking about the same thing IoT, but considering industry-specific applications. And there are certain industry-specific requirements that are there, which will have to be catered to. But for IIoT as well, like IoT sensors and actuators are the core technologies.

These are the core components, which are used and these are the ones, which basically form the backbone behind the collection of all these different data and making different changes dynamically to the system. Sensors are basically the primary source of IIoT data. There can be different types of data, that can be sensed using different sensors, the sensors themselves can be analog or digital sensors.

And these sensors need to be deployed in the industrial scenarios typically are going to collect lot of analog data, digital data and not only lot of data, but data, which are big in nature. So, this big data that I talked about in a previous lecture so, all these big data properties are basically going to come if you are going to have industry scale sensors deployed and connected to one another and to different machines.

The data that are collected by the sensors will have to powered with; will have to be powered with intelligence. So, this data will have to be processed, to process in order to get information and knowledge out of the data from this processing. And followed by that followed by the processing, the analysis, that is done from the data that is collected in real-time in typical scenarios, some real-time actuation can also be done. And this actuation can be done following control decisions.

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There is a need of sensing for the industry. And these sensors that are used in the industry should help in promoting higher degree of automation, raising the productivity, improving the quality of these different products, quality of the processes, that are used for manufacturing, improving the overall safety and reducing the downtime of the machinery.

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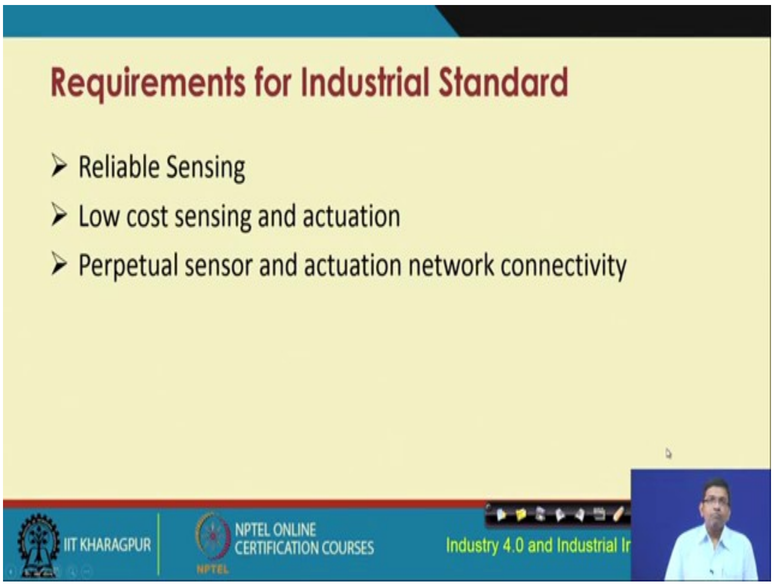

In terms of the requirements for industrial standard, it is required to have reliable sensing, low cost sensing and actuation, and perpetual sensor and actuator network connectivity. So, what is meant by these requirement is that we need to have low cost, but higher performing reliable sensors. Low cost because we are going to use large number of these different sensors, it should not happen that one sensor is so costly, that only you can use it for one machine. Because you have to now in the industrial internet or IIoT you have to internet work all these different machines and consequently these different sensors.

These sensors themselves if you want to replicate and scale up, you need to have these to be very cheap. Otherwise you cannot have multiple such sensors to be deployed in different machines, so they have to be low cost. High performing because, these sensors will have to perform for long durations of machine use under extreme conditions these sensors will have to perform.

And they have to be reliable, because not only they have to operate for long durations, but will also have to throw in data which can be relied upon; they have to be accurate and reliable. So, these are some of these requirements for industry related, industrial-related sensors being used.

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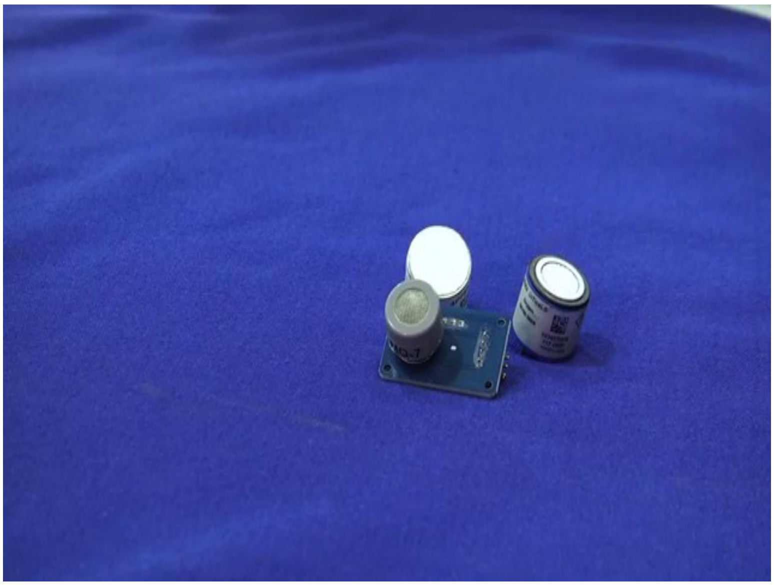

So, let me now show you some of these different sensors. So, here this is one type of; so, here I will show you three different sensors, these are three different gas sensors. So, this is the carbon monoxide sensor and then you have the methane sensor, this is the methane sensor, as you can see over here.

This is the methane sensor with three different pins at the bottom of it. And this one is an oxygen sensor, this is the oxygen sensor, here also you have three different pins for connectivity purposes. These pins are there for connectivity purposes. So, we have three different types of sensors, I just wanted to show you the samples of these.

And these are industry-grade sensors these have higher performance, higher efficiency, they are very reliable. And they are relatively cheap, but they are much more reliable than the low cost ones, lower cost ones that are available in the market. So, for example, for instance, this sensor I will show you one by one, this is the methane sensor.

So, this methane sensor; basically continuously measures that how much is the methane concentration in the environment in which it is operating. And the operating temperature of this methane sensor is quite broad spectrum; from roughly about minus 20 degrees centigrade to about plus 55 degrees centigrade, this methane sensor can work. It can work in different hazardous environments such as nuclear power plants, underground mines, and so on.

It also can be used for different safety critical environments for designing different safety critical environments. And it has a sensitivity of about 24 ± 4 milli volts per percentage methane. So, this is highly sensitive to any kind of methane concentration change, so the is this methane sensor.

Now let us look at this sensor, which is the oxygen sensor. So, this oxygen sensor is basically a electrochemical sensor, the composition is the way it is fabricated it is a electrochemical sensor. And it can detect different it is highly accurate and can detect any changes in the oxygen concentration.

It is also quite rigid, quite robust, it can work under different extreme conditions, different extreme environmental variations, and so on, and temperature variations. And also it has the output signal, which is about 0.1 ± 0.02 milli-ampere in the air ok. So, this is this methane sensor so this is this oxygen sensor. And then we have this normal, carbon monoxide or general gas sensor, which is highly sensitive to changes in different gases such as carbon monoxide.

And the detecting range for carbon monoxide for this particular sensor is about 20 ppm to 2,000 ppm. So, this can be used in cars in different industries for monitoring the concentration of carbon monoxide and so on. So, these are all industry grade sensors. And as you have seen that these sensors are highly accurate, they are very much sensitive, and sensitive to the changes in the gas that they are supposed to sense.

And they are quite robust and can operate in broad temperature ranges, under different varied environmental conditions and so on. So, these are some of the higher level specific requirements for serving industrial applications.

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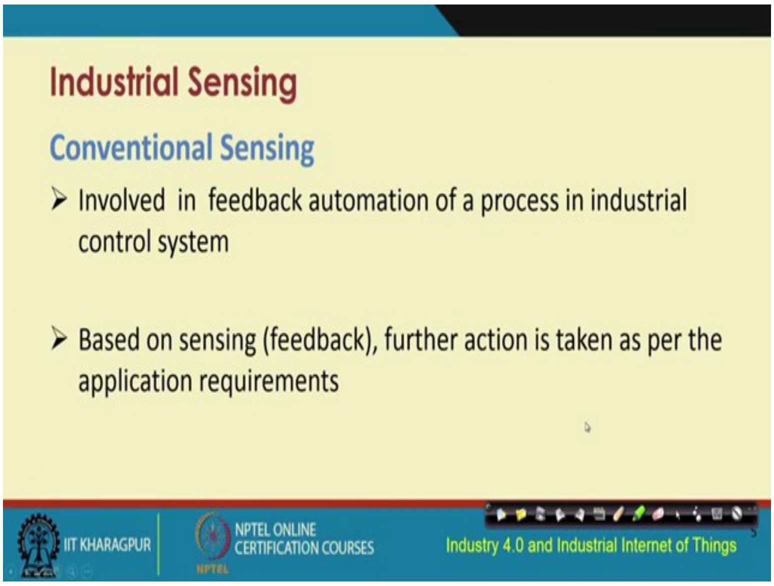


Now let us go ahead and look at sensing, in further detail, industrial sensing. So, when we talk about industrial sensing there are these conventional sensors that have been there since long. Again sensors have been there for decades, but then now recently they have become even more popular in the recent years, with the popularity of IoT and IIoT.

So, conventional sensing it involved getting some kind of feedback, automation of a process, in an industrial control system. And it was based on some sensing or then getting some feedback for taking some further action to serve certain specific application requirements. And these conventional sensors have been there since long as I just said.

But the way you are evolving these sensors making them much more intelligent connecting them to the internet getting value out of the deployment of these sensors in a big scale and making processes much more efficient, in the industries, is what has made IIoT much more exciting.

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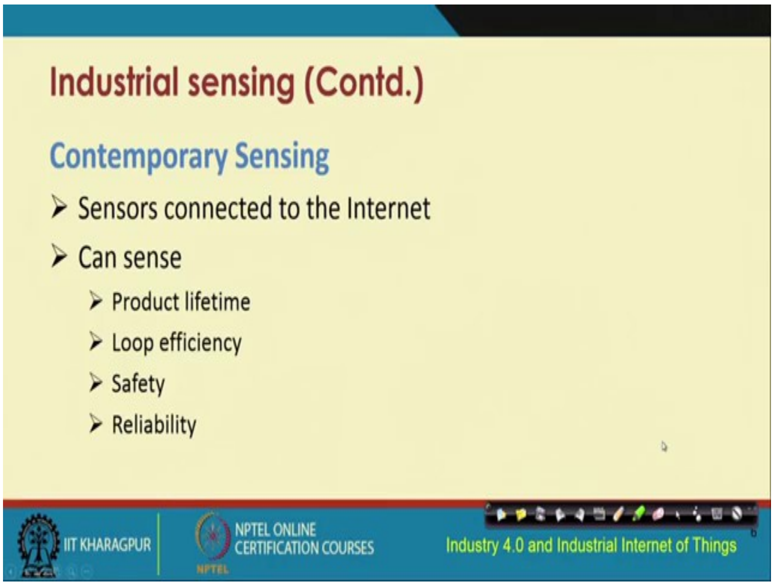


In contrast, to the conventional sensors the contemporary ones the recent ones. These can be connected to the internet. So, it is possible to connect these sensors to have industrial internet or industrial IoT applications. These contemporary sensors are much more intelligent. They can sense product lifetime, loop efficiency, safety, reliability these are some of these different properties.

But it all depends, which sensor is supporting and type of application. And who has what type of attractive properties it all depends on the type of sensor. Typically, what happens is the more you make these sensors much more competent, intelligent, robust, the price also increases. But at the same time it should not be too expensive to be not being able to use easily in most of the IIoT applications.

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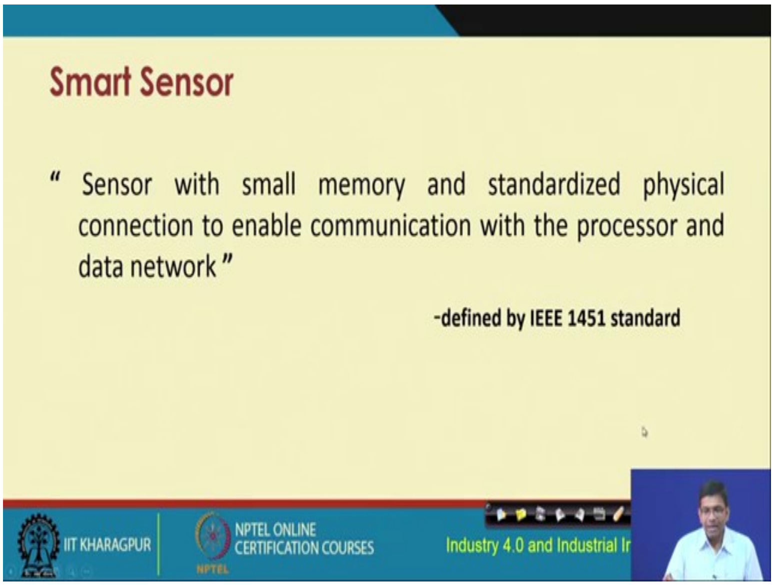


So, smart sensors are the ones, which have small memory and standardized physical connection to enable communication with the processor and data network. And this is as per the IEEE 1451 standard, this is a smart sensor and we are talking about the definition of a smart sensor having some kind of small memory and connectivity, attached to it.

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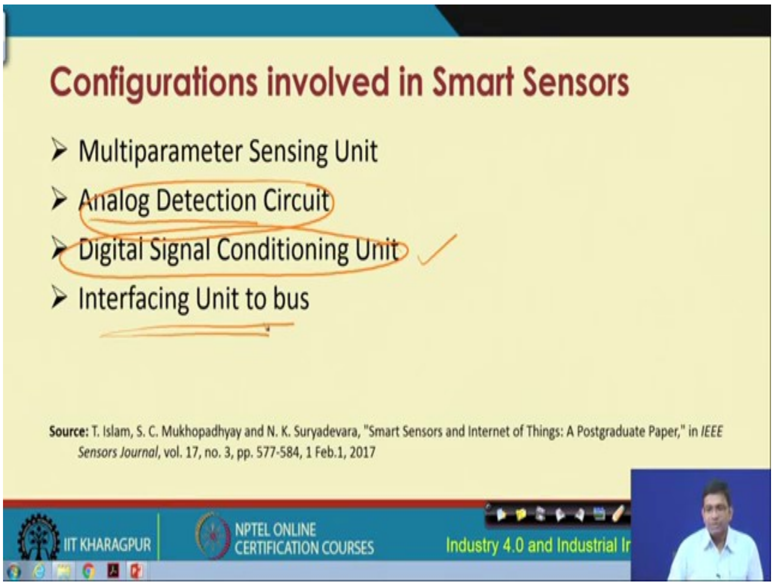


So, the configurations that are involved in the smart sensors are it is possible to have a multi parameter sensing unit. Multi parameter sensing means different parameters in the same sense, through the same sensors it is possible to measure multiple parameters. So, same sensor can be used to measure multiple gases for example. Then we have the analog detection circuit, digital signal conditioning unit, and interfacing unit to the bus. These are the different components, which will be used to configure the smart sensors. So, what is this multi-parameter sensing is what I just said, but what is this analog detection circuit. So, most of these sensors basically, analog sensors.

But in order to connect them to the internet. And to get and to perform multiple intelligent stuff you need to convert this analog signal into digital data. So, this analog detection circuit is required, then you need to have some digital signal conditioning unit, this digital signal conditioning unit will, after the analog signal is collected and then you want to digitize you want to have digital data out of the signals you need to digitize it. So, before you digitize you need to do some kind of conditioning. So, conditioning of the analog signals and this conditioning is done through different means.

For example, amplification filtering of the signals and then digitize. So, this is basically the work of the digital signal conditioning unit. And then you have the interfacing unit to the overall bus. So, this interfacing unit will help you to connect these different sensors to the information bus.

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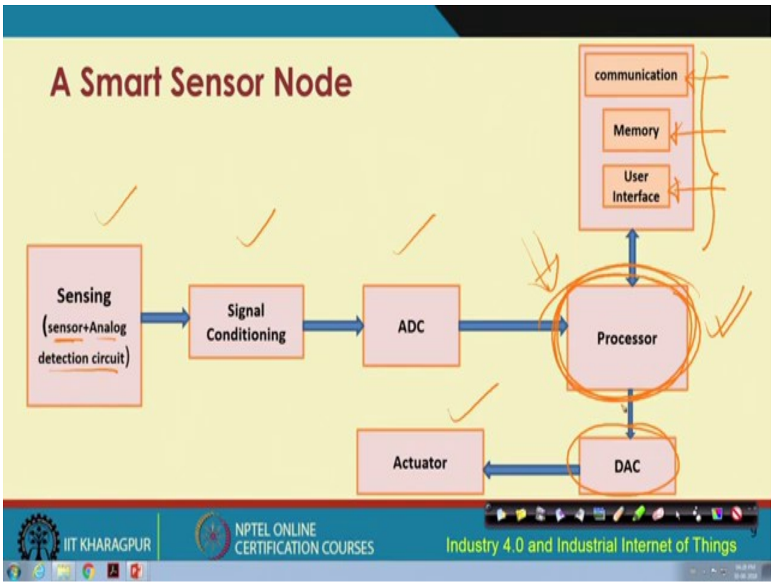


So, let us look at the architecture of a smart sensor node. A smart sensor node has the sensing unit, which again has a sensor, an analog detection circuit. There is this signal conditioning circuit or component that is there. And this signal conditioner will basically do the things like amplification, filtering of unwanted stuff.

So, signal conditioner, then you have the ADC, the analog to digital converter and the processor. So, processor is the one, where all this processing are taking place all these computations different algorithms can be executed at this processor. So, this is basically very important in a smart sensor node and intelligent sensor nodes. Intelligence come through algorithms, and these algorithms can basically be executed at this processor.

Interface with different components such as the communication unit, the memory unit, and give some user interface components. So, all of these finally, based on the processing some kind of actuation would have to be made. So, for that the actuators will be, will have to be invoked, will have to be started and this DAC Digital to Analog Converter sits in between to help in the process.

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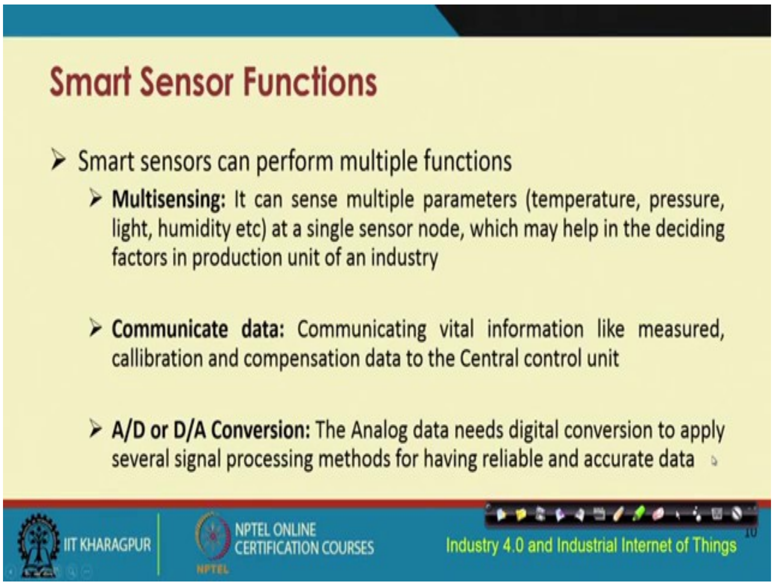


Smart sensors can perform multiple functions. Multi sensing as I told you before it is about sensing multiple parameters such as temperature, humidity, light, pressure, and so on. In a single sensor node, communicating the data that is measured, calibrating the data, and then compensating the data. And sending it to the central control unit is the next important function of a smart sensor node.

And then the other component is the AD or DA converter, Analog to Digital, and Digital to Analog converter. The analog data needs digital conversion to apply several signal processing methods. Because unless you make it digital, digital signal processing methods cannot be applied. So, digital signal processing methods will have to be applied for having reliable and accurate data.

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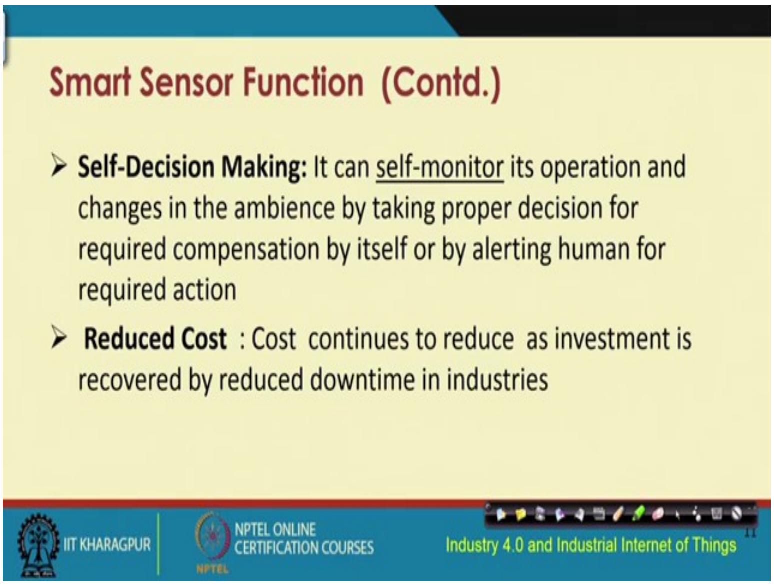


So, the next important function is the self-decision making. Because it is a smart sensor, an intelligent sensor, it has to do things on it is own. So, it has to self-decide, it can self-monitor, and based on the ambient conditions, it can make certain decisions on its own. And this would be possible with the help of the processor that is inbuilt into this smart sensor.

And then you have the reduced cost, the most important function I would say of a smart sensor. Because if cost is not reduced then, it is not possible to replicate and scale up to build to have more copies of these different sensors and replicate it further.

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So, let us consider the example of the milk processing unit. Let us say that you are talking about a smart milk packaging unit. And let us talk about the sensing in a smart milk packaging unit much more specifically.

So, in a milk packaging unit you need to install the sensors in line with the outlet tab. Then there would be some impellers, which would be attached to the sensors. These impellers would spin, when the milk moves. So, impellers I think most of you have already seen that it is something very circular and has some grooves blades and so on, on its surface.

So, when some fluid such as milk will flow then it is going to rotate accordingly. So, impeller spins when the milk moves and sends the electrical signal to the control unit. And the controller would interpret the amount of fluid flow and stop, when the threshold is reached.

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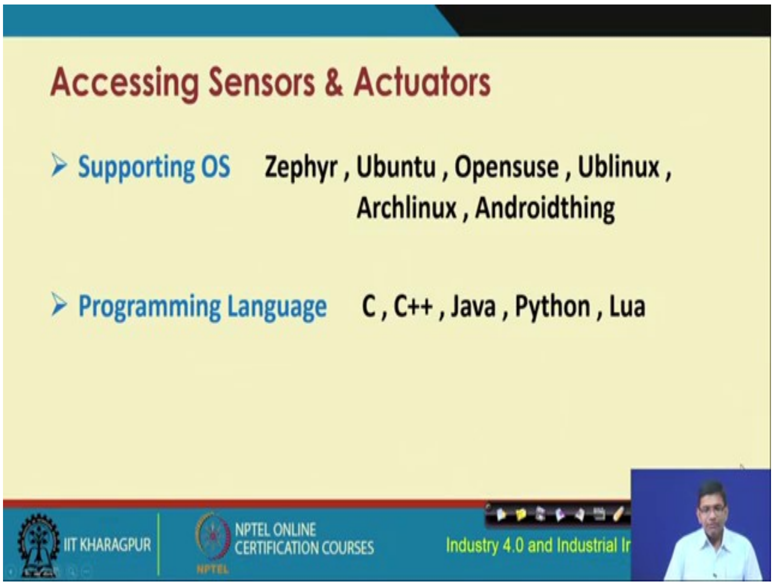


So, there are different sensors which would sensors and actuators industry scale which would support different operating systems, such as the ones that are mentioned over here. Zephyr, Ubuntu, Opensuse Ublinux, Archlinux, Androidthing, these are some of the different operating systems that are used in the smart sensors and actuators.

The different programming languages that are used for applications of smart sensing and actuation are C, C plus plus, Python, Java, Lua, and many other languages are also coming up in the recent years for use in the smart sensing and actuation environments and programming those environments.

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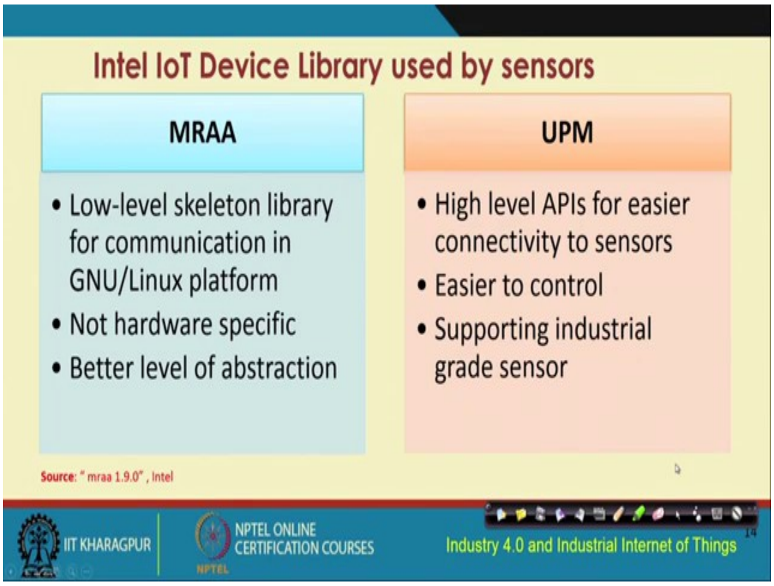


So, different device libraries are also available for the programming purpose. Intel IoT device library is one such library and there are different components in it. One is the MRAA component which is a low-level skeleton library for communication in the GNU Linux platform.

There is another component, which is basically, which provides high level APIs for easier connectivity to the sensors. And also UPM helps in control applications. These UPM MRAA together they help in supporting industry grade sensing.

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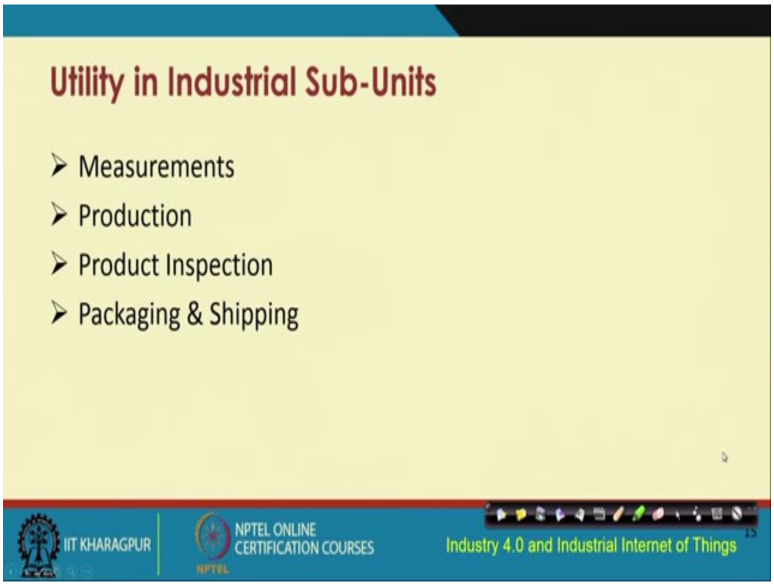

So, utility in industrial subunits measurement production, product inspection, packaging, and shipping, these are some of these utilities of industrial sensors and their use, in different industrial subunits.

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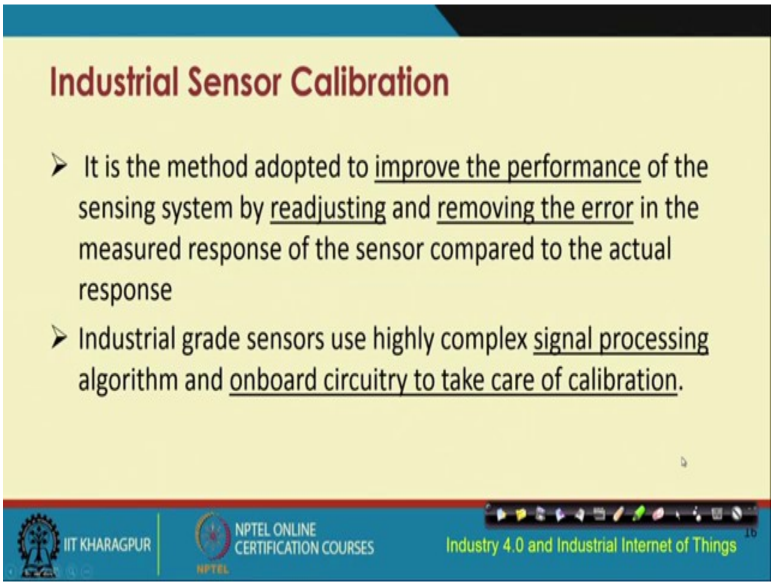


Calibration of any sensor is very important. Calibration has to be done in order to improve the performance of a sensing system through different adjustment, readjustment removal of errors, and so on this calibration can be done. And calibration has to be done because certain sensors would not behave the same way with passage of time. So, you have to calibrate and you have to re-calibrate a sensor. Industry grade sensors use highly complex signal processing algorithms and on-board circuitry to take care of calibration.

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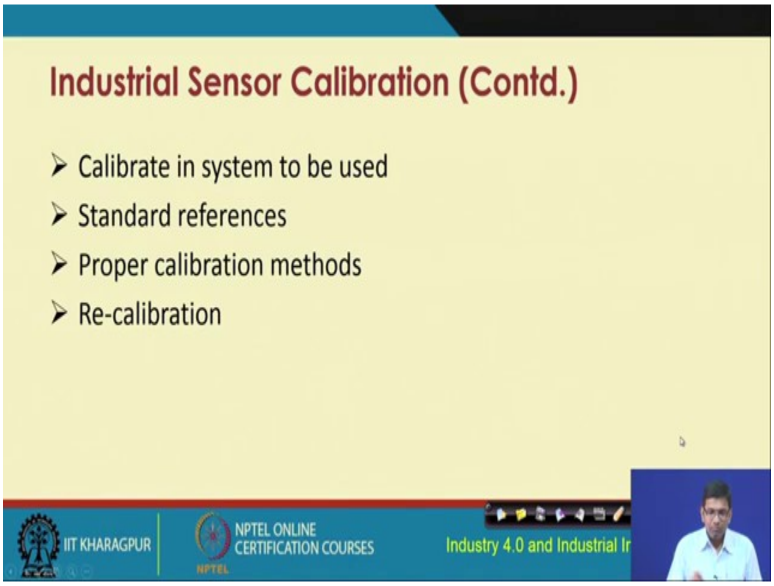


So, it is required to calibrate the sensors in a system. And it is also required to have some kind of standard reference against which the calibration is going to be done. Because if you do not know what the sensor is supposed to do and how much the actual measurement should be, then you cannot do the calibration, if you do not have that kind of standard reference.

Standard difference has to be there. Then proper calibration methods will have to be used and if required sometimes what happens is certain sensors do not behave the same way over passage of time. So, they will have to be recalibrated.

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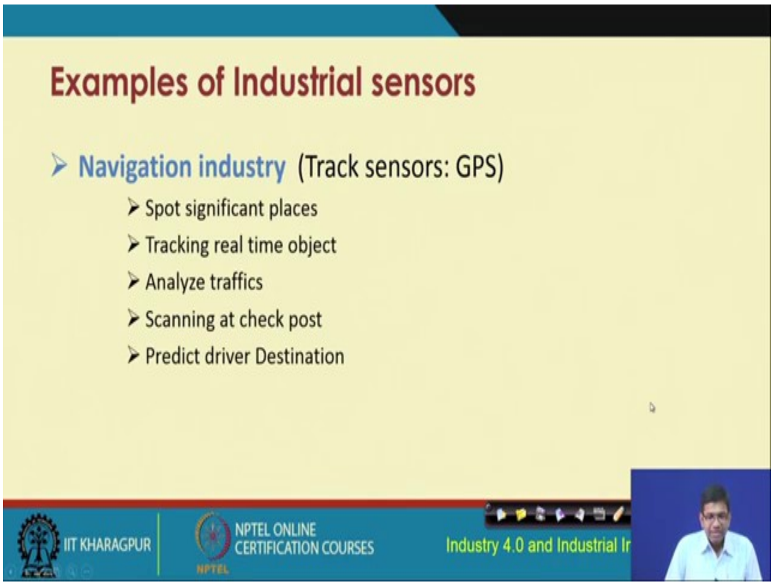


Examples of industrial sensors, industrial sensors can be used in the navigation industry, for tracking and so on. GPS based sensors are the ones that can be used in the navigation industry for tracking purposes, tracking of shipments, tracking of logistics, tracking of trucks.

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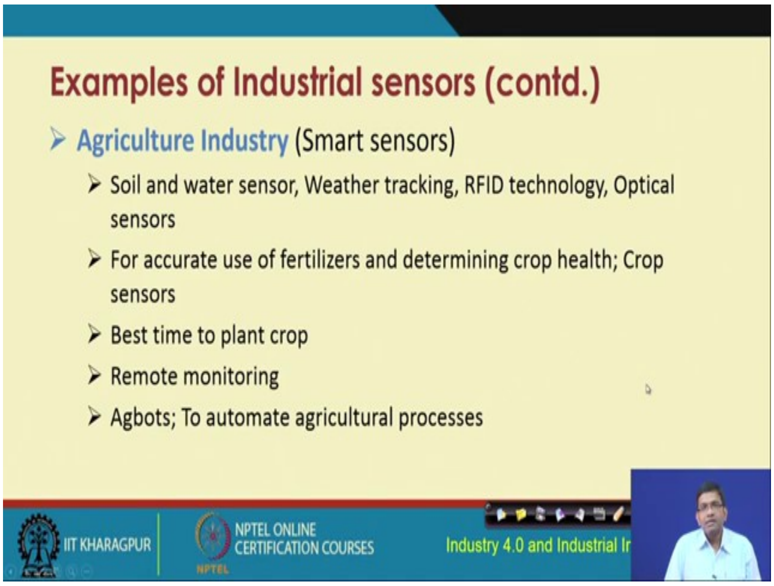


In the agricultural industries, smart sensors can be used for monitoring the soil condition, water condition in the soil, soil, moisture, water level in the soil, different weather parameters, then different other parameters such as the fertilizer content, the nutrition content of the soil to be used by the plants. So, this is this agricultural use of smart sensors.

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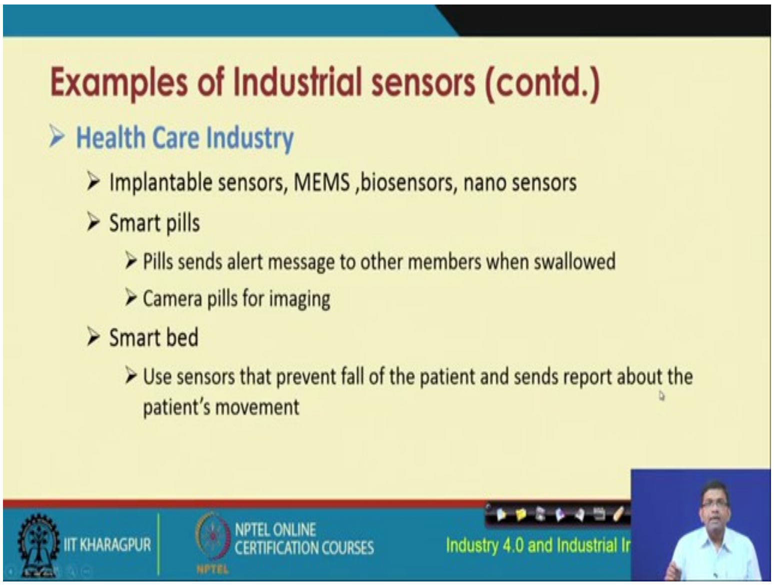


In healthcare industry as well different sensors, such as the regular ones for example, different biosensors like this pulse oximeter sensor, body temperature sensors could be used. Similarly, ECG, EMG, EEG different sensors the traditional, conventional ones could be used. But now there are some smarter sensors for healthcare purposes that have also come up. There are smart pills which basically can be swallowed and these pills go to the human circulatory system.

And they send, they sense the human physiological parameter that they have been designed to sense and then basically those physiological parameters wirelessly they are going to send those parameters to the doctors for further monitoring. Smart beds in the hospitals also use sensors that prevent the patient from being falling down and sending report about any kind of movement, suspicious movement of the patients.

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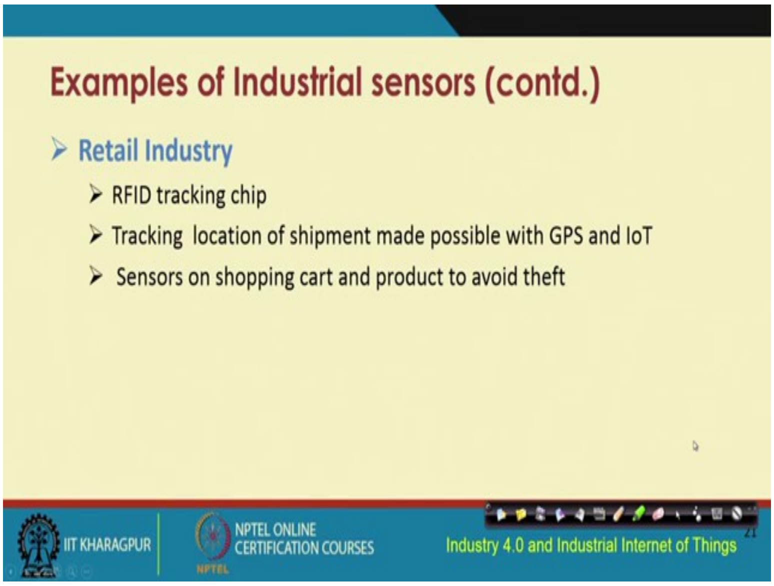


In the retail industry, also industrial sensors are used, for example, RFID tracking chips, tracking location of shipments made possible with GPS and IoT, sensors on shopping cart are also deployed. And by doing so it is possible to avoid theft of different products from the supermarkets and so on.

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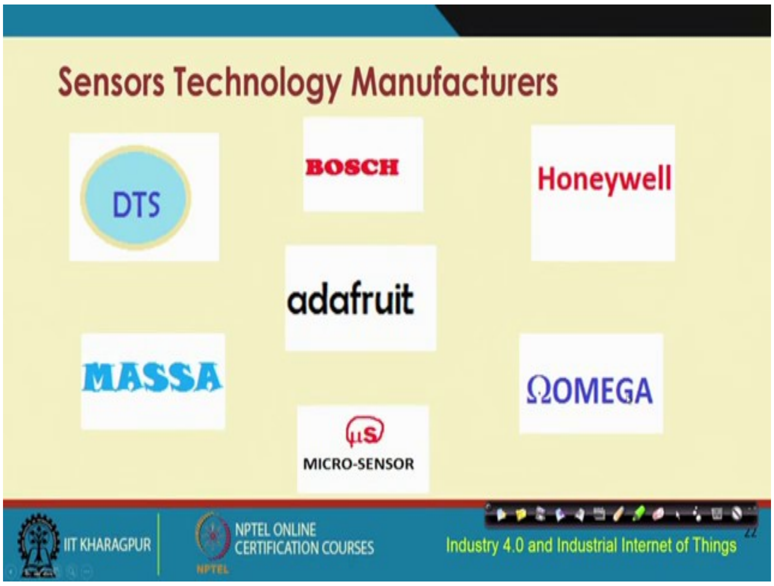


So, there are different players of these sensors, sensor manufacturers are there who develop different (different) types of sensors. You have the DTS, Bosch, Honeywell, OMEGA, these are some of the common sensor manufacturers. Like this, there are different other sensor manufacturers globally, that produce different types of sensors.

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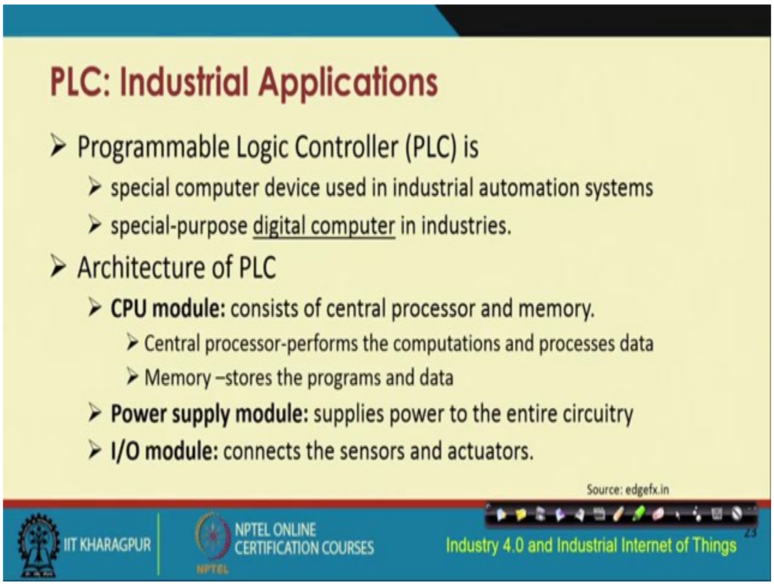


Now, when we talk about sensing at the same time we also need to talk about actuation. And in industry actuation is very important, use of PLC is very important to serve actuation platforms. PLC stands for Programmable Logic Controller and these programmable logic controllers are some kind of special purpose digital computers that have certain special capabilities.

Special capabilities for automating the industrial processes, industrial machinery, and so on. So, these PLC's are quite widely used in the industries to automate, for automation purposes and these PLC's could be extended further to be able to serve the industrial internet and IIoT requirements. So, a typical PLC has three different modules.

The CPU module which consists of the central processor and the memory, and then you have the power supply module, which the name says it all, it supplies power to the entire circuitry, and the input output module which basically connects the sensors and the actuators. How this PLC's work?

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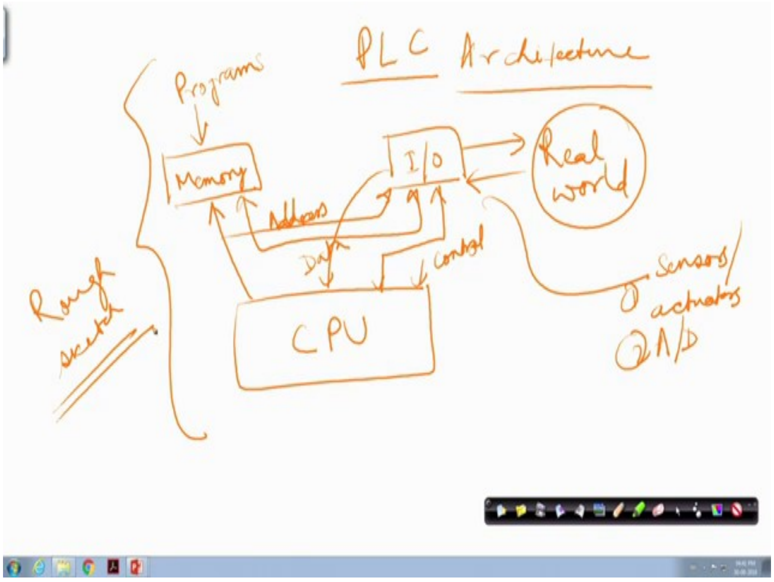


So, we will talk about the architecture of a typical PLC system. So, a typical PLC system has memory, and the input over here are different programs, which run these PLC’s. Then you have the central processing unit and the input and output. Through this input-output, there is interaction with the real world.

So, this input output component in fact, for the interaction with the real world connects two different sensors, actuators, which can sense different parameters. And these could be of analog or digital type. Basically the interaction happens between the CPU to the memory. The memory to the input-output, and also between the input-output and the CPU.

All of these things are interconnected and they are going to send data. First of all we are going to send this memory is going to send the address. The data could also be sent from the input-output to the CPU. And also it is possible to control the CPU’s by sending suitable control signals.

And these control signals can come from take input output. So, this is at a very, it is a rough sketch of the different components in the architecture of a typical PLC. Now, let us go little further and talk about the different, the most important thing that happens in a PLC.

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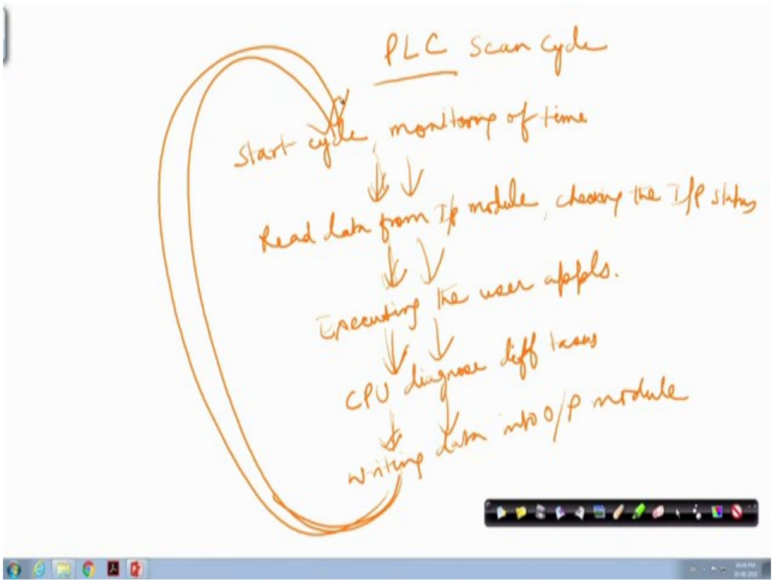


PLC basically in most of these machines PLC goes through different loops. There is something called the scan cycle, PLC scan cycle. So, in the scan cycle, basically this looping happens. So, you have first of all the starting of the cycle and monitoring different parameters; monitoring different parameters such as time.

Then you have reading the data from the input module, the input module and checking the input status. The next thing in the cycle is executing the application, the user applications. Then you have the CPU basically diagnosing different tasks. Finally, writing the output, basically the data into the output module.

And it is called a cycle because these activities will have to be done. And after they are done you go through another pass, when the machine, until the machine continues to operate. So, this cycle so basically it goes through this side these all these tasks and again repeat from the start. This is how the PLC scan cycle looks like. This loop is very important in PLC's and they continuously, they keep on doing the stuff to continuously do whatever they are designed to perform.

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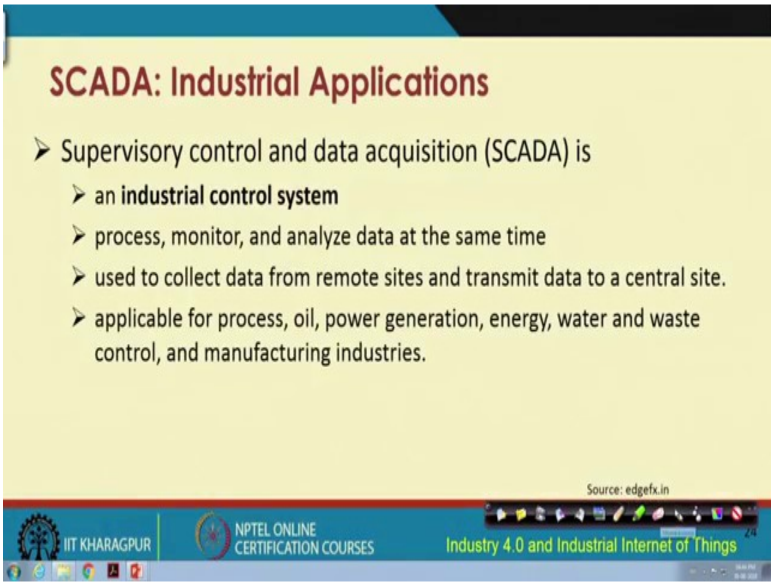


So, let us now again go back and look little further. So, these PLC's are very important in something known as the SCADA systems. So, SCADA is very important in industry applications. SCADA basically stands for Supervisory Control and Data Acquisition. And it is basically an industrial control system, an advanced industrial control system, which can do many different things such as; processing, monitoring, analyzing data, all at the same time can be done, with the help of industry grade SCADA systems.

These systems basically would collect the data from different sites, different locations. And transmit the data to the data acquisition system for further processing. So, typically water industries, oil industries, power generation industries, they all use SCADA based systems.

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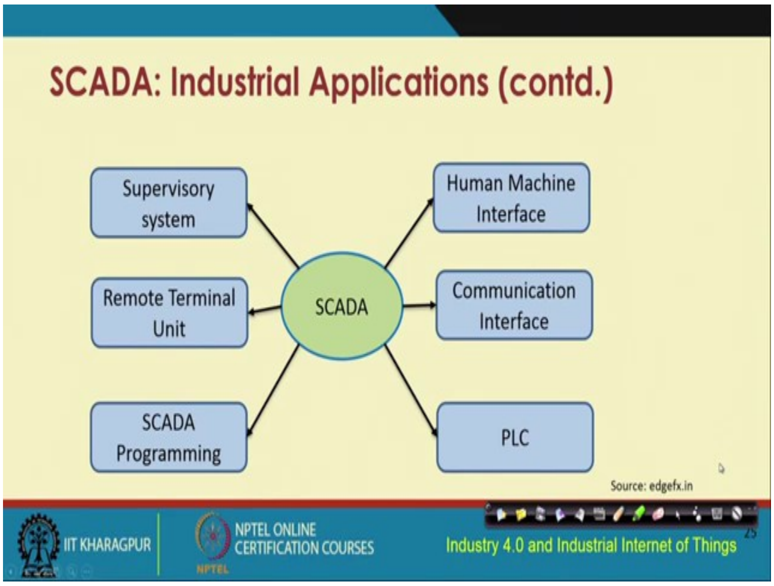


SCADA has different components. So, there is a supervisory system, there is a human machine system, there is a remote terminal unit component. There is a communication interface system or component, the SCADA programming is another one.

And the last one is this PLC that I talked about before, the architecture of which the rough sketch of the architecture of which I have shown you. And we also talked about this PLC cycle, which continues to operate the tasks are continuously done in the cycle as these PLC machine keeps on operating, until the machine keeps on operating.

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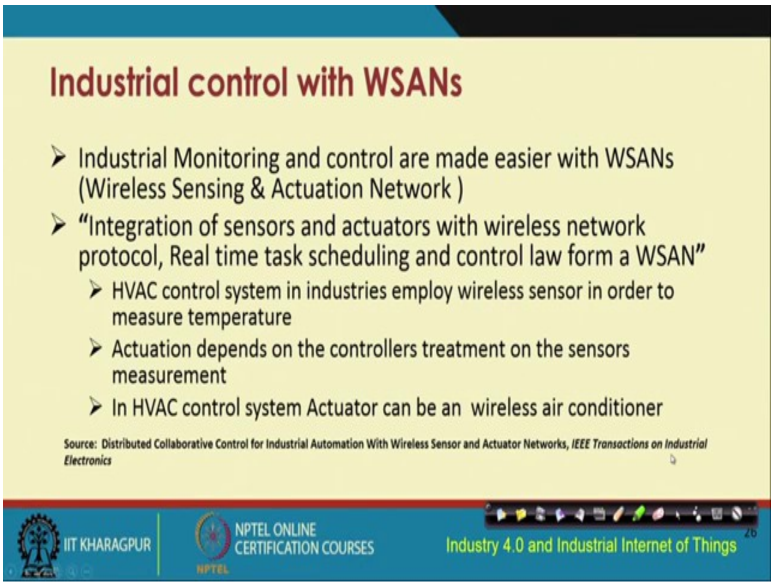

So, industrial control can be done with the help of all of these different technologies, different sensors, different actuators, based on PLC's SCADA and so on and there are different sensors and actuators that are used.

We have a wireless sensor and actuator network in the industry scale connecting different machinery, working in order to perform the different monitoring activities of these different machines systems, humans, and humans talking to machines. So, all these different interactions can be monitored, controlled, and so on.

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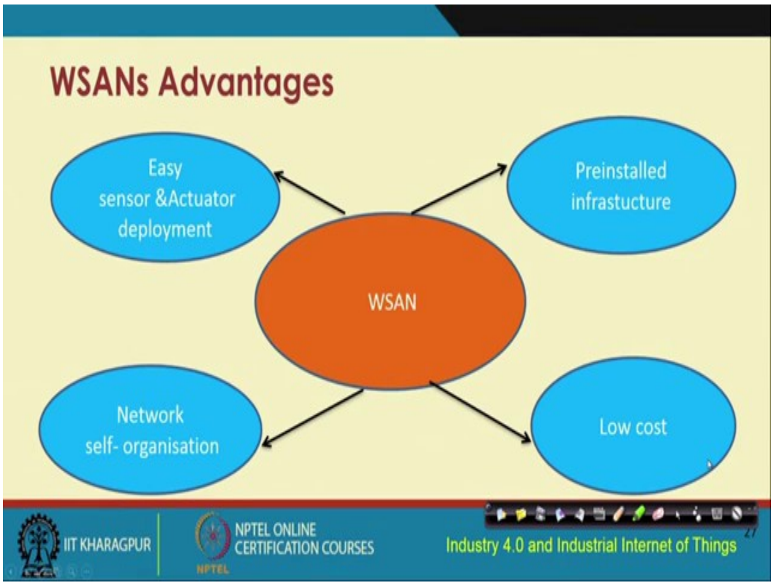


The advantage of use of wireless sensor and actuator network; is that it is not so difficult as we have seen so far. Sensors are common, once you get the sensors, once you get hold of the actuators, it is not so difficult to deploy the sensors and actuators. So, once you have deployed the sensors and actuators you can have these sensors being networked to be able to talk to each other.

To self-organize the system, the communication platform, the network. And there is some pre-installed infrastructure, that could also be used. And overall this wireless sensor and actuator network technologies are low cost. So, that is why holistically this well is sensor an actuator network technology in the industry scale are low cost.

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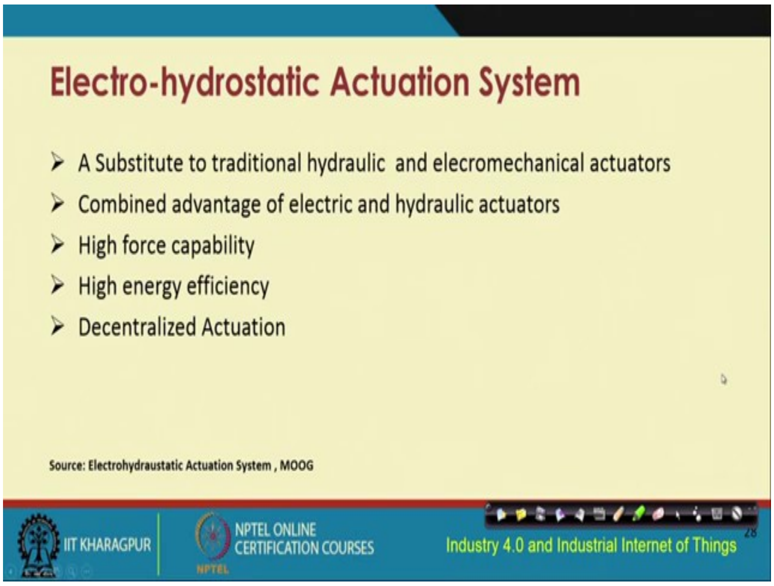


So, in terms of these different actuators could be used electro-hydrostatic actuation system. We have seen different actuators in the introductory lecture, we have seen different types of actuators being used. Many of these could be used for different purposes in the industries.

But there are some industry specific actuators that are at the higher end and could be used to serve industry applications. So, this electro-hydrostatic actuator is a substitute to the traditional hydraulic and electromechanical actuators. They have some combined advantages of both the electric and hydraulic actuators as these name suggests.

So, essentially these electro-hydrostatic actuation systems by combining the advantages of their electric and hydraulic counterparts together can have higher force capability, higher energy efficiency, and decentralized actuation.

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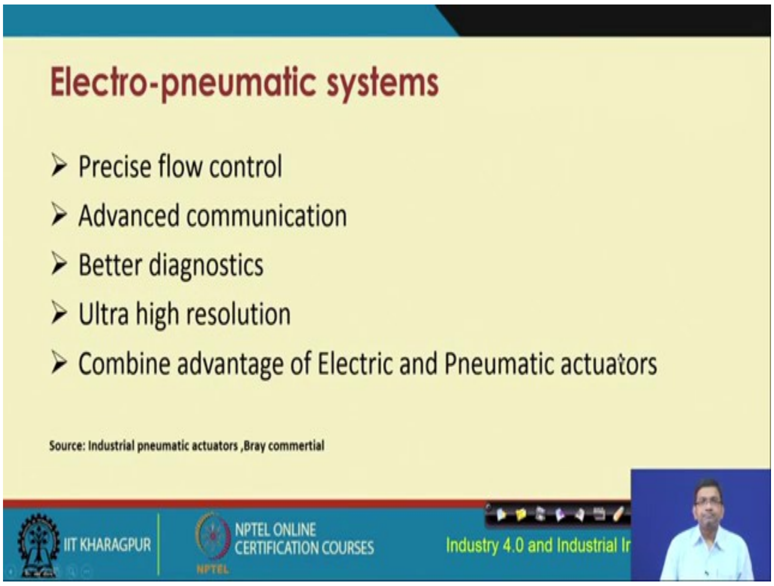


Then there are the electro-pneumatic systems, which have precise flow control, advanced communication capabilities, improved diagnostics than the previous traditional actuators. And ultra-high resolution and combined, they also have the combined advantages of the electric actuators and the pneumatic actuator.

All these actuators are typically the hybrid ones, which will combine the electric pneumatic and different other capabilities mechanical actuators. So, all of these capabilities combine together, becoming much, making these actuators much more advanced, much more powerful and accurate.

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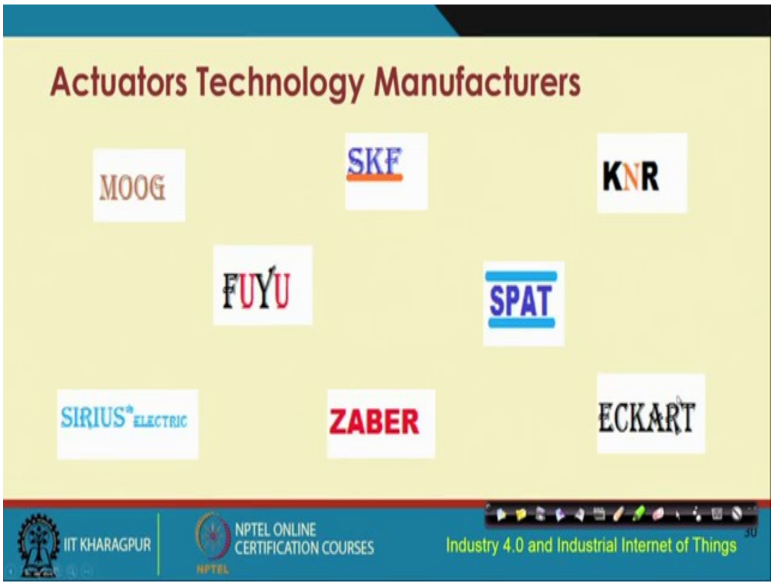


These are some actuator manufacturers.

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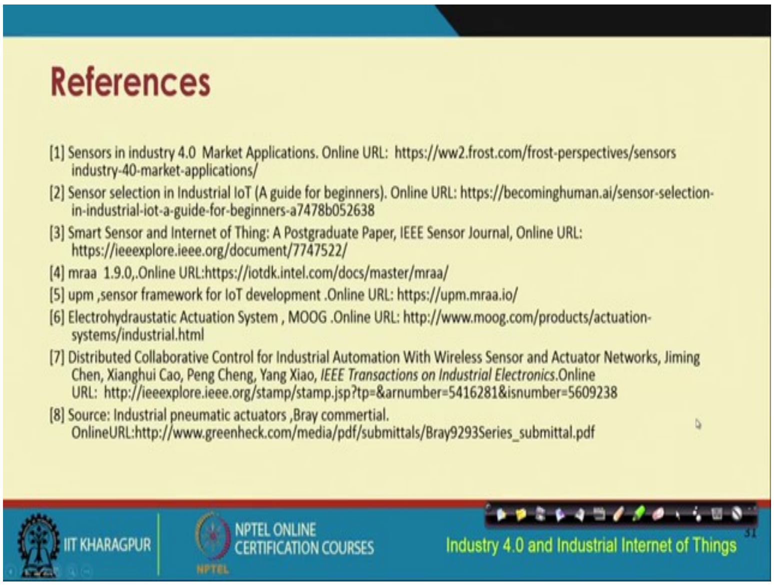


So, with this we come to an end of industry skill sensing and actuation lecture. And what I have done is I have shown you these different types of industry-scale sensors that could be used. I have also talked about PLC, SCADA and the corresponding architecture. Here are some of these references, which will help you to dig further deep into each of these that I have talked about, if you are interested further.

And so remember one thing that industry grade sensors and actuators have higher requirements, but at the same time, they have to come in lower cost. Unless you have low cost sensors and actuators, even in the industries nobody is going to pay for them to deploy them.

Because if the cost of these sensors and actuators in the industries are going to be higher, then the cost of the products is also indirectly going to be increased and that is not something that any of the industries would readily want to have. These are different references and with this we come to an end of this lecture.

Thank you.

**Introduction to Industry 4.0 and Industrial Internet of Things**
**Prof. Sudip Misra**
**Department of Computer Science and Engineering**
**Indian Institute of Technology, Kharagpur**

**Lecture - 20**
**Basics of Industrial IOT: Industrial Processes – Part 1**

In this module, we will be talking about some of the basic concepts of Industrial IoT. To start with, we will talk about some of the issues concerning different industrial processes, what industrial processes are, and what are some of the important aspects of industrial processes that need to be understood in order to incorporate IoT into the industrial processes.

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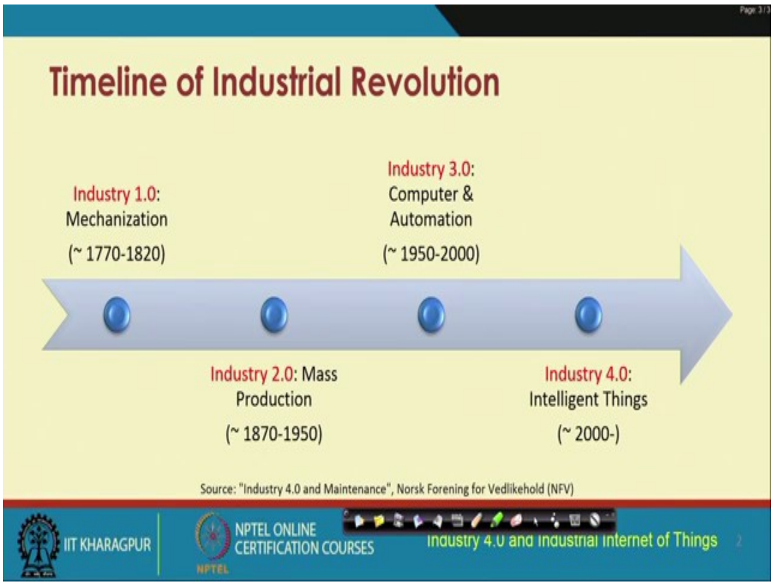


First of all, let us think about, how the industrial revolution has happened over the decades. It is started with Industry 1.0, which was all about mechanization in the 1770s to 1800s. So, it was Industry 1.0, which was particularly focused on mechanization.

Then came in the 1870s to 1950s came the Industry 2.0, which was about mass production. Then came in 1950s to 2000s, the Industry 3.0 revolution, which was about the incorporation of computers and automation in the industries. Industry 4.0 is a recent happening in the last few years, where we are talking about transformation of the industrial processes, with the help of advanced computers, automation, communication, sensors, cyber physical systems, and IoT.

Industry 4.0 is the recent happening; it is the current revolution in the industries that is happening globally. Unlike, in the case of Industry 3.0, where computers were also used, and automation was done. The focus was on automating separate, separate jobs, let us say the processes will be automated, separate from the supply chain. So, everything was done separately using computers.

In the current generation of Industry 4.0, we are talking about the same automation, but here we want to have complete autonomous systems in the industry, where this individual, separate, automated systems will also be talking to each other, they will be all interconnected. So, communication is very important in the context of Industry 4.0, because we want to have connected everything.

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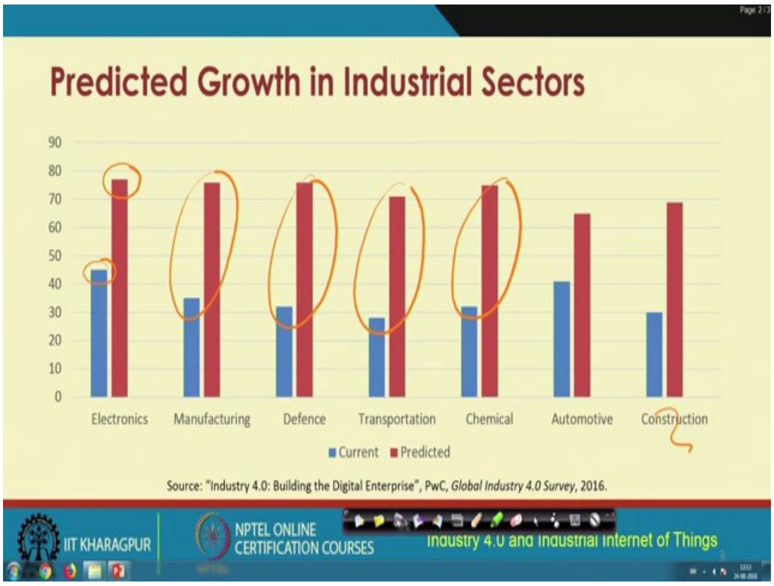


So, Industry 4.0 has become very popular. In this particular plot, as you can see, for different sectors electronics, manufacturing, defense, transportation, chemical, automotive, and construction. What is the current production, current growth, and with respect to that how much is the predicted growth?

For example, for electronics market, the current growth trend is about 40 to 50 percent. And it is predicted that with the incorporation of Industry 4.0, IIoT. The growth is going to be accelerated from about 70 to 80, it is a huge leap. Likewise, for manufacturing also we see, defense also we can see a similar kind of growth pattern. So, these are all huge leaps in growth that are going to come in the industrial sectors, the different industrial sectors with the incorporation of Industry 4.0 and Industrial IoT, in general.

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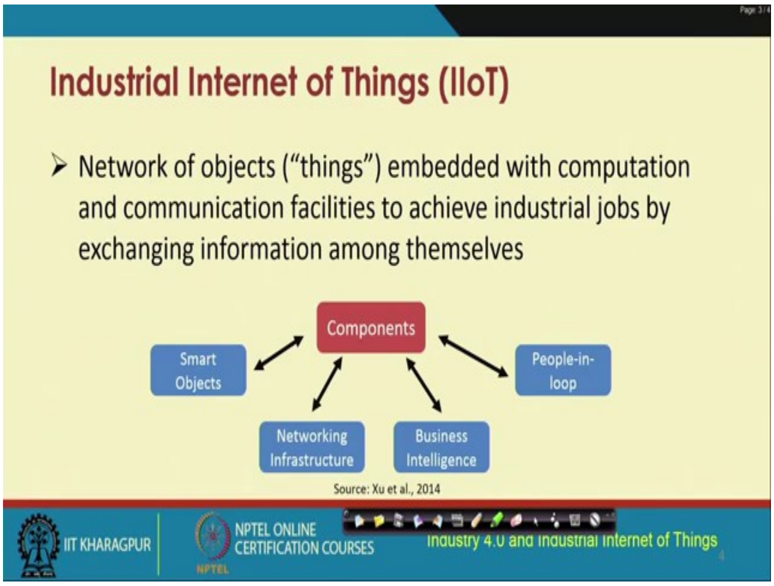


So, we need to understand some of the basics of Industrial IoT. Industrial IoT is essentially IoT for industries. So, here whatever we have learned about in IoT in the fundamentals in the first module, everything is applicable here as well. But, here additionally we are talking about consideration of industrial machinery, and industrial things, basically the industrial machinery, and industrial objects interconnecting them using sensors and actuators. And overall improving the industrial processes, their efficiency, productivity.

In Industrial IoT we are talking about networking of different industrial things or objects that have different embedded objects, which can perform different computation and communication facilities. They can together achieve industrial jobs by exchanging information among themselves. Basically sensing, actuation, computation, communication, everything put together in the industrial setting for improving their industrial processes, making the different machinery in the industries smarter.

So, we will have the different components of IIoT as the smart objects that means, the smart machinery, so basically all these industrial objects that we are talking about can be made smarter. Networking infrastructure has to be there, because the data will have to be sent from these smart objects elsewhere for further processing that elsewhere could be cloud, it could be server, it could be server forms or anything.

Then business intelligence is another component. Business intelligence means like collecting all the data from these different smart objects, and trying to improve upon the business processes. Predicting the business outcomes, improving upon the business outcomes through the incorporation of different intelligence. So, different predictive techniques such as machine intelligence, statistical interference. All these techniques will be incorporated to improve upon the business intelligence.

The last one is people in the loop. People in the loop means, like decision makers, different other stakeholders, they will be also have to be kept in loop, so that overall not only these different objects, the connected objects, but everybody together will be achieving the improved ecosystem of industrial IoT.

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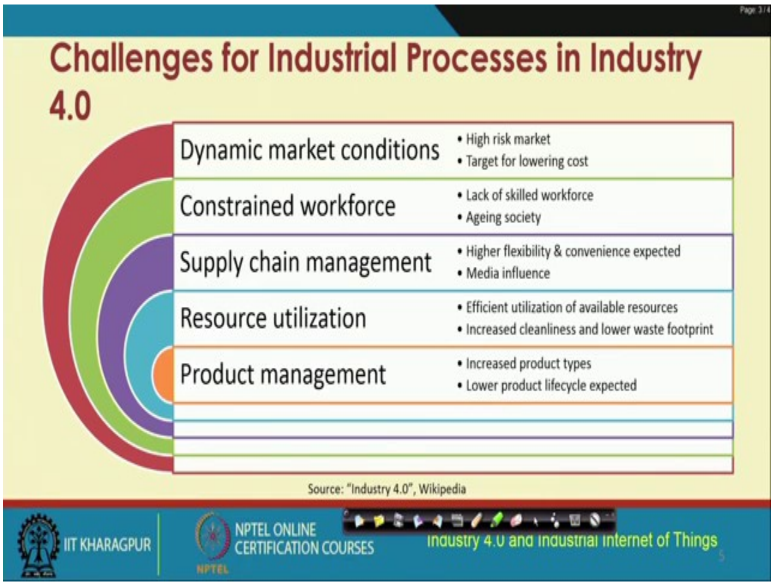


So, looking back Industry 4.0 if you are talking about incorporation of IIoT in the Industry 4.0 ecosystem, there are different challenges that are going to be faced for industrial processes. So, basically adoption of IIoT for improving industrial processes, different challenges are going to be faced. So, these are some of these different challenges categorized in different ways.

The first one is about dynamic market conditions. So, here we are talking about things such as high risk market, target for lowering cost, etc. So, these are the things that are going to happen, if you are gradually transforming towards Industry 4.0, with the incorporation of IIoT.

Constrained work force means, the work force that that is already existing is not already skilled to adopt industrial IoT. They do not already have the requisite skills that are required. So, they do not have, so they have to be skilled, that is work force will have to be skilled in order to be able to use IIoT for industry 4.0 compliance and improving upon these industrial processes consequently.

Supply chain management, the challenges over here are higher flexibility and convenience expected, due to the incorporation of IIoT in these industrial processes. So, higher flexibility is expected in the supply chain management. Media influence is also going to be there, so all these things will have to be handled. Resource utilization, efficient utilization of available resources that is what is expected, you want to improve upon the resource utilization. And there has to be increased cleanliness and waste disposal.

So, all these things are advantageous, but at the same time these are challenging. And we will have to be done adequately with properly skilled workforce. Product management is about increased product types. Here with the incorporation of different heterogeneous components, heterogeneous machinery, which were not connected before, what the challenge that we are inviting over here, is that we are having large number of different types of products, which will have to be interconnected.

And consequently what is going to happen is that the product life cycle is also going to be changed, it is going to be lower the number of that the duration of time, that a product will be developed over is going to be reduced. These are all advantageous, but at the same time this will also pose challenges for the industrial processes that would be required for complying with Industry 4.0.

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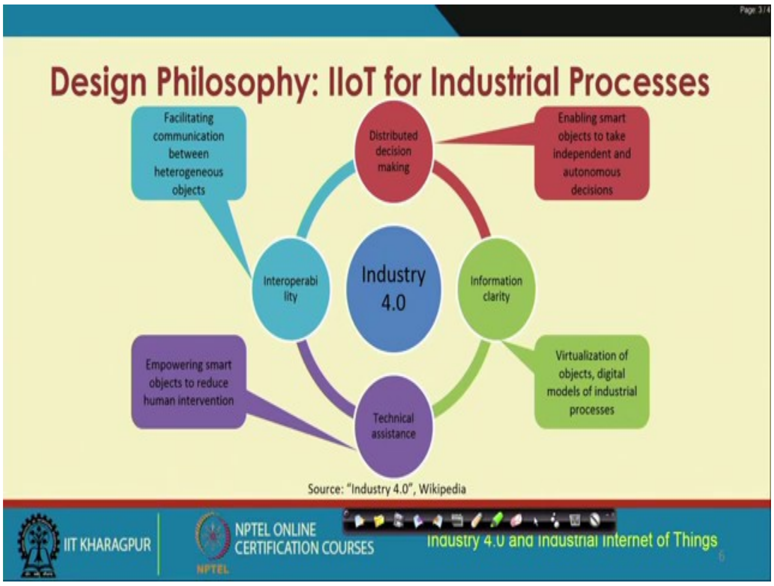


So, let us look at the design philosophy behind the inclusion of IIoT for improving the industrial processes. The first thing, so there are four different facets that we have considered. Number one is interoperability, second is distributed decision making, third is information clarity, and fourth is technical assistance. So, let us take up one by one.

Interoperability is about facilitating communication between heterogeneous objects facilitating communication between heterogeneous objects, heterogeneous machinery running different, different, because these are now smart objects. In the IIoT world we are talking about smart machinery and smart objects. These are all heterogeneous. And now you want to have communication between them, and that is what is the objective of Industry 4.0.

The second thing is distributed decision making, because these different machineries the physical objects and so on. They are now interconnected in the Industry 4.0; they are all interconnected. So, distributed decision making will have to be done. So, each of these different machines will locally perform certain decisions themselves, certain analytics will be performed in them individually plus together also they will have to do something, for the holistic good.

So, the third one is information clarity, where we are talking about the visualization of the objects. So, basically all these different objects, the digital models of these different objects, the data that are procured from these objects, these will have to be visualize, the data visualization aspect of it for information clarity. This is what is the third component of the design philosophy. And the fourth one is the technical assistance. And here we are talking about empowering smart objects to reduce human intervention. And this kind of technical assistance will also have to be incorporated into the design philosophy of IIoT for industrial processes.

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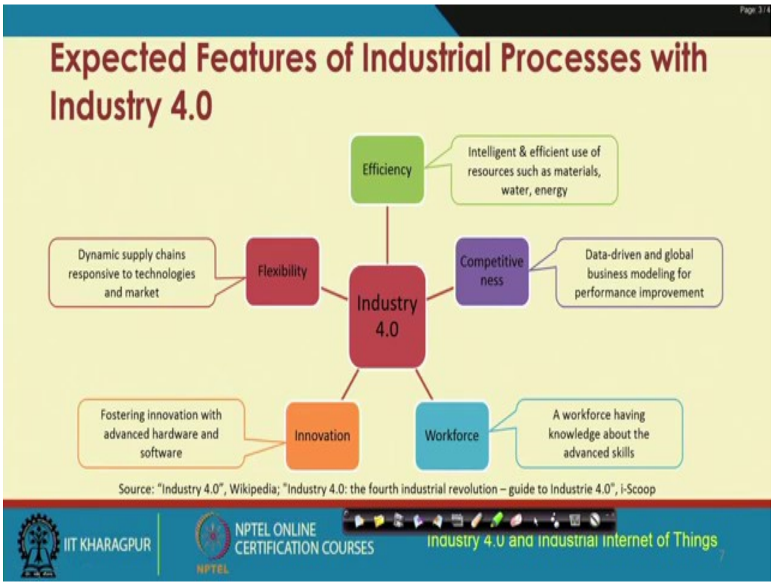


So, what are the expected features of the industrial processes with Industry 4.0, what are the expected features, what is going to achieve, what is going to be achieved. So, number-1 is efficiency. So, we are doing everything in order to improve upon the efficiency, of course that brings in challenges like the ones that I just mentioned a while back, but overall the efficiency in the industrial processes are going to be improved with the incorporation of Industrial IoT.

So, basically efficiency means like, we are talking about intelligent machinery, performing things efficiently. So, basically, even if you are talking about resources, efficient utilization of energy, efficient utilization of water, or other resources, and other materials that are used. These are all going to be efficient, and the reduce consumption of all these resources is also going to happen, with the incorporation of Industrial IoT. So, overall efficiency resource utilization, reduction in resource utilization, these are the things that are going to come with the incorporation of Industrial IoT.

Second thing is competitiveness. In the Industrial IoT era is that everything is going to be data driven, data are going to come from all these distributed machineries. And this is not going to be just local within a particular industry, but across different industry, and also you can scale it up to the global level. So, global business modelling for performance improvement is what is desired. So, everybody is going to compete with one another, but the data will serve as a basis for improving upon this competitiveness individually by each of these different industries.

Third is the work force. Here we are going to talk about is skilled workforce, which will have advanced skills in all these domains of IIoT, and that knowledge has to be built up. So, this is the third feature. The fourth feature is about innovation. So, in overall what is going to happen is through the incorporation of hardware, software, and the connected behavior between these different objects. You are going to foster innovation, and improve upon the efficiency. These are also interconnected. So, improve upon the efficiency through this innovation.

And finally, the flexibility this is also a prime feature of the incorporation of IIoT for improving upon industrial processes. This is flexibility about having dynamic supply chains, which are responsive to technologies, responsive to market changes, and so on. So, these are the different features of expected features of industrial processes for Industrial IoT or Industry 4.0.

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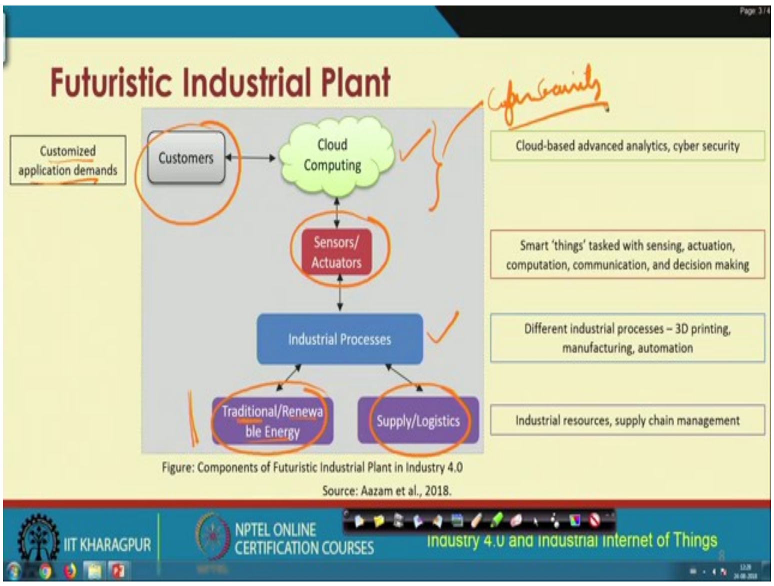

So, let us look at in the IIoT world, how a futuristic industrial plant typically is going to look like. So, what we are going to have is something like this, we are going to have different energy sources, traditional energy sources, or the renewable energy sources. And renewable energy sources like solar, wind. And traditional means like whole-based energy, electricity, and traditional forms of electricity, plus you have all these different energy sources plus these supply and logistics. So, industrial resources, supply chain management, these are considered in this particular layer. So, these will help in improving these industrial processes. Different industrial processes in this layer will be considered like manufacturing processes, automation, 3D printing, and so on. So, these industrial processes with the help of these traditional or renewable forms of energy plus supply and logistics these are all going to show in this data, and with the help of the sensors and actuators, this data are going to be in fact collected.

These smart objects, the smart things, the smart machinery will be touched with sensing, actuation, computation, communication, decision making. And all these data will be sent to the cloud for further analytics. So, based on the analytics, the customers based on their customized application demand are going to get all these different services.

So, cyber security is also another consideration. And particularly in the context of cloud, people have lot of considerations about cyber security. And cyber security is something that we have already talked about in the context of Industry 4.0. So, cyber security is a fundamental consideration, because people do not want to, people are very much considered, very much concerned that the data that are coming from all these different machineries in different industries. They should not be compromised either through the network through, which the data are flowing or wherever the data are being processed, at the cloud end. So, cloud security is a very important consideration in the context of Industrial IoT.

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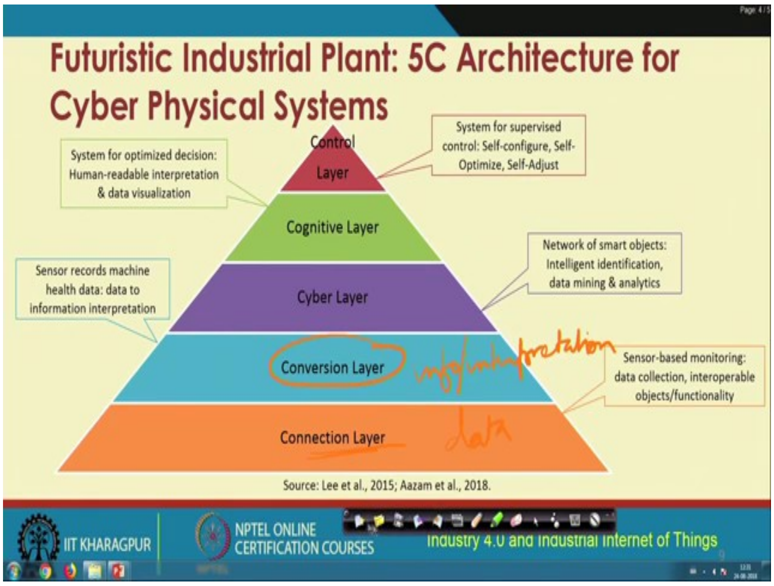


So, when we are talking about this kind of futuristic industrial plant, the 5C architecture. And this is actually an architecture, which has been proposed for cyber physical systems. And when we are talking about Industrial IoT, the connected machinery that we are talking about having all these smart interfaces through sensors and actuators.

So, what is going to happen, these machineries are all going to behave as cyber physical systems. And what is a cyber-physical system? That we have already seen in a previous lecture, what is a cyber-physical system, and the different properties of it, we have already seen in a previous lecture, we have understood what is cyber-physical system is, but now we need to understand that what are the different considerations from an architectural view point for these futuristic industrial plant, which use these cyber physical systems and IoT.

So, we will start from the connection layer. Connection layer is talking about the use of different sensors, the sensor-based data collection, interoperability, issues of objects, physical objects, smart objects, functionality of these different objects, all these are issues at the connection layer. Then comes the conversion layer, here we are talking about sensor records, machine health data monitoring, prediction, information interpretation, and so on. However, in this layer we are talking about the conversion of the data into information, and its interpretation. Then comes the cyber layer, and the cyber layer is talking about this networking aspect of it, network of smart objects, intelligent objects, which will need some kind of an identifier, and from this objects the different data are going to be retrieved. And you need to run some kind of analytics to mind the data that is received to you need some kind of analytics, and basics of analytics also we have already understood in a previous lecture.

And then the cognitive layer, cognitive layer basically talks about having systems for optimized decision making. So, here we are talking about data visualization, human-readable interpretation, and so on. And finally, the control layer, this basically talks about actuation control, supervised control, then self-configuration, self-optimization, self-adjustment, which are different in different perspectives in the control layer. These are all important considerations in the 5C architecture for cyber physical systems.

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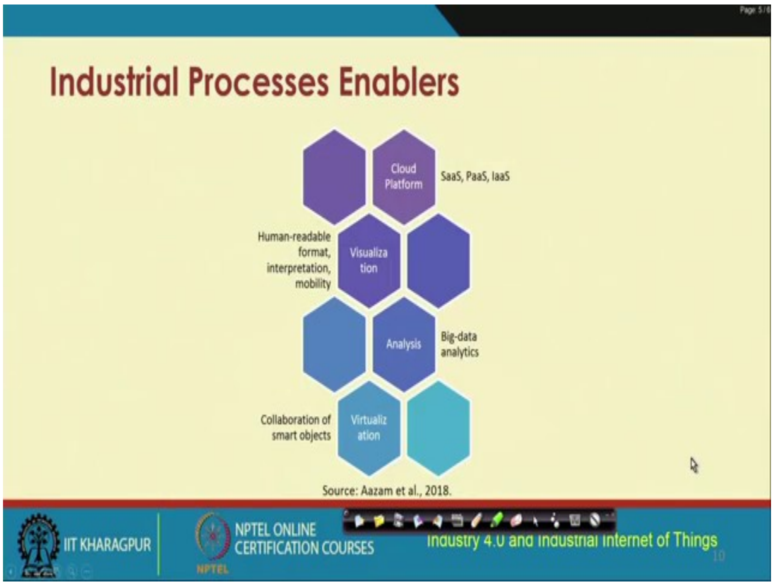


Now, what are the different enablers of the industrial processes in the Industry 4.0 concept different things, cloud platform offering different services like software-as-a-service, platform-as-a-service, in infrastructure-as-a-service.

Second is the visualization aspect, which is about receiving the data, reading the data, interpreting the data and so on. Then comes the analysis which is about use of different analytical method statistical wants big data, machine learning-based analytics. And finally the virtualization, which is about the collaboration of the smart objects, which are the different enablers of industrial processes.

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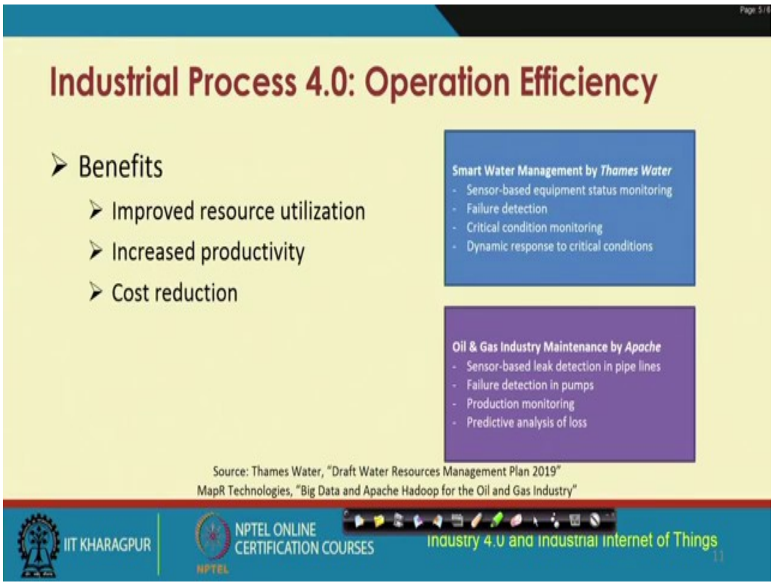


Now, let us look at one by one the different the different aspects of the industrial processes in the Industry 4.0. So, the first one will start with is operational efficiency. So, operational efficiency will have to be improved, it gets improved with the incorporation of Industrial IoT for Industry 4.0 in the industrial processes.

So, the benefits that are going to be resulting from this kind of transitioning is that we are going to have improved resource utilization. So, all these different resources, the machinery. The utilization of these resources are all going to be improved in the Industry 4.0 world. Second is that the overall productivity through the use of the industrial processes in the Industry 4.0 are going to be increased. There is going to be increased productivity in the industrial processes, and cost reduction.

Some of the examples of different industries, which I have used the solutions are Thames water for smart water management. Apache for oil and gas industry maintenance, and the different innovations that they have had in terms of the incorporation of IIoT, these are all mentioned in front of you.

So, these are basically they start with sensor-based equipment monitoring--the status monitoring, detection of failures, critical condition monitoring, and dynamic response to any kind of critical condition, that might be happening that happens for any kind of this kind of smart systems developed by all these different industries like Thames water by apache for oil and gas industry maintenance. So, it will start with the monitoring status monitoring, failure detection, control critical condition monitoring, and the dynamic response to critical conditions.

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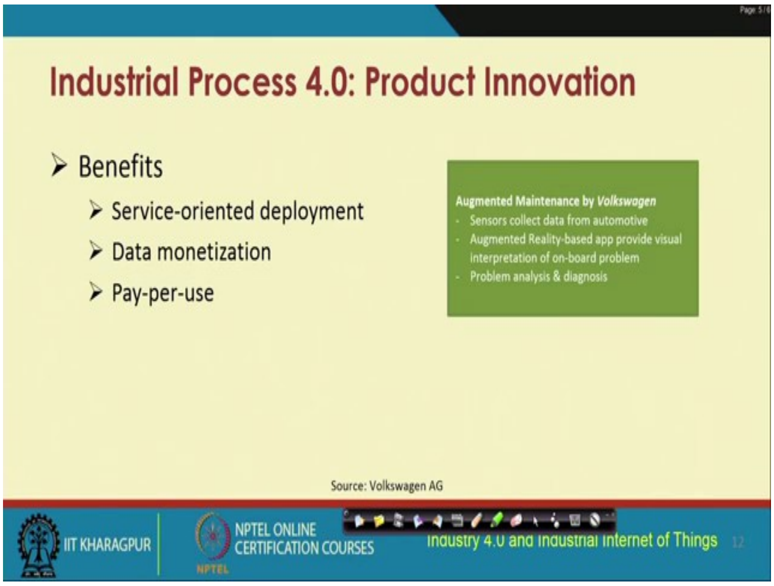


Product innovation; the benefits are service-oriented deployment, data monetization, all these data that are going to be retrieved huge volumes of data these are very much resource full. So, data can be used, it can be monetized. And companies like Volkswagen have already benefited out of it. So, they have started with the augmented maintenance, where they are talking about the use of technology is like augmented reality, and smart sensors, to improve upon the detection of different problems on board these machinery, and also the analysis and diagnosis of the different faults that are going to happen in these different machinery. So, product innovation is going to happened through this kind of transformations. And Volkswagen or augmented maintenance is an example of such kind of product innovation.

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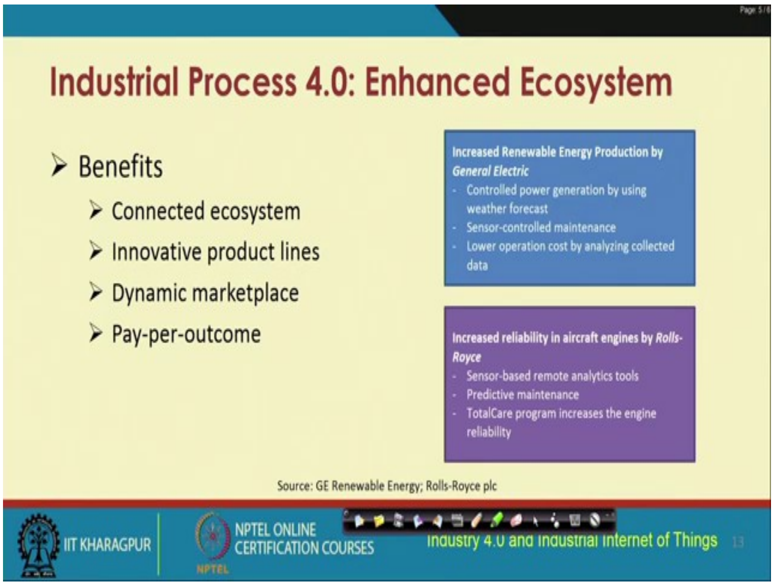


Third is enhanced ecosystem, the benefits are that we are going to have a connected ecosystem, where there are going to be innovative product lines, supporting dynamic marketplace, and there is going to be pay-per-outcome kind of ecosystem. So, pay per outcome means based on the outcome the users are going to be the users are going to be built, and they have to pay per the outcome that they are going to receive, company is like General Electric, they have come up with increased renewable energy production.

Then another company Rolls Royce increased reliability in aircraft engines, and this also they have achieved through a number of different mechanisms, and these are the different features that have been given for each of them. So, I am not going to mention them over here explicitly, but these are the different features for each of the systems that are produced by these companies like general electric and Rolls Royce, who basically supply the engines for the different aircrafts.

But, as you can see over here; here also you have sensor-based monitoring, predictive maintenance, then total care is basically there program, which increases this engine reliability in Rolls Royce. So, these are some of these things that they have achieved through the incorporation of IoT in their industrial processes.

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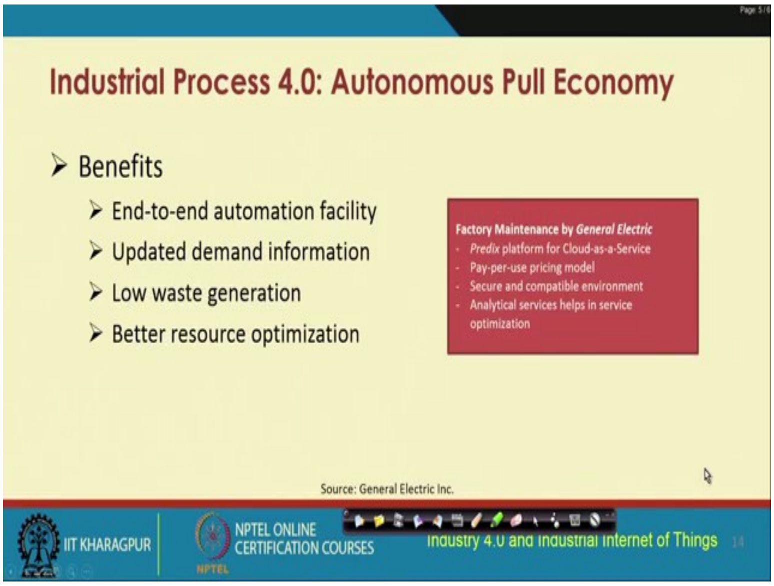


Next comes autonomous pull economy. Here the benefits are that we are going to have end-to-end automation facility, updated demand information, low waste generation, low waste footprint overall, this is very important, low waste footprint, and better resource optimization. So, the company general electric, they have come up with their factory maintenance system, which basically achieves these features through the incorporation of IIoT.

They have come up with a platform which is the Predix platform, they use this platform for offering cloud-based services. They have a pay-per-use pricing model in this particular platform. They have a secure and compatible environment for use of factory maintenance and analytical services, that helps in service optimization. These are the different features of the factory maintenance system by general electric, which is the Predix system.

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So, essentially we are transforming into the future, where we are going to have smart factories. And the different application areas for the smart factories are smart facility management, connected factory, inventory management, so basically smart inventory management, smart production line management, smart process safety and security, smart service quality control, smart supply chain optimization, and smart packaging and management. These are the different applications of the incorporation of IIoT and the industrial processes the different industrial processes for building IIoT based systems in the Industry 4.0 scenario.

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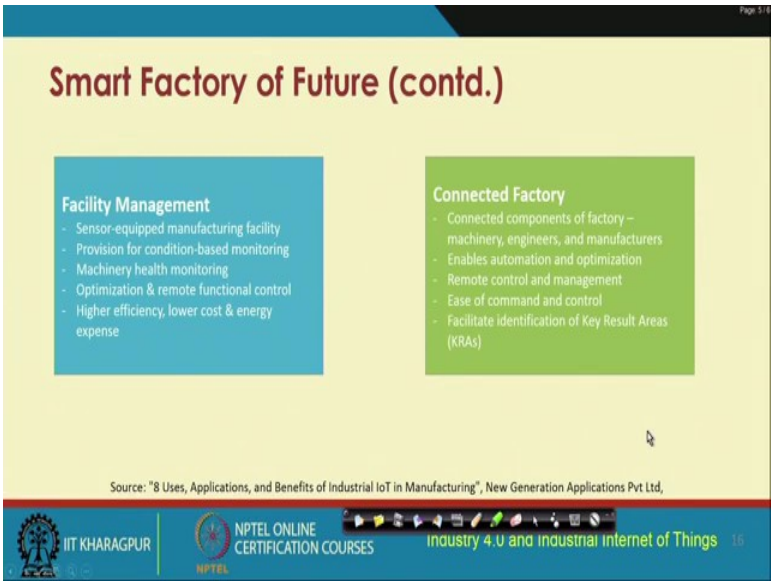

So, these are the ones like facility management, here we are talking about sensor equipped manufacturing facility. There would be provision for condition based monitoring, monitoring of machine health, optimization, and remote function control, and improving upon the efficiency, lowering the cost, and the energy expense.

Connected factory, here we are talking about connected components of the factory such as the machinery components, engineers will also be connected manufacturers will all be connected. So, it is not just machinery, but engineers, manufacturers, machinery, everything connected together in a smart factory. Enabling automation and optimization, remote control and management, ease of command and control, and facilitation of the identification of the KRAs, are the key result areas.

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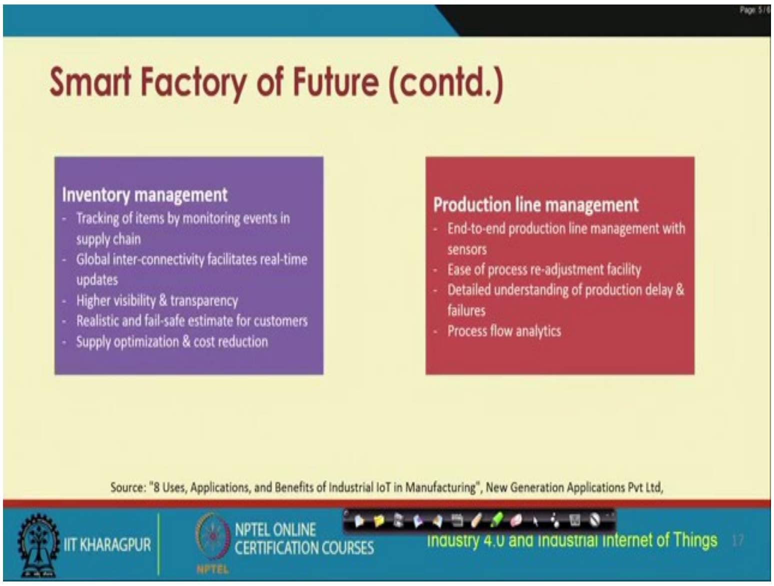


Inventory management, it talks about tracking of items by monitoring events in the supply chain. Global inter-connectivity facilities in real-time, and providing real-time updates. Higher visibility and transparency, a realistic, and fail-safe estimate for customers, and supply optimization, and cost reduction.

Production line management here we are talking about end-to-end production line management with different sensors, actuators. Automating the entire product line; then ease of process re-adjustment facility, detailed understanding of production delay and failures, and process flow analytics.

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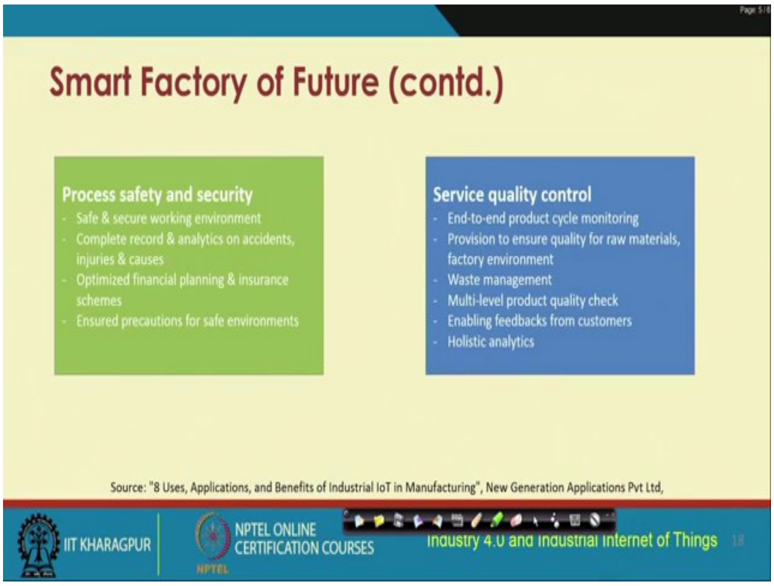


Process safety and security, here we are talking about safe and secure working environment. Safe and secure processes, safe and secure environment, these are all going to be performed with the help of these different IoT devices, these different sensors actuators. And we are going to get complete record based on the data that are received from these different IoT devices. And this will help in financial planning, optimized financial planning and insurance, planning about the insurance schemes that will have to be used.

Service quality control is another one, which is about end-to-end product quality life cycle monitoring, product life cycle quality monitoring, provisioning to ensure quality of raw materials that are procured, factory environment, monitoring and automation, waste management, reduced waste management, multi-level product quality check, holistic analytics, enabling feedback from customers. So, all of these things, the service quality aspects, and the control of them are all going to be performed with the help of smart factories.

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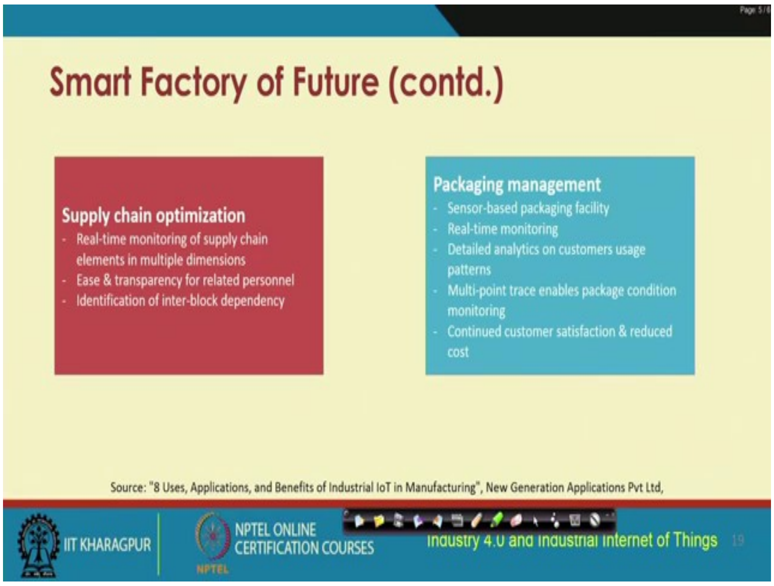


Next comes supply chain management and optimization. Here we are talking about real time monitoring of supply chain, elements in multiple dimensions, ease and transparency for related personal, and identification of inter-block dependency. Packaging management talks about sensor based packaging facility, real-time monitoring, detailed analytics on customer's usage patterns, multi-point trace enabling package condition monitoring, continued customer satisfaction, and reduced cost.

So, multi-point trace means what? Like tracing basically if a particular package is lost, where it is lost, not only lost if it is misplaced. All these tracking and from multiple points tracking of these different packages would be possible in a smart factory. And this is a common problem actually, tracing and tracking is a common problem in factories, and through the use of smart factory IIoT, the industrial processes will help in this kind of tracking affairs.

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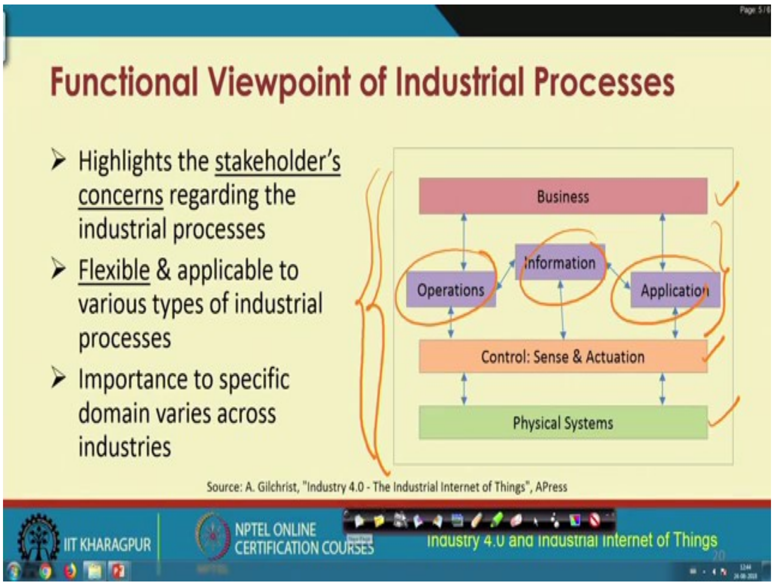


So, now let us look at the functional viewpoint of industrial processes. So, physical system, then we have the control, which is basically talking about sensing and actuation, and on top we have business layer. So, in between we have the operations, information, and application, which will basically help in growing up this entire model.

So, basically we are talking about highlighting the stakeholder's concerns regarding the industrial processes, and flexible and applicable system for use of various types in the industrial processes. So, all these things are going to be performed with the help of this kind of functional viewpoint architecture of these different processes industrial processes in the Industry 4.0 world.

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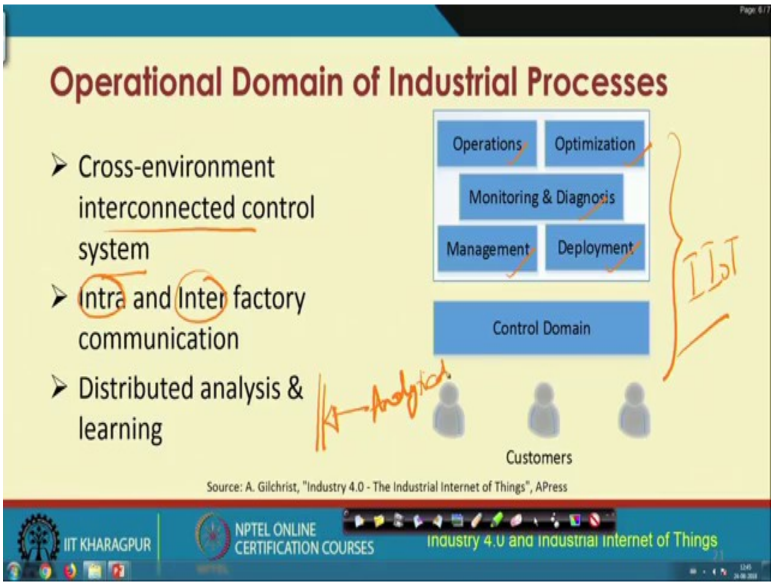


The operational domain of the industrial processes includes the control domain, the management, deployment, monitoring and diagnostics, operations, and optimization. These are self-explanatory, so I do not need to explain them further, but what we are going to have is a cross environment interconnected system in the IIoT world. And that is where this interconnected control system is also very important interconnected control system.

And so we here because it is interconnected, if we are talking about not only intra-factory communication, but also inter-factory communication. And all these data from inter-, intra-factory communication. Those will have to be analyzed, and different kinds of analytics will have to be executed with the help of statistical methods and different other machine learning and AI techniques.

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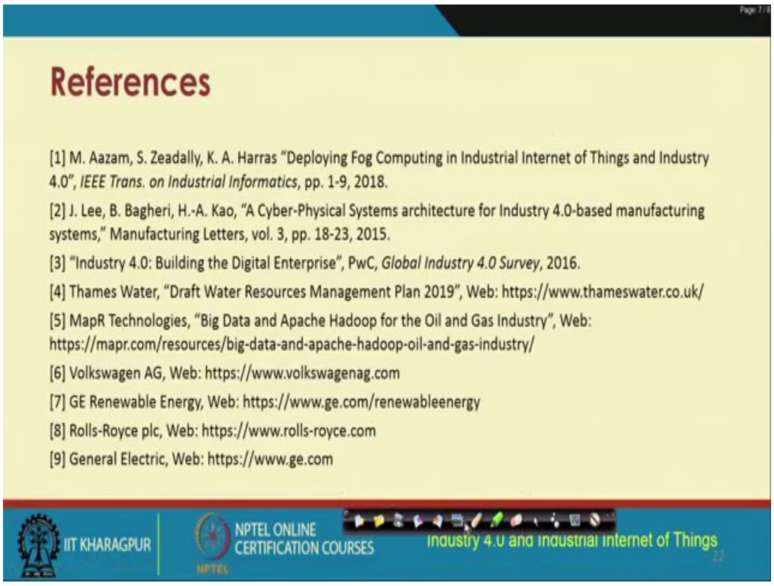


So, before we go to the references, I wanted to show you something at the end to highlight the importance of (the importance of) the incorporation of IIOT in the industrial processes.

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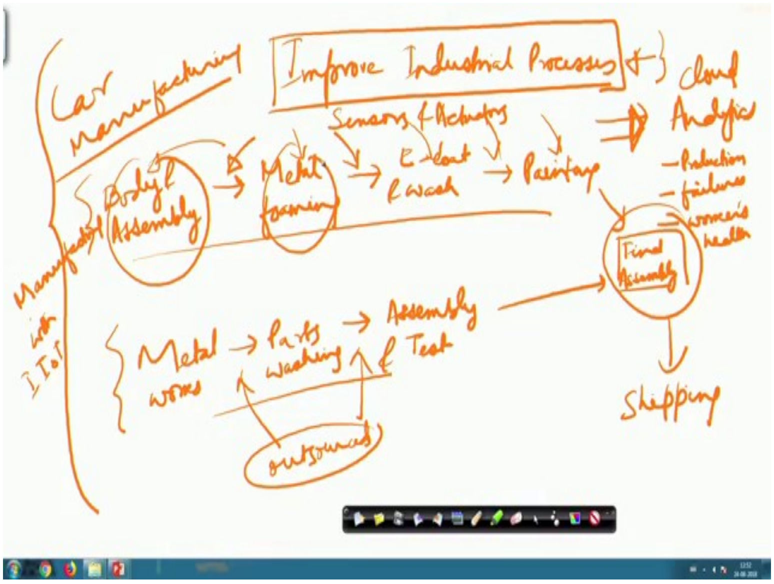


So, we want to do what, we want to improve industrial processes this is the overall objective. So, industrial processes are varied depending on different industrial requirements, different industries have their own set of processes. So, industrial processes are different. So, let us take the example of a car manufacturing process; car manufacturing process.

So, here we are talking about, let us say just an example body and assembly, body and assembly. Then thereafter, we will have something like metal foaming, these are this is a typical traditional process in a car manufacturing plant. Then something like a layer of coating e-coat and wash, then painting, full painting, of these different machinery that the different parts and so on.

In parallel, there would be metal works, their needs to be parts washing, there needs to be assembly and test, and after all of these things together, so this row, as well as this row together, finally will give you the final assembly. So, what we mean is these processes, they are going to be performed in parallel and together will get into the final assembly. And after final assembly, it will be shipping. So, this is a very broad high level view of the industrial process, a traditional industrial process, in a traditional kind of car manufacturing industry.

Now, let us look at we want to make it smarter, we want to make it smarter with the incorporation of IIoT. So, we want to use these different IIoT components, sorry, in this IoT components in it in order to have improved industrial processes, which will have better efficiency, and manageability, product production is going to be improved and all these different features that we have talked about in this lecture earlier, so going to have that.

So, now if you want to do this, these are the things that you can do. You could use table sensors over here sensors and actuators, you could use different sensors and actuators here and not only in these different transitions, but also in each of these different phases. So, throughout you can use the suitable sensors and actuators.

So, this will continuously monitor, and do any kind of actuation that might be required. So, sensors and actuators will do the continuous monitoring of these different units and the different phases. Likewise, here also you are going to have all of these. So, this will be like let us say that these are outsourced, they maybe outsource or they may not be outsourcing.

So, even if they are outsource component, but with the help of these different sensors and actuators, and different other monitoring units, you could be end-to-end this continuous monitoring could be performed. Now, what is going to happen, these sensors and actuators are going to throw in lot of data. From this data you can run different analytics.

And these analytics could be run at different server, server forms or whatever or in the modern day we can used cloud-based services for these analytics. So, we can use cloud-based analytics. So, we could use cloud, and we can come up with different predictions about let us say production predictions about the future production rate, production rate, we can have predictions about failures. We can have predictions about workers' health, and we can do monitoring of the different the health condition of these different machinery.

So, essentially what we are doing is that this is the example of use of IIoT in a typical car manufacturing with IIoT. So, the previous one was without any sensors, actuators, without any kind of computational facility, no cloud, no analytics, nothing. Some maybe if you are talking about Industry 3.0, some individual components might be using separate computers separately, but in the Industry 4.0, we are talking about this holistic connectivity.

And holistic monitoring lots of predictions autonomous behavior of the systems, autonomous monitoring, maintenance, prediction everything together of these different industrial processes. So, this is the example of how IIoT can transform, and improve upon the existing industrial processes for improving the productivity, efficiency and safety.

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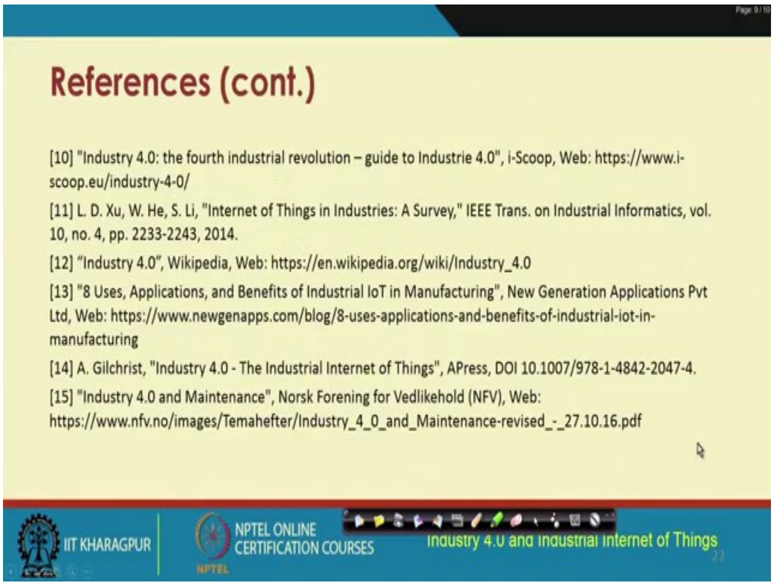


Now, let us go back and look at the differences that we were talking about, these are the list of different references. And if you are interested, and I would encourage you in fact to go through some of these references to have further understanding about the industrial processes, the different aspects of it, what are the I know in this particular lecture, we have talked about the car manufacturing.

But, I would also encourage you to look at other industrial processes, particularly if you are taking a course, and you come from a particular industry sector like car manufacturing could be coming from different are the industrial sectors. Like let us say steel plants or, food processing industry or, pharmaceuticals industry. You can also think about how you can transform your existing processes in your industries to be more modern efficient with the incorporation of IIoT, and trying to be compliant with the expectations and objectives of Industry 4.0.

Thank you.

**Introduction to Industry 4.0 and Industrial Internet of Things**
**Prof. Sudip Misra**
**Department of Computer Science and Engineering**
**Indian Institute of Technology, Kharagpur**

**Lecture - 21**
**Basics of Industrial IoT: Industrial Processes – Part 2**

In the previous lecture, in the part one of industrial processes, we have gone through the different functional aspects of industrial processes, the different attributes of smart factories particularly from a process point of view. In this lecture, some of the case studies of the implementation of Industrial IoT in the industrial processes. So, brief case studies, which all different companies have already implemented Industrial IoT in their different production processes manufacturing processes.

We will go through some of the examples, and that will be at a very high level and each industry has its own in depth understanding about how it has done the different implementations and deployments and so on. So we will just go through some of these snapshots to understand at a very high level, how which all companies and which all companies have adopted the IIoT. So, these things we are going to get a high level understanding about.

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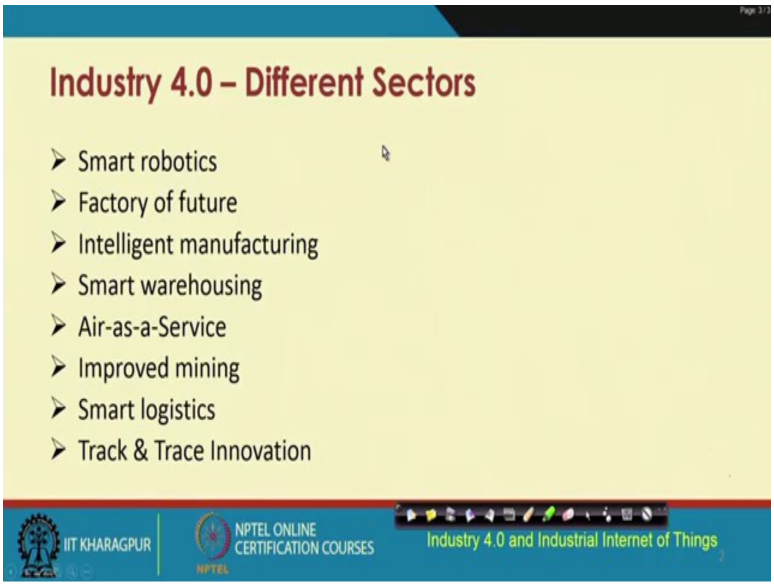


So, when we talk about Industry 4.0, there are different perspectives, there are different sectors, that will need to be considered. Smart robotics is very important, in the context of IIoT, industries in general robotics is very important. Machineries are robotic equipped. So, basically these machines are run autonomously and in most cases, there is no human intervention; and even if there is human intervention, it is minimal. So, smart robotics is widely deployed and used in different industries.

And second is factory of future, intelligent manufacturing, smart warehousing, air-as-a-service. Air-as-a-service is a term that was coined by one of these industries we will go through shortly. So, here basically it is air compressor that we are talking about making it smart, making a air compressor smart and we will look at it in further more detail, improved mining, smart logistics, and tracking and tracing. So, in all of these different sectors IIoT has been already used and their machinery, their different processes in manufacturing and carrying on different other activities in these industries these have been made smarter, with the help of incorporation of IIoT.

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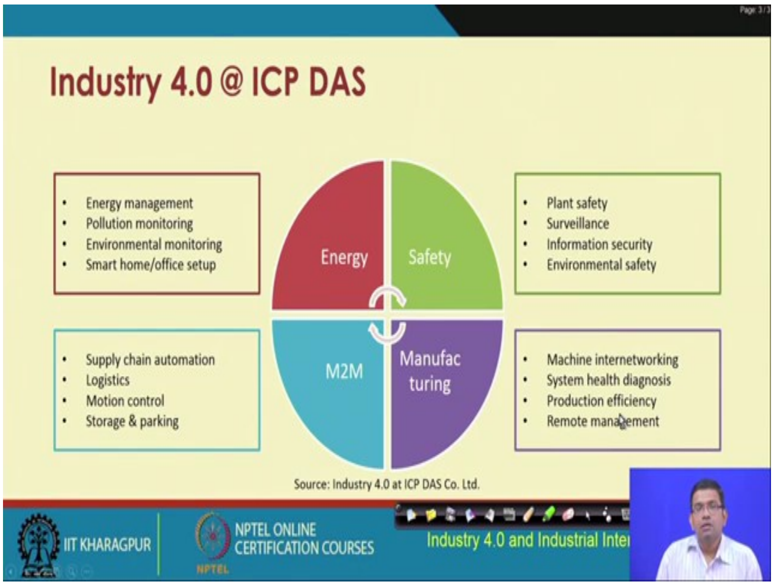


So, there is this company ICP DAS, what they have done is they have different sectors. So, they have the energy sector, M2M, manufacturing sector, and safety. And they have incorporated Industry 4.0 in each of these different sectors. So, basically in the energy sector they have incorporated, Industrial IoT solutions for energy management, pollution monitoring, environmental monitoring, smart home and smart office setup.

In the context of M2M, supply chain automation, logistics, motion control, storage and parking. In the context of manufacturing, machine internetworking, system health diagnostics, system health monitoring, production efficiency, remote management and so on. In the context of safety, plant safety, surveillance, information security, environment safety, so these are the different domains, sectors, in which this company ICP DAS has been working for incorporating IoT solutions to make it Industry 4.0 compliant.

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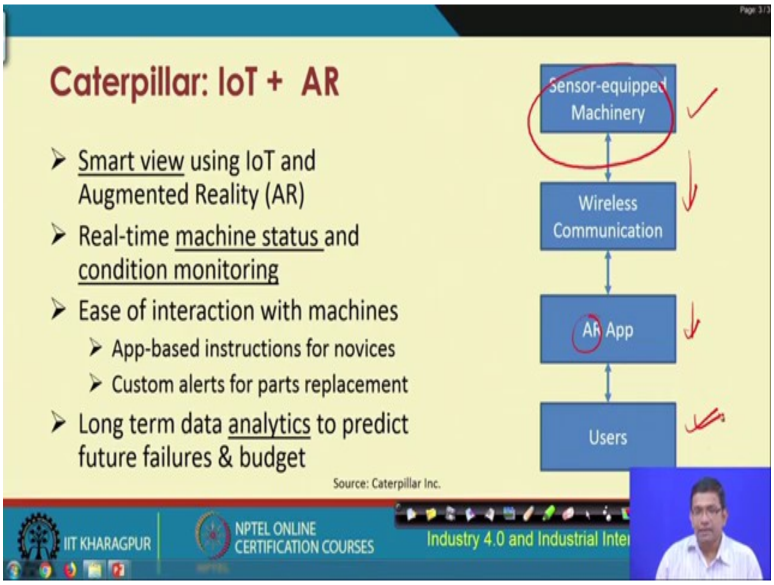


The company Caterpillar, and I think most of you are already familiar with this company Caterpillar. This is in the heavy machinery domain; this company has different products in the heavy machinery domain. And so Caterpillar basically has implemented IoT and augmented reality solutions and that is basically a step forward towards Industry 4.0. So, basically what happens is with the use of IoT and augmented reality, one is able to get a smart view about the real-time machine status and the condition of the machines of the different machines that they have. So, basically they have made these machines that they produce smarter.

So, real-time machine status monitoring can be done their, their conditions can be monitored and so on with the help of IoT and augmented reality. So, basically these machines are also interconnected, and they send different data from one point to another. And all these data are also made available through different apps in the form of different instructions or these different data are made available to the users. And this data can be used for further prediction to predict future failures, and if there is any budget issue and so on.

So, so, basically what they have is sensor-equipped machinery, these smart heavy machineries that are sensor-equipped, actuator-equipped and these sensor-equip machinery throw in lot of data, which are sent through a network typically wireless network. And there is a AR app Augmented Reality app and augmented reality, we have discussed it in another lecture what is augmented reality we have already understood it. So, they have an AR app. And finally, the users are able to get access in a smarter way, they are able to get access and view the system, that they are using.

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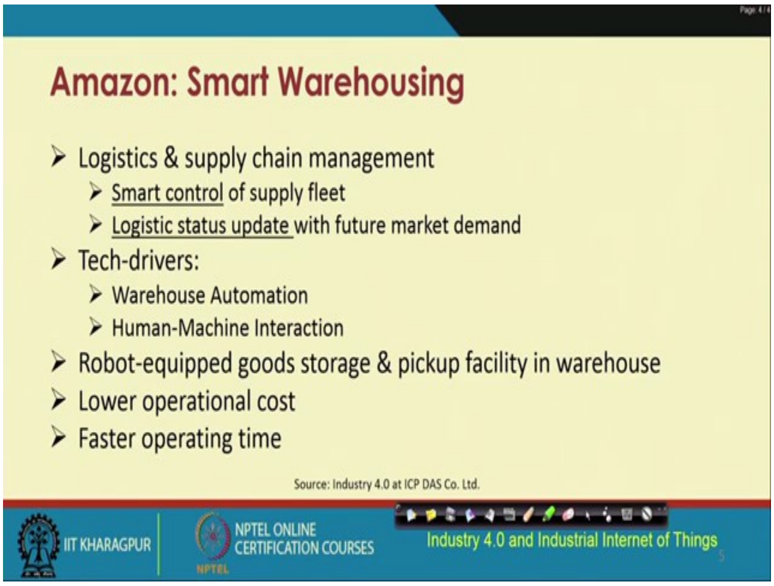


Amazon, I think everybody is quite familiar with this company Amazon, because it is quite popular in the logistics sector. So, Amazon has, every company has, Amazon also has their own supply chain. So, supply chain management, smart logistics etcetera, have been have been done by Amazon through the incorporation of IoT. So, basically smart so they are able to achieve smart control of their supply fleet, and also they are able to get the status update of their logistics with future market demand.

In the context of the smart warehousing basically they have different tech-drivers that are used technological drivers, where one is the warehouse automation and the human-machine interaction. They also have robot-equipped, good storage, and pickup facility in their warehouses. Basically all these things have been done in order to improve upon the overall operations and to have faster operating time, lower operational cost with faster operating time.

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Boeing company, it is in the airspace sector. Boeing has its own aircrafts. Boeing has incorporated IoT in different sectors, for improving the efficiency of their different processes, the efficiency of their machines the way they operate, the, the production process, and so on. So, they have the smart and digital manufacturing facility, which helps in the assembly of millions of aircraft parts.

So, it is a smart process and this is achieved with the incorporation of different sensors and actuators. These basically this smartness in the efficiency in the manufacturing process, improves the overall efficiency in terms of lower assembly delay and lowered response time, reduced errors in the manufacturing process, enhanced production capability.

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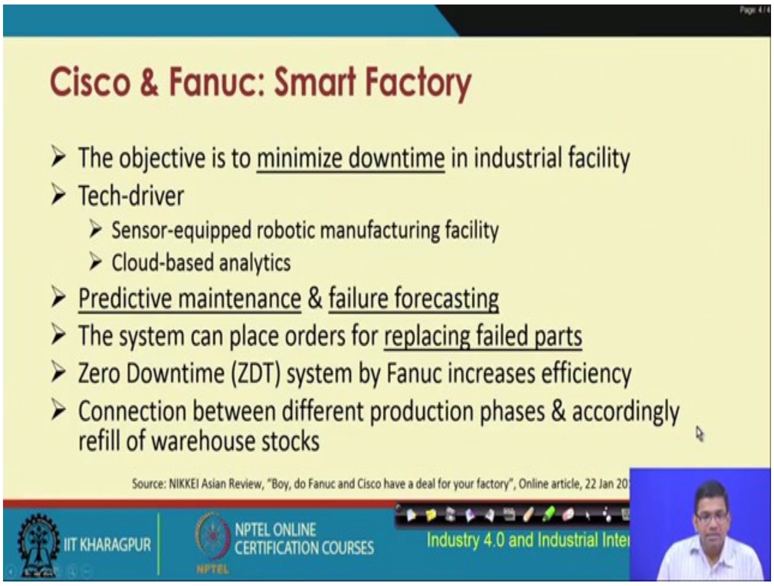


Cisco and Fanuc, they are basically in the they are in the telecommunication sector. And they have developed their smart factory, where the objective is to minimize the downtime in the industrial facility. Their main tech-drivers are basically the sensor equipped robotic manufacturing facility and cloud based analytics. Basically, they are able to perform predictive maintenance and failure forecasting.

And predictive maintenance means like trying to know beforehand even before a machine fails trying to know when a particular machine would need maintenance, further maintenance, and so on. And this basically will reduce the overall downtime, because these parts can be the, the parts which are likely to be failed in the future, they can be replaced beforehand, so that the entire system does not get, does not get crippled and as we can understand that this basically will reduce the downtime of the system.

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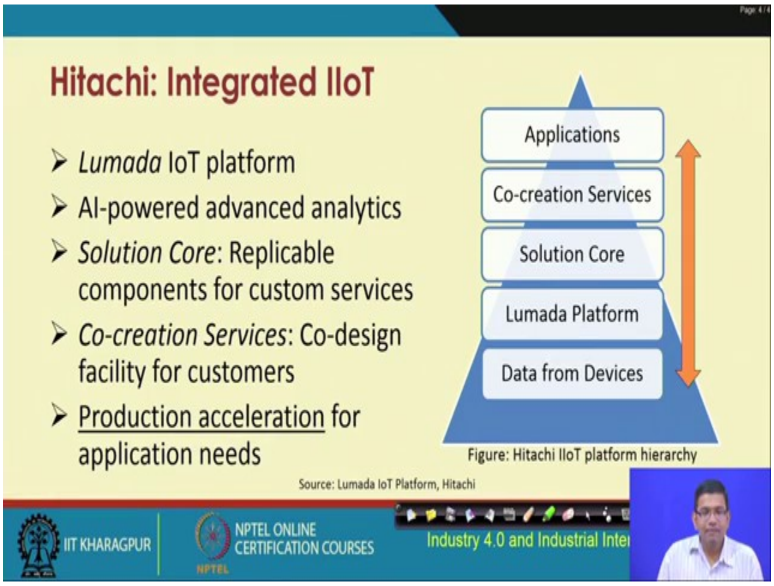


Hitachi is a company that is well understood and well-known. And this company is also incorporating integrated IIoT solutions. They have the Lumada IoT platform and this platform is the key driver in their IIoT solution. So, this platform provides AI based Advanced Analytics, which can help in predicting a particular thing is going to happen in the future and then taking requisite actions.

The other platform the other component that they have in their IIoT platform is the solution core, which has replicable components for custom services. So, essentially through the integration of IIoT solution what they want to achieve is the production acceleration. So, depending on the user needs, depending on the application needs, they are able to produce efficiently, but in an accelerated fashion, whatever they are producing in the market.

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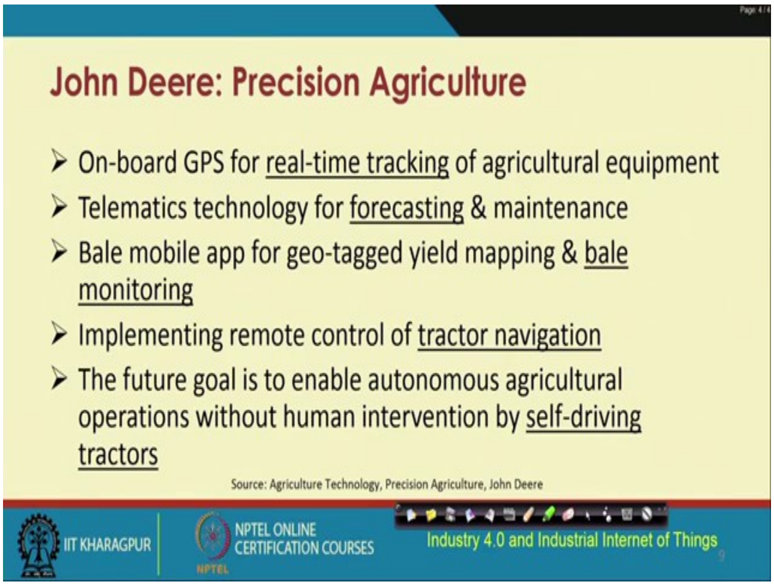


John Deere is a company which is in the agriculture space. They have equipments which are basically different machinery, which can be used like tractors etcetera, which can be used for precision agriculture and these heavy machinery, that are produced by them traditionally, John Deere. So, these machineries are equipped with different sensors and different other devices like GPS, for real-time tracking, understanding the overall health of these machines, telematics solutions are deployed by them. And these telematics solutions can help in forecasting maintenance.

And they also have the bale mobile app the bale mobile app is used for geo-tagging and yield forecasting. They also have different solutions for making the tractors smarter, for example, having some kind of remote control equipment attached to the tractors for aiding in their navigation. Nowadays they are also working on coming up with self-driving tractors, so something very similar to the self-driving cars, self-driving tractors.

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This is this air as a service, which is being worked upon by Kaeser Kompressoren, which is a company which is into the manufacturing of air compressors. So, their air compressors are basically sensor-equipped, nowadays, most many of these air compressors are sensor-equipped, which is in the prediction of future failures. And the this again basically will help in reducing the downtime and saving some of the maintenance cost that is typically high in this particular in, this particular market segment. So, air-as-a-service is basically where users are able to pay per cubic meter of air from these companies own compressors. So, this is a facility that they are providing air-as-a-service. Based on the units of usage, the company earns the revenue.

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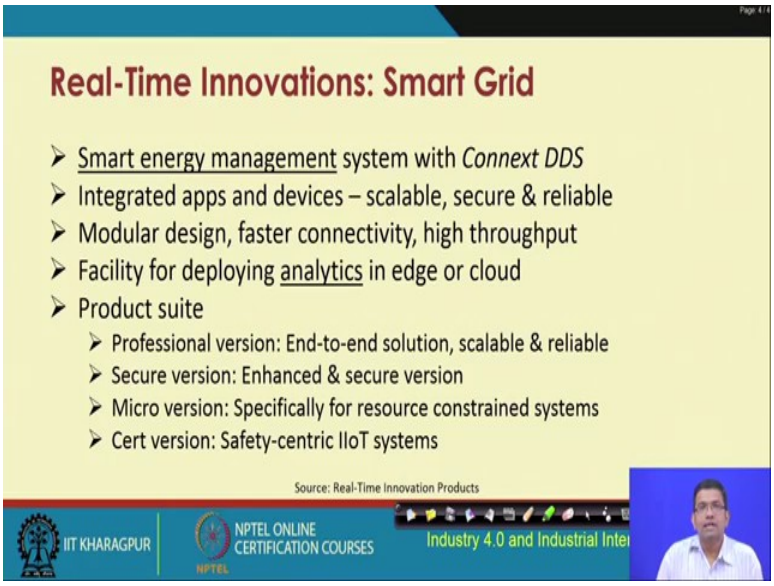


RTI, Real-Time Innovations is another company, which is into the smart energy management space. And they have a solution, which is the Connext DDS, which has different apps and devices and. These apps and different devices, they collect all these different data from the different equipments. And based on this, the different analytics are performed, either at the edge or at the cloud. These data and the analysis of the data basically help the users in acting and making different performing different actions, in a smarter way.

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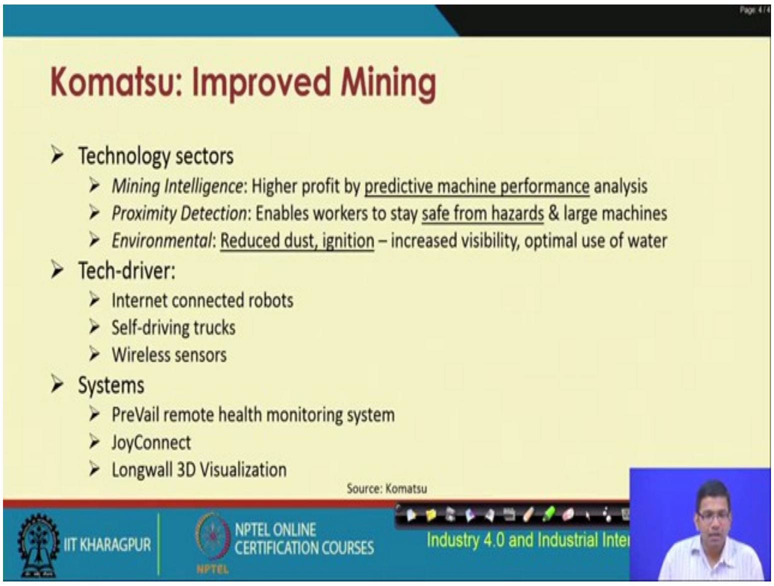

Komatsu is a company, which is into heavy machinery in the mining sector. And their equipments are also made smarter in terms of introduction of different sensors and actuators. And they also use the data that are collected from their different machinery for performing different intelligent actions; intelligent actions which can lead to higher profit by predictive machine performance analysis.

So, they are also into they are also addressing the issue of environment, which will basically, which is basically the use of IoT solutions for reduced dust and ignition, and improving the visibility in the operations, increasing the visibility in the operations of these machinery. Their machinery are internet connected, they are basically robotic internet equipped machinery. They have self-driving trucks, where there are different wireless sensors, that are deployed in them.

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Another company in the mining sector is the Rio Tinto, which has the central control facility with visualization and collaboration tools. They have the capability of real-time monitoring and optimization of the supply chain. So, they have different systems the autonomous haulage system - AHS, which is a fleet of autonomous trucks. The automated drilling system ADS, which enables in the remote enables in the remote operations, in the control draining drilling in the mining space.

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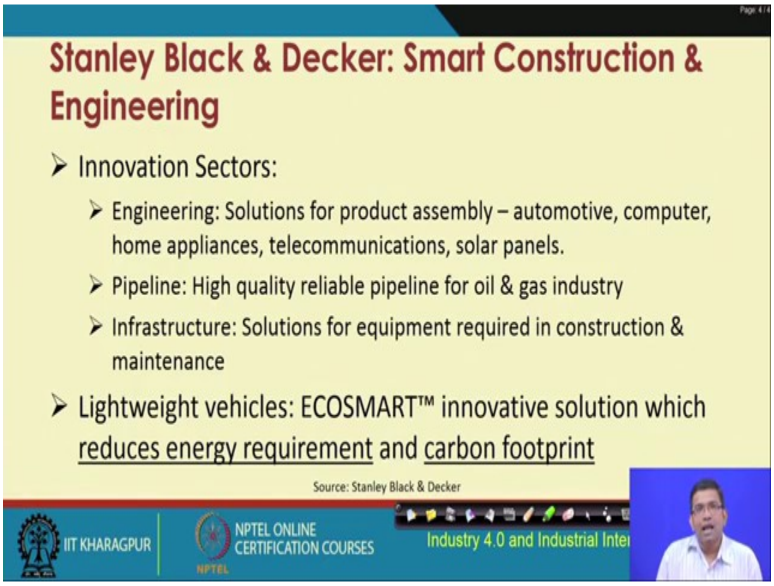


Another company it the Stanley Black and Decker company, it is in the smart construction and engineering sector. So, here also they have different solutions, in terms of incorporation of IoT. In the innovation sector basically, they have solutions for product assembly, automotive, then computer, home appliance, telecommunication, solar panels and so on.

Then for pipeline monitoring high quality reliable pipeline for oil and gas industry and for infrastructure solutions for equipment, which are required in construction and maintenance. They are also gradually into the lightweight vehicles space, they have the eco-smart innovative solution, which basically helps in reducing the energy requirement and the overall carbon footprint.

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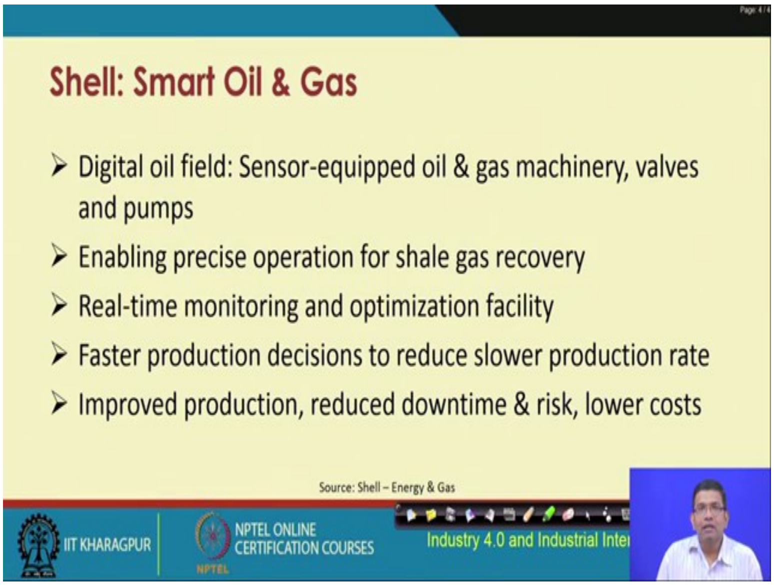


Shell is a very well known company worldwide. It is in the oil and gas sector, supply of oil and gas. And they have now also transformed themselves into smarter solutions. They have smarter solutions for the supply of oil and gas. They have the digital oilfield, where basically you have number of different sensors that are equipped that are deployed basically in these different machinery that are used in oil and gas. So, they also have smarter valves, smarter smart pumps and so on, which are used to pump out oil from the different fields, in which these different machineries are deployed.

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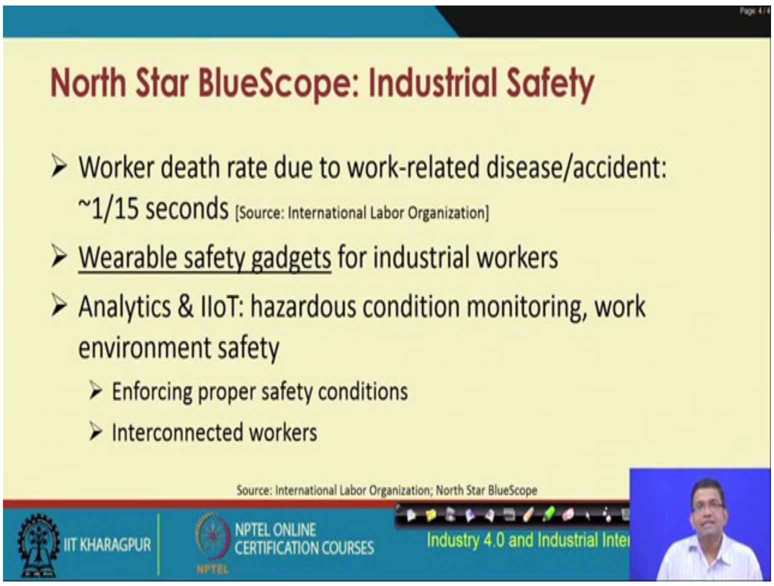

North Star BlueScope, this company is into the industrial safety space. Industry-related work-related deaths are very common, and is increasing every day. So, here is some statistic one death occurs every 15 seconds due to different accidents in the industry. So, this particular company is working on coming up with smart wearable safety gadgets, which can be used by the industrial workers to improve upon the industrial safety.

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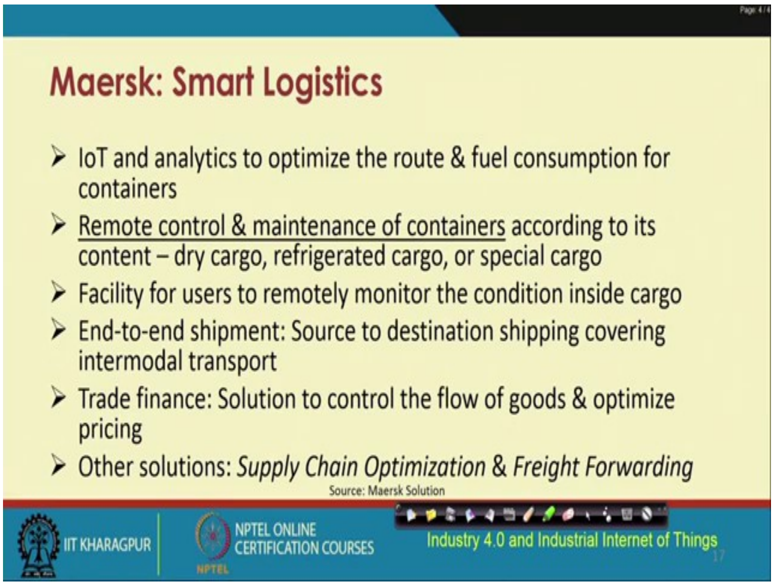


Maersk is basically a company in the smart logistics domain. It has different solutions which are IoT enabled, which used analytics to optimize the route and fuel consumption for containers. So, they have the remote control and maintenance of containers, according to the condition of these different containers. These containers are basically made smarter and they can be monitored remotely. So, they have the dry cargo, refrigerated cargo or, special cargo. And each of these different types of cargoes can be monitored and can be maintained remotely through the use of these smart equipments that are deployed in them. So, they have the smart logistics solutions.

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Magna Steyr is in the smart factory domain, where they have digital mapping of entire production timeline. So, they have vehicle engineering solutions, product production line implementation solutions, and the intelligent production systems are developed by them, which can be help in achieving accuracy, scalability, reliability and also being able to change in terms of the dynamic requirements, change in the dynamic requirements. And they also have the full autonomy of factory, they have a network of humans, machines and resources, they have solutions like driver assistance system, alternative energy storage system, lightweight design, and joining system.

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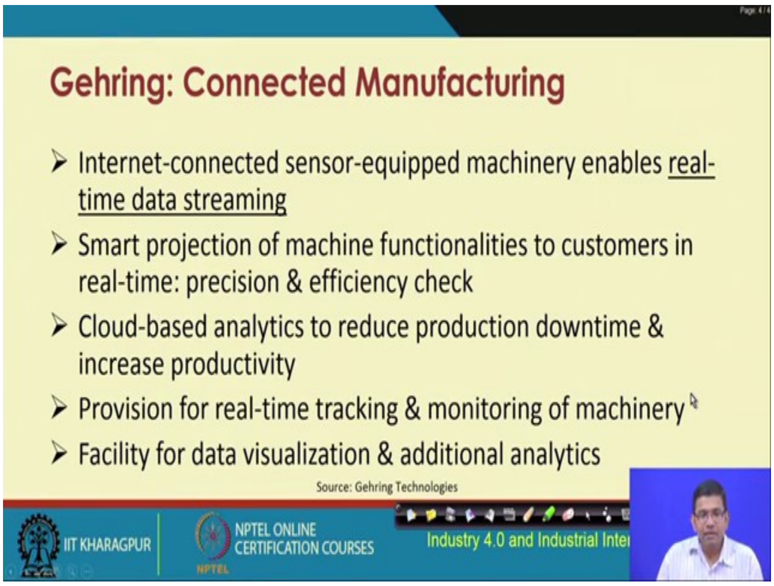

Gehring is in the space of connected manufacturing. Here they have different manufacturing systems which are internet-equipped, these are sensor-equipped and these systems basically in real-time they throw in lot of data, they stream in lot of data. So, they have smart projection of missing functionalities to customers in real-time, which basically helps the customers to know in real-time, what is happening with these different systems. So, this basically helps in improving the efficiency and improving, improving the precision.

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Bosch has a very intelligent solution for tracking and tracing of different parts machine parts different other goods and so on. So, these basic the solution that they have is also sensor-equipped, and they can be these tools and parts can be tracked and traced, there is reduction in searching time, and risk for using wrong tools. So, basically their solutions will help in improving, the asset management, work management, improving the manufacturing processes, because everything is integrated, its integrated manufacturing. They also have a tools as a service solution, which is a new business model, which can help in improving the efficiency of productivity, enhancing the safety, and improving product quality.

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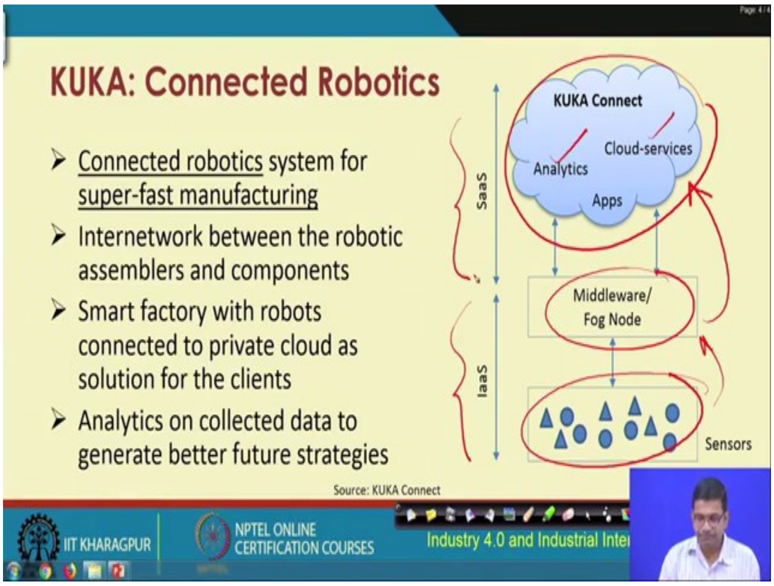


KUKA is a company, which is into the connected robotics domain. So, they have systems, which are connected robots that can be used for improving the manufacturing process, so improving the time that it takes for manufacturing. So, they have super fast manufacturing processes through, the use of connected robotics and this is the KUKA architecture. They have all these different sensors at the very bottom, then there is the middleware and the fog node. Basically, the fog node is the one, which will take the data and process it locally close to the source, close to the source means close to the sensors. And all the other data are going to be sent to the cloud for performing different analytics and so on at the cloud. So, they have a combination of infrastructure-as-a-service, and software-as-a-service solutions.

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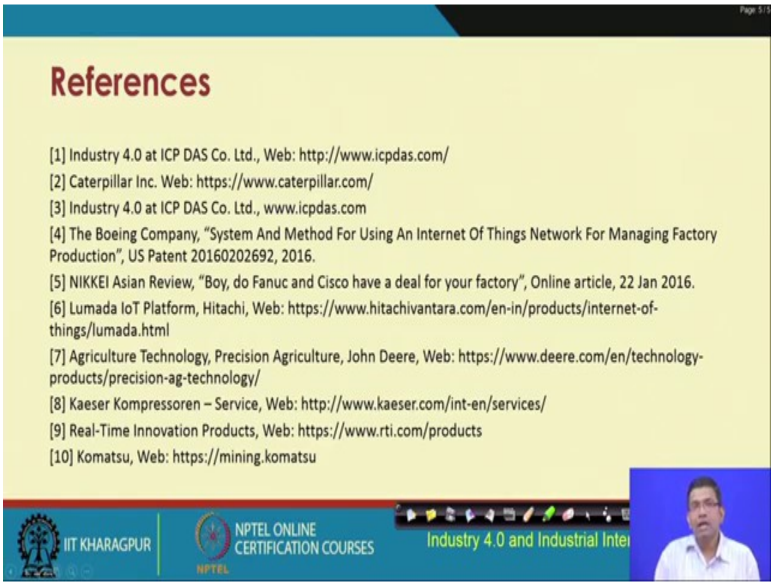


With this we come to an end of this lecture. So, these are some of these references that are used. And so what we have done is we have gone through an assortment of different, different solutions that are there in the industries. And if you are interested this was just a glimpse a highlight of these different solutions that are there in the different industries. And many of these in are in the works, the industries are transforming two Industry 4.0 gradually and these are in the works.

So, if you are interested please feel free to visit these company websites to, to know more about their systems, their smarter systems, and so on. So, with these are the different references and with this we come to an end.

Thank you.

**Introduction to Industry 4.0 and Industrial Internet of Things**
**Prof. Sudip Misra**
**Department of Computer Science and Engineering**
**Indian Institute of Technology, Kharagpur**

**Lecture - 22**
**Business Models and Reference Architecture for IIoT: Business Models – Part 1**

So, far what we have covered are basically the different fundamental concepts in Industry 4.0 and IIoT. In this lecture, what we are going to go through are some of the fundamental concepts, behind the business aspects of IIoT.

Although this course is technically oriented, but from a holistic perspective, I think the understanding will be clearer, if we go through, if we have little bit of knowledge about what are the business aspects of IIoT, and particularly because IIoT is supposed to be used in the industrial settings. And thereafter, we will go through in the other lectures, we are going to go through the more in depth aspects of the technicalities of both IIoT as well as Industry 4.0.

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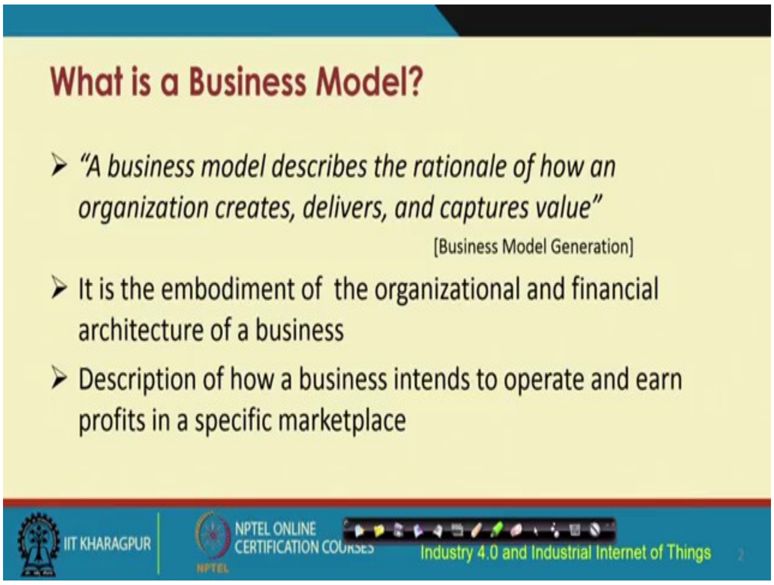


Let us now look at some of the fundamental aspects of IIoT. So, from the business perspective, we need to understand what are the different business models? And first of all the question is that, what is a business model? So, a business model basically it captures the different aspects such as the rationale behind how the organization is created, how it is going to deliver value to the customers, capturing the value, delivering the value, and so on.

So, these are the different aspects that are captured in a business model. And it is basically this business model is an embodiment of the organizational and the financial architecture of a business. So, these models basically will give the description of how the business wants to operate, its different operations, how it is how they are going to be performed. And how it is going to the business is going to be positioned with respect to the different finances, the financial aspects, how it is going to earn the different profits, and how it is going to be positioned with respect to the specific marketplace that it is going to cater to.

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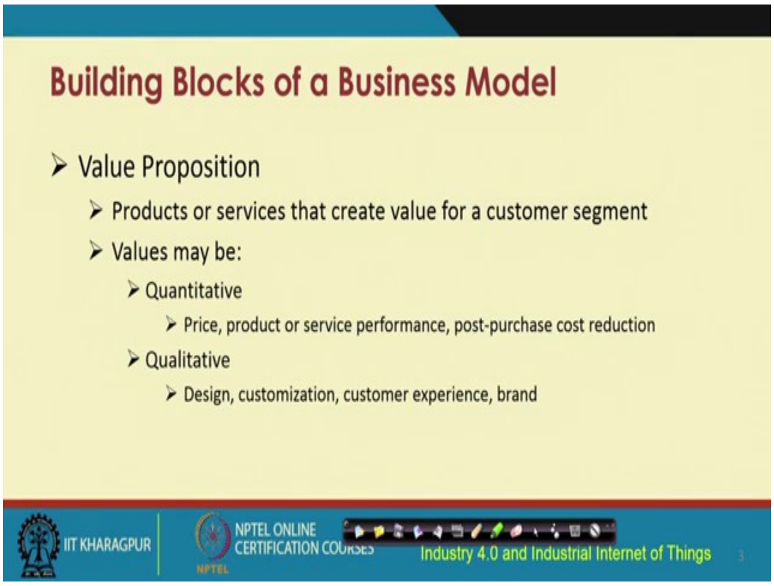


Let us now try to understand; what are the different aspects of the business model, that we should try to understand, before even we go through the different the different aspects of the business model for use in IoT, as well as IIoT.

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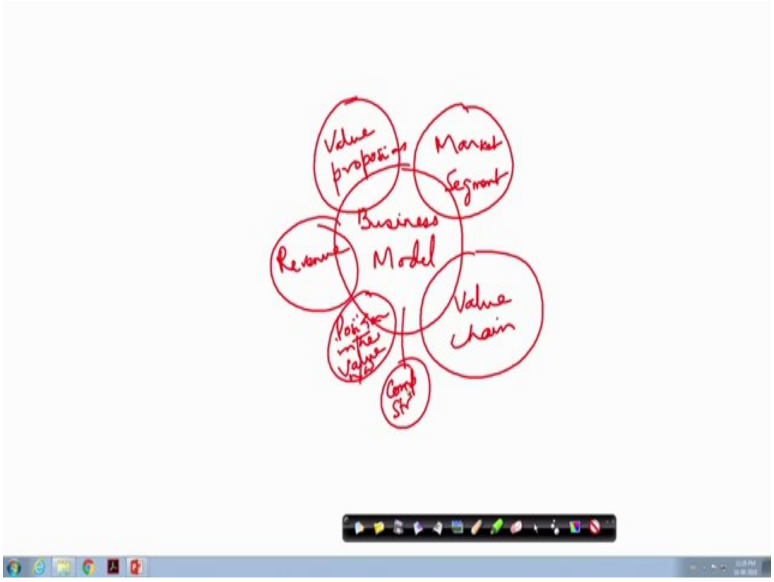


So, let us try to look at the different aspects of the business model. Let us assume, that this is the business model, let us consider that we are talking about the business model. So, what are the different building blocks of it. So, the first one that we should understand is what is the market segment.

The market segment the business is supposed to cater to. Then we should understand the what is the structure of the value chain. The different value propositions, the revenue generation, and what are the different margins in that revenue model. And what is the position in the value network. And also another very important thing is the competitive strategy.

So, these are the different broadly, these are the different aspects the building blocks, let us say of any business model. So, these concepts are very important in the next things that we are going to discuss on how these business models should be understood in the context of IoT. And thereafter, in the next lecture about the different aspects in the context of IIoT as well more specifically.

So, having understood this let us now go back to our different building blocks that we have seen in the little while back. So, the first one is the value proposition, let us take up the value proposition first. So, value proposition we are talking about offering values to the customers. So, what are the different products or the services that will create the values for the customer segments that the business wants to consider. These values could be quantitative such as the price aspects of price, product, service performance, etcetera or these could be qualitative in nature such as the design that has to be considered the customization, the customer experience, the branding, etcetera etcetera. So, these are basically the value proposition aspects.

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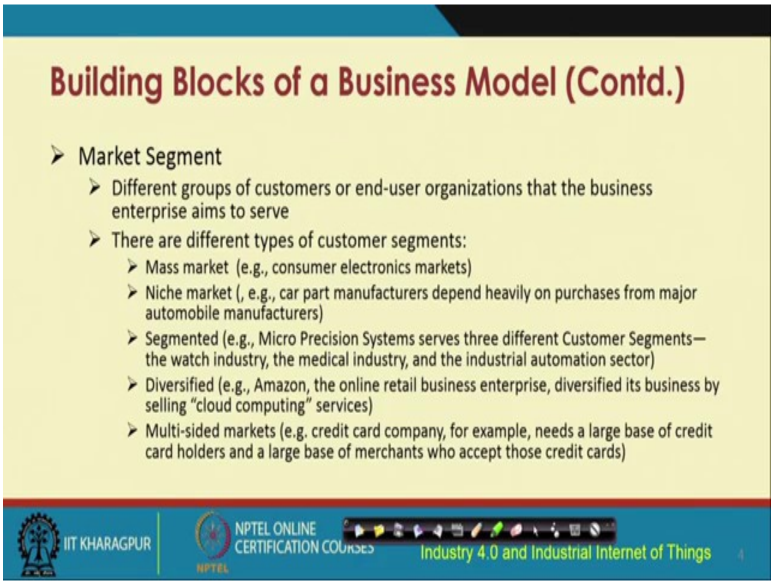


The next is the market segment. Markets segment basically talks about what are the different segments of the market that has to be considered. So, different groups of customers, the end-user organizations that the business enterprise aims to serve. And there could be different types of customer segments. For example, one customer segment could be something like the mass market. Mass market means, like for instance the whole market. So, the whole market that is going to be considered, for example the consumer electronics market is an example of a mass market.

Niche market means, the specific type of market that will be considered by the business. For example, if we are talking about a car manufacturer, so the car manufacturer basically heavily depends on the purchases from different automobile manufacturers. Thereafter, the segmented customer segment which means like the micro mechanical micro sorry micro-precision systems that it is going to serve, the different customer segments of it. For example, the watch industry, the medical industry, and the industrial automation sectors; these are all like different segmented customer segments.

Thereafter, we have the diversified one. So, diversified customer segment means like a particular business might be serving, a particular type of customer base for some time. And thereafter, they want to diversify to another type of customer base. For example, for example the company Amazon. So, Amazon is originally primarily, it is a retail business online retail business enterprise. But, in recent times it has diversified its business to selling cloud computing services.

And this is diversified customer segment and we can also have multi-sided segments. For example, if we are talking about a credit card company, so credit card company has to deal with the credit card holders on one side, and the merchants, who are going to accept those credit cards; so, those on the other side. So, these are like multi-sided markets.

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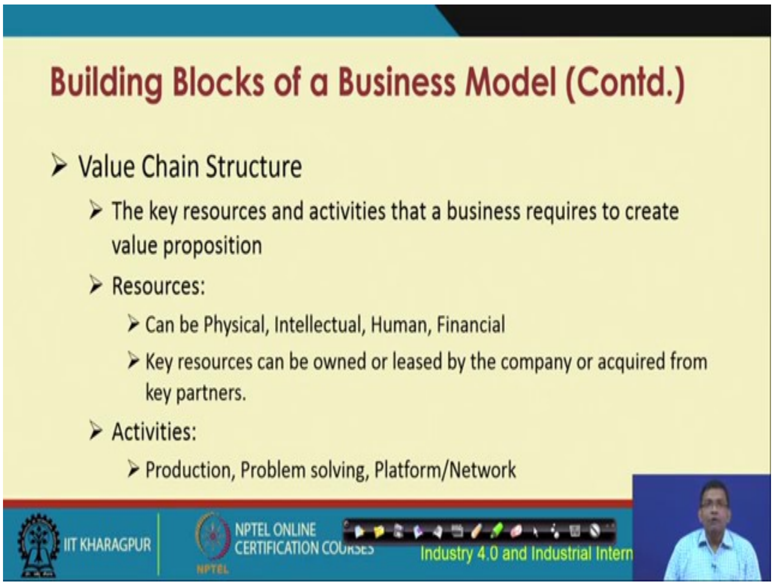


So, next one is basically the value chain structure that is the third building block that we should try to understand. So, value chain structure basically these are the key resources and the activities that a business requires to create the value proposition. So, these value chain structure depends on the different types of resources that are being used, and the different activities that are performed. These resources could be physical resources, intellectual resources, human resources, financial resources, and so on.

And these key resources can be owned or they can be leased by the company or they can they can be even acquired from different partner's business partners. So, these are the different types of resources, these are very important in the value chain structure. And the activities, activities for example production, problem solving, platform that is considered the network etcetera, these are the different activities. So, these together are important considerations of the value chain structure.

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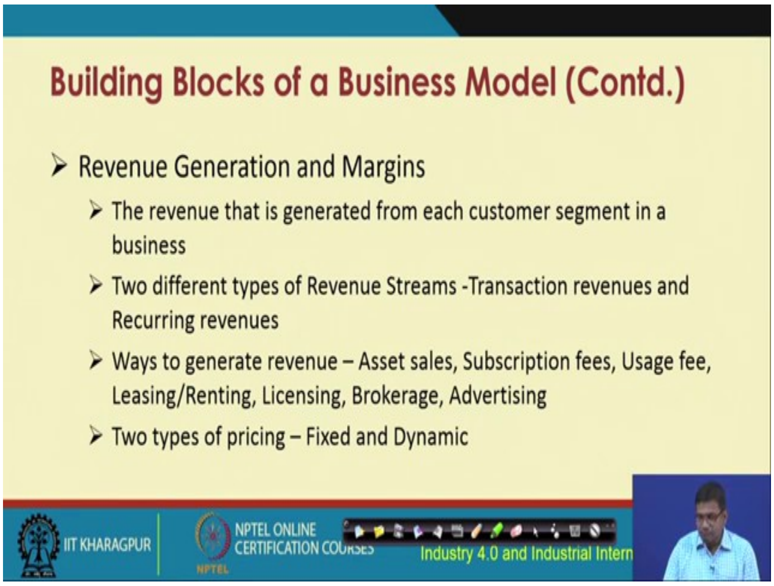


The (third the) fourth building block is basically the revenue generation and the margins, which basically talks about the revenue that is generated from each customer segment in the business. And these different revenues could be streamed from two different sources. So, one could be the transaction revenues, and this could be the recurring revenues. So, transaction revenues means, the revenues that are generated from the different transactions that are performed. And recurring revenues means, like there could be a revenue model from which in a recurring fashion, the revenues are generated from the customer base.

So, these revenues could be generated in different ways. These revenues could be generated from sales of assets from subscription fees, from usage (fee) fees or, from fees, that are obtained from the rental or the leasing out of these different resources or the services, the licensing fees, the brokerage, the advertising, etcetera (etcetera).

So, there are two different types of pricing that can be considered in any revenue model. One is the fixed pricing, the other one is the dynamic pricing. So, we do not need to really understand about each of these in too much of detail, I think this much of information will be sufficient for you to understand the more important aspects, like how this information would help in in setting up an IoT or rather an IIoT kind of infrastructure, and generating revenues in that kind of environment.

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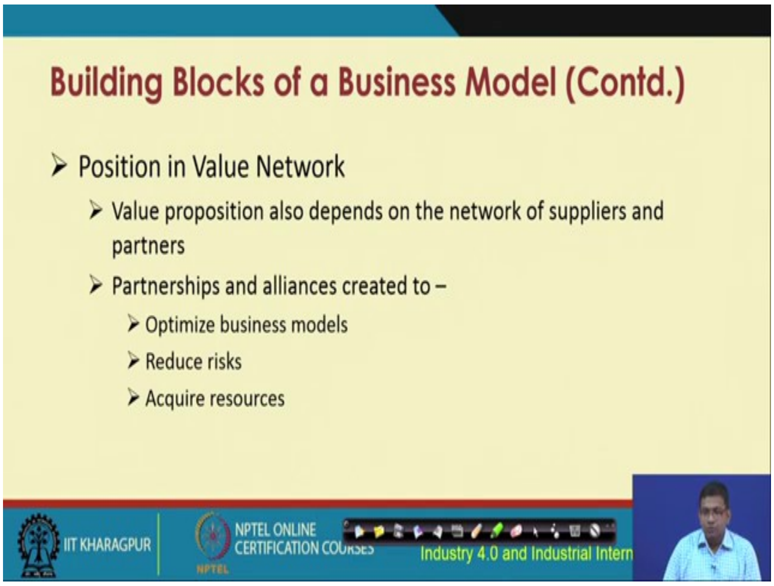


The next building block is the position in the value network position in the value network. So, this position basically also depends on the different networks of suppliers and the partners. And these partnerships and these alliances will be created to optimize the business models, to reduce the risks, and to acquire the resources.

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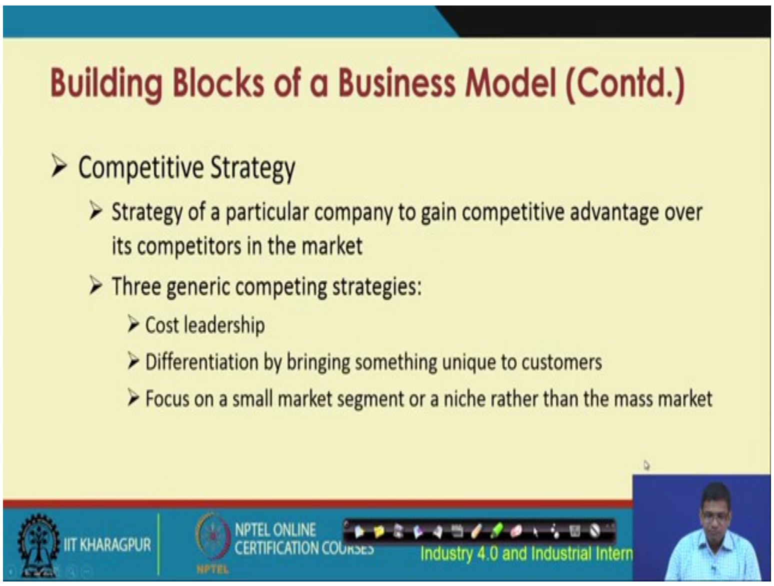

The next building block is the competitive strategy. So, competitive strategy means, the strategy of a particular company to gain competitive advantage over its competitors, in the market segment. So, there are three different types of competing strategies that typically a business considers. The first one is the cost of leadership, the second thing is the differentiation by bringing something that is unique to the customers, and the third is the focus on a small market segment or a specific type of market segment, a niche market segment, rather than considering a mass market, if a bigger market.

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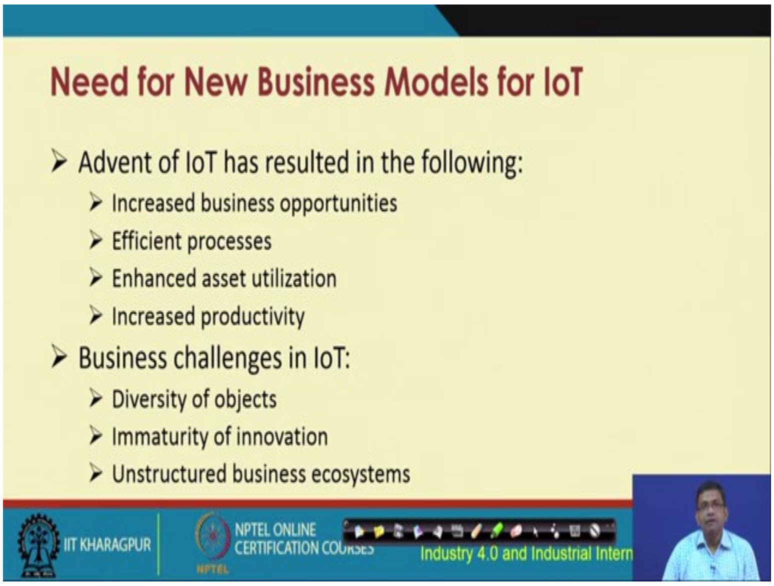


So, having understood all these different types of building blocks of any business; let us now switch our here, and try to understand that why we need these business models, and how they are important for IoT, in general. So, if we are talking about IoT, the advent of IoT basically has resulted in different (different) features from a business perspective. It has advent of IoT has increased, the opportunities for different businesses. IoT is IoT infrastructure can help in improving the efficiency of the processes can help in improving or enhancing the asset utilization, and increasing productivity.

From although there are so many different types of advantages of IoT, from a business perspective; there are different business challenges as well in the adoption of IoT. The first one is basically the diversity of the objects, and this is very key because in the IoT world what we are talking about is diversity of different aspects. Fundamentally, diversity of the different physical objects, the things that are connected.

So, we have we are talking about in the IoT world, we are talking about an internetwork of different physical objects. These different physical objects will have different sensors, and these sensors will acquire the data. And these data are going to be sent across to some remote server, for further processing.

Basically, these different objects typically in the IoT world, they are of different types and are interconnected together, so that basically only technically, but from a business perspective, this aspect of diversity of interconnecting different objects, it poses a huge challenge for the businesses.

The second thing is the immaturity. IoT, IIoT is also new, and the innovations that IoT posed to the business. So, from that particular perspective, because the innovations are new, there is lot of immaturity in terms of innovation, that has to be dealt with in the businesses, in the business. So, this is very important for consideration, when we are talking about the adoption of IoT in a particular business setting. The third one is that the business ecosystems, they are not structured in the IoT world. They are typically unstructured business ecosystems that are typically encountered in these IoT environments, unstructured business ecosystems.

And this unstructuredness, it arises because of this diversity that I talked about at the very beginning, there is diversity, there is immaturity, and as a result of which these business ecosystems, are typically unstructured. And we are talking about not one business in a true IoT world, we are talking about connecting different business segments. And these different business segments are not all, they do not all function in the following a particular business model and because of which this unstructured behavior, this property of unstructured, this arises in these business ecosystems.

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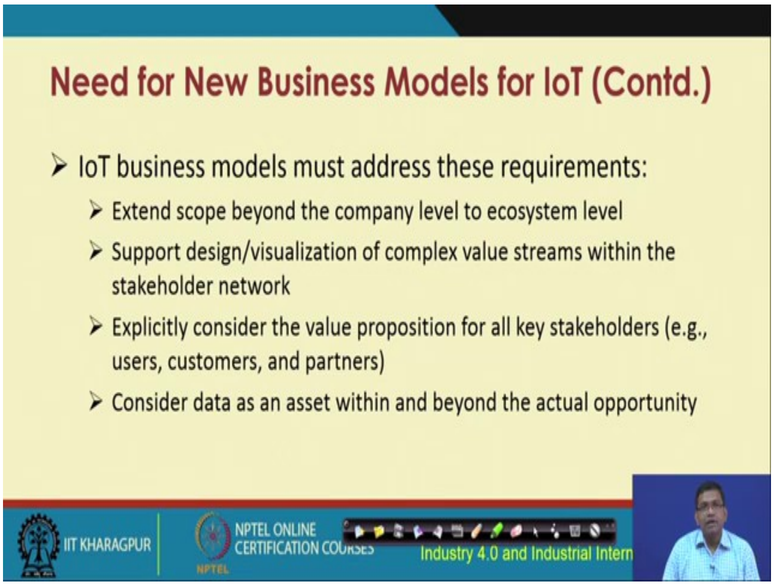


So, these IoT business models must address different requirements, this would extend the scope beyond in the company level to the ecosystem level. This is what I actually I was talking about in the previous slide. So, we were talking about that we are not talking about single companies, we are not talking about IoT serving a single company. So, we are talking about a business ecosystem, where several companies are going to play different, different roles. So, this is a very important requirement, if we have to come up with a business model for IoT the companies should, the industry should consider this very seriously.

The second consideration with respect to the business models for IoT environments is that there should be support for design as well as the visualization of complex values is value streams within the stakeholder network. So, there are different stakeholders and these different stakeholders have different requirements, from a business perspective. So, there should be support for the design as well as the visualization of this complex value stream that will be created from this stakeholder network.

The next one is basically the explicit consideration of the value proposition for all the stakeholders, which includes the users, the end-users, the customers, the different partners with which the business they have different MOUs or they have different understanding between the different other businesses. And the last one is basically the consideration of the data as an asset within and beyond the actual opportunity that is created. So, when we talk about IoT in a business world, we are talking about lot of data, data that is generated. And this is a very important consideration in IoT. And this data it is very important, because it serves as an asset beyond the fixed infrastructure assets that are there in the company that. So, this data the IoT data is very important asset within the company. And this is not only within the company that it is an asset, but also beyond the actual opportunity that is created within the company.

So, in other words, this data can serve as an asset to other organizations, other partner organizations or even the other organizations within the geographic territory of the company, where it is operating that means within the country or, within the region and outside the region. So, it does not have any limits, this data is an invariable asset for the company, that has created this data that has collected the data, and also for the other companies.

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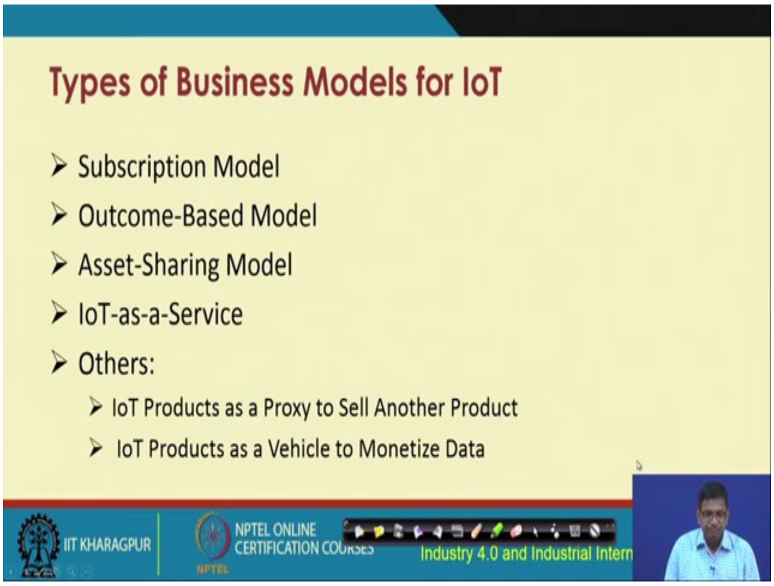


So, there are different business models for IoT. The first one that we should understand is the subscription model. So, we will go through it what it means by the subscription model so subscription model. The next one is the outcome based model. Asset-sharing model, and IoT-as-a-service plus I am also going to go through some of the other types of models that are there in the literature for use in IoT.

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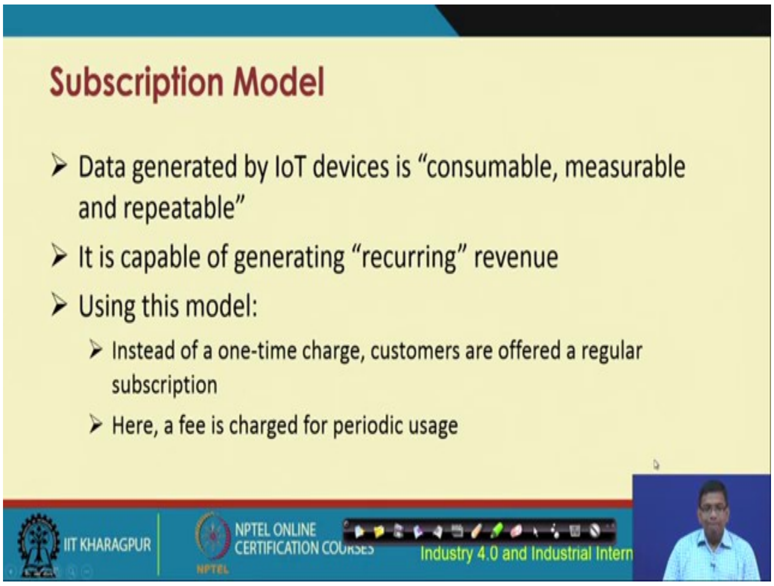


The first one is the subscription model for IoT. So, essentially what is happening is the data that is generated by the IoT devices. These data are consumable, they can be measured, they are measurable, and they are repeatable. So, it is basically this data that is generated, it is it has different facets. And it is also capable of generating recurrent revenues for the organization.

So, using this kind of subscription model, you are not talking about is one-time kind of charge to the customers, but these customers can be offered some kind of services. And they can be charged based on the subscription that is offered.

So, basically IoT services, the customers are going to subscribe to and they are going to be charged based on the units of subscription, that the customer has subscribed to and the units of usage. So, there so what is going to happen is we are not talking about a one-time kind of charge, and we are going beyond this one-time kind of charging mechanism that already exists for other types of businesses. And on a regular use on a paper use kind of basis, based on the periodic usage, the fees are going to be charged to the customer.

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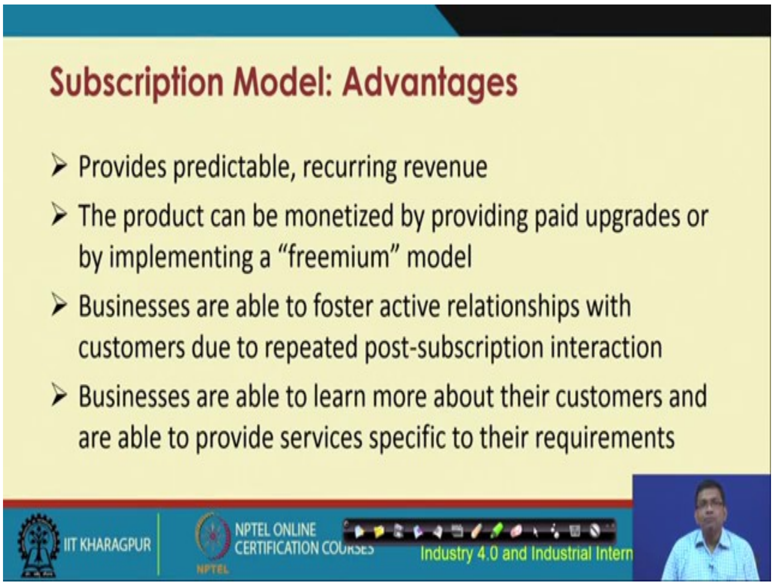


So, there are different advantages of the subscription model, it is a predictable kind of model, where you can predict how much revenue is going to be generated. The product can be monetized by providing paid updates or by implementing a freemium model. So, freemium means, like the certain levels of service the basic services, they can be made free to the customers and the premium services can be charged.

And other advantages are the businesses are able to foster active relationships with customers, due to the repeated post-subscription interaction. The businesses are also able to learn more about their customers to using this kind of subscription model. And they are also able to provide, feedback back to the back from the customers. The customers can provide feedback to the businesses, so that the improved services can be offered by the business.

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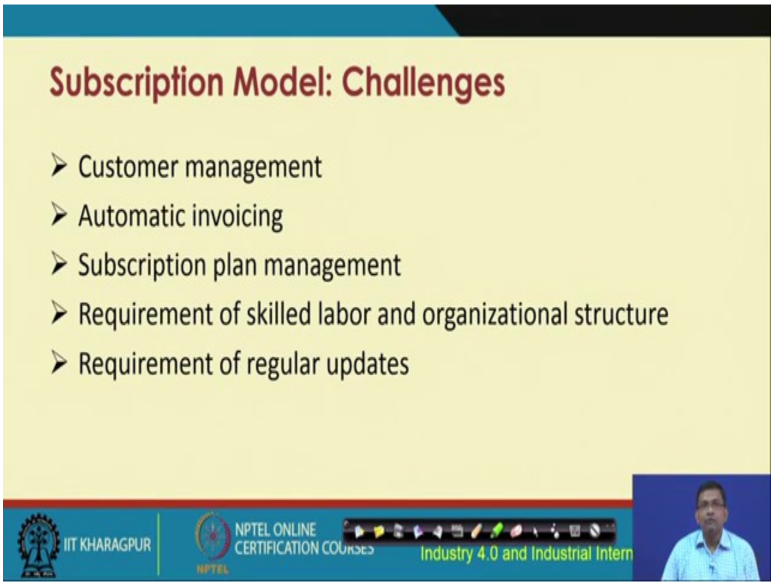


So, there are different challenges as well. So, advantages we have understood, there are different challenges behind the use of the subscription model. So, all these things like customer management, automatic invoicing, because that is required. And different types of based on the different types of usage, automatically you have to invoice the customers.

So, automatic invoicing, subscription plan management, requirement of skilled labor, requirement of regular updates; these are different requirements, which are also posing as different challenges to the businesses. So, these challenges have to be considered by the businesses, which go by the use of this kind of model the subscription model.

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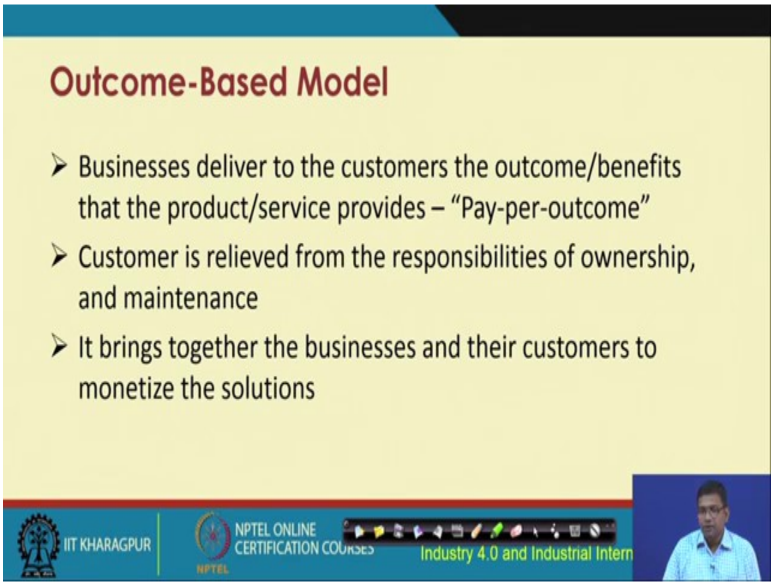


The next one is the outcome-based model, where the businesses they deliver to the customers the payment, the outcomes or the benefits that the product or the service provides. So, basically it is a pay-per-outcome kind of model paper outcome. So, based on the outcome, the customer pays based on the outcomes. So, customer is basically relieved from the responsibility of ownership, and maintenance. And it brings together the businesses and their customers to monetize the solutions. So, these are some of the different features of the outcome-based model.

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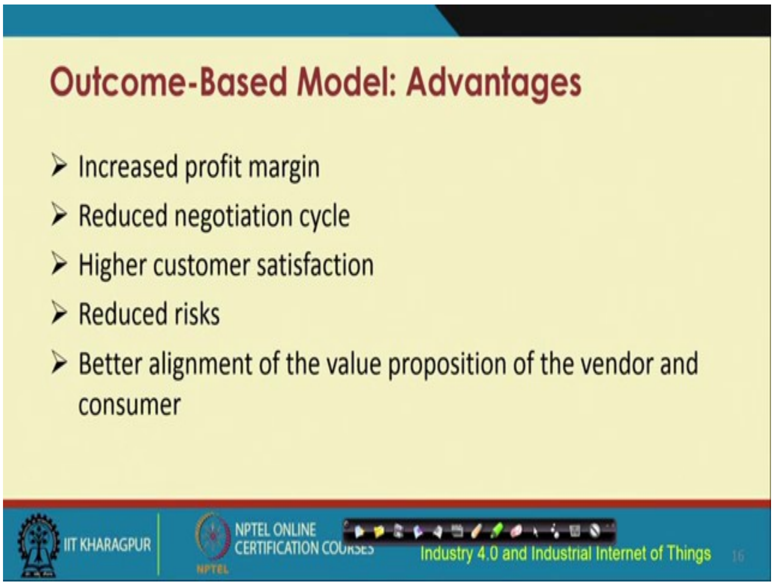

So, like the subscription based model, there are separate distinct advantages of the outcome based model as well. These outcome-based model, it leads to increased profit margin, reduced negotiation cycle, negotiation cycle with the customer. So, between the customers and the business this the negotiations that happen, the outcome based model basically reduces it.

The third one is the higher customer satisfaction, increased customer satisfaction let me call it that way, reducing the overall risks in the business. Better alignment of the value proposition of the vendor and the consumer. So, these are different advantages of the outcome-based model.

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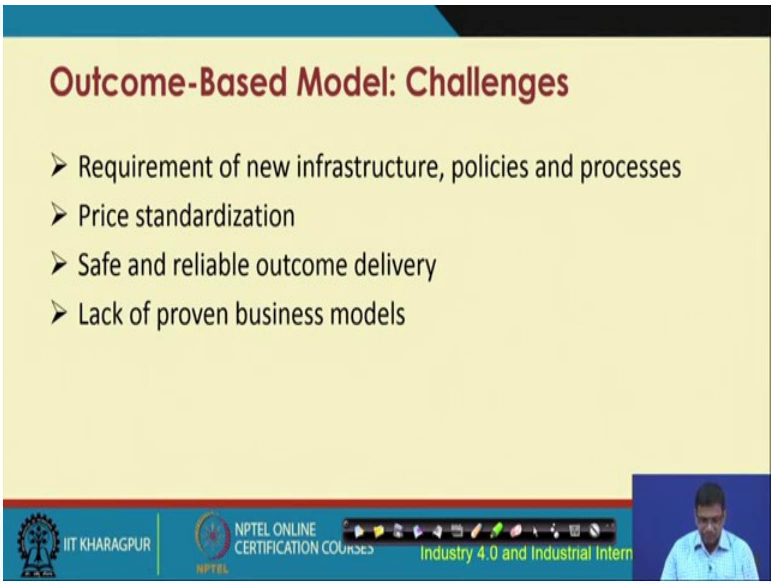


Similar to the subscription based model, there are different challenges also. If somebody if a business is adopting, the outcome based model, there are different challenges. Challenges with respect to the standardization of the price, challenges with respect to the requirement of new infrastructure, policies, processes, safe and reliable outcome delivery, lack of proven business models etcetera, these are different challenges behind the use of outcome based model.

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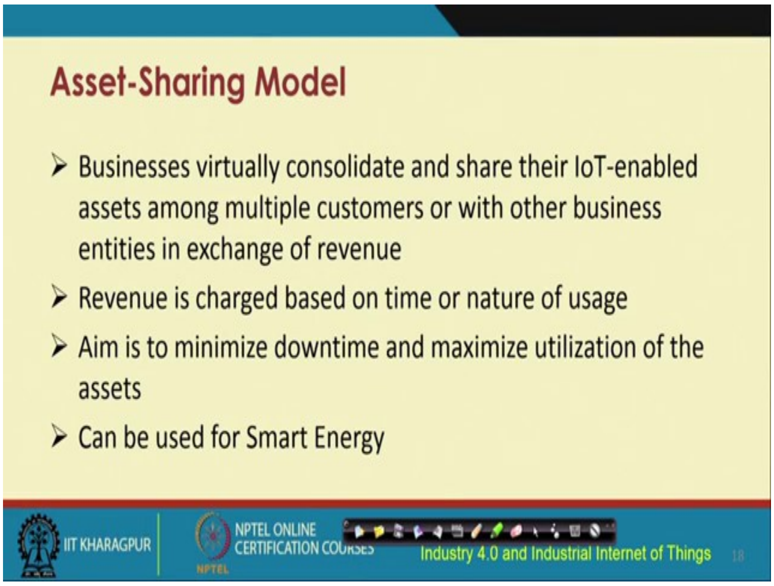


The next one is the asset-sharing model, where the businesses virtually consolidate. And share their IoT-enabled assets among multiple customers or with other business entities in exchange of revenue. So, this is something like we have seen the use of tractors for example. So, somebody owns the tractor and that tractor can be given in exchange of some kind of revenue to the other customers, so that this is basically a kind of asset sharing model, this is an example of an asset-sharing model.

So, their customers are basically charged with the revenues based on the time or the nature of the usage, how much duration the tractor has been lent or any other machinery by the industry, has been lent to another customer. So, they can be charged, the revenues can be charged, based on the duration, and the nature of usage. You know what are the different what are the different aspects of the machinery that is used by the customer, so that is also an example of how the customer can be charged with the revenues, based on the nature of the usage.

So, the aim is basically to minimize the downtime, and maximize the utilization of the assets, so this is very advantageous. Because, if the customer, if somebody if a business has a particular machinery. If the business was using just for their own purpose, then it is quite likely that the machine will be used for certain duration of time. And for other durations of the time, it will be left unused. Instead using the asset-sharing model, what can be done is that other people can use the same machinery. And they can be charged with the charged based on the time of usage, and the nature of usage of the machinery.

So, for example smart energy smart energy in IoT, this is an example of assets-sharing model. So, somebody has the energy generation infrastructure, and the energy that is generated can be used by different customers. So, and so this is basically an example smart energy is an example of asset-sharing model.

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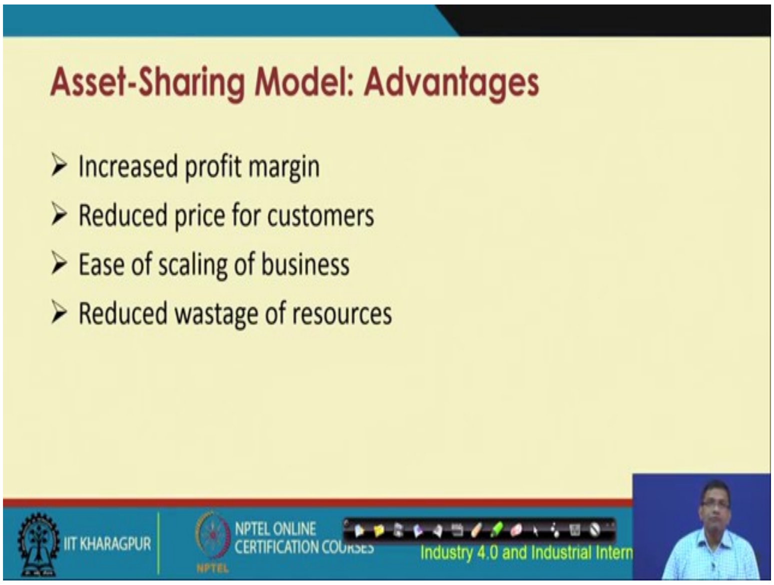


So, like the previous models that we have discussed so far. There are different advantages of the asset-sharing model as well. For example, increasing the profit margin, reducing the price of the customers, easing out of the scalability of the business, reducing the wastage of resources. So, these are some of the different advantages of the use of the asset sharing model.

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There are different challenges as well; challenges with respect to the security offering the security of the products and the services. So, once you lend out these different assets to other users, so security of the physical security of the products, the physical security of the services that are offered. These have to be considered separately, the security of aspects of these, they are very important.

The other challenges are like for example, the mutual arrangements among the different business entities will have to be taken into consideration, asset configuration is very important, and the device synchronization, and the synergies between these different devices, these are very important in the asset-sharing model.

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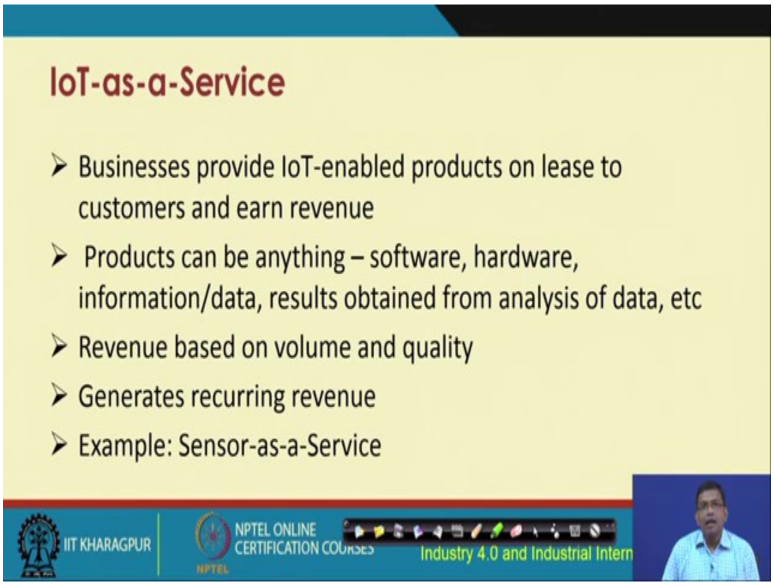


The next one is IoT-as-a-service. So, you will find, some literature talking about offering IoT-as-a-service. So, as this name suggests, we are talking about businesses providing IoT-enabled products on lease to customers, and then earning revenue from that leased out IoT infrastructure. So, these products can be anything software, hardware, information or the data, the results that I have obtained from the analysis of the data. Basically, anything can be a product in the IoT-as-a-service model.

The revenues are generated in this model, based on the volume of the data that is generated, the volume of the different resources that are used, the quality of the resources that are offered. So, all these different (different) aspects will help in coming up with the revenue model in the IoT-as-a-service. So, sensor as a service our research group, the SWAN research group, at IIT Kharagpur. We have done a lot of work on offering sensors-as-a-service. So, this is basically a specific instance of IoT-as-a-service. And this is very important in the IoT world this kind of business model is very important in the IoT world.

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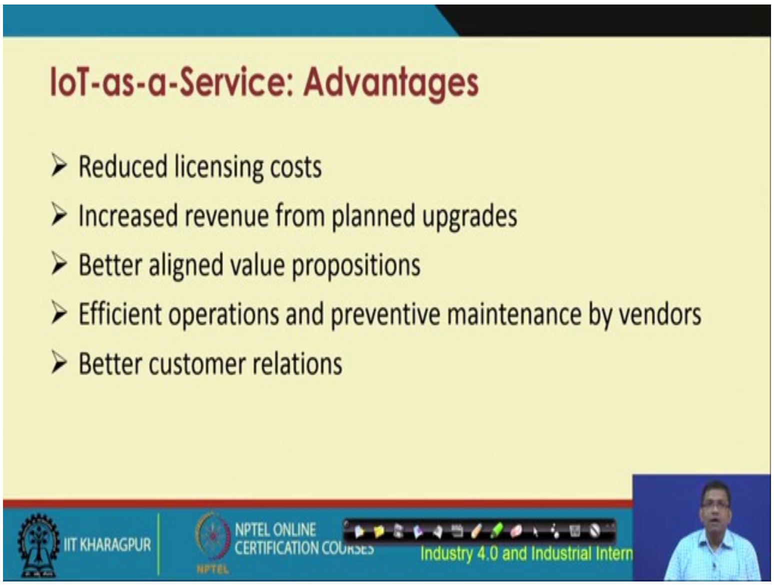


So, here are different advantages of IoT-as-a-service. For example, reduced licensing costs, increased revenue from planned upgrades, better alignment of the different value propositions, efficient operations and preventive maintenance by vendors, improved customer relationships customer relations. So, these are different (different) advantages of IoT-as-a-service.

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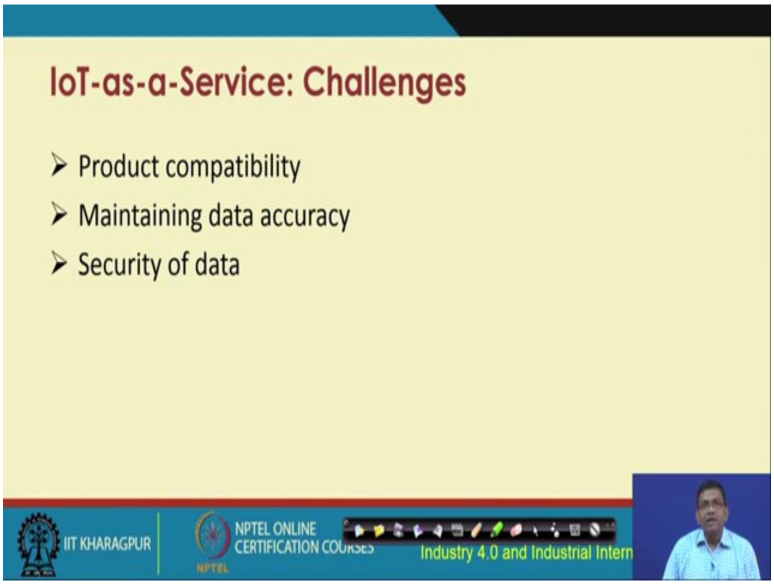

So, on the other side, there are different challenges also. Product compatibility, maintaining data accuracy, security of data, these are different challenges with respect to the adoption of IoT-as-a-service.

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So, as I was telling you earlier; so there are beyond these different business models, there are different other business models, that are also available, that have been proposed in the literature. So, let me just talk about some. So, IoT products as a proxy to sell another product is another kind of business model; so IoT products can be used as a proxy to sell another product.

In other words, IoT products are sold at the cost price or at a loss to sell other products. For example, IoT devices can keep track of the status of the products and perform the actions accordingly. And these can be used by manufacturers to sell products which require refills. So, this is a type of model that is attractive for IoT-based products.

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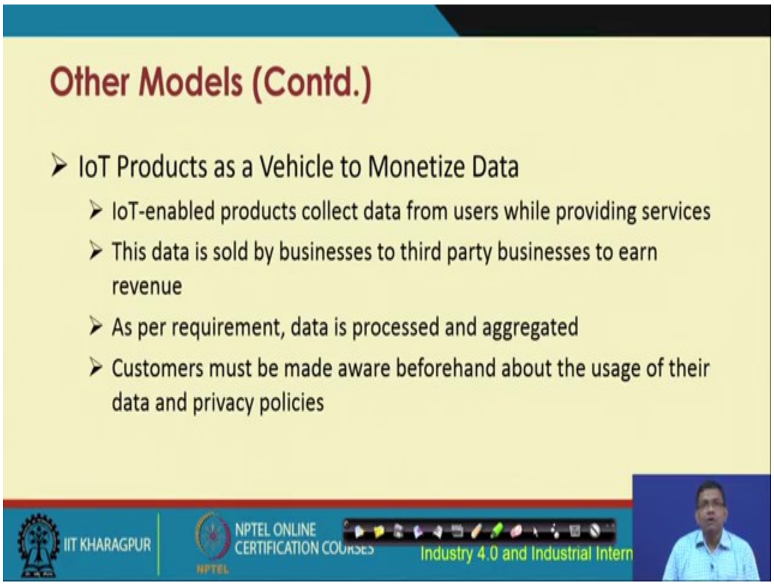


IoT products as a vehicle to monetize data; this is another type of model that is used for IoT based services, IoT based products. So, this is a kind of business model that is very attractive in the IoT world. So, IoT-enabled products collect data from the users, while providing services. And this data is sold by the businesses to the third party businesses to earn revenue. And as per the requirement, the data is processed and aggregated. And the customers will have to be made aware beforehand about the usage of their data and the privacy policies. If they are adopting, if the business is adopting the; this kind of business model in the IoT world.

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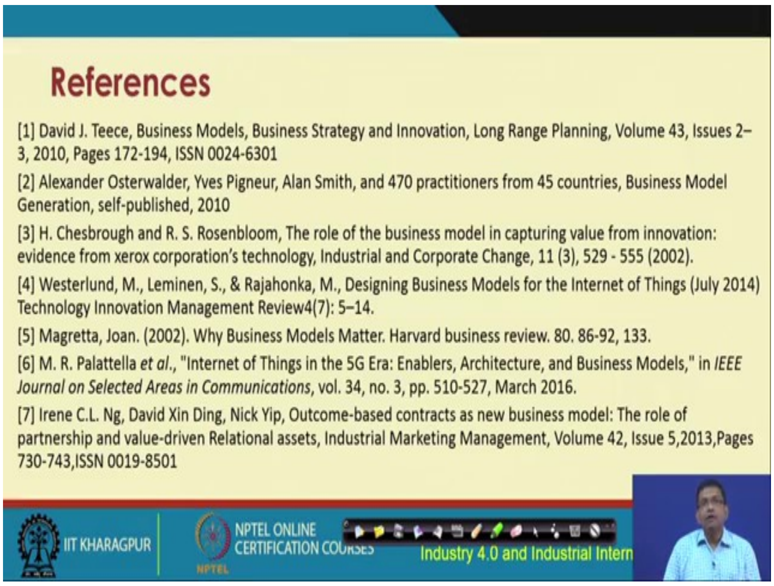

So, with this we come to an end of the first part of the business aspects of IoT. So, we have initially we have gone through the different business models, that are available and the different types of business model, that are available in the literature not just IoT, but any kind of business model the different types of it that are available in the literature.

Thereafter, we have gone through the IoT specific business models that are attractive in the community. And some of the businesses are already adopting these different proposed business models for IoT. And we have also gone through the different not only the features of each of these business models for IoT, but we have also gone through the different advantages and the challenges in the adoption of each of these different business models for IoT.

So, these are some of the references that you see in front of you. So, if you need to understand any of these things in more detail, then you can go through these different references. But, I think from the holistic point of view of understanding IoT, IIoT as well as Industry 4.0, the concepts behind it, only this much of understanding should be enough in order to understand the business aspects of IIoT.

So, far in this lecture, what we have covered are only the business models, the business aspects of IoT. And in the next lecture, we are going to look into the business models and the different other related aspects for IIoT, Industrial IoT. So, there we will diversify a bit, and we will talk about the specific issues of IIoT, and the business aspects concerning it.

Thank you.

**Introduction to Industry 4.0 and Industrial Internet of Things**
**Prof. Sudip Misra**
**Department of Computer Science and Engineering**
**Indian Institute of Technology, Kharagpur**

**Lecture - 23**
**Business Models and Reference Architecture for IIOT: Business Models – Part 2**

The next lecture is about IIoT-Business Models, the second part of it. In the first part, what we have gone through in the previous lecture was some of the fundamentals of the business aspects of IoT. The business models, the different types of business models not just for IoT, but the different types of business models that are there in the literature. And then thereafter, we also went through some of the specific aspects of business models for IoT, the features of it, the advantages, the different challenges in adopting them for IoT and so on.

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And in this lecture, we will focus specifically on Industrial IoT, the business aspects, the business models for IIoT, specifically. In the Industrial IoT, IIoT context, for any business, there is uncertainty. So, uncertainty of different types, but any uncertainty as we know also has some associated risks, and this uncertainty and the risks can have either these can be either positive, they can have some positive impact on the business or it can be negative.

So, the entrepreneurship theory, basically encapsulates the positive aspects. So, positive aspects such as asset-driven opportunities, opportunities out of the assets that are created for instance. The service innovations which aid in the manufacturing; service-driven opportunities targeted at serving certain end-users and the information infrastructure ownership; so, these are the positive aspects.

But, there are some associated negative aspects, which are basically captured through the transaction cost theory, things like non-ownership contracts, performance contracts, performance means like any machinery, any instrument in the industry degrades it is performance over time, which basically can be optimized again, the performance can be optimized over time as well. These are the things that are captured under the transaction cost theory. These things will have to be considered, when we talk about the business aspects of IIoT.

These service innovations, they can aid in manufacturing. The service-driven opportunities targeted at end-users or the information infrastructure ownership. These are the positive aspects of behind this uncertainty or the risks that are created. And those basically are part of something known as the enterprise theory.

So, I also told you that the positive aspects are there, there are some negative aspects as well. So, negative aspects such as non-ownership contracts, performance contracts. Performance contracts means like the business is offering different assets. The assets are going to perform, for example assets means like machinery. They will have their own different types of performance different times; they will have different performance are going to degrade.

Contracts between the service offerors as well as the so basically the service providers and the service consumers; so basically the company as well as the end-users who are consuming. So, these are the different negative aspects that will also have to be considered. And these come under the transaction cost theory. So, we have the enterprise theory, and then we have the transaction cost theory.

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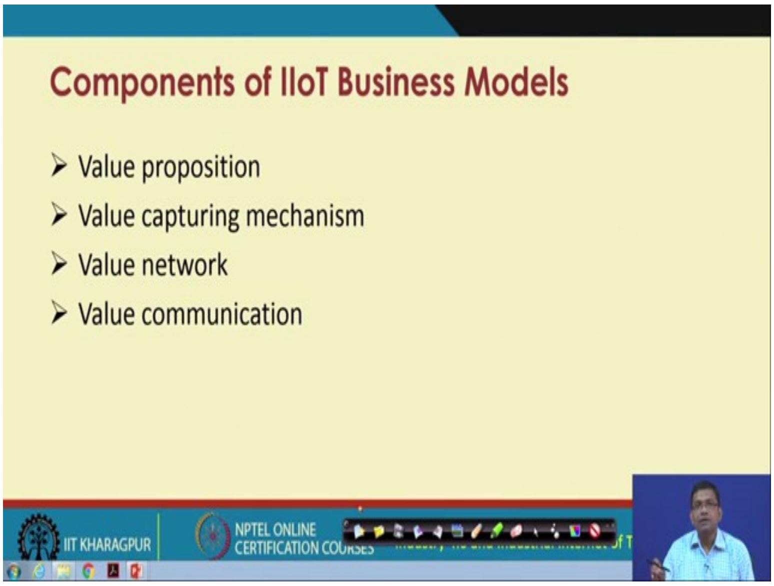


So, there are different components of IIoT business models; value proposition, value capturing mechanism, value network, value communication. Value means, value to the end-user. So, to the end-user what is the value proposition, how the value is captured, what is the mechanism behind it, what is the value network, how the information, is how the value are going to flow between the different groups in the end-user community or the customer community, and the value communication. How within that network, how the value is going to flow, how the value is going to be communicated across different groups, across different segments.

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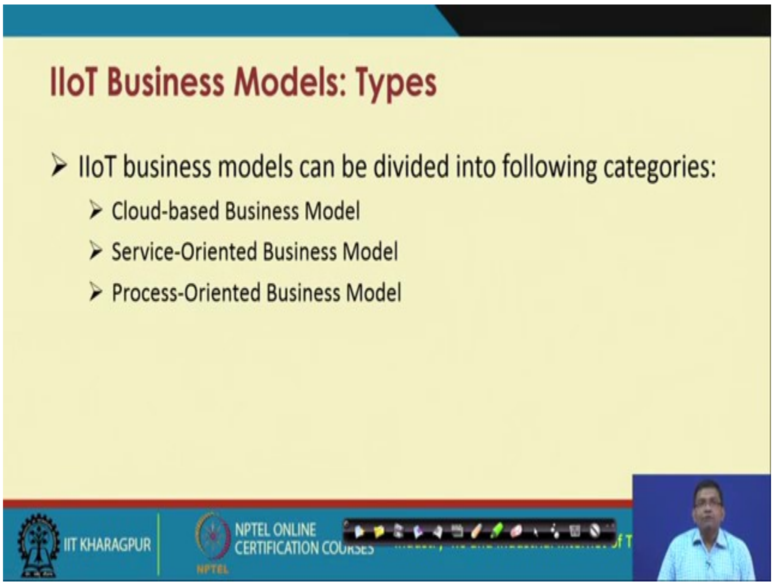

So, there are different types of IIoT business models. And they could be cloud-based business model, service-oriented business model or process-oriented business model. So, I am going to talk about each of these, in little bit more detail now.

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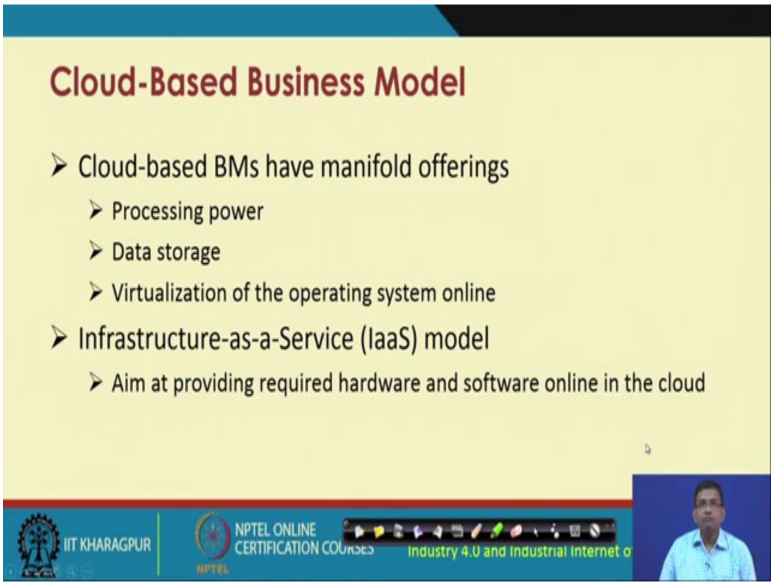


So, cloud-based business model as the name suggests is this kind of business model, basically are heavily based on cloud cloud-services. So, cloud-services means, we are talking about the processing, we are offering cloud-based processing capabilities, storage capabilities of the data, the data storage, the virtualization of the operating system.

So, these are like the different features, different aspects of the cloud-based business model. So, we have things like infrastructure-as-a-service model (IaaS), in this kind of model, some kind of hardware infrastructure, the computing infrastructure will be offered as a service, so we have infrastructure-as-a-service.

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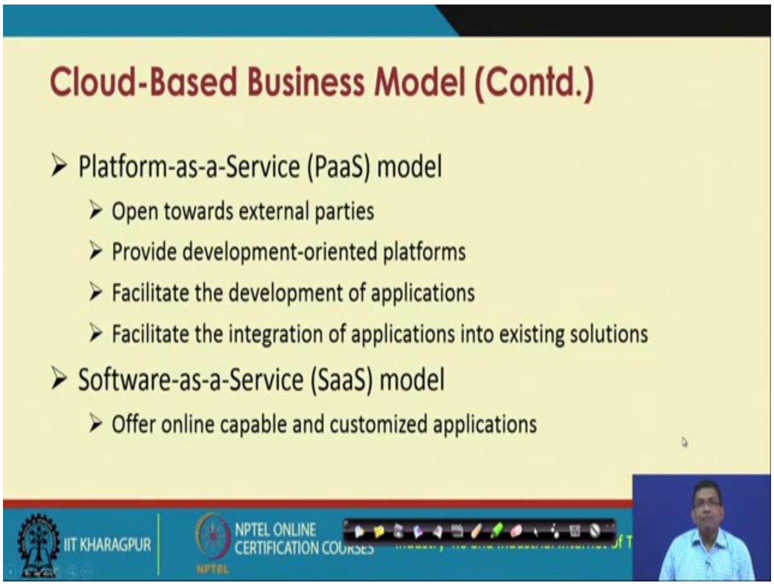


We have platform as a service, which is basically the computing platform, the development platform that is going to be offered to the customers as a service for further development of different applications, integration of different applications, which have been developed in different platforms integration of it under a common platform; these are platform-as-a-service model.

And then the last one is the software-as-a-service model, where we are talking about offering online capable a capabilities and customized applications to different customers. So, we have infrastructure-as-a-service model or we have platform is a service model or we have software as a service. So, primarily these are the three different types of service models, cloud-based service models. But, it started with these three, then we have different other, these as a service that as a service different types of other types of cloud-based service models are also available.

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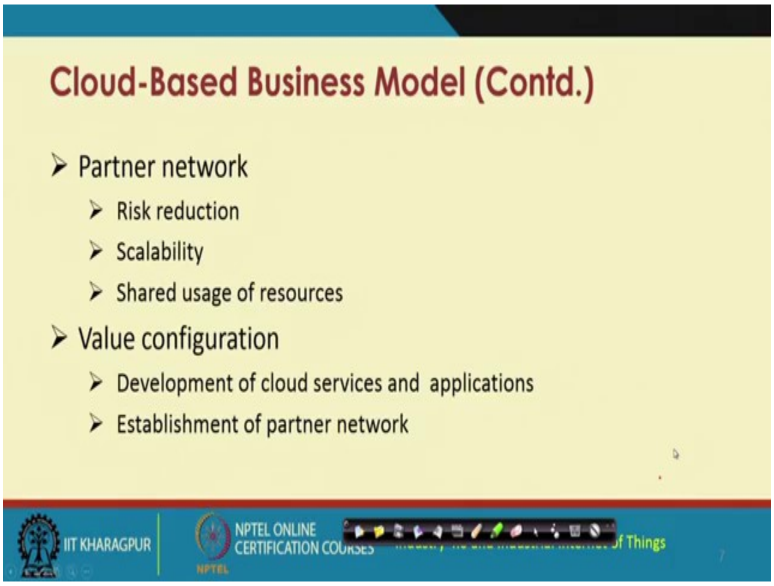


So, then we have in the cloud-based service models different aspects. For example, the partner network, this is very important. The partner network should be considered in such a way that the model is scalable, it reduces the risks, and the different resources are shared across the different stakeholders properly, stakeholders including the different partners. So, the different resources have to be shared across the different partners.

Value configuration is very important. So, value configuration with respect to the development of cloud services, and the different applications. And the value behind this kind of offering, this is very important. And the establishment of the partner network, this is also very important.

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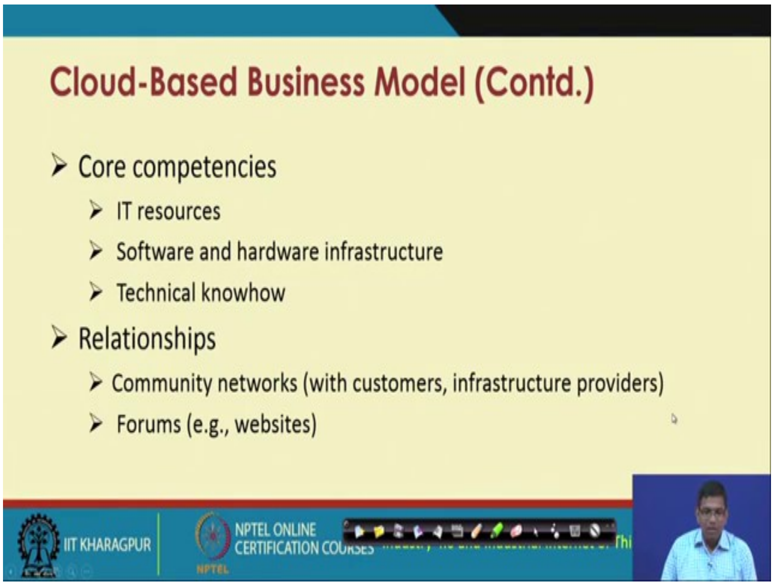


So, the next one is the core competencies. So, if we are talking about the cloud-based business model, what is very integral is the core competencies like the IT resources IT means, Information Technology resources, the software that is used, the hardware infrastructure that is used. The technical knowhow that is also very important, the overall the technical knowhow has to be considered, and that is also very important and these are the three primary, the IT resources--software, hardware infrastructure, and the technical knowhow, these are the key things to be considered under core competencies.

And the relationships; relationships, for example relationships between the different stakeholders, the community networks with the customer, with the infrastructure providers between them, across them and so on. And also things like the different forums that are considered, websites, different other, distribution lists, the different (different) forums, these are very important. And particularly in the cloud-based model, most of the services are offered through websites right.

So, typically these are end-user can get infrastructure as a service with respect to some kind of a compute platform. Certain units of RAM, certain units of CPU, certain units of storage, these are offered through some kind of a subscription, using a particular website. So, this is an important feature of the cloud-based business model.

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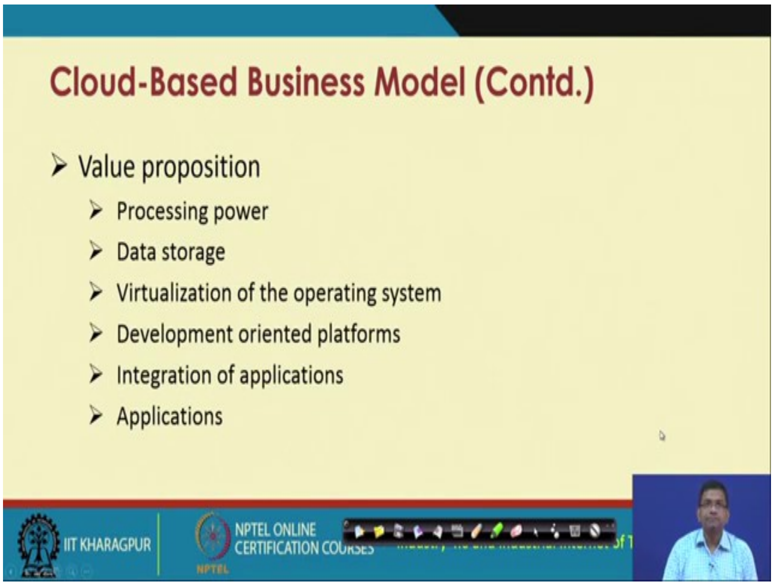


Value proposition with respect to the processing power, data storage, virtualization of the operating system, development oriented platforms, integration of applications, applications specifically the applications, so applications and their integration essentially; so these are the different value propositions. So, essentially we are again falling back on infrastructure infrastructure-as-a-service, platform-as-a-service, and software-as-a-service. So, different applications and their integration software-as-a-service; so, these are the different value propositions in the cloud-based business model.

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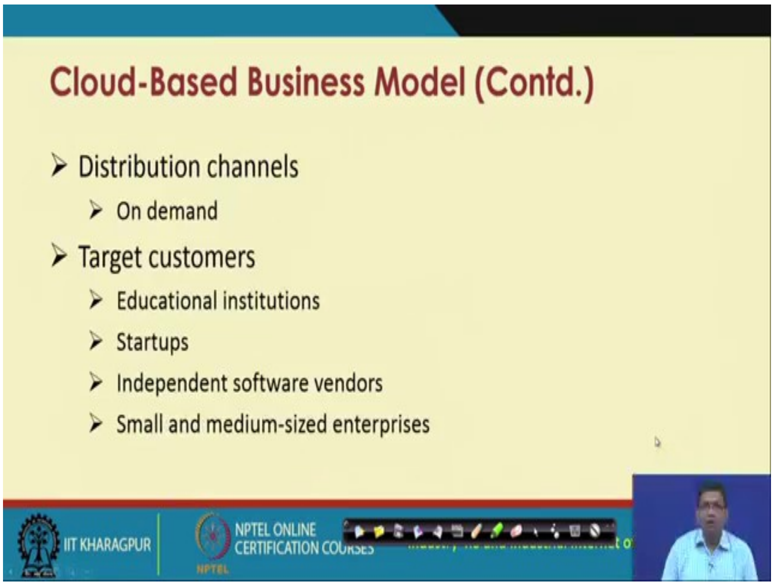

So, distribution channels typically, we are talking about in a cloud-based business model, we are talking about on demand. So, on demand whenever computational resources like infrastructure software is etcetera are going to be required on demand, these are going to be offered to the customers. And finally, let us look at who are going to be the target customers in the cloud-based business model. So, cloud-based business models are already very popular, they are used by different types of customer bases.

So, one type is basically the educational institutions; so presently worldwide, educational institutions use these cloud-based business model quite extensively. Startup companies are also falling back on the cloud-based business models, because that becomes cheaper, that becomes cheaper. So, startups typically have very small revenues to start with, they have very less capital to start with.

And it is often very convenient to adopt some kind of a online cloud service, instead of procuring infrastructure in the form of different types of servers, different other computing platforms etcetera, so that becomes more costly. So, start startups typically are heavily using the cloud-based business model. Independent software vendors, small and medium medium-sized enterprises, they are the different target customers of this kind of business model.

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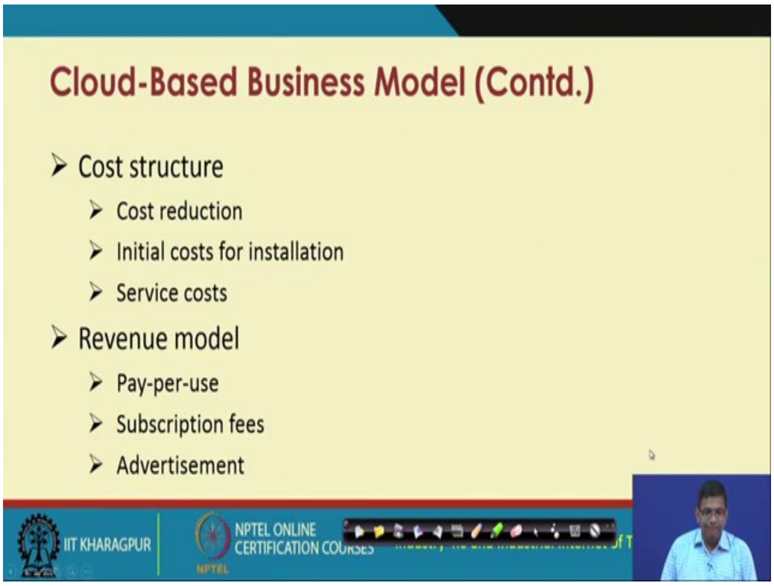


Cost infrastructure, sorry, cost structure, considerations are important. Cost reduction, initial costs for installation, service costs, these are very important considerations.

Likewise, the revenue model, for instance the whether the pay-per-used model is going to be used, this is the typical model that is used this kind of revenue model is typically used in the cloud-based business model. And subscription fees, advertisements, etcetera. These are the different considerations to come up with the revenue model in the cloud-based business model.

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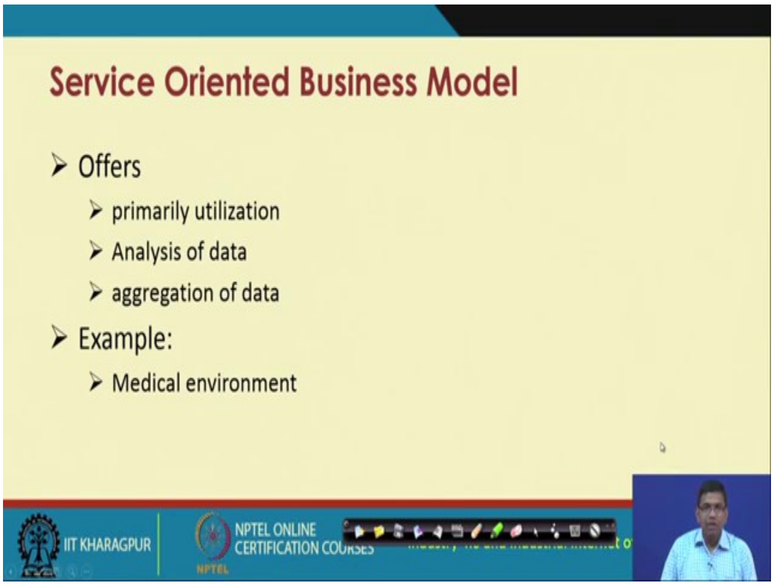


Now, let us try to understand the service oriented business model. The service body oriented business model, it is all about services it is all about services. Service offerings such as the primary utilization, the data that is collected, analysis of the data, aggregation of the data etcetera, are very important in the service oriented business model; examples are medical environments.

Medical environment, so let me just give you an example of it service oriented business model. So, in our swan lab in IIT, Kharagpur, we have developed the AmbuSens system, this is basically for this is an IoT based system for ambulatory healthcare. So, in the ambulances patients can be the health condition of the patients can be monitored.

So, essentially in this kind of model, we are talking about utilization of the data by different stakeholders like the doctors, the patients themselves, the near and dear ones of the patients, the paramedics. So, all are different users of this kind of system the AmbuSens system.

And there is huge data is generated, this data are aggregated at different levels in the system. And they this data are also analyzed and this analysis of the data is done, and that analyze data is again offered to these different stakeholders that I just mentioned. And they can get the different pictures from the analysis of the data from the data that are collected by from the patients that are in the ambulances.

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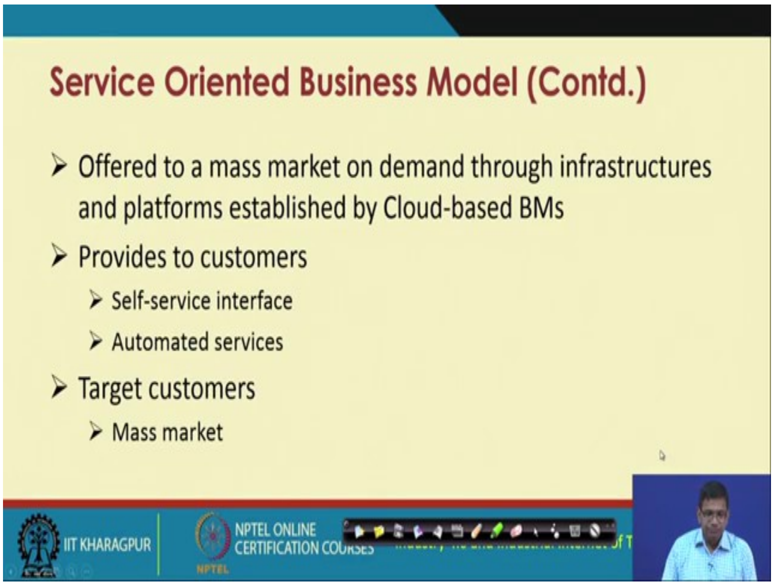


So, typically this kind of typically, but not necessarily; this kind of business model is an adopted in mass market kind of situations, where there is a mass market, and on-demand these infrastructures and the platforms could be made available, typically through some kind of cloud based service.

So, in the AmbuSens as well, we are falling back on the cloud based service for offering the services to the customers. A customers means, we are talking about the patients who are onboard the ambulances traveling from one hospital to another hospital. So, the customers are provided, self-service interfaces, automated services. And as I was telling you that the target customers are basically the mass markets, but not necessarily so.

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So, partner network is very important. So, the community that is there. So, the community the infrastructure providers, the platform developers, these are different, they are the different aspects that different people that join hands in the partner network. And the distribution channels on demand or the different platforms that are used, so these are also different important considerations in the Service-Oriented business model.

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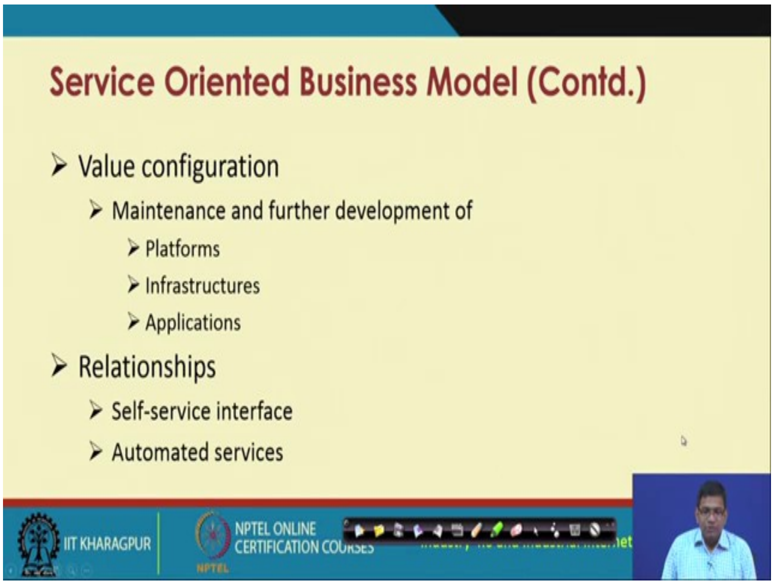


With respect to value configuration, the maintenance, and further development of the platforms are very crucial in this kind of business model. The infrastructure, the platforms, the applications, the maintenance of them and not only maintenance, but for the development; these are very important in the service-oriented business model.

And the relationships; so self-service interfaces, automated services etcetera offered to the different customer. So, we have the business, who is offering it, and we have the end-users. So, between the end-users at the end-user as well as the businesses, the different interfaces, the self-service interfaces, the automated servicing interfaces etcetera, that are offered; these are very crucial features in this kind of business model.

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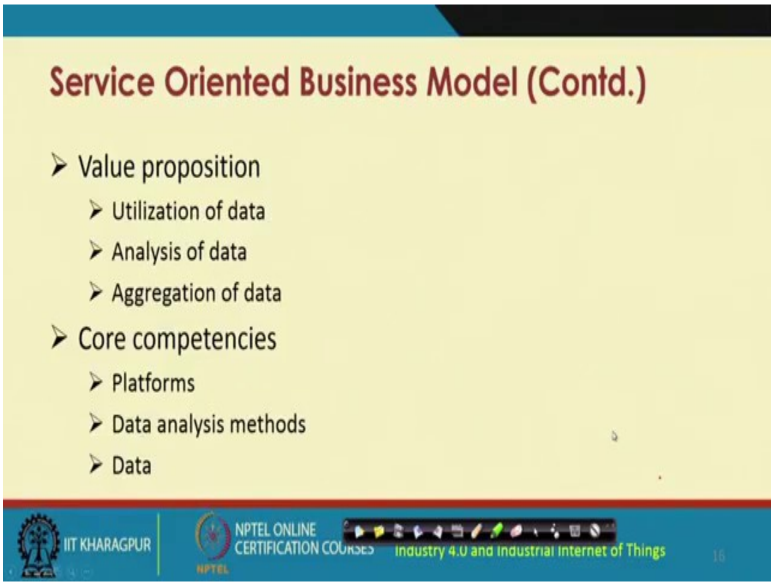


In terms of the value proposition, the utilization of the data, the analysis of the data, the aggregation of the data, these are important and also the core competencies such as the platforms, the data that is generated by itself, the methods, that are used to analyze the data that is generated. So, all these are important aspects of core competencies in this kind of business model.

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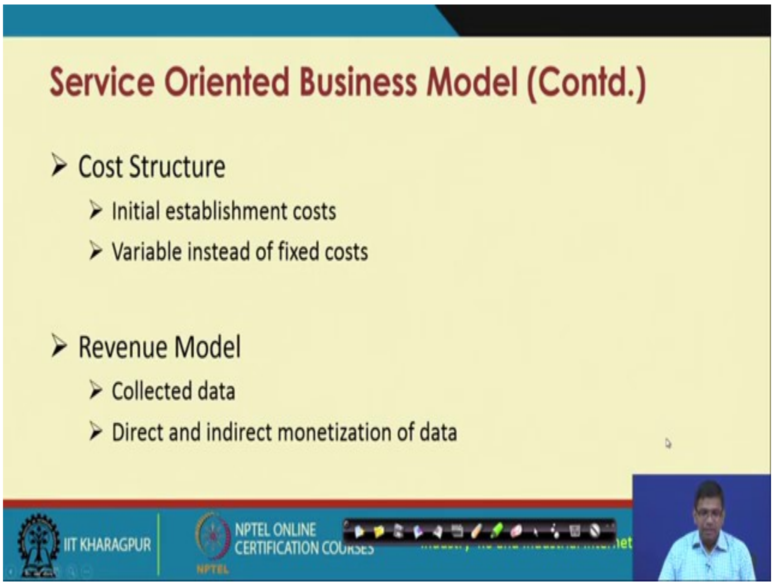


Cost structure. The initial establishment costs, the variable versus fixed costs, these are important considerations. The revenue model, collecting the data, and also monetizing the data that is collected directly or indirectly monetizing from the data that is collected; so collecting and monetizing from the collected data directly or indirectly, these are important aspects in this kind of business model.

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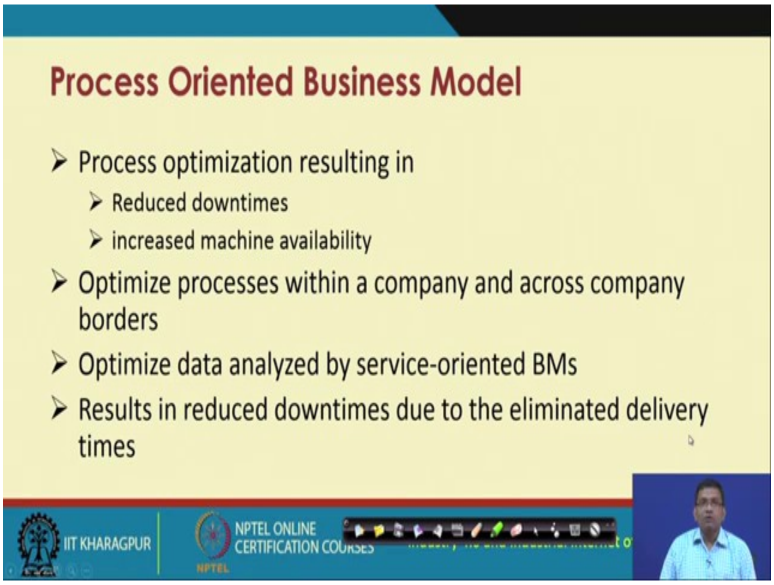


So, the next one is the process-oriented business model. So, here we are talking about the processes, optimization of these different processes, reducing the different down times of the machinery that is available. And making these machinery available for increased durations of time to different (different) customers, this is the whole idea behind this process oriented business model. So, reduced down time, increased machinery availability, these are important considerations in the process optimization sorry in the process oriented business model.

So, these have to be optimized, that means, that you increase the availability of these machinery to different customers not just one customer, but many different customers, making these machineries available to many of them. So, the processes will have to be optimized within a company, and across different company border borders. So, earlier I was telling you about this particular thing, in a different context as well.

So, what is important in the IoT world; IIoT world, more specifically, is we are talking about not a single company, but we are talking about a situation a scenario, where these different companies, the borders between these different companies are going to be removed. And these companies are going to join hands for optimizing their resources, and the processes that are there, in the use of these different resources.

So, optimizing of optimization of these different processes; optimization of the data that is analyzed by the service oriented business model, that we talked about earlier. And the result of this process oriented business model is reduced downtime, due to eliminated delivery types.

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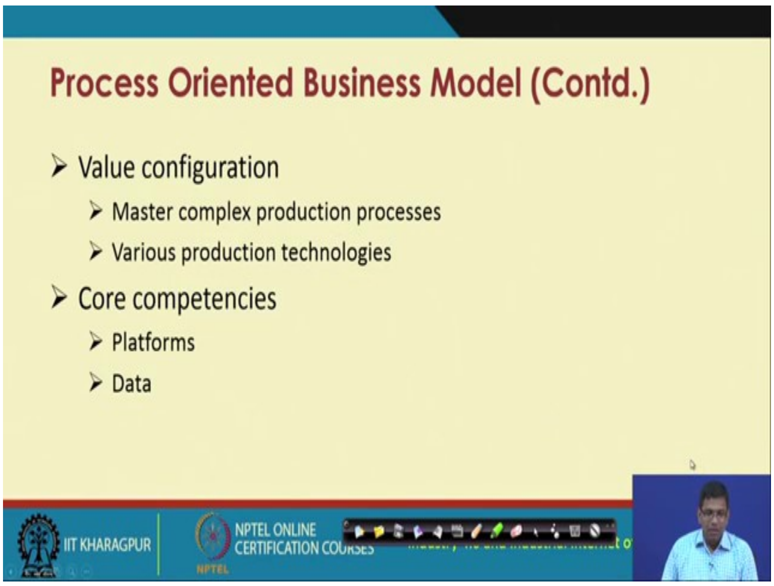

So, in terms of the value configuration, we are talking about master complex production processes. So, we are talking about a complex kind of production process, right. We are talking about the complex production process, where not just one kind of business will be involved, but multiple businesses might be involved as well.

So, mastering this complexity is very important. And also trying to deal with various types of products and technologies, this is very important in the process oriented business model. In terms of the core competencies, the platforms are very important. The data that is generated is very important. So, these will have to be dealt with very carefully in this business model, the process oriented business model.

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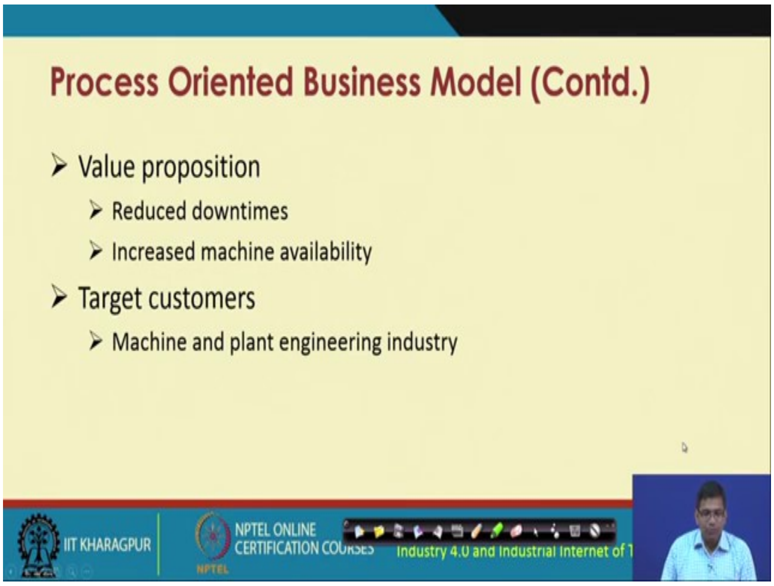


The value proposition is that this kind of business model leads to reduce downtime, increased machinery availability. So, these are some of the important features attractive features of that option of process oriented business model. And the next one is the target customers for use of this kind of business model the process oriented business model are basically the machines and the plant engineering industry, machine and plant engineering industry. These are target customers of this kind of business model.

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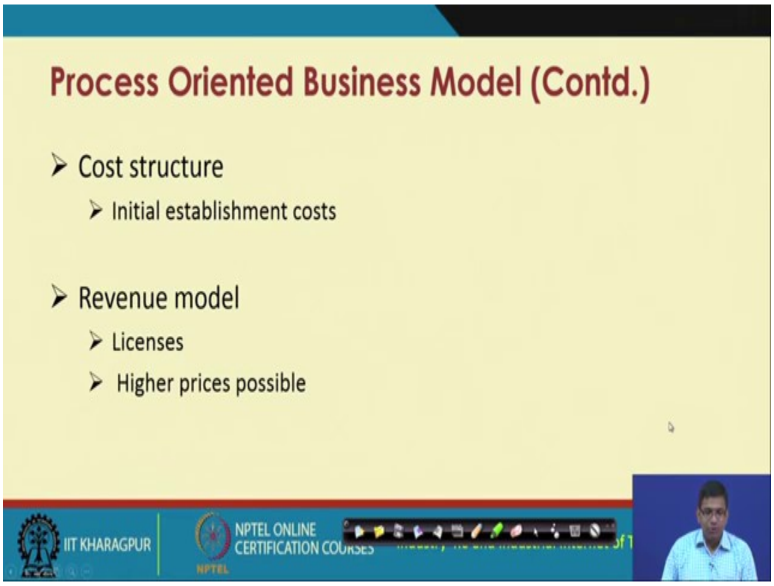


In terms of the cost structure, there is some initial establishment cost that is important, before one uses or adopts this kind of business model. And the revenue model, for example, the license costs are important the higher, higher prices might be possible in the in adopting this kind of business model. So, this is also an important consideration to come up with the license costs, higher prices possibility of higher prices, existence of higher prices; these are important considerations, while coming up with the revenue model.

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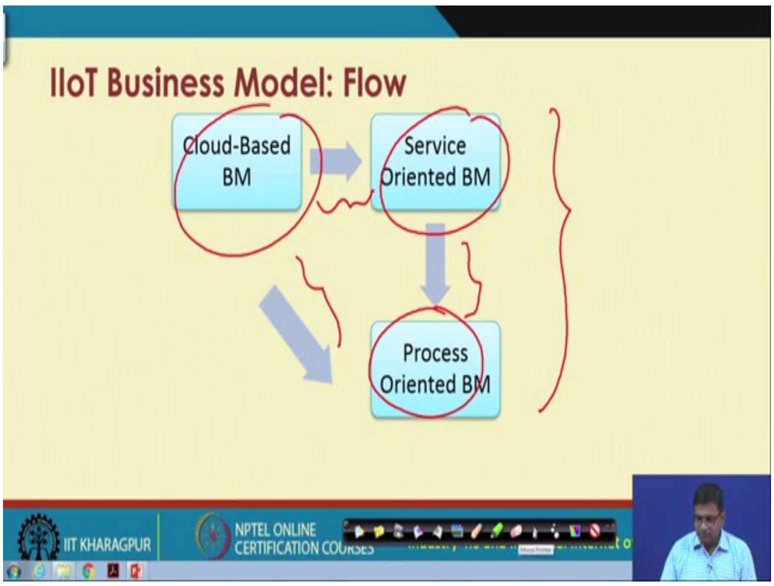

So, we talked about cloud-based business model, we talked about the service-oriented business model, we talked about the process oriented business model. So, so all these three we have individually talked about, but as we can see over here we have these inter-linking these different business models. So, there is inter-dependency between these business models. So, in other words they do not work in isolation, they are all interdependent, right. So, this is something that we have to keep in mind, while choosing the right business model for the IIoT scenario that we talk about.

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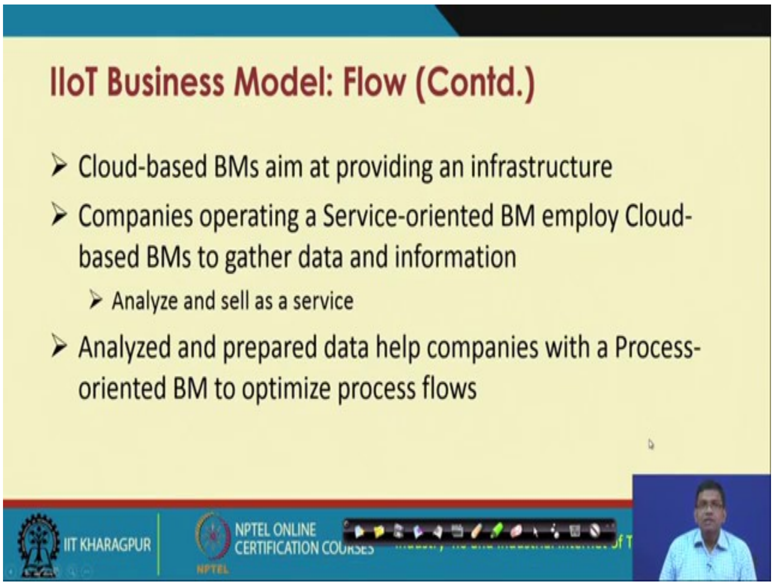


So, cloud-based business models aim at providing an infrastructure. Companies operating a service-oriented business model employee cloud-based business models to gather data and information. And this analyze data are prepared and they help the companies with a process-oriented business model, to optimize process flow. So, as we can see that we are not talking about any of these business models in isolation. But, in a real kind of IIoT setting, these business models are interlinked. So, they depend on each other, and they can be used, the choice of the business models should consider this inter dependency as well.

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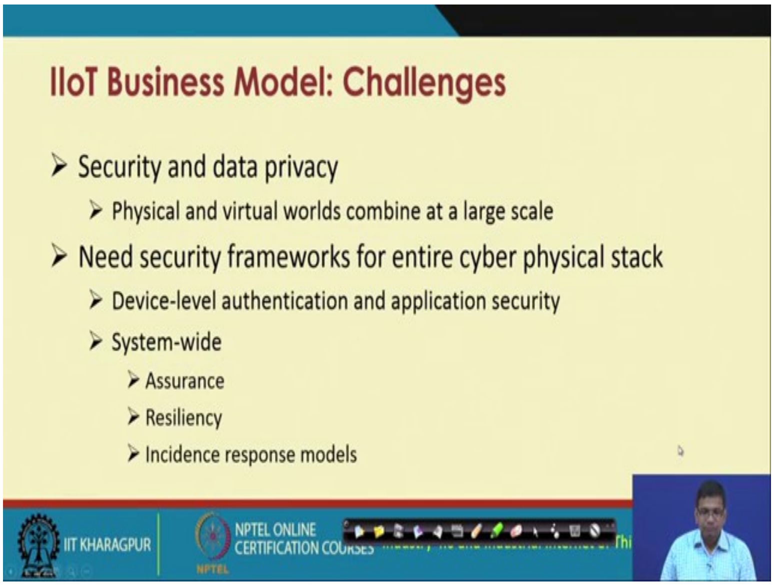


So, in terms of the challenges; security and data privacy, challenges are there. Obviously, so I do not need to elaborate on this. And there is need for securing the entire cyber physical infrastructure that is there. This is very important for IIoT, IIoT systems are typically, cyber physical systems, typically, but not necessarily these are cyber physical systems. So, security the physical security of these infrastructure the frameworks, and the associated infrastructure are very important.

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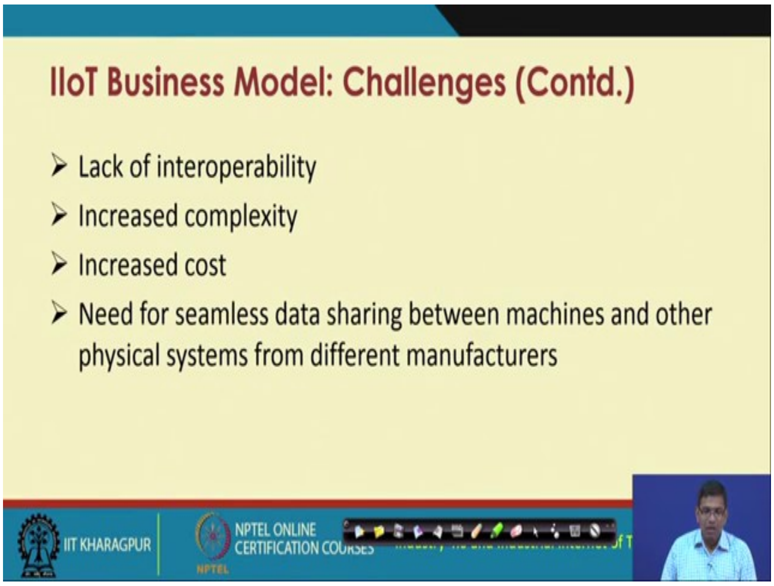

In terms of other challenges lack of interoperability is important. Increased complexity is quite obvious. Increased cost need for seamless data sharing between the machines, and other physical systems from different manufacturer, because different manufacturers, different vendors are providing different machines, that have been developed in isolation.

So, there is what is very important is to ensure that there will be when you are integrating all of these different machinery, there will be seamless integration of this data. And they are going to be shared, seamlessly between these different machines and machines, and the different other instruments, that are there in the cyber physical system. And they have been developed by the different vendors.

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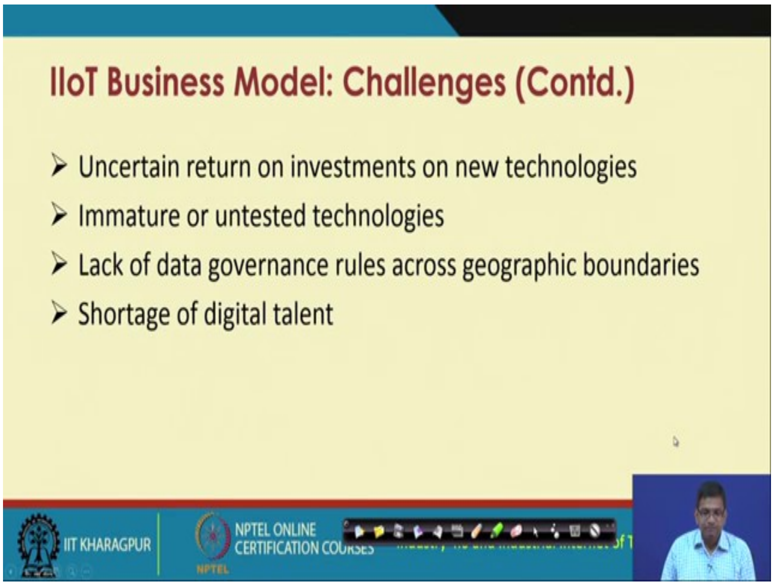


Other challenges include uncertain (Refer Time: 25:15) on new technologies, immature or untested technologies, lack of data governance, shortage of digital talent. So, these are the different other challenges that will also have to be considered by a business, before coming up with the adoption of a suitable business model.

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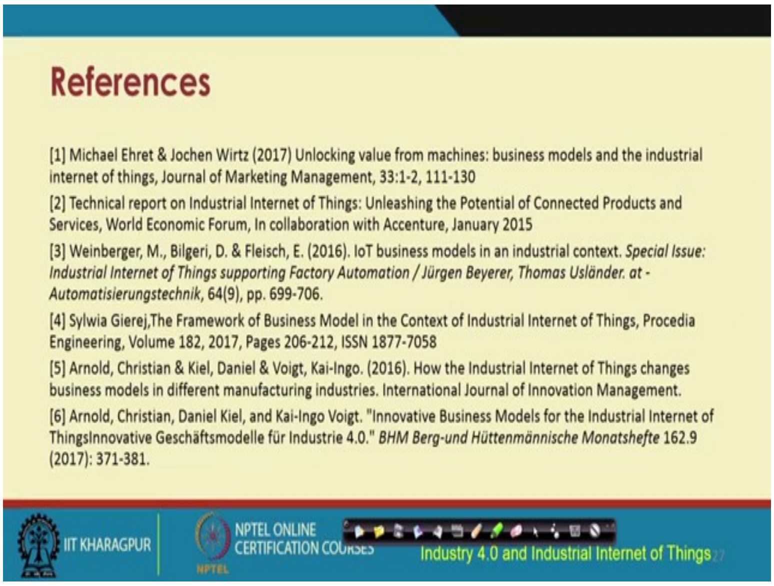


So, in this particular lecture, what we have gone through are some of the specificities in terms of business models, the business aspects of IIoT. When somebody is adopting IIoT in the company in the industry, then there are certain aspects with respect to the business, they are that will have to be considered. So, those aspects we have gone through some of the different aspects I mean these are not the only ones, but some of the important ones we have gone through. So, we have understood the different aspects of IIoT business models, the advantages, the features, the advantages, the different challenges, and so on.

So, with this in the previous lecture as well as the as well as in this particular lecture, we have gone through the different aspects of business, the different aspects of the features of the different business models, that can be used for IoT and IIoT respectively. And the advent advantages, and the different challenges, that are going to be encountered in the adoption of these technologies IIoT and IoT, in general, these technologies in a particular industry.

So, we have these are the some of the references that one can go through. In order to understand in more detail, but as I said earlier as well that this understanding should be sufficient about the business aspects, these understanding of the business aspect should be sufficient, in order to have the holistic view of holistic understanding about IIoT. The technicalities are covered in the other lectures, but these business aspects are also something that cannot be ignored by the technical folks in the industry. So, there has to be some basic understanding about these business aspects, and this is what we have tried to ensure imparting you with this kind of knowledge. And so these references, if somebody wants to go through in further more detail. And with this we come to an end of the understanding about the business models for IIoT.

Thank you.

**Introduction to Industry 4.0 and Industrial Internet of Things**
**Prof. Sudip Misra**
**Department of Computer Science and Engineering**
**Indian Institute of Technology, Kharagpur**

**Lecture - 24**
**Business Models and Reference Architecture for IIoT: Reference Architecture – Part 1**

In this module, we have talked about the business models that could be used for Industrial Internet and Industrial IoT scenarios. In this particular lecture, we are going to talk about the difference architecture. In the context of the business, we have talked about the possible business models, that could be used in the previous lectures in this particular module, but we should be also able to use the different architectural platforms for transformation of the business for the adoption of Industrial IoT. Let us look at the IIoT reference architecture.

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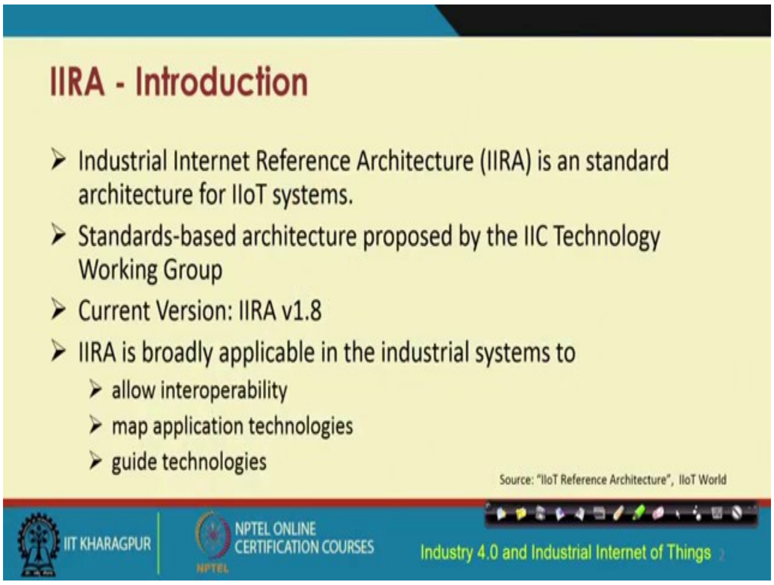


IIoT reference architecture is governed by the Industrial Internet Reference Architecture. This is sort of a standard architecture that IIoT systems globally tend to use and tend to follow. IIRA - Industrial Internet Reference Architecture is the architectural standard, that is used for most of these IIoT applications in these industries. So, it is a standard based architecture, which was proposed by the Industrial Internet Consortium – IIC, their technology working group came up with this architecture. The current version of it is

IIRA v1.8. So, 1.8 is the current version of the Industrial Internet Reference Architecture. And this architecture broadly applies in the industrial systems to allow interoperability, mapping application technologies, and in guiding the use of these technologies by different application users.

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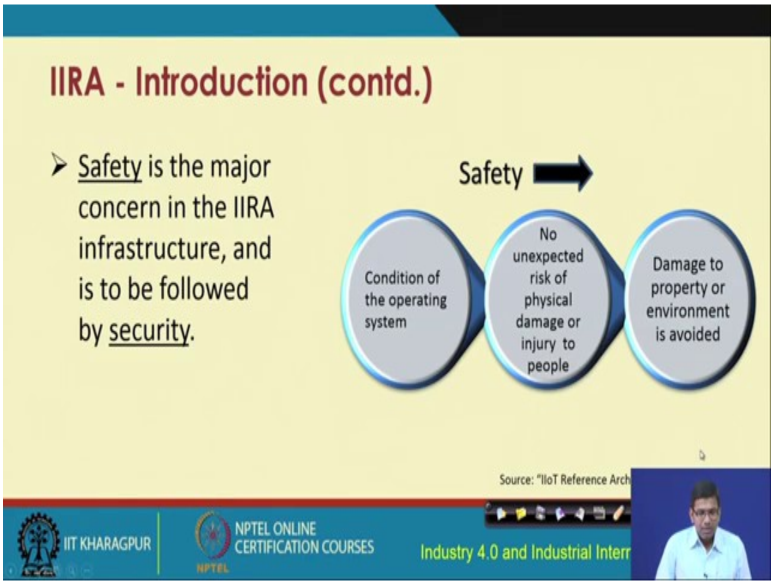


So, for the IIRA one of the central thematic concerns is the safety. And many of these architectural elements basically have been designed in such a way that safety has been kept in mind. IIRA safety concern is important and after safety is the issue of security. Security in terms of everything, security of information, security of data security of the systems and so on. Safety and security are paramount and central thematic considerations while coming up with the IIRA architecture for use with IIoT industrial applications.

In terms of safety, it is important to know for the system that is operating, what is the condition of it. It is also important to ensure that there is no unexpected risk of physical damage or injury to people due to some malfunctioning or potentially malfunctioning systems in the future. And third safety concern is to ensure that there is no damage to property or environment, due to any kind of malfunctioning now or in the future.

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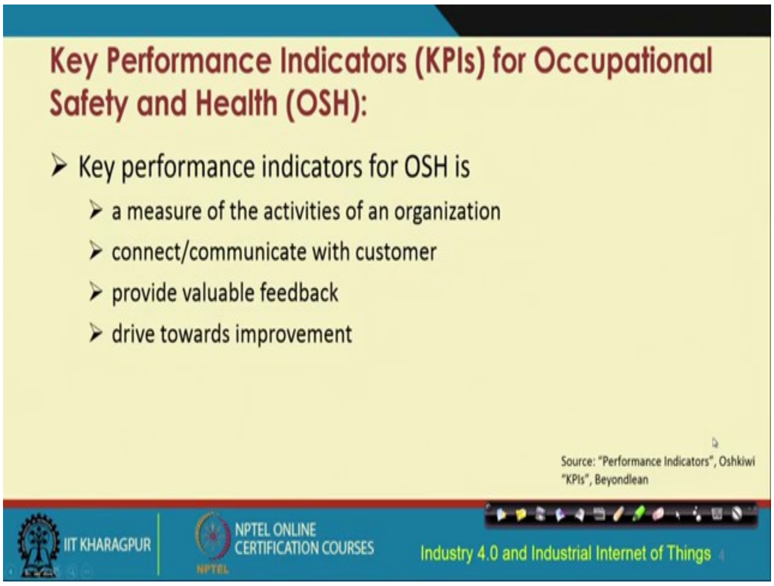


These are some of these KPIs for occupational safety and health. These KPIs are basically a measure of the activities of an organization. These KPIs also help measure the connectivity and communication with customers, providing valuable feedback to the customers, and driving towards further improvement; there are different KPIs.

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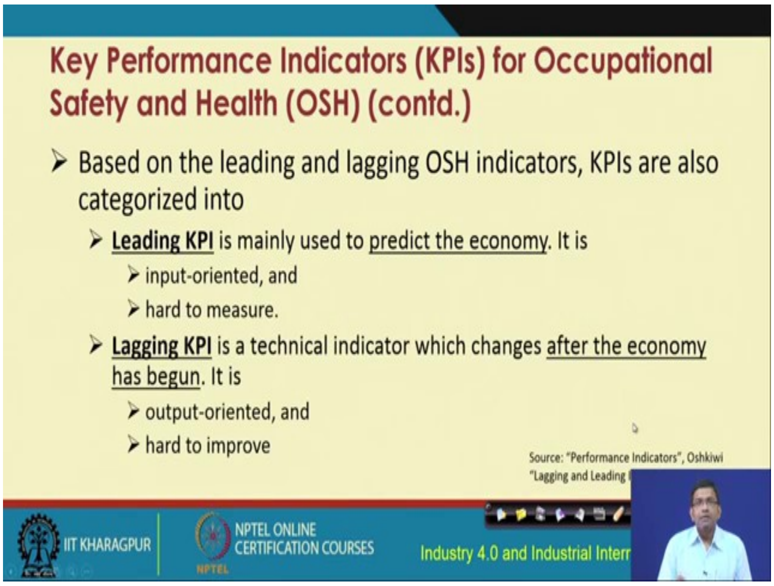


So, these KPIs based on their types can be categorized into two types. One is the leading KPI, and it is mainly used to predict the economy, it is input-oriented, and is hard to measure. And as the name suggests the latter category is the lagging KPI, which is a technical indicator, which changes after the economy has initiated. So, unlike the leading KPI, which is input-oriented, the lagging KPI is output-oriented, and this is hard to improve. Leading KPI talks about predicting, predicting the economy. And lagging KPI talking about after the economy has started to improve. So, basically these two perspectives are different. Leading KPI and lagging KPI are the two different KPI categories for OSH.

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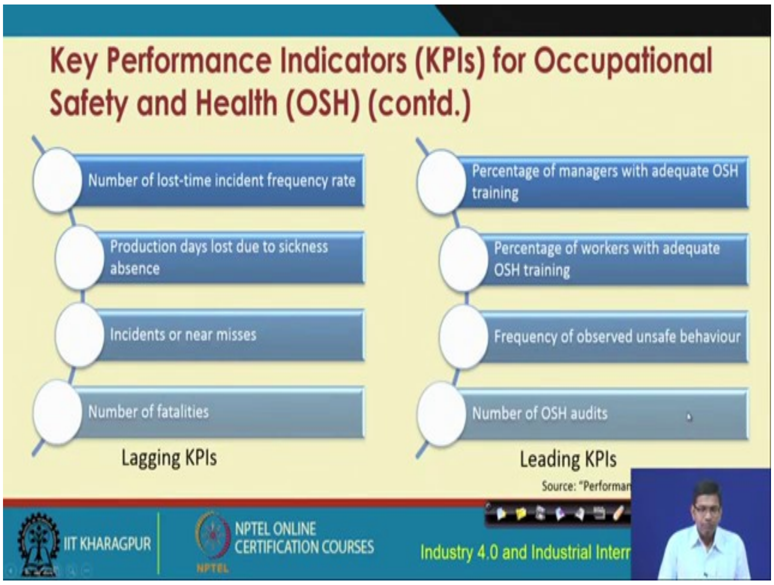


So, leading KPIs for example, percentage of managers with adequate operational and safety, health safety training, percentage of workers with adequate operational and safety training, then, frequency of observed unsafe behavior, number of OSH audits, these are some of these different KPIs under the leading KPIs category. Under the lagging KPIs category, we have number of lost-time incident frequency rate, how many times the different incidents have occurred, and we have lost time due to those incidents, and the frequency of occurrence of those incidents. Production days lost due to sickness absence, incidents or near misses, and number of fatalities, these are the lagging KPIs.

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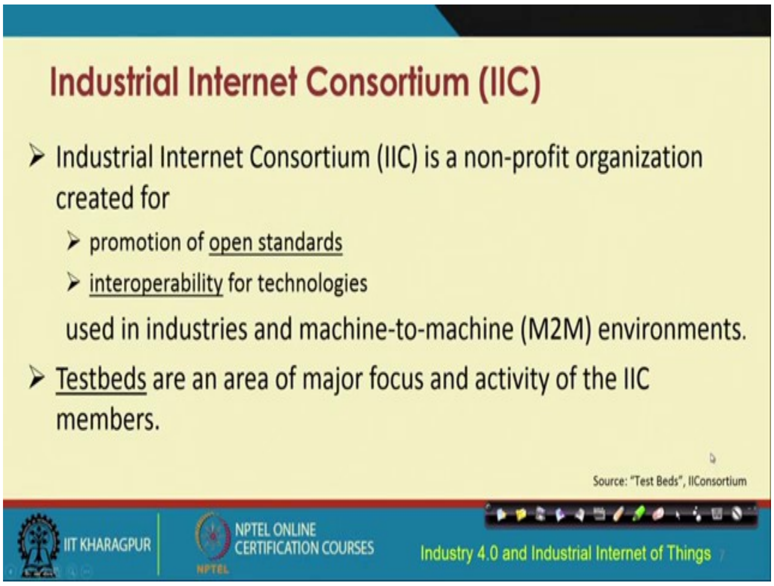


So, I was talking about the IIC, which is the Industrial Internet Consortium, which is a non-profit consortium doing different things promoting open standards, standards for interoperability, supporting architectures for promoting interpretability across different technologies. And these technologies open standards, interoperable standards these are used in industries and for M2M communication, in these industries.

IIC is the one which came up with that the Industrial Internet Reference Architecture, IIRA architecture. Industrial Internet Consortium - IIC has also among its focus areas and activities has the development of Testbeds for different trials also a major concern. So, testbeds are an area of major focus and activity of the different IIC members.

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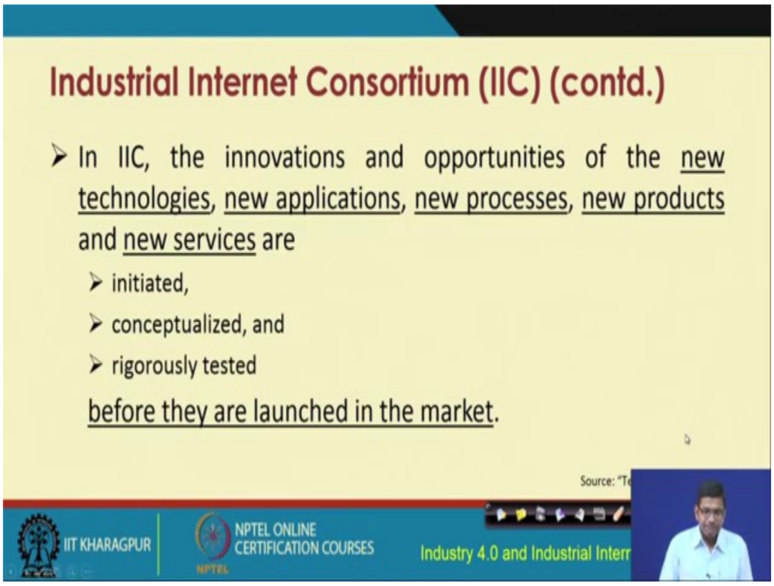


So, Industrial Internet Consortium continues to do different activities, tasks and so on, they have their different working groups. So, these working groups do different things they innovate, they come up with different opportunities of the use of new technologies, new applications, new processes, new products, new services, etcetera, which could be initiated, conceptualized, and could be rigorously tested, in the different testbeds that I just talked about a while back.

And these could be done before they are actually launched in the market. These are the ones these are the different activities that are promoted by the IIC.

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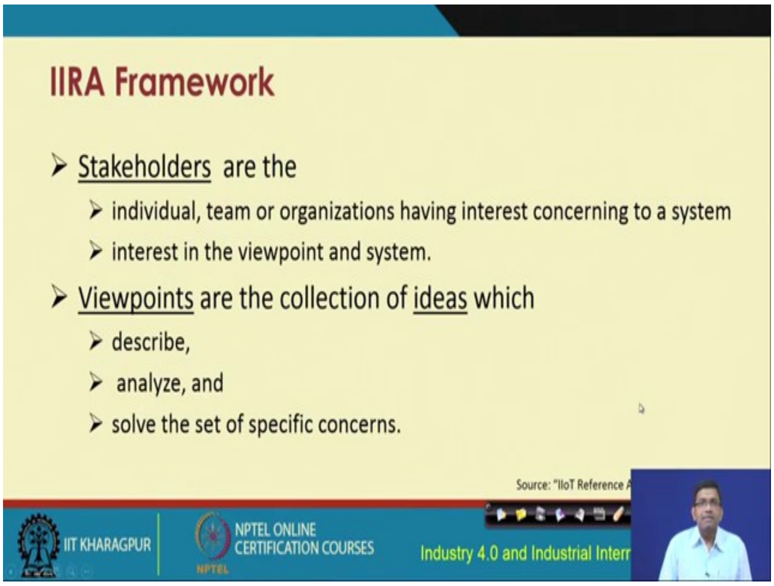


So, II Reference Architecture (IIRA) - Industrial Internet Reference Architecture, IIRA has different architectural components, which are part of their framework, number one is the stakeholder. So, we need to understand some of these different concepts. So, number one is the stakeholder stakeholders are individuals teams or organizations having interest concerning the system.

The next concept is linked to the stakeholders; these are the viewpoints. So, these stakeholders have some interest in the viewpoints and the system. So, viewpoints are from the stakeholders, which are basically the collection of different ideas from the stakeholder's collection, grouping of them, describing these different ideas, analyzing the ideas, and solving the set of specific concerns.

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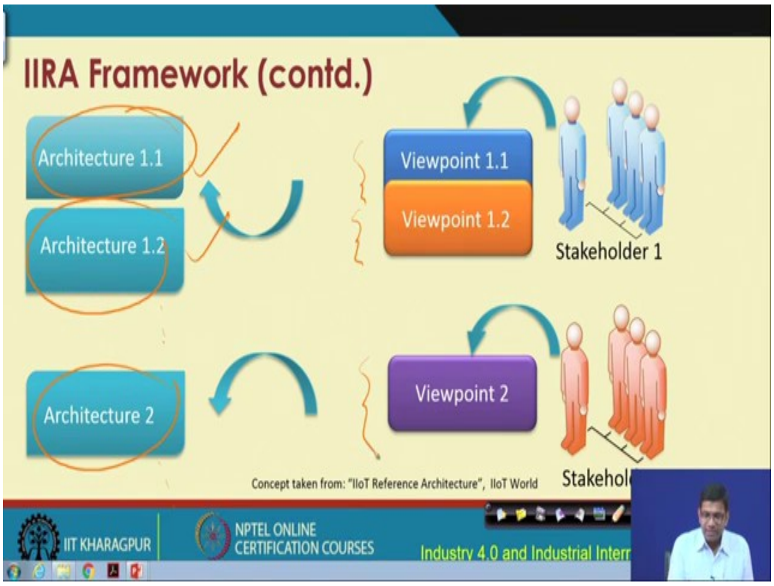


This is the IIRA framework. So, as you can see over here let me just explain it to you. So, this shows that there are different stakeholder groups--stakeholder group 1, stakeholder group 2. These stakeholders have different framework sorry have different viewpoints, viewpoint 1.1, viewpoint 1.2, etcetera.

Similarly, stakeholder 2 would have their own viewpoint, which could be again classified as 2.1, 2.2 etcetera, as the case may be. So, that is the concept of the viewpoints, which is basically a, a collection of different ideas from different stakeholders. So, these step these stakeholders come up with different viewpoints and these viewpoints essentially help in coming up with these different architectural components architecture 1.1, 1.2 etcetera, and architecture 2, 2.1, 2.2 etcetera, mapping directly to these different viewpoints.

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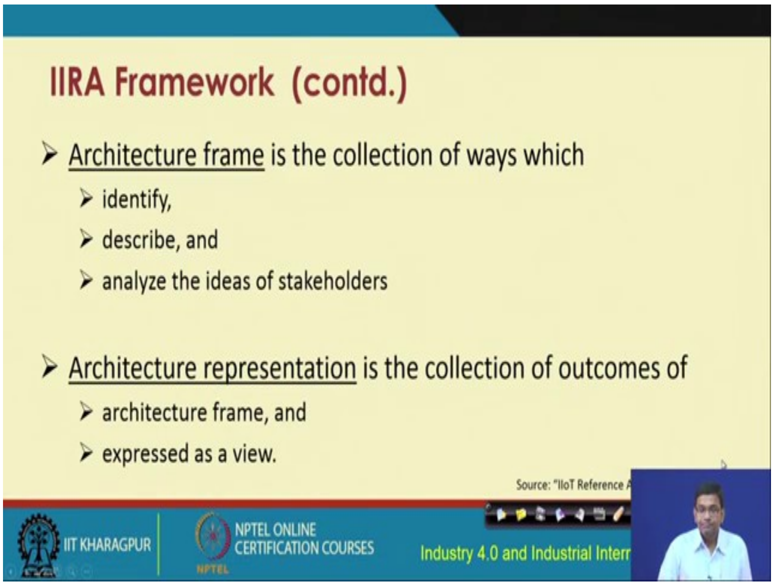


Next comes the concept of the frame, the architectural frame, which is a collection of ways which identify, describe, and analyze the ideas of the different stakeholders. The concept of architectural representation is important; it is the collection of outcomes of architectural frame and are expressed as views.

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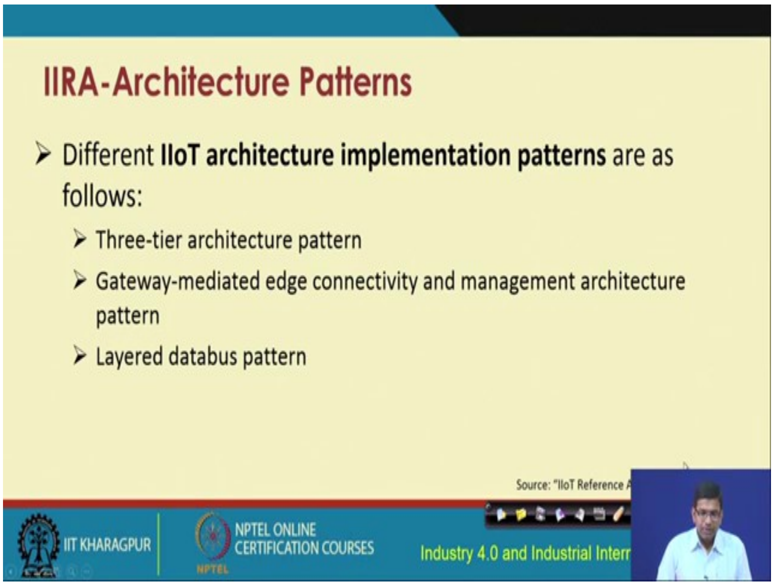


Different IIoT architecture implementation patterns are have been proposed. So, we will go through three different patterns, number one is the three-tier architecture pattern, number two is the gateway mediated edge connectivity, and management architecture pattern, and third is the layered data bus pattern.

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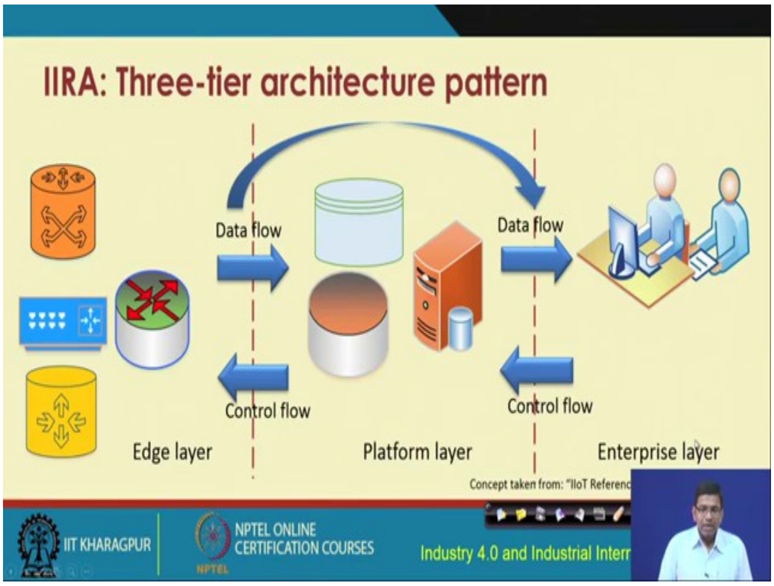


So, let us go through each of these, to start with we will first go through the three-tier architecture pattern. In this three-tier architecture pattern, we have three different layers we have the edge layer, the platform layer and the enterprise layer. So, edge layer basically talks about all these different edge devices, basically the device is connecting to these different gateways at the edge and so on.

And these devices and the gateways etcetera are going to send the data to the platform layer, these are this is the platform layer, where the data are going to be analyzed, and so on. And further the data are going to be processed and sent to the enterprise layer. The control flow is in the reverse direction, data could flow from, the edge layer to the platform layer directly, or could directly also flow to the enterprise layer.

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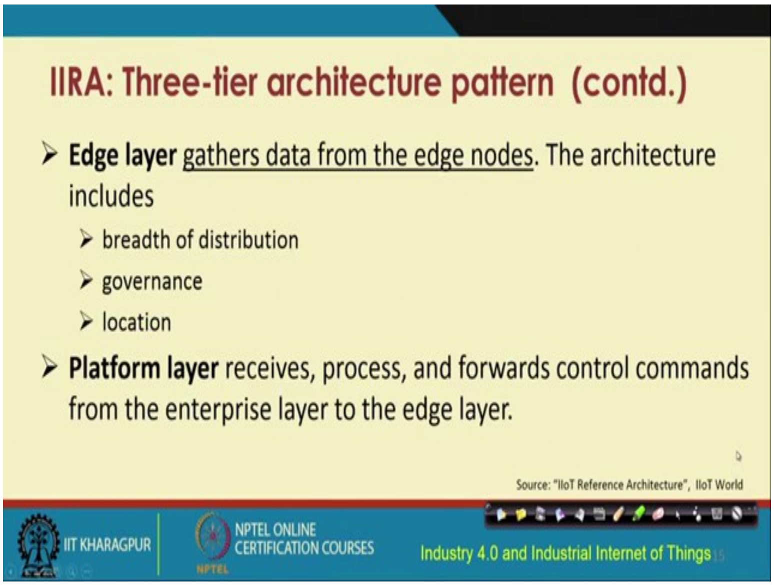


So, this three-tier architecture pattern let us go through the different components, in further more detail. So, we have the edge layer, which gathers data from the edge nodes, the architecture includes the breadth of distribution, governance, and location of the data. Breadth of distribution of the data, governance of the data, and the location of the data meaning that where from the data are coming from these individual devices. Platform layer basically it is concerning receiving, processing, and forwarding control commands from the enterprise layer to the edge layer.

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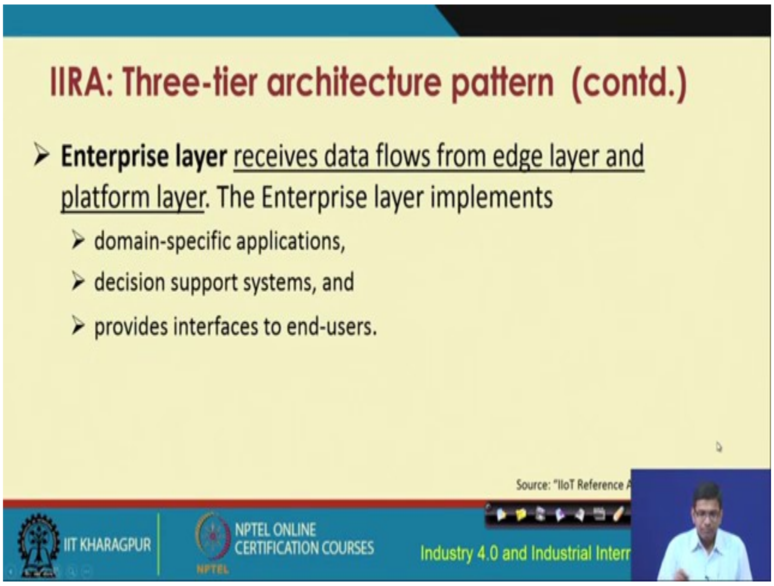

And finally, the enterprise layer concerns receiving data flows from the edge layer and the platform layer. So, I mean directly from the edge layer, the enterprise layer could be receiving the data or it could be from the platform layer, which again receives the data from the edge layer. So, the enterprise layer basically implements domain-specific requirements, decision support systems, and other requirements such as interfaces to end-users.

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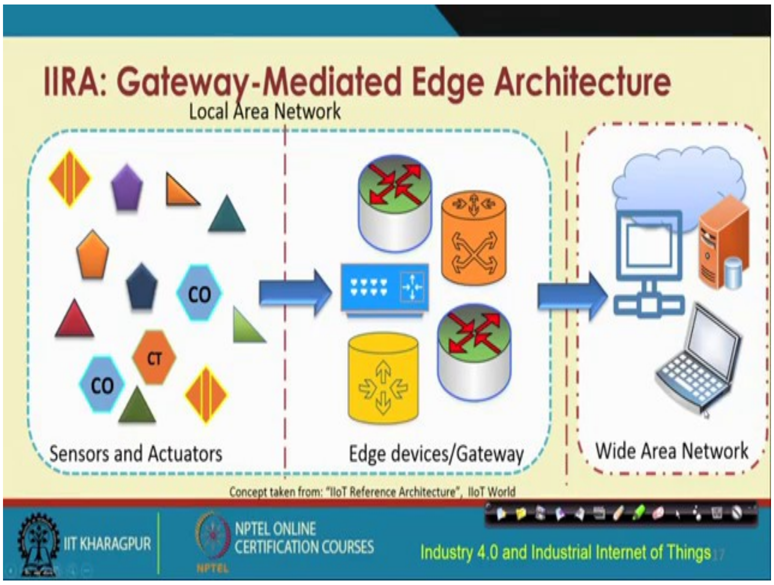


The next type of architecture is the gateway-mediated edge architecture. Here basically we are talking about incorporation of the, the gateway, gateway concept. So, we have all these different sensors and actuators, these sensors and actuators throw in lot of data. And through the different gateway devices, edge devices, gateway devices and so on the data are sent to the wide area network for further dissemination of different information and so on.

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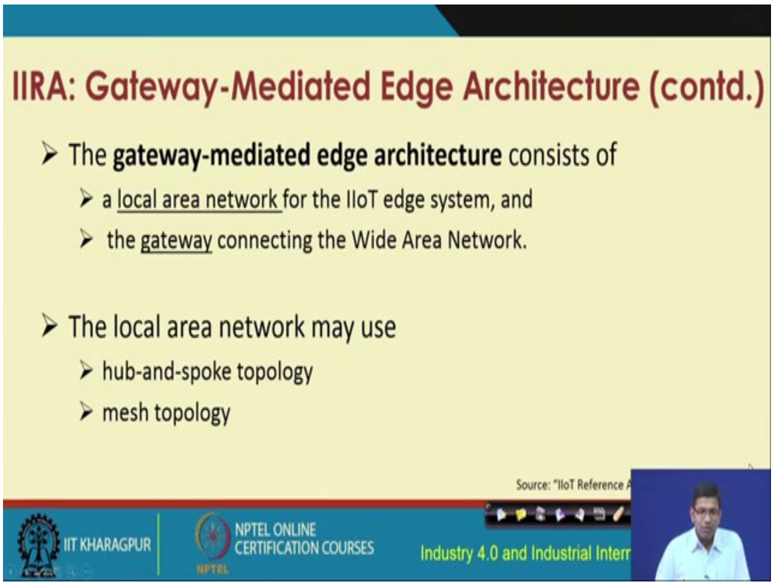


So, like the previous architecture here again let us go through each of these architectural components of the gate gateway-mediated edge architecture, in further detail. So, this gateway mediated edge architecture consists of a local area network for the IIoT edge system and the gateway connecting to the wide area network. The local area network may use a hub and spoke topology or, a mesh topology.

Mesh topology is one where the different nodes are connected to one another in the form of a mesh. So, there are lot of different links redundant and many different links are there. So, basically what happens is if one link has broken, still, then the different nodes may not be completely disconnected from one another, because there might be some alternate links directly or indirectly, which will basically handle the problem.

So, the other one is the hub-and-spoke topology, which is very similar to the star topology where you have the hub and there are different spoke are connected to the different other edge nodes and together, you have a central kind of hub device connecting to these different other IoT devices, other edge devices. So, this becomes a star kind of topology or a hub-and-spoke topology.

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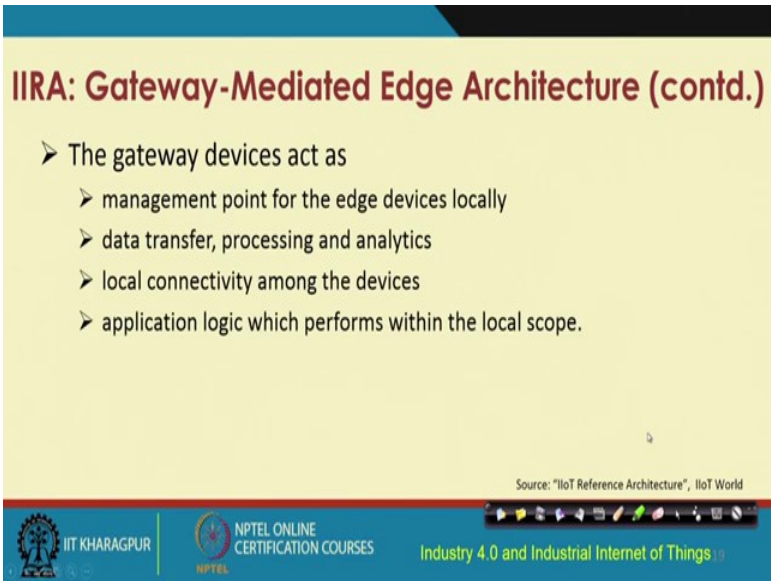


So, you have this local area network, which supports two different types of topologies, the mesh topology and the hub-and-spoke network topology. Then you, we have these gateway devices acting as the management points for the edge devices locally transferring helping in the transferring of the data, processing of the data, and analysis of the data.

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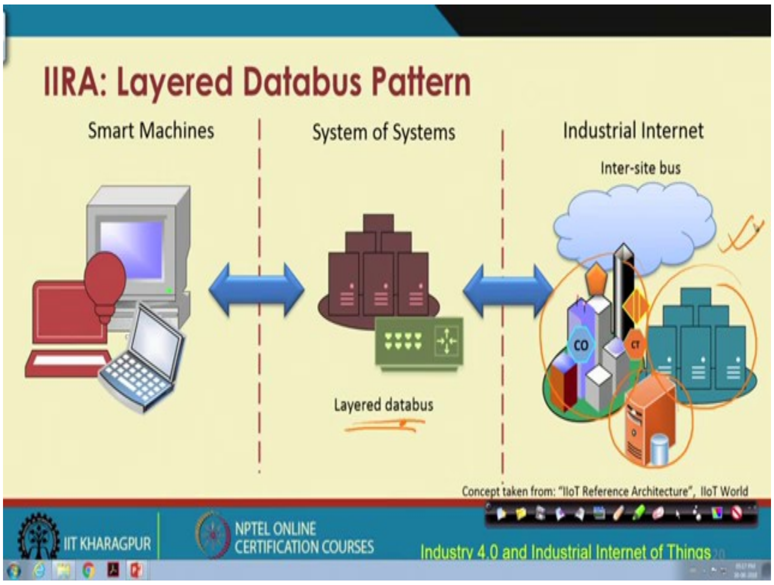


The third type of architectural pattern is the layered databus pattern. So, one thing I should mention before we go any further is all these different architectural patterns are sort of like common templates, which could be used in order to, which could be used as reference architectures in order to deploy IIoT solutions in the industries.

So, now let us go through this third architectural pattern, which is the layered databus pattern. So, here we have three different tiers, we have the smart machines, then we have system of systems, and the industrial internet. So, a system of systems is basically a complex system consisting of different, different subsystems together working together generating lot of complex, executing lot of complex algorithm, generating lot of data handling to be handled, and processed to get lot of insights about what is going on down underneath. This is what is done by the layered databus.

And then you have the industrial internet. We have these different applications running on the industrial internet in different industrial application sites, same site, same site in the same industry different groups or different, different sites of the same company or it could be that different companies are interconnected together. So, this is the layered data bus layered data bus pattern, which is different from the previous two patterns that we have just discussed.

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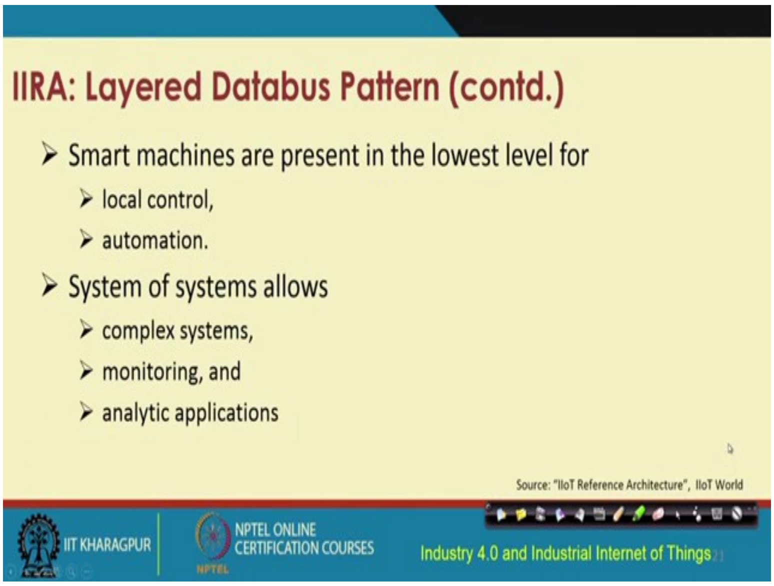


Let us go through this pattern also little bit, in further detail. So, here we are talking about use of smart machines. So, these smart machines at the lowest layer will help in local control and automation processes. System of systems layer allows complex systems to be executed, complex monitoring, complex processing, and analytic applications, all of these things could be executed at this particular layer.

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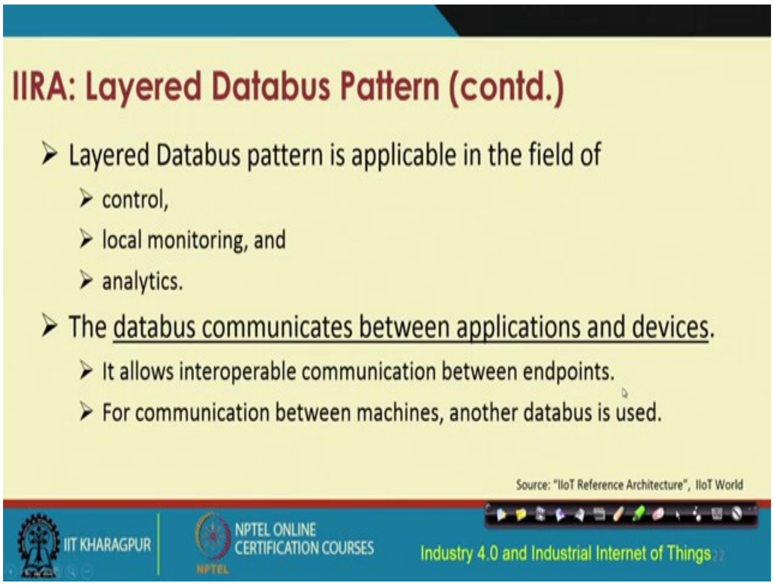


Then you have the layered data bus pattern, which is applicable in the field of control local monitoring and analytics, and the database basically communicates between the applications and devices through this communication is enabled with the help of the data bus. This communication will essentially help in allowing interoperable communication between different endpoints, between different machines.

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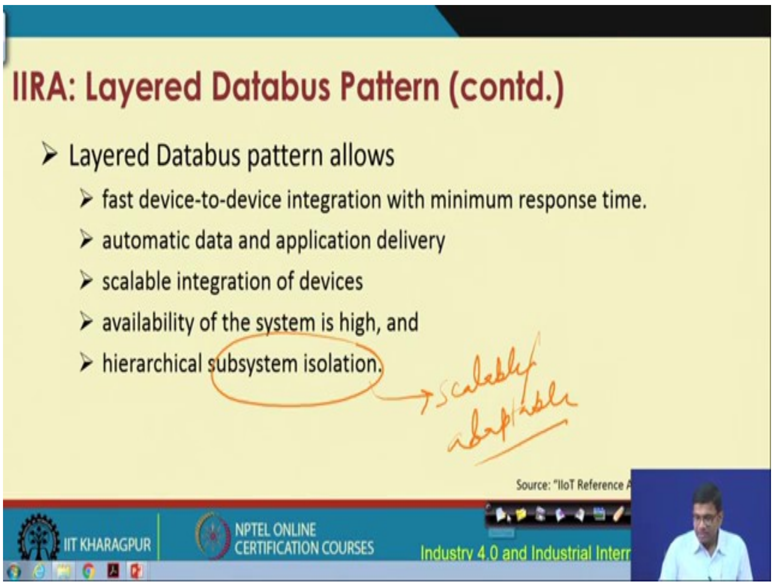

Layered databus pattern basically allows first device to device integration with minimum response time, automatic data and application delivery, scalable integration of devices, availability of the system making, it higher and hierarchical subsystem isolation. So, this isolation part is very important subsystem isolation, because this will help in making the solutions much more scalable and adaptable, adaptable to what; adaptable to different changes.

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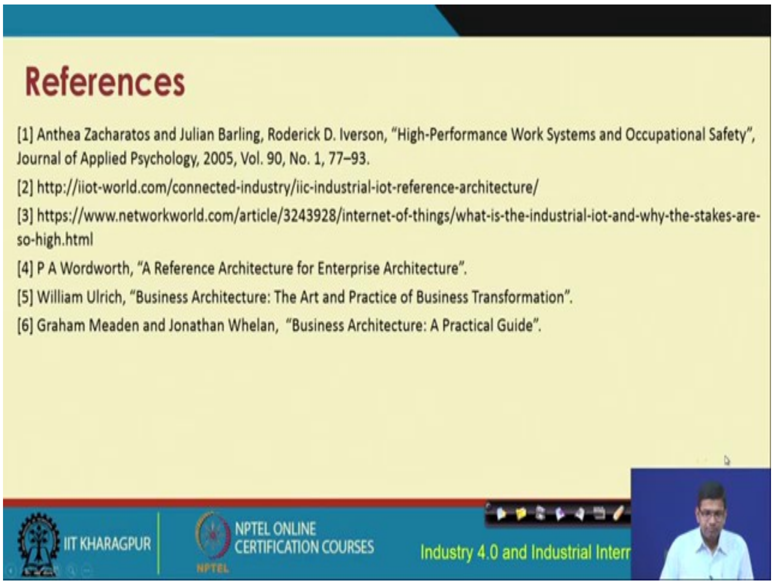


With this we come to the end of the first part of the reference architecture. So, we have seen that this IIRA reference architecture is sort of like a de facto kind of standard being used for the implementation of IIoT in the industries. And this connects well with the business model of this particular unit in the business model, we have seen the different types of business models that could be adopted and this reference architecture is the one which takes it further technically. This reference architecture is sitting between the business issues and the technicalities. And it is trying to map the business requirements with the technical requirements by providing different, different architectural solutions, common architectural solutions, which could be adopted in order to deploy IIoT solutions in the industries. These are some of these references, which you could use and go through further. You could also dig on your own to find out more different other differences on this topic.

Thank you.

**Introduction to Industry 4.0 and Industrial Internet of Things**
**Prof. Sudip Misra**
**Department of Computer Science and Engineering**
**Indian Institute of Technology, Kharagpur**

**Lecture - 25**
**Business Models and Reference Architecture for IIoT: Reference Architecture – Part 2**

In the previous lecture, part one of the reference architecture of this module on business models and reference architecture for Industrial IoT we have seen the IIRA framework, that has been proposed by the technology working group of the Industrial Internet Consortium, IIC.

So, this particular IIRA industrial internet difference architecture has different architectural components, one of which is basically the viewpoints. We have one through in the previous literature a previous lecture the different types of patterns that could be used, in order to implement IIoT in a particular industry. So, we go further ahead and look at the different aspects of viewpoints the further technicalities into the viewpoints and how there are different types of viewpoints, which could be adopted for catering to the requirements of different industrial needs.

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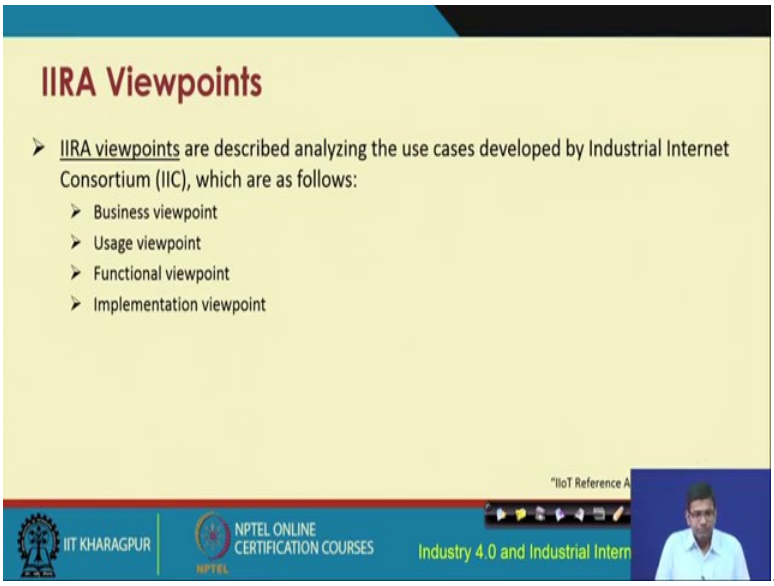


So, we have these different viewpoints IIRA viewpoints, which can help in analyzing the use cases developed by the Industrial Internet Consortium, which could be of different types. We have the business viewpoint, usage viewpoint, functional viewpoint and the implementation viewpoint. So, just as a recap this viewpoint is something, which is like a collection of different ideas and this collection of ideas are coming from the stakeholders. These viewpoints are essentially coming from different stakeholders.

So, we have the business viewpoint which is coming from the stakeholders, who are concerned about the business aspects of it, from the usage viewpoint of different stakeholders what are the concerns what are the ideas that will need to be implemented, same goes for the functional viewpoint and the implementation viewpoint.

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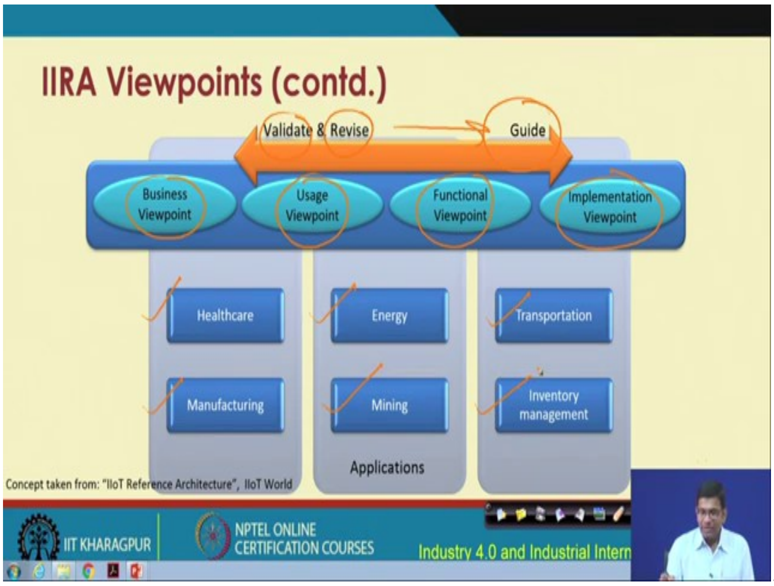


So, this is now architecturally shown over here in the form of a picture. So, you we have these different viewpoints, the business viewpoint, the usage viewpoint, the functional viewpoint, and the implementation viewpoint, and all these viewpoints are basically coming from these different stakeholders. These viewpoints of these ideas are revised and they are validated and finally, after division, these will be helping to guide further guide in the implementation and deployment of the different ideas.

So, these ideas could be implemented in different sectors healthcare, manufacturing, energy, mining, transportation and inventory management are a few to name.

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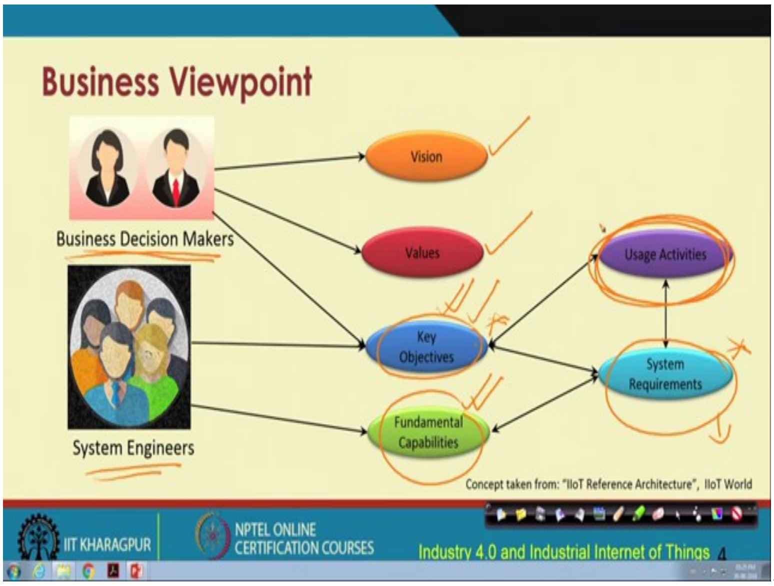


Let us look at each of these viewpoints in a little bit further detail. So, we have at first we have the business viewpoint. From the business viewpoint we are talking about business decision makers, we have the business decision makers, who have a certain vision and have certain values, in terms of improving the customer requirements, meeting the customer requirements, satisfying the customers, and the business decision makers also have certain key objectives.

On the other hand, we have these system engineers who have certain objectives and have certain fundamental capabilities. These key objectives plus the fundamental capabilities together would help in driving the listing of the system requirements of the IIoT system to be deployed. And this will also help these system requirements together with this objective the system requirement together, with this objective will help in arriving at the usage activities, for meeting the business requirements so, this is the business viewpoint.

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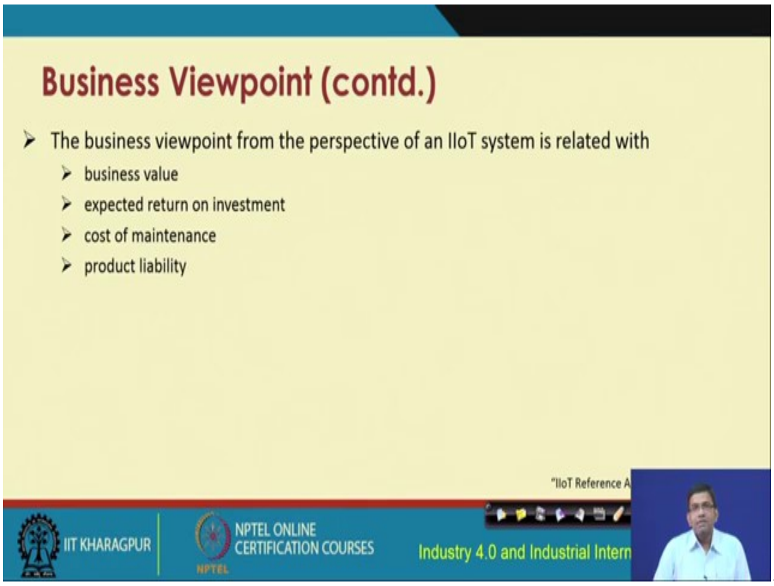


So, the business viewpoint from the perspective of an IIoT system is related to the business value, expected ROI, cost of maintenance, and product liability.

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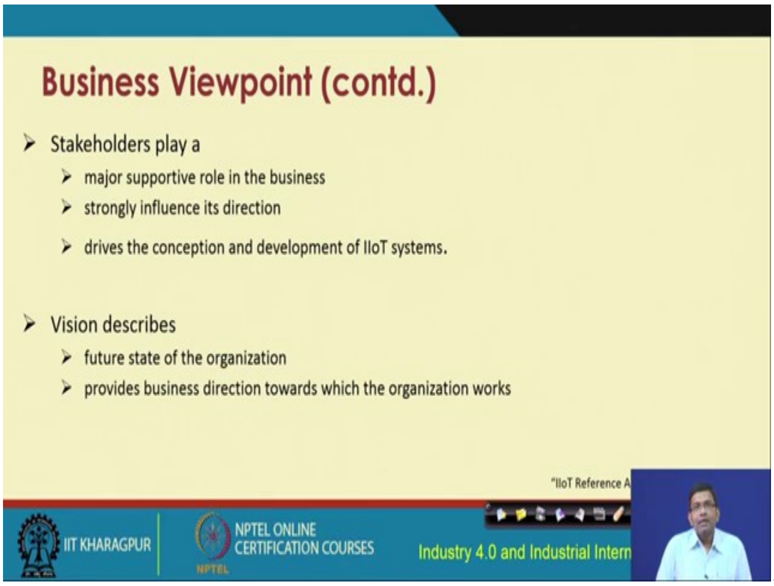


Stakeholders play a very important role in the business viewpoint, the stakeholders play the major role in supporting the business, they strongly influence the direction of the business, and driving in the conception, and development of IIoT systems. The vision attribute in the business viewpoint describes the vision of the organization where the organization is going to be in the future, and providing direction to the business towards which the organization is going to work further.

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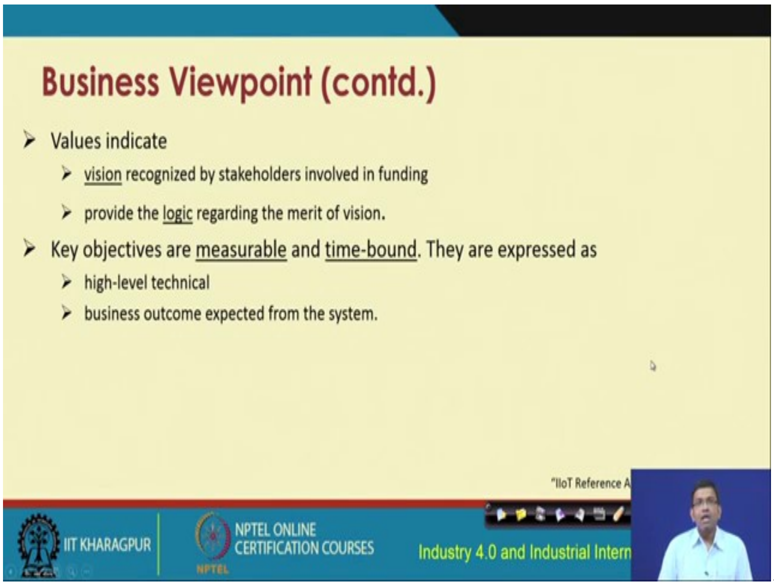


The values in the business viewpoint indicate the vision, recognized by the stakeholders, who are involved in funding providing the logic regarding the merit of vision, and so on. And there are certain key objectives these key objectives should be time-bound and should be measurable, and they are expressed as high level technical business outcome expected from the system.

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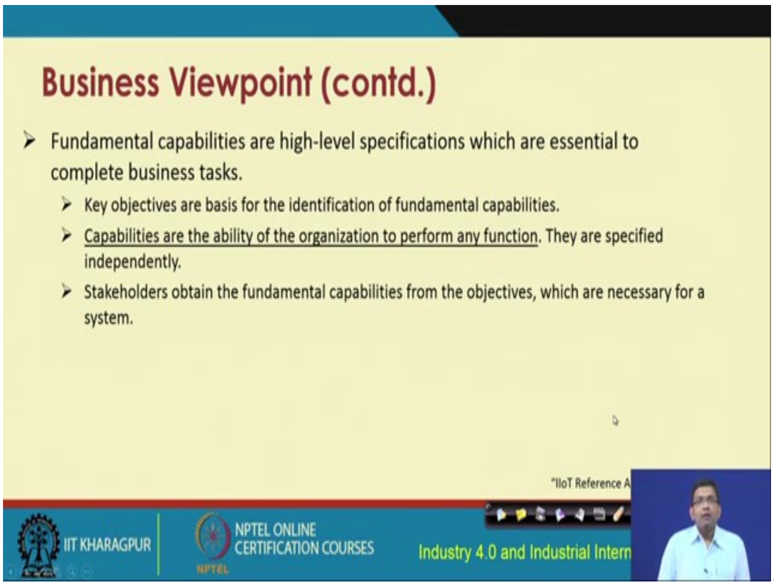

Fundamental capabilities are high level specifications, which are essential to complete business tasks. The key objectives are basis for the identification of fundamental capabilities, fundamental capabilities means the capabilities, which are fundamental in nature, which are the abilities of the organization, to perform certain basic core functions. So, they are basically specified independently. Stakeholders obtain the fundamental capabilities from the objectives, which are necessary for a particular system.

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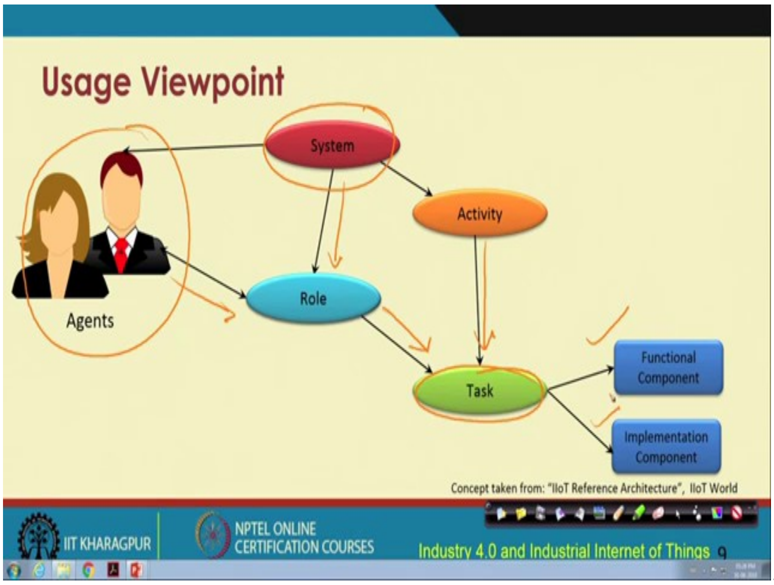


Let us now after the business viewpoint look at the usage viewpoint and as we can see over here it is basically guided through the concept of the agents. So, the agents basically are control, agents control the system. The system has certain roles, the agents basically will have certain roles on the system, in the system rather. The roles and the activities of the system will help in defining the task, the tasks to be performed. There are some functional components and implementation components of these different tasks.

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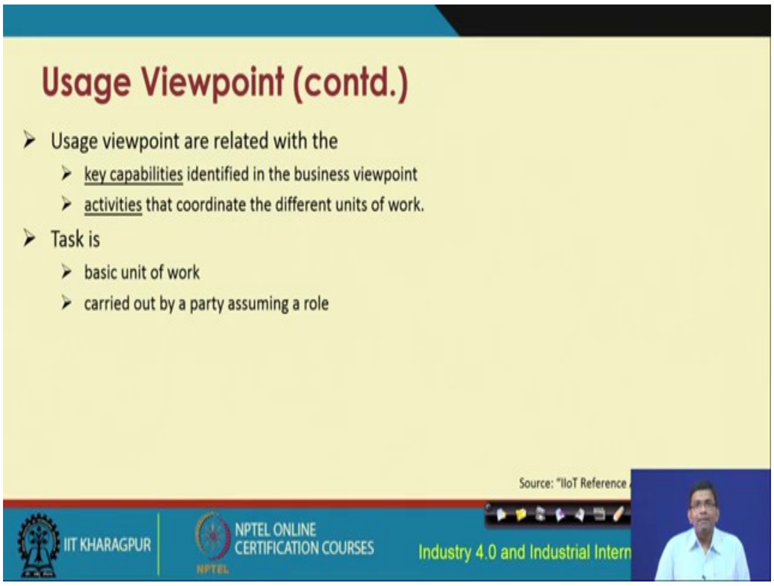


So, usage viewpoints are related with the key capabilities that are identified in the business viewpoint and the activities that coordinate the different units of work. So, the task is in the context of usage viewpoint, the task is a basic unit of work, that is carried out by a party, that assumes a specific role.

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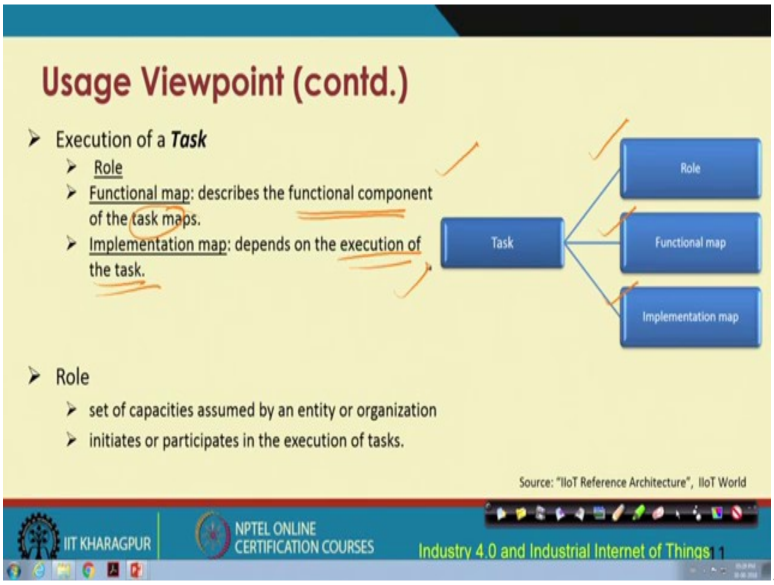


Now this task will have to be executed, these task will be executed by certain roles, and these tasks will have a functional map and an implementation map. So, these tasks basically have their roles the functional map and the implementation map, the functional map basically talks about the functional component of the task maps, and the implementation map talks about the execution of those tasks, execution of the functional component of the tasks functional map, and the execution of the tasks implementation map.

So, the role is the set of capacities that are assumed by an entity or an organization, the roles are initiated, and roles are basically the ones, which basically help in interacting with the system for the execution of the different tasks.

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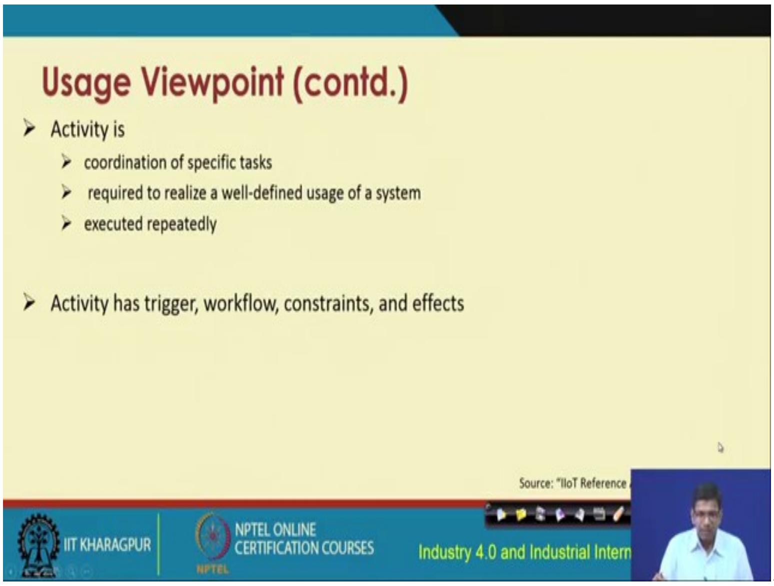


Activity is the coordination of specific tasks, that are required to realize a well-defined usage of a system and activities are executed repeatedly. Activities trigger the system execution, trigger the workflow, trigger different constraints from being executed and also interact based on the different effects of execution the interactions that happen are also taken care of by the activity.

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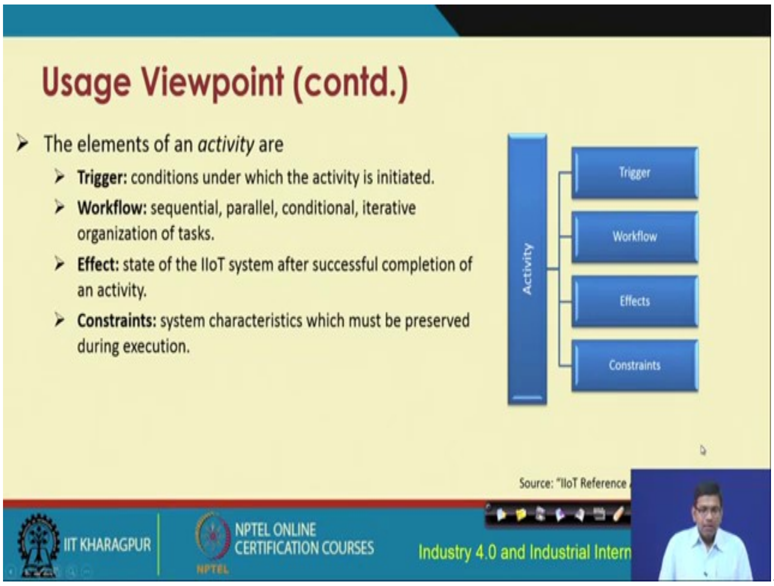


The elements of an activity are triggered, workflow, effects and constraints. Trigger basically are the conditions under which the activity is initiated, workflow can be sequential, parallel, conditional, iterative, and so on. So, workflow is basically the workflow among the different tasks that flow of different tasks. Effect is the state of the IIoT system after successful completion of an activity and constraints basically talk about the system characteristics, which must be reserved during the execution.

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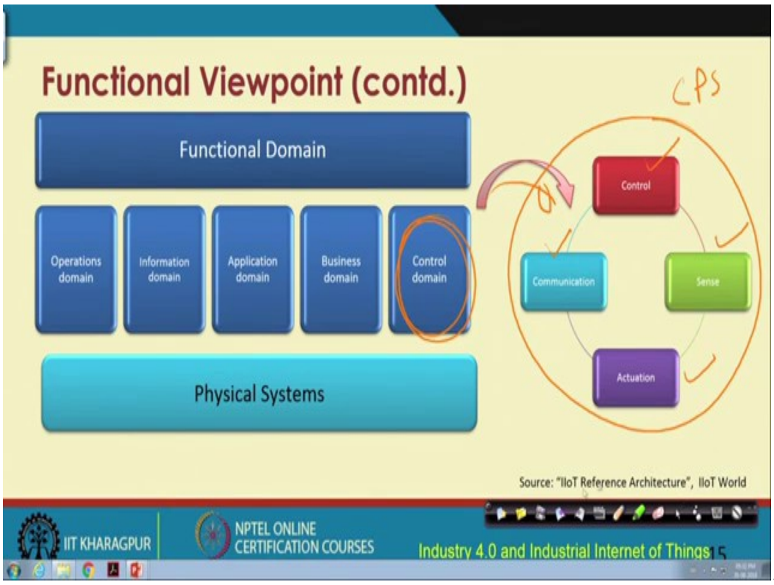

This is the functional viewpoint we have the control domain, operations domain, information domain, application domain, and the business domain. So, this is how this functional viewpoint works. The main component over here is the domain component the control domain component. So, this control domain component basically takes care of the cycle control sends actuation and communication. So, together basically this is also a cycle, which drives in the cyberphysical systems. So, this control domain and it is role in this particular cycle is a very important viewpoint, which is basically the functional viewpoint.

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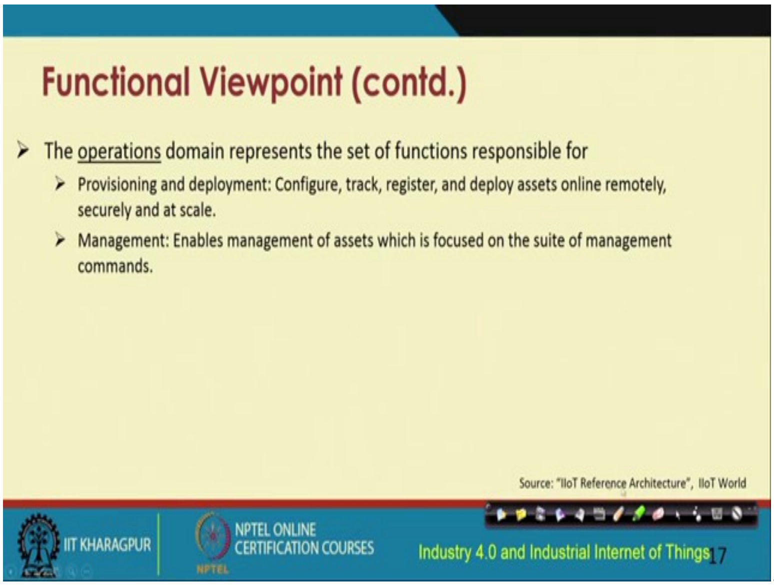


The control domain represents the set of functions that are performed by the industrial control system and these could be of different types sensing; that means, reading the data from the sensor nodes, actuation writing data and controlling signals into an actuator and communication, which basically talks about connecting the sensors, actuators, gateways, and other edge devices.

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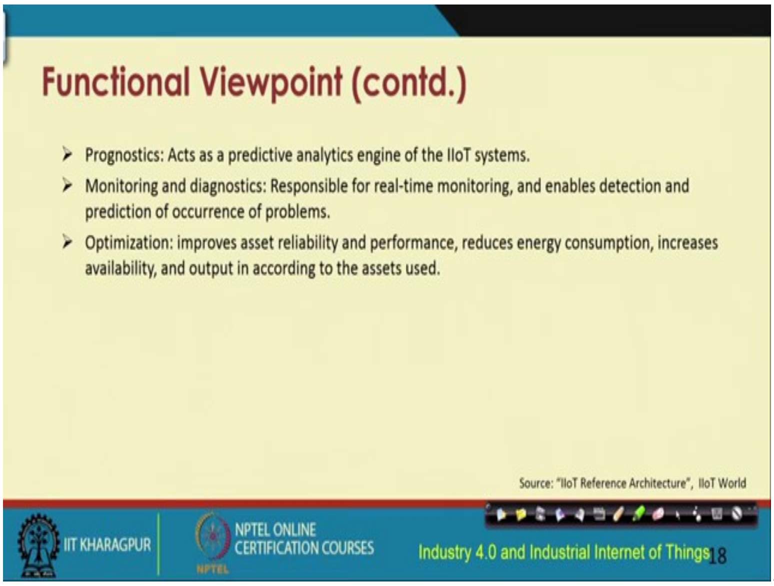


So, from a functional viewpoint few concepts are important prognostics, which is basically the act prognostics, basically is the action of some predictive analytics engine of the IIoT system. Then we have the diagnostics and monitoring, which is responsible for real-time monitoring, and enabling detection, and prediction of occurrence of problems and optimization, which improves asset reliability and performance, and reducing the energy consumption, increasing availability, and the output in accordance to the assets, that are being used.

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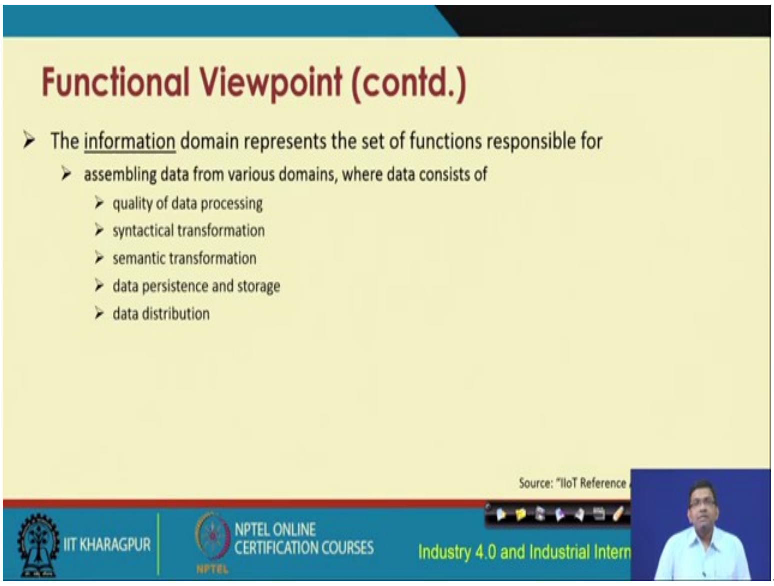

So, the information domain represents the set of functions responsible for assembling the data from various domains, where the data consists of quality of data processing, syntactic transformation, semantic transformation, data persistence, and storage and data distribution.

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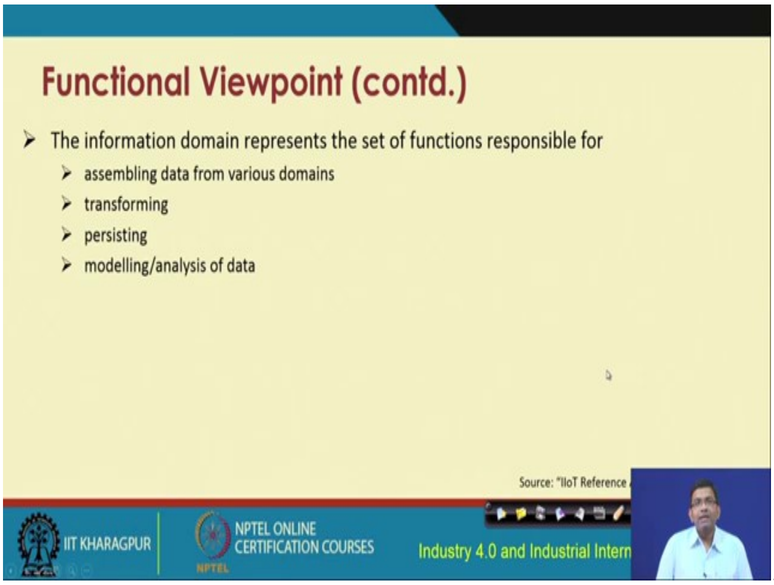


Functional domain represents the set of functions that are responsible for assembling the data from the various domains, transforming the data, persisting the data in the system and modelling and analyzing the data.

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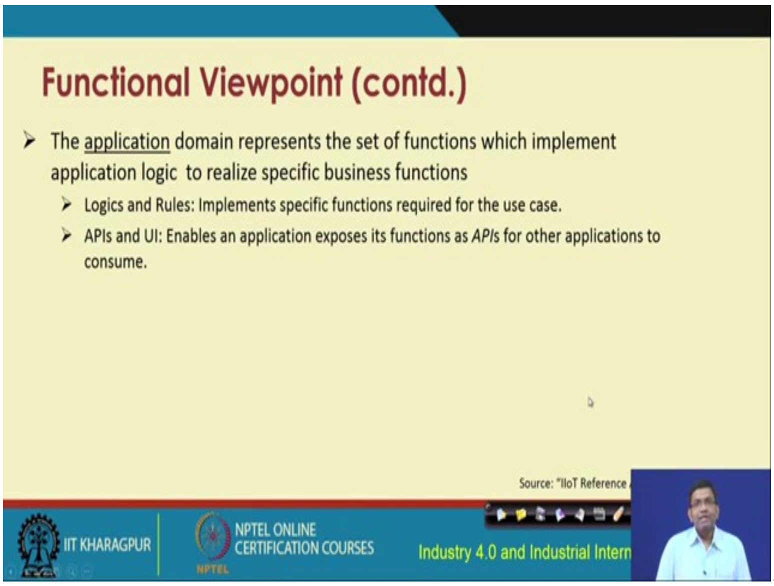

The application domain represents the set of functions which implement the application logic to realize the specific business functions. So, here basically you are talking about logics and rules APIs and UIs.

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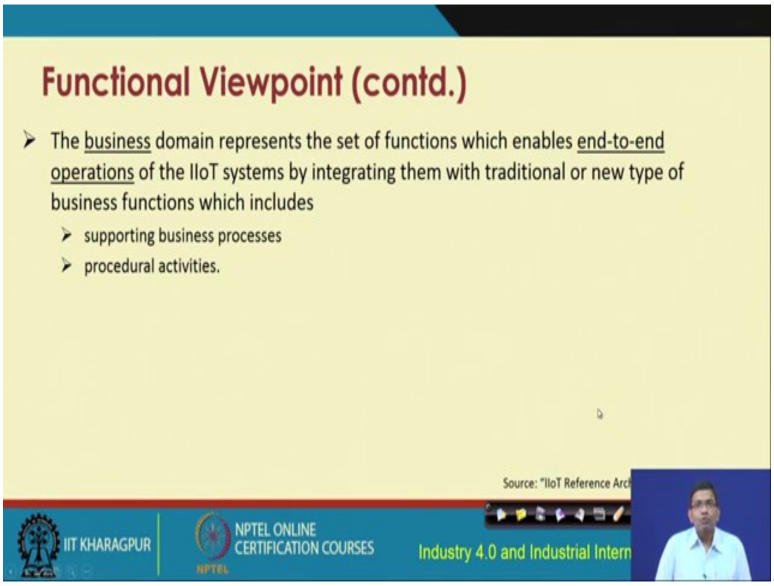


The business domain represents the set of functions which enables end to end operations of the IIoT system by integrating them with the traditional or, new type of business function, which basically includes supporting business processes and procedural activities.

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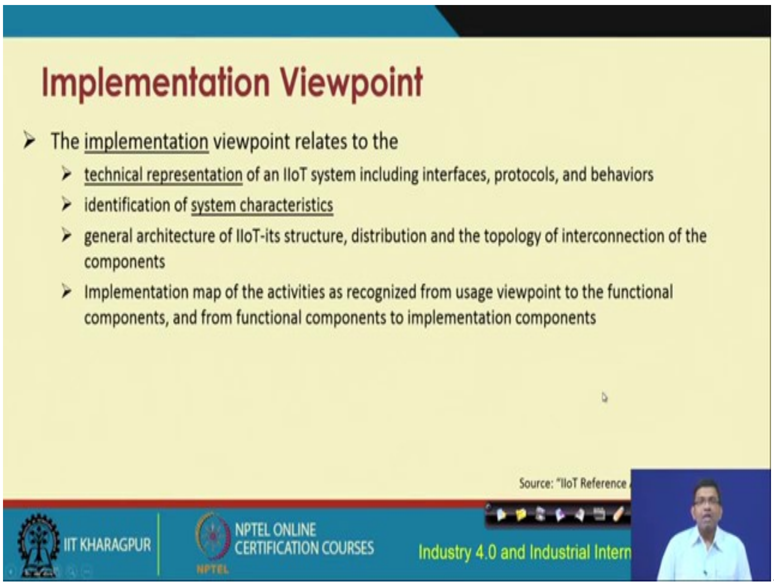

Implementation viewpoint relates to the technical presentation of the IIoT system generating architecture of the IIoT, it is structure distribution topology of interconnection, and interconnection of different components, and the implementation map of the activities, as recognized from the usage viewpoint to the functional components.

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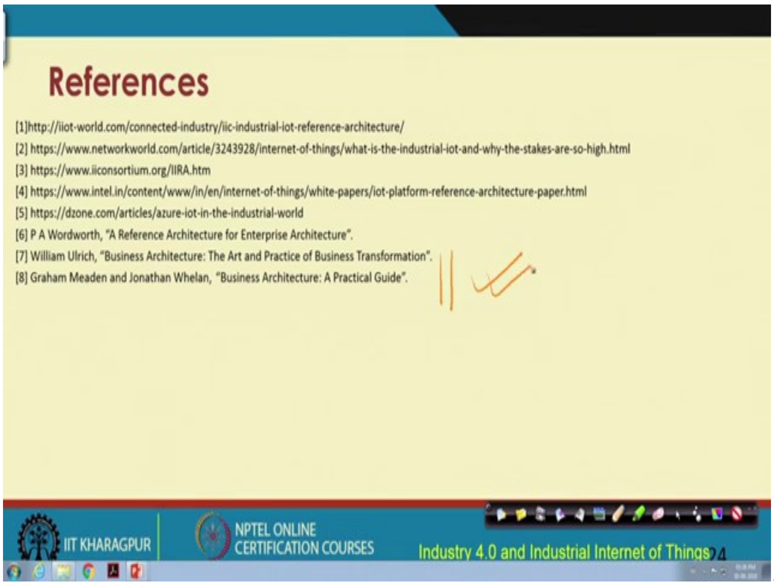


With this we come to an end of the lecture on the reference architecture that is proposed by the IIC it is the industrial internet difference architecture IIRA, proposed by the technology working group of the IIC we have in this module looked at the different business models the different types of business models, which could be adopted to transform towards the transform towards IIoT adoption, and so on. And then we have seen at some of these different patterns architectural patterns, the common patterns that could be used in order to implement technically implement these business requirements into action implement, those in order to transform the business to satisfy the IIoT requirements and expectations.

So, these are these references if you are interested you may go through them particularly these books are important this literature this will help you to have better understanding about the business architecture, in the context of IIoT and so on. So, with this we come to an end.

Thank you.

**Introduction to Industry 4.0 and Industrial Internet of Things**
**Prof. Sudip Misra**
**Department of Computer Science and Engineering**
**Indian Institute of Technology, Kharagpur**

**Lecture – 26**
**Key Enables of Industrial IoT: Sensing – Part 1**

In this module, we are going to go through, some of the Key Enablers for Industrial IoT, and the basics of which we have already gone through in the previous lectures. But we need to understand these key enablers, in little bit more detail and so we will start with the Sensing. So, sensing is I would say that it is the most important element in industrial IoT in smart applications, and so on. So, we will start with sensing and try to understand how these sensors work and what is the utility of these sensing elements in the overall smart IoT, Industrial IoT applications?

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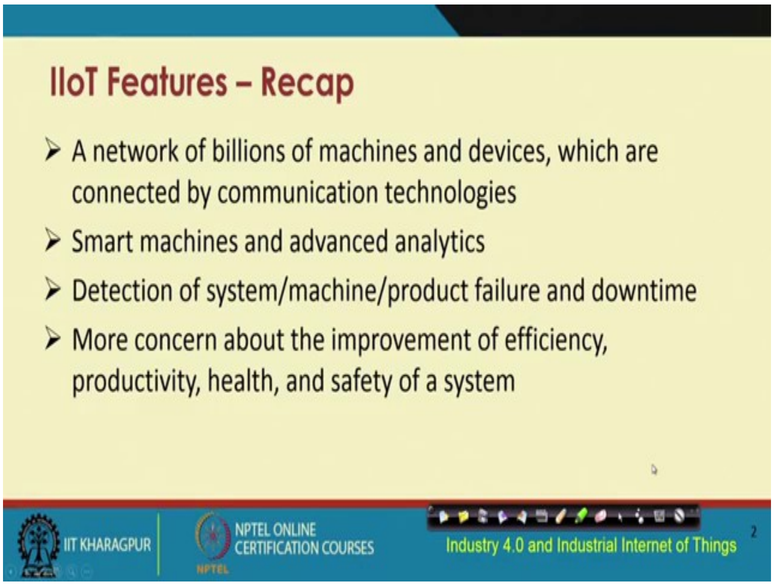


So, if we take a recap of the IIoT features, we have in IIoT we are talking about large number of industrial machines, connected machines, having different sensor nodes devices, and so on. These sensor devices are connected themselves, through different communication technologies. So, basically these different sensor devices are connected to one another, which in turn makes these different machines, the host machines connected to one another.

And the smart machines basically, which have these different sensors produce lot of data, which are typically analyzed either locally or, off site, maybe in a cloud or, in a data center or, something of that sort, and intelligent inferencing is made and based on which, maybe there is some actuation that is performed.

So, here basically we are talking about smart machines, smart objects and so on. So, these smart machines are also smart because they can detect by themselves, if there is any failure at point of time, or in the production line, if there is any failure in any point in the production like line and also if there is any, machine downtime or, production downtime or anything like that. So, everything will have to be detected on their own by these different smart system, smart machines in these industries.

We are talking about improvement of efficiency, productivity, health, safety, etcetera of the systems. So, how can this be done and autonomy, autonomously, automatically, basically these things are going to be detected, whether any machinery or, any parts of the machines are defective or, anything is going wrong or anything like that. So, everything has to be detected on their own. So, how it is possible the core element for making it possible is the sensing element. We need to understand these sensors, in more detail.

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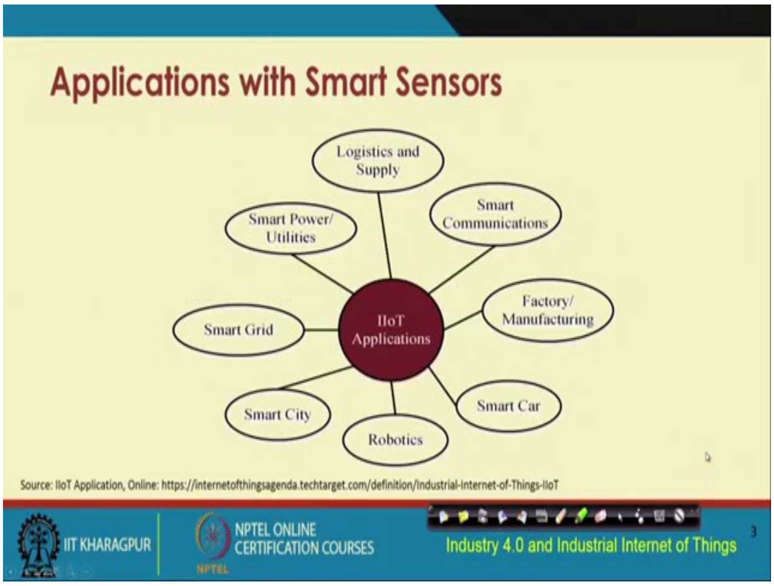


So, before we do let us take a recap also of the different applications of these smart sensing elements. So, smart sensors basically drive different IIoT applications in the power, sector utility sector, so smart power or utility, smart logistics and supply, smart communication, smart factory, smart manufacturing, smart car, smart robotics, smart cities, smart grid, everything basically this smart component is primarily due to the existence of these smart sensors embedded in these different machinery devices and the system, as a whole.

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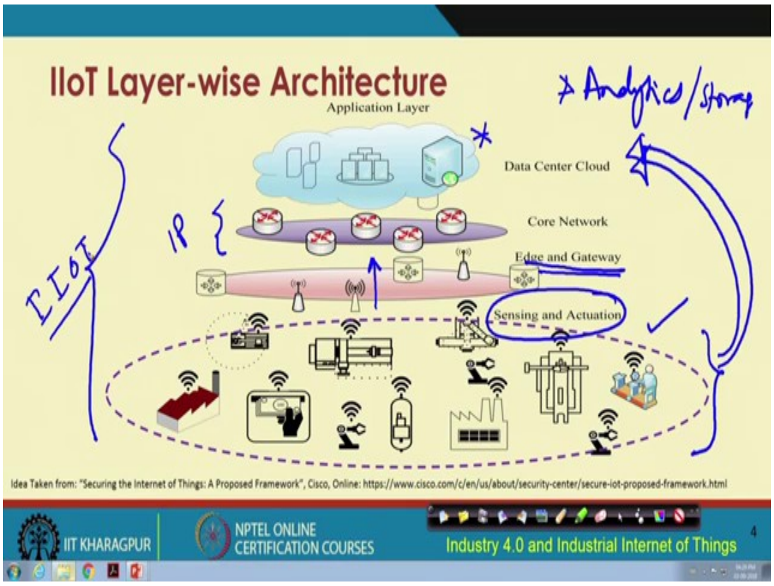


So, we need to understand this part in more detail so, if we look at the IIoT, if we look at holistically. This smart sensing element, the smart sensors are basically at the very bottom. So, we have these different smart sensors and actuators in the bottom most layer.

These smart sensors basically, what they do they send the sense, and the sensed data are basically sent to some data center or some cloud or something like that for further analysis. So, before these are sent the data basically the sense data will pass through some kind of gateway device. These are the gateway devices, through which this data is going to pass through, and then it is going to go through the four backbone network maybe the IP network or, something like that and then finally, the data will reach the data center where all the different analytics are analytics and storage are performed. This is sensing and actuation, which is the most important part behind driving IIoT, and the smart manufacturing, smart factory applications.

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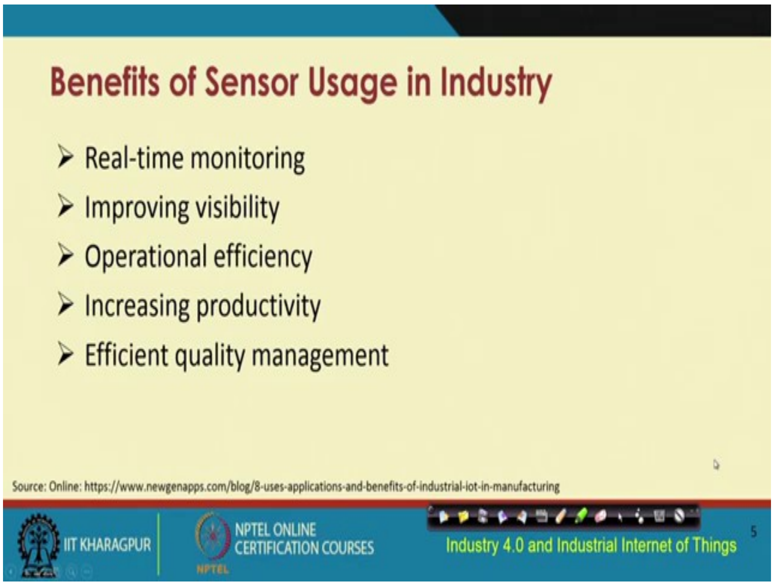


So, what are the benefits of sensor usage in the industry with smart sensors we would be able to do real time autonomous, monitoring of different machine parts, different processes, manufacturing processes, everything can be done in real-time monitoring, can be done in real-time. Then second utility is basically improving the visibility of what visibility of the machine status, in the device status and so, on improving visibility, operational efficiency will also be improved with the help of use of different sensors likewise increasing productivity, improving quality, efficiency, quality management, efficiency.

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And then improving safety, minimizing downtime, improving the prediction and prevention of system failure, remote diagnostics, all of these things can be done, in a much more efficient manner, with the help of use of these different sensors or, smart sensors.

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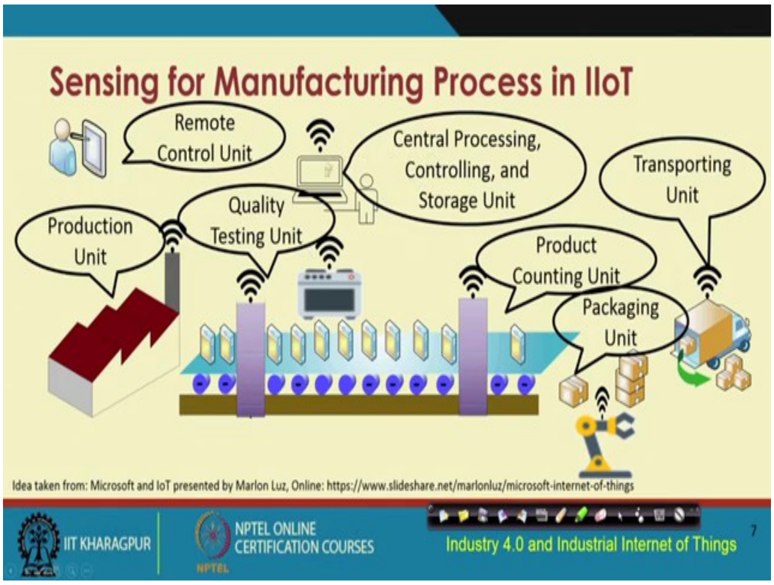


So, let us try to look at the sensing holistically in a, smart manufacturing plant, let us say that we have a manufacturing plant, and we want to look at how these sensors, play a role. So, we will start one by one with all these different elements. So, let us say that in this figure as you can see this is the smart, this is the central processing controlling and storage unit. So, let us say that this is the central processing controlling and storage unit, which is basically the central controller.

Then we are also the processing not only the processing, but also the storage take place then we have, the remote control unit, this is sort of like the control station from which the production processes over here are all going to be monitored. So, this is the remote control unit so, basically this is the place from where the controller or the user is going to start the process with the switching on or, off of any button for instance, so, this is the remote control unit. Then we have this one is the production unit, we have the quality testing unit.

Basically after production the different manufacture parts, let us say, that these are the manufactured parts or manufacture products. These manufactured products will go through a conveyor belt. The quality testing is going to be done over here. Let us assume, then the parts will get quality tested and move forward and finally, it will it is going to come over here and we are going to have the counting of these different units of product taking place over here.

Counting will take place here and then after counting, the packaging takes place, we have a robotic arm or robotic device, which is helping in this packaging and finally, the units that are manufactured are going to be boxed or packaged and transported. So, the smart logistics, are going to come into picture from this point on.

So, what did we that these are the different components of a smart manufacturing plant. And these different components as you can see these are all these have different sensing units in them and not only sensing units, but these units they can also talk to each other. They can sense and they can send the information to somewhere, and typically in this case this information is sensed and sent all these different information from all these different units are going to be sensed and sent to this central processing unit or central controller or the storage unit, over here.

So, either it is going to be sent directly or through multi-hub communication maybe through this particular node which is a intermediate node, which is going to collect all this data from all these different points in the manufacturing plant, and send it over to the central processor.

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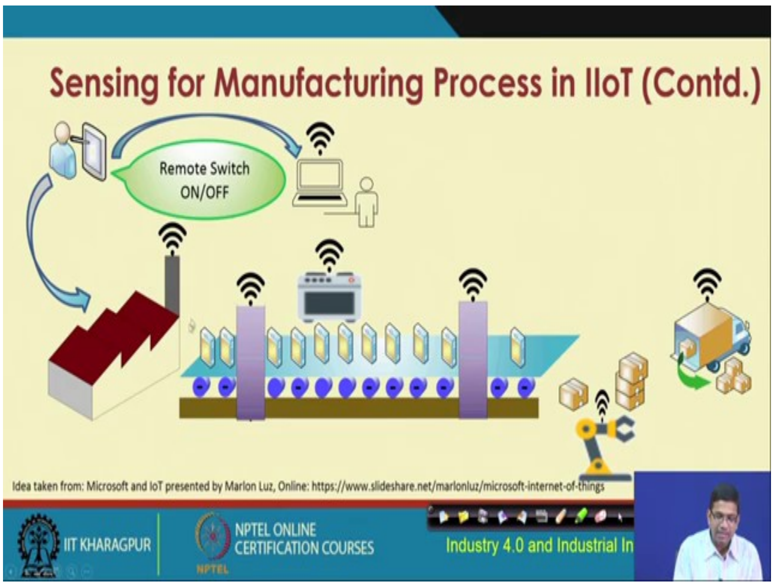

So, we have this remote switch on or off, which basically starts the process or switches of the process and that is from that central controller where the user is sitting and then let us say, that it is switched on. So, you turn on the process so, once it is switched on that data is sent to the central processing unit and it is also sent to one signal is sent unit signal is sent to that factory, the production plant it is sent. So, the production process starts from here.

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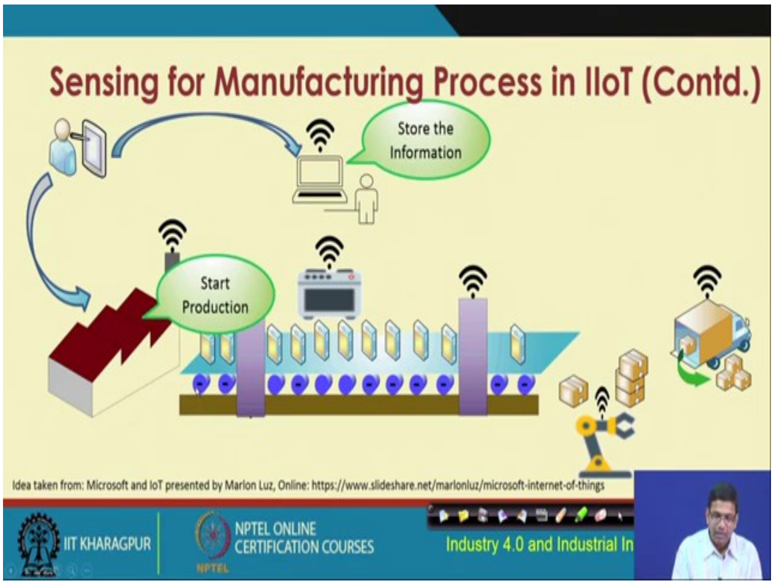


So, if then that all these data that are sensed and sent are stored in this central processing unit like this.

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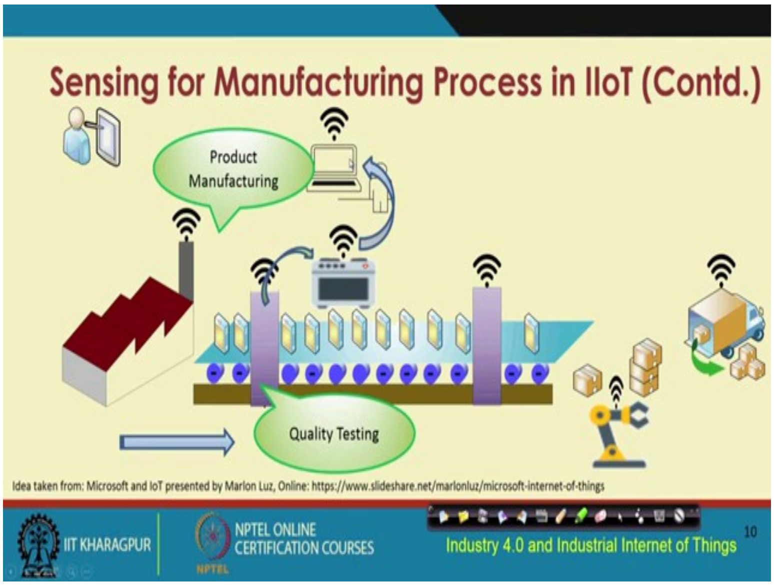


So, the production starts, manufacturing starts, and then each of these manufactured units are going to be produced, and put on the conveyor, for further processing. So, the next step on is basically to quality test; test the quality of these manufactured products, unit by unit.

So, this unit is going to do this quality testing, and then this data is going to be sent from here in this particular scenario, as you can see from this point it is going to be sensed and sent over here. And this is sort of like an intermediate hop current kind of like an aged device, which is going to collect all these different data, and then either it will process partially over here or fully this data, is going to be sent to the central processor.

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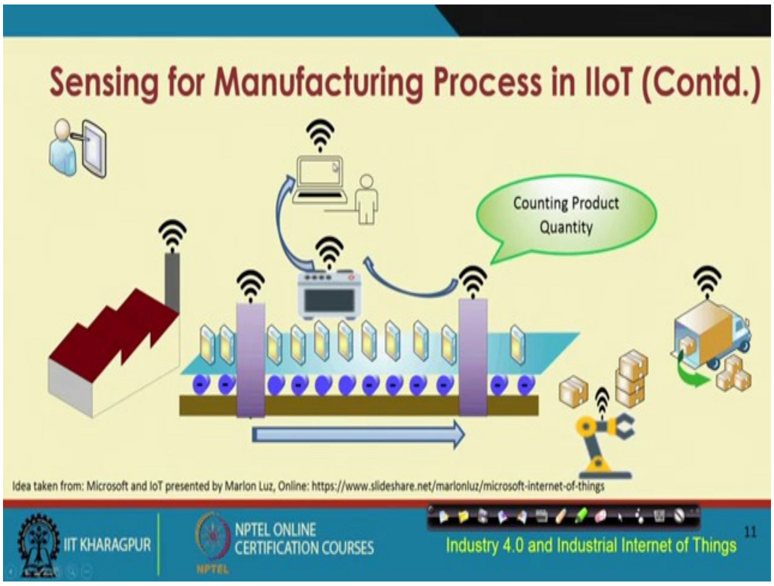


Then the product moves on comes to this particular point, where the counting of the number of units of production, the units, which have been not only produced, but tested over here this counting takes place counting of these products takes place. And then this data again is sensed is sensed and is sent over here to that intermediate node, this intermediate node again sends it to the central processor for further processing and storage this information.

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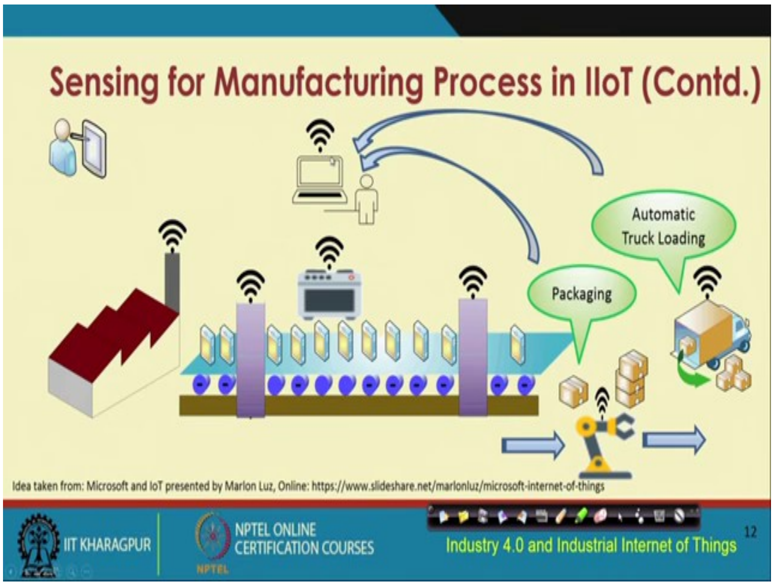

Then the product moves on further, it is packaged and that information again is sent directly not over here, as you can see over here, this is showing that it is sent directly to the central processor. In the previous example all these units, were sending it to that intermediate node and this intermediate node, in turn was sending it to the central processor and over here, this packaging unit, whatever information it has it sends it directly to the central processor. And as I was telling you that there are two ways of doing this thing.

So, one way is basically, that you send it to some intermediate node, and which is not far off from the point of sensing, and that basically is this example shown over here and once it is done the advantage is that you can have quicker response to the sensed data in terms of processing, but because not typically these intermediate nodes are not well-equipped to do lot of processing, they are not very high power computational devices typically. So, partially they can do some processing, but then the rest of the information they will be sending it to the central processor like the data center or, cloud or, whatever, for further processing.

And in this case, in this example the alternative was to send it directly to the central processor, and this is what this packaging unit is doing sending it directly to the central processor instead of taking help of this intermediate node and that is also an alternative. So, there are advantages and disadvantages of doing both. The product moves on further, after the these are packaged and automatically the products are loaded on the trucks or any vehicle, that is going to carry these products the packages are loaded on the truck and that information is also sent to that central processor.

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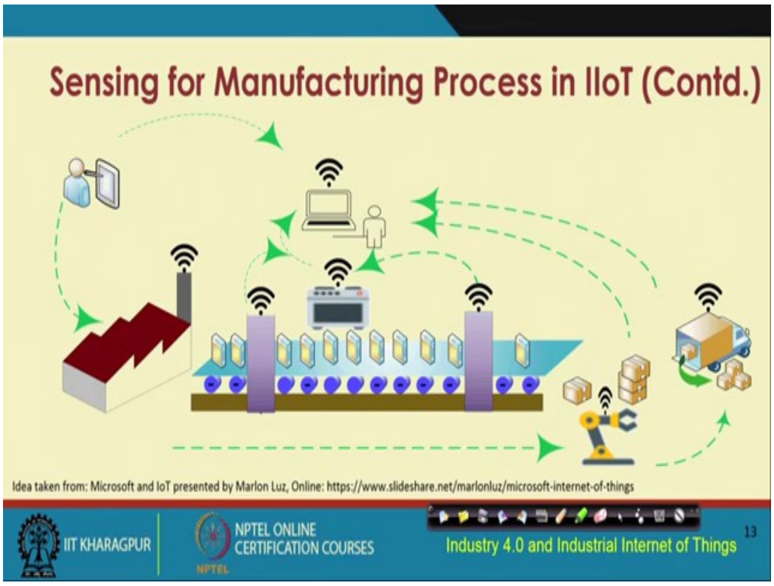


So, overall this is how this these arrows basically show you where the sensing and then the communication took place the sensing took place at all of these different points, but then these green arrows will show you how those sensed data are going to flow through this through this manufacturing plant to the central processor, this is what is shown over here.

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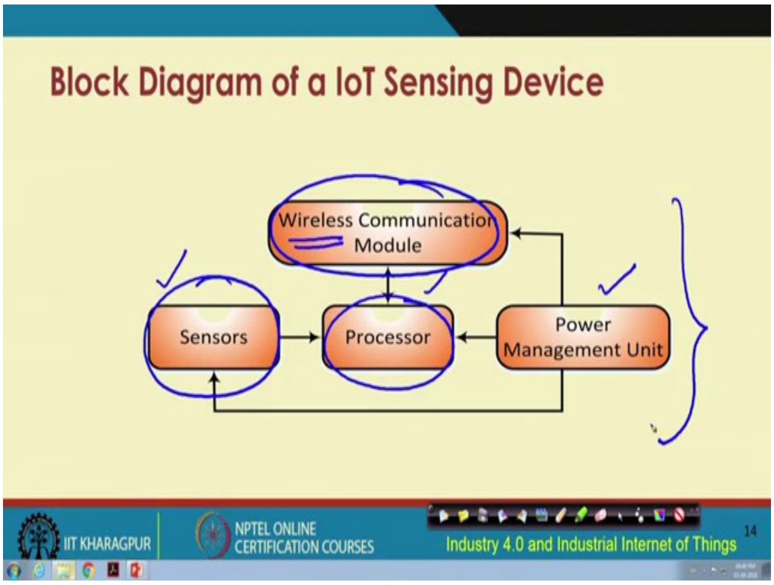


So, going back we have seen that these sensing devices are very important. So, these sensing devices have the sensor, which will which is actually the element, which is sensitive to these changes of environment or any other thing, that they are supposed to sense. So, these sensors are the central ones, then, we have the other components, the processor, the power management unit like battery or whatever processor is the one, who will do a little bit of processing and then for communication, typically, it is the wireless communication module. But it is not necessary that it has to be wireless, but typically, it is wireless in IOT, but it can be wired as well or, it can be a mix of both wired and wireless communication. So, this is the typical structure or the block diagram of an IoT sensing device.

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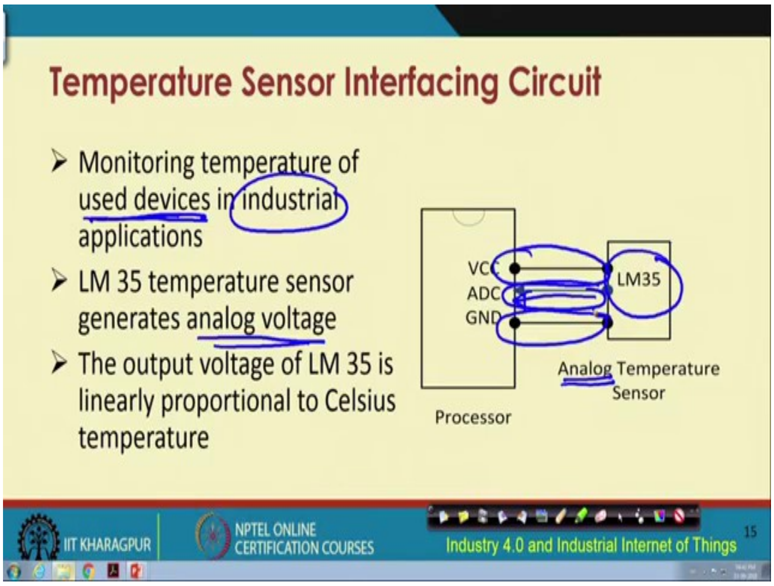


So, let us look at each of these sensors one by one so, we will start with the temperature sensor. So, there are many (many) different types of sensors that are used in the industries and temperature sensors are the common once temperature sensors are required to see or, to monitor, whether certain parts of the product that is being manufactured the temperature of it stays below a certain threshold or a certain compound compartment, a chamber in the factory is staying below a certain temperature threshold.

So, temperature monitoring is very common it is very much required in most of the smart factories and manufacturing plants. So, we have the example of a temperature sensor which is the analog variant, the analog temperature sensor. So, we can have analog temperature sensors, we can have digital temperature sensors. This variant, this model, LM 35 is it a is an analog temperature sensor, that generates analog voltage.

So, this temperature sensor could be used in industrial applications, to check the temperature or to monitor continuously monitor the temperature of the different devices that are being used in the manufacturing process. In this example, this LM 35 produces some output voltage; some output voltage, which is linearly proportional to the Celsius temperature, which is proportional to the Celsius temperature.

So, we have in this case this LM 35 comes with three different pins one is this voltage one the VCC, ADC is for Analog to Digital Conversion, and then we have the ground. So, let us look at each of these components over here.

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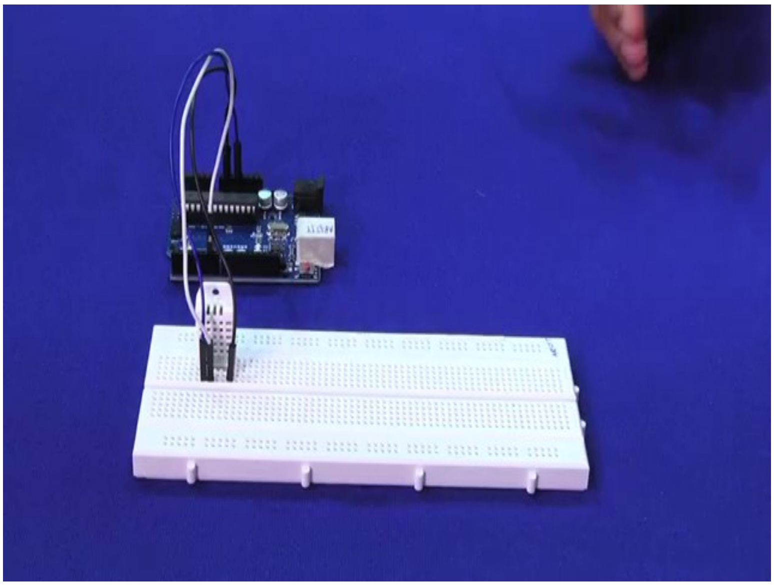

So, this is an example of a temperature sensor not the LM 35, we do not have the LM 35 model, but this is the one we are using this temperature sensor as you can see and so, I told you that it has three different pins. So, one is basically the ground, the second one is for actually sending the signal, and the third one is for sending the highest voltage, typically, it is the 5 volts. It can be 5 volts or 3.3 volts in this case for this particular sensor it is 5 volts.

So, this one this blue-coloured wired is basically the one, which is connecting to the 5 volt. This is the microcontroller to which the sensor is getting connected. This blue colored one is connecting to the VCC 5 volts. Then we have this ground this ground is the black colour wire. So, the black color wired is put on the is connected to the ground of this microcontroller and then we have this white colored one which basically sends the signal the temperature value the actual temperature value is sensed and is sent through this particular wire. So, this is how it is going to look like if you connect these sensors to the microcontroller's, this is how it is going to look like.

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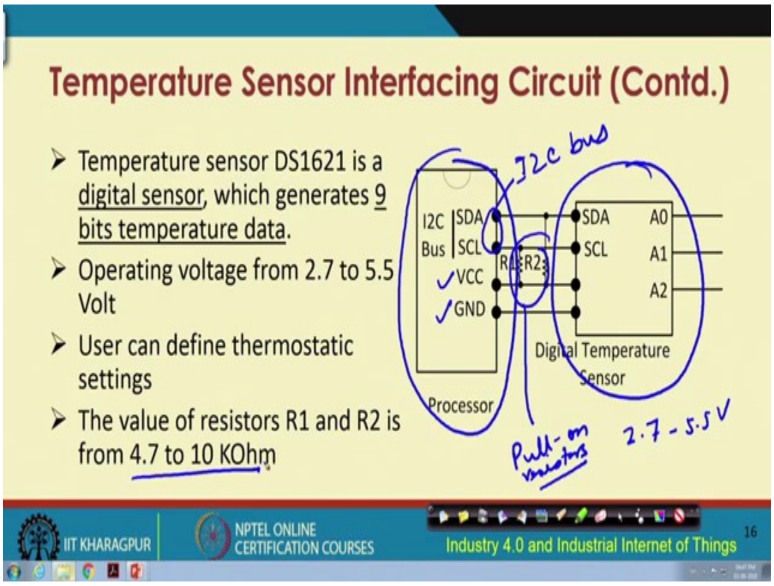


As I was telling you that temperature sensors are very important I have shown you an analog temperature sensor, but we could also have digital temperature sensors. The functioning of a digital temperature sensor is bit different from the way, the analog sensors work. This is an example of a digital temperature sensor, the model is DS1621 and this particular sensor will generate 9 bits of temperature data and this sensor digital sensor operates in the range 2.7 to 5.5 volts.

So, the user can define the thermostatic settings using this particular sensor and as you can see over here, it is connected to this processor or the microcontroller this is this microcontroller unit and we have the ground, the VCC, and these are basically the ports on the I2C bus. This SCL is basically for clock synchronization and this DA is the one that will carry the data the data acquisition for data acquisition. So, this is for the I2C bus these ports are there and these registers are the one, which do the pull-on.

So, we have these pull-on registers, which basically help in this connectivity process in a certain way. So, I am not getting into the details of these pull on registers, but these pull on registers are required and they operate in the range 4.7 to 10 kilo ohms.

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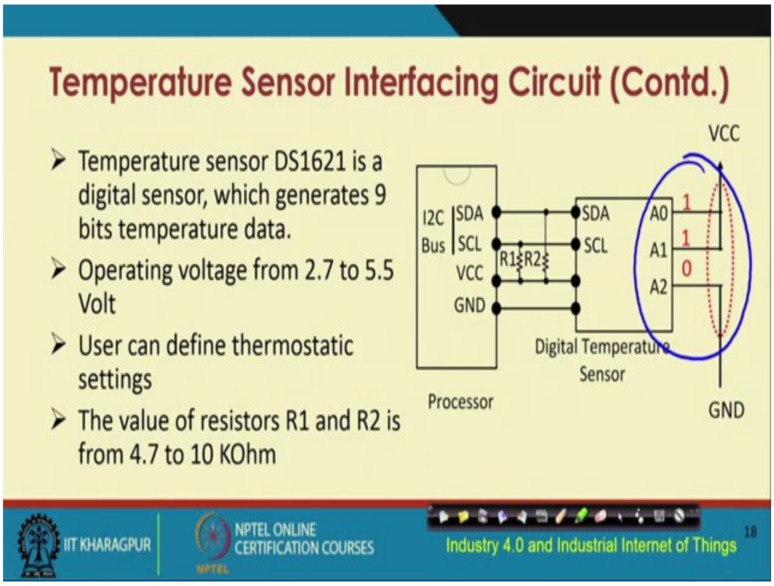


So, we have then this output produced from these digital sensors in this manner. So, these are the different outputs which can be. So, I told you that the outputs are basically generated as 9 bits of temperature data and these are the last three bits, that are shown over here, and we can have a combination of all of these, it could be 000 or a permutation basically permutation 011, over here it is 011. These are basically the different sense, I mean each of these 000 will correspond to one type of sensor connect connection to one of these sensor device, then 011 for another one.

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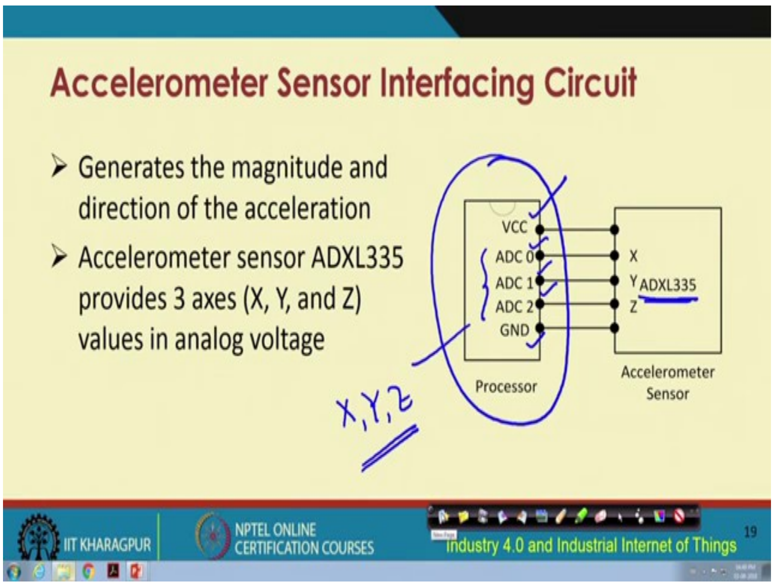

Then we will have a look at another very commonly used industrial sensor, which is the accelerometer sensor, and this is this accelerometer sensor that is shown over here the this is basically how this ADXL335 accelerometer sensor looks like and these are the different pin configurations. These accelerometer sensors are connected to a microcontroller in this manner, the first one corresponds to this VCC the maximum voltage of operation.

Then you have these ADC's, ADCI so, 0 ADC 0, 1, 2 and the ground and these are the ones, which will be responsible for actually carrying the data and why we have 3 ADC's over here? Because accelerometer data come as X, Y and Z coordinate values and these analog voltages will have to be; will have to be captured in this processor in this manner through these different ports 0, 1 and 2.

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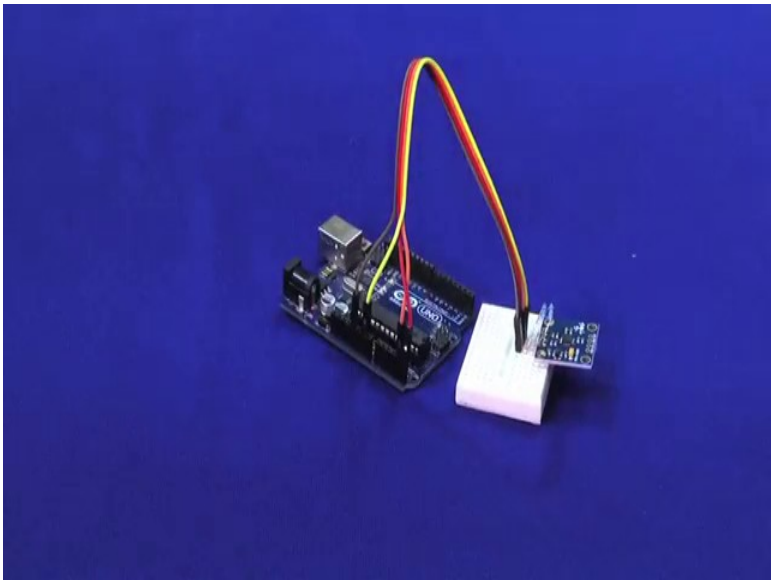

So, let me show you the example of an accelerometer sensor over here, this is an accelerometer sensor; this is an accelerometer sensor it is little small. So, you not be able to see it very well, but I think this will give you a fair enough idea, if I tell you about how this pin configuration works. So over here as I was telling you that we need so, we have 4 wires over here, unlike the previous analog temperature one so, we have 4 wires. So, we have 4 wires and we have 2 registers, these are those pull-on registers, that I was telling you earlier. These are the 2 pull on registers, you can see these blue colored ones these registers. So, what are these pins corresponding to what do they correspond to?

So, the blue colored one sorry that the. So, these two the blue and sorry the yellow, and the gray colored ones they are the ones, which basically connect the ground and the VCC; ground and the VCC. The red and the orange colored ones are the ones, which are getting the accelerometer values. So, you cannot see over here very well because it is very small in size, but what I would like to impress upon you is you can get any of these different sensors look at their pin configuration, if it is a open hardware you can get easily get access to these pin configurations. And from these pin configurations you will come to know, which pin basically connects to which port of the microcontroller. So, this is then what you do is basically you connect the sensor to the microcontroller in this manner; this is the accelerometer sensor.

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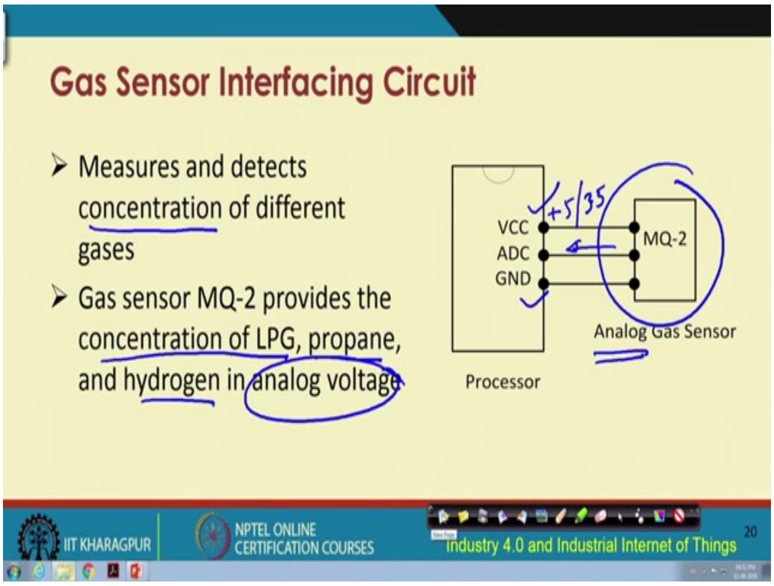


Then, we have another sensor which is also very common for industrial use which is the gas sensor and there are different (different) variants of gas sensor; this MQ-2 is a very commonly used gas sensor for industrial applications. It is a analogue gas sensor here we have three pins only; one is the maximum voltage the VCC then we have the ground; ground is basically like 0 volts, this is like your plus 5 or plus 3.5 volts, and then you have this ADC any ADC is the one, which is actually carrying the signal about what has been sensed in that gas sensor.

So, this gas sensor basically measures and detects the concentration of the different gases and this has been made in such a way to monitor the concentration of LPG, propane and hydrogen in the form of analog voltage. So, like before let me show you the example of a gas sensor.

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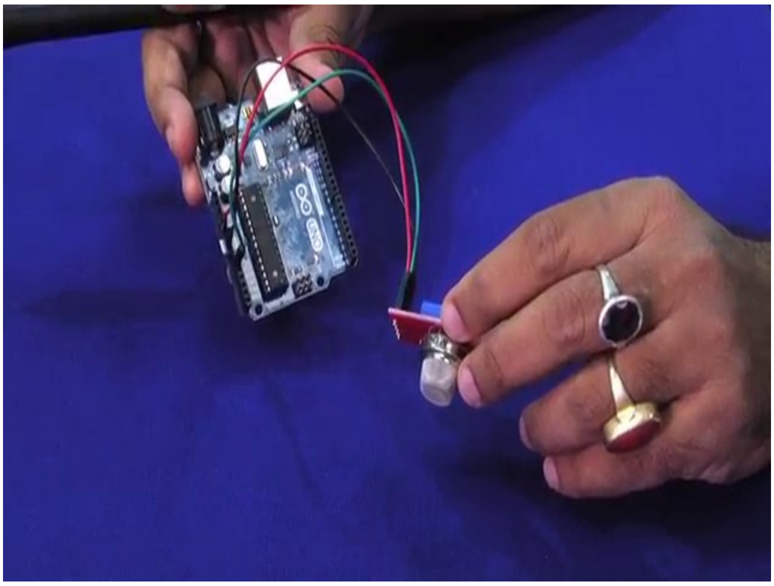

Let us show you let me show you the gas sensor. So, this is the gas sensor, this is a gas sensor, and this gas sensor basically like the previous sensors as you can see has 3 pins 3; pins, 3 ports. So, this you need to know as I told you that which pin basically corresponds to what.

So, the red one basically corresponds to this VCC, this red wire is connecting to the VCC which is the port for 5 volts. Then you have there is another pin over here in this particular sensor the way it has been made, there is a digital output which we are not connecting because we are interested in the analog variant of it which is the analog output. And this analog output is connected, through this blue colored where sorry the green colored wired from this sensor to this microcontroller and this is the one through which actually the signal about the gas concentration is coming.

And then, we have the ground this ground is basically the one, which is connected using the black wire. So, this is how you connect the different sensors you connect to the microcontrollers. So, I have shown you 3 examples; the first one was the analog temperature sensor then I have shown you the example of the accelerometer sensor, and how it connects to the microcontroller and this one is basically a gas sensor, and how it connects to the microcontroller?

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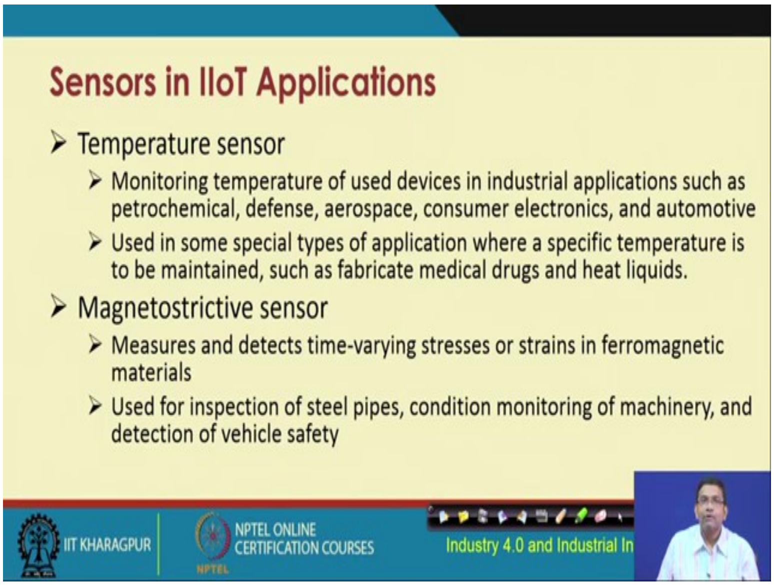


So, temperature sensors are used in industrial applications such as petrochemical, defense, aerospace, consumer electronics, automotive, and so on, and these are very important. Pharmaceutical industries also use a lot of these temperature sensors for monitoring the heat of the temperature of the liquids. Apart from temperature sensor, there could be magnetostrictive sensors, which basically measure and detect the time varying stresses or, strains in ferromagnetic materials. These are typically used for inspection of steel pipes, condition monitoring of machinery, and detection of vehicle safety.

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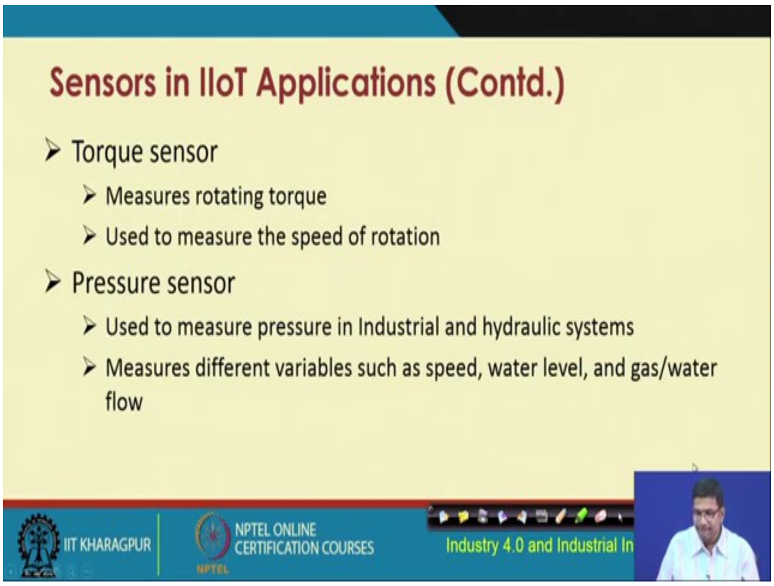

Other industrial sensors are like torque sensor, pressure sensor, vacuum sensor, acceleration sensor, speed sensor, PIR sensor.

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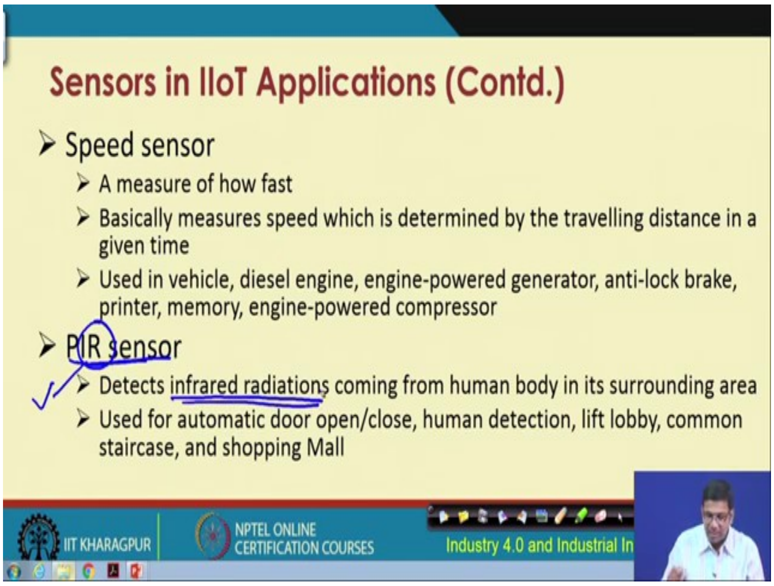


PIR sensor basically detect the infrared radiation coming from the human body in its surrounding area it is used for automatic doorbell, close closer, human detection, then the elevators in the lobbies, then common staircase, and shopping malls. PIR sensors are very commonly used, IR actually stands for infrared. So, these are basically based on infrared radiation.

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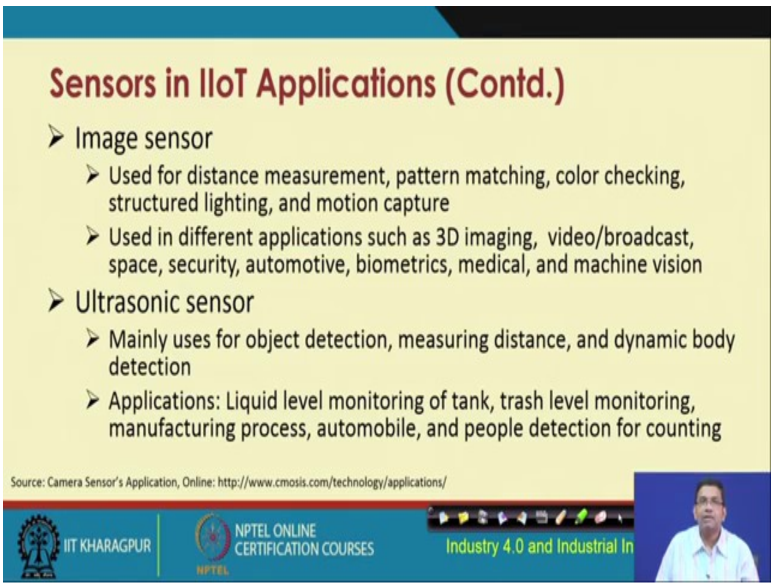

The we could also have other types of sensors like image sensors, ultrasonic sensors like based on sending ultrasound, sound waves are sent these are ultrasonic sensors are also commonly used for object detection, measuring distance, dynamic body detection, liquid level monitoring of tanks, trash monitoring, manufacturing process, automobile, people detection.

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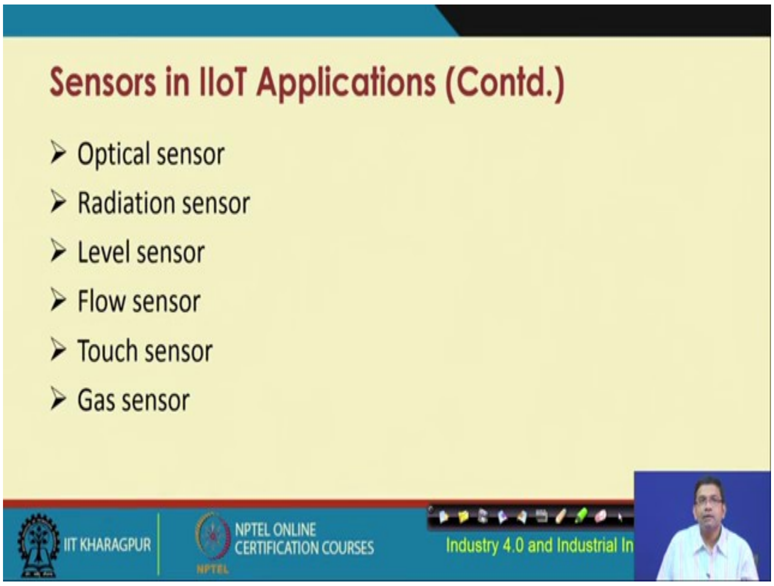


Other sensors are also possible different (different) other sensors for industrial applications like optical sensor, radiation sensor, level sensor, flow sensor, touch sensor, gas sensor, and so on.

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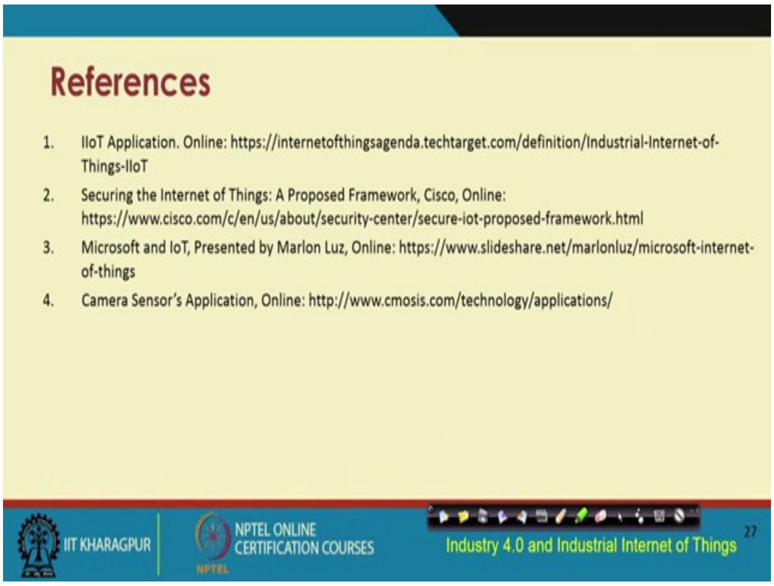


So, in this particular lecture we have seen the use of these different types of sensors for making smart applications in industrial scenarios. We have looked at the pin configurations of 3 types of sensors--analog temperature sensor, then accelerometer sensor, and third is the gas sensor, and each of these different sensors, they are pin configuration and how they connect to the microcontrollers, open hardware microcontrollers that also we have seen. And this is the small building block, which will be required to be expanded further; extended further in larger scale to build smart factories, smart applications in smart factories and so on.

Here are some of these references that you could go through there are many others on smart sensing and this is a topic by itself sensors are a topic by itself. So, you could basically find lot of literature on these different sensors, the way the sensors are made and so on. There are people who work solely on sensor fabrication and for one type of sensor fabrication it may take several months to several years for fabricating a single sensor for the first time.

If you are trying to come up with a sensor for the first time, depending on the type of sensor being made the complexity of it. It could take several months to several years to come up with the design of a particular sensor. And these are some of these common sensors that I have shown you which are readily available in the market.

So, you do not need to really worry about the designing of a particular sensor, the manufacturing of it, the fabrication of it, because that is a completely different ballgame and we really unless we are very much interested, and we dig deep into each of these, we will not be able to master the sensor fabrication. So, easily it's a completely different story altogether.

With this we come to an end of it the part 1 and then in part 2 basically we will go through the in more detail we will take up one of these different sensors the gas sensor and how you produce the gas sensors. So, how what is done? So, I will show you how the working principle of a gas sensor is.

Thank you.

**Introduction to Industry 4.0 and Industrial Internet of Things**
**Prof. Sudip Misra**
**Department of Computer Science and Engineering**
**Indian Institute of Technology, Kharagpur**

**Lecture – 27**
**Key Enablers of Industrial IOT: Sensing-Part 2**

In the previous lecture on Sensing; that means, sensing part 1. We have gone through the use of different types of sensors, for different industrial applications. We have seen sensors such as temperature sensor, accelerometer sensor, gas sensor, there could be different other several different types of sensors. And in typical factory smart factories we are talking about the use of large number of different variants of different different types of sensors.

The beauty about this sensors is that particularly for industrial applications not only they are supposed to sense, whatever they have been made to sense, but also they will have to with stand the harsh environmental conditions they will have to withstand so they have to be robust enough. They have to be robust enough to withstand the harsh environmental condition the industrial conditions in which they are going to be deployed.

Keeping that aside, we have also seen that as I told you in the previous lecture that; the designing and fabrication of a sensor is a multi month multiyear program. And it is a completely different ball game if you are trying to come up with a sensor for the first time. Those who have already up with a design and it is a well tested well proven principle that is simpler. Basically, in all we need to do is once you have a proven concept you take it and you go for mass production.

But for the first time if you are coming up with a unique type of sensor the designing of it and fabrication of it is quite complex and is typically done by researchers, who take interest in micro-electronics, sensor fabrication, and so on that is completely different. But I thought that let me give you a brief idea about one of the sensors the gas sensor. Along with a colleague we have taken interest in IIT Kharagpur to built gas sensors and deploy them for monitoring the air quality.

So, in this particular lecture I am going to run you through this kind of sensor, the efforts that we are taking. And taking together basically as I told you that the experts is completely different, that is required to come up with a gas sensor. So, I am going to talk about the working principle of a gas sensor and then I am going to take you to one of labs of one of my colleagues, who is basically fabricating a gas sensor at IIT Kharagpur.

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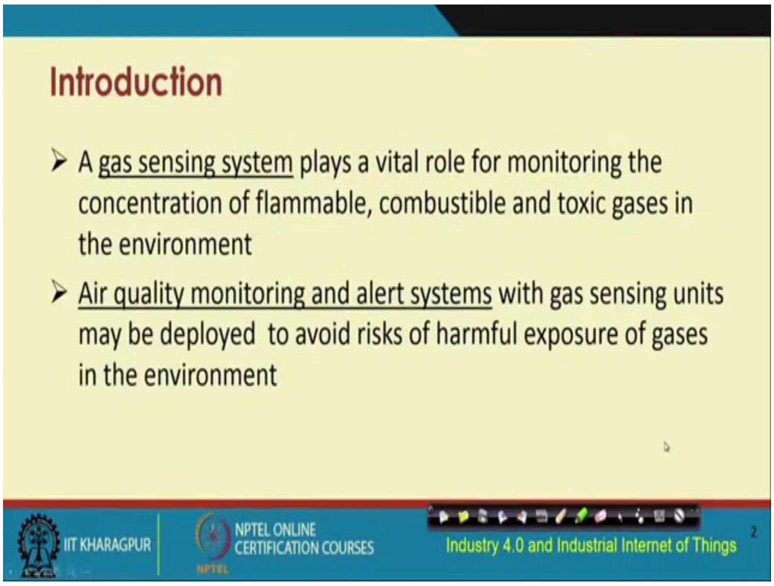


A gas sensor basically plays a vital role for monitoring the concentration of flammable combustible toxic gases in the environment. Gases such as methane, NOx gases.

SOx gases, these are toxic and are very dangerous gases so; they will have to be detected monitored continuously. If we are talking about air quality; air quality monitoring is very important in today's world; because the entire world throughout the entire world somewhere less somewhere more the air quality has degraded, due to the emission of lot of harmful gases into the environment.

So these, quality of the concentration of the different gases harmful gases like NOx gases SOx gases, etcetera, methane etcetera, these will have to be monitored continuously. So, as not to risk the individuals the humans living on the earth, and other organisms living on the earth. So, as not to harm these individuals from exposure to these harmful gases, that are emitted in the environment by different automobiles.

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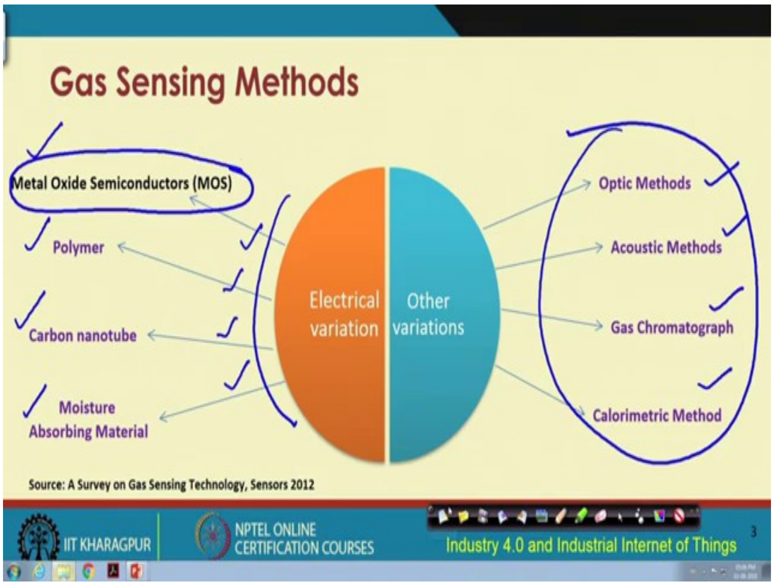


So, there are different methods for gas sensing. Gas sensing basically can be done with the help of optical methods, acoustic methods, chromatographic methods, calorimetric methods, can be done with moisture absorbing materials, carbon nanotube-based materials, polymer materials, and metal oxide semiconductor materials. These one's basically are the electrical variants; that means, that these type of gas sensing methods like this one's, they look at the change in the electrical properties of the environment where these different gases are.

Changes in electrical properties like changes in the current characteristics, changes in the voltage characteristics, changes in the resistive, characteristics of the material the environment, where these harmful gases are the concentration are rising raising. And these then basically sent these different signals, in the form of resistance value or resistance or current or voltage or whatever these methods basically are they different other methods.

So, we will look at in little bit more detail about how to fabricate a metal oxide semiconductor based gas sensor because that is the facility that, we have in our campus. And I can brief you little bit about this particular method of metal oxide semiconductor based gas sensing.

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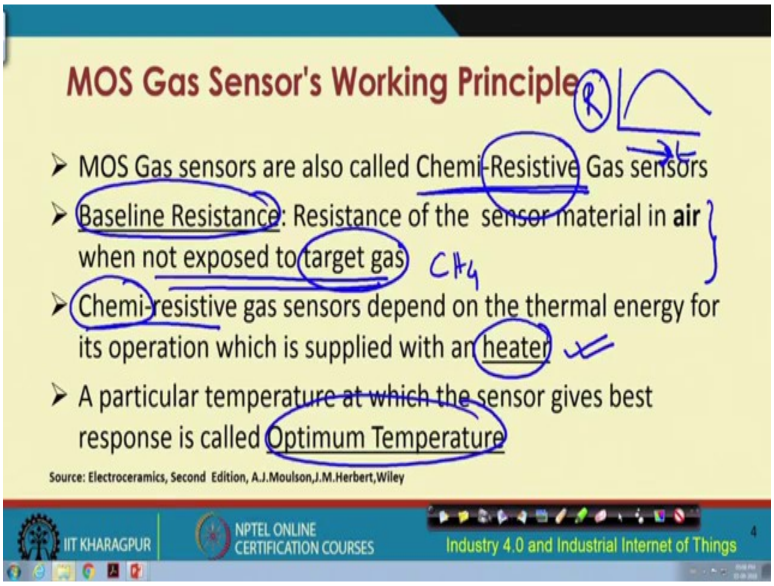


So, this is this MOS gas sensors working principle. This MOS gas sensors are chemi-resistive gas sensors. Chemi-resistive means; like there is some chemical reaction that happens with the sensor material that is there. Because of which the resistive property of that material will change. And what is required is to measure this resistive property with changes in something may be change with time or, whatever.

You get the change in the resistive property of that particular material when the concentration of the gas increases. So that means, that you need to have specific selected materials for targeting specific gases it is not like one material will be able to sense large number of different types of gases it is not like that. So, these are basically selective materials for selective gases. And these selective materials will have the change in the resistive properties, with the with the change in time or change in temperature or whatever.

So, basically we need to understand this chemi-resistive property, but before that we need to understand the concept of the baseline resistance. This is basically the resistance of the sensor material in air when it is not exposed to the target gas. So, this target gas could be let us say methane. So, when it is not exposed to methane, what is the baseline resistance? This is something that is required to be calculated or you need to have this information.

And then these chemi-resistive gas sensors will depend on the thermal energy for it is operation which is basically supplied through some heater. Because this chemical reaction will have to take place for which the heater will heat up that particular material and then that will help in changing the resistive property. So, a particular temperature at which the sensor gives the best response will have to be taken that is optimum temperature.

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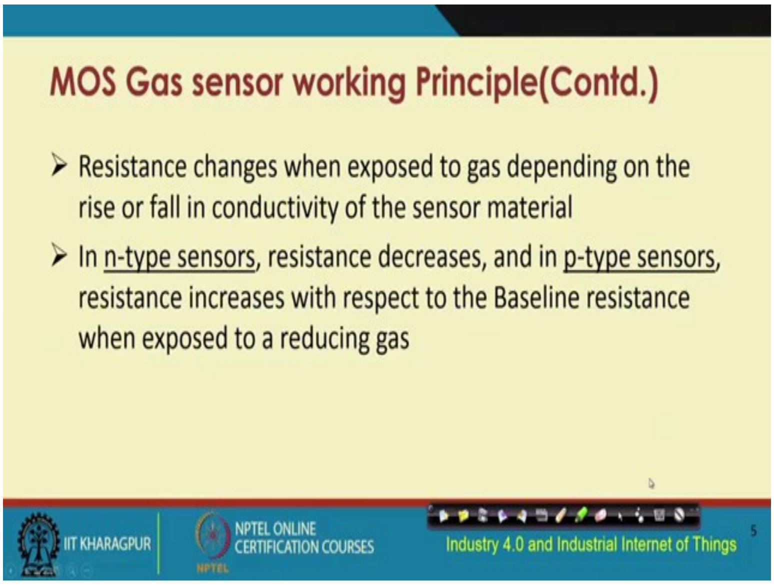


So, the resistance value basically changes when the material is exposed to gas depending on the rise or fall in conductivity of the sensor material. So, it is a choice of the particular material is very important depending on the gas that is being targeted to be sensed. So, in n-type sensors basically the resistance increases and in p-type sensors the resistance increases, sorry. In n-type sensors the resistance decreases and in p-type sensors the resistance increases with respect to the baseline resistance when that particular material is exposed to a target gas.

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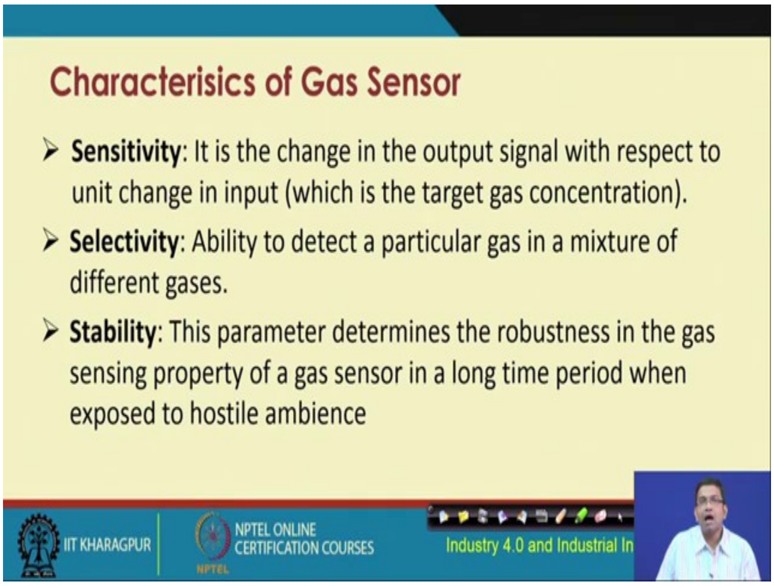


So, there are different characteristics of the gas sensor changes in the sensitivity; that means, it is the change in the output signal, with respect to the unit change in the input. Input means the target gas concentration. If you are changing the target gas concentration unit concentration change, how much is the unit change in the output signal, with respect to it.

Selectivity is the ability to detect a particular gas in a mixture of different gases. Stability characteristic is basically the parameter, which determines the robustness in the gas sensing property of a gas sensor in a long duration of time, when it is exposed to hostile ambience.

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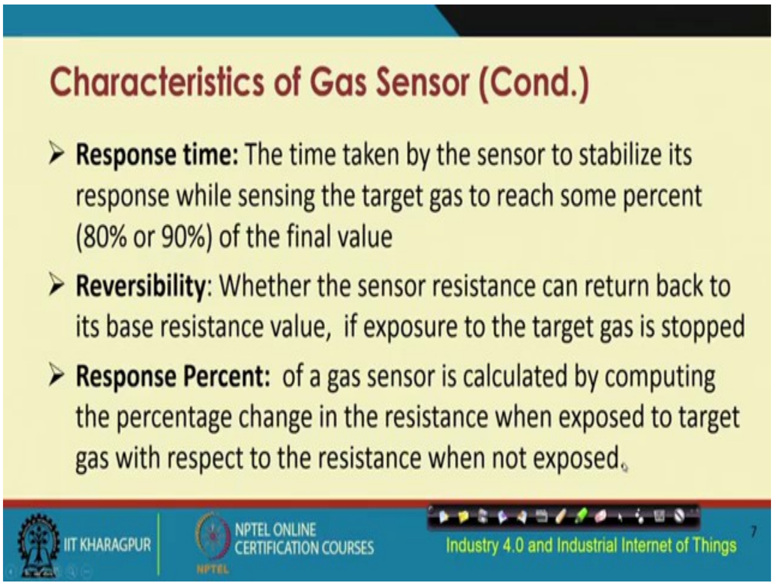


Response time is the other characteristic, which basically captures the time taken by the sensor to stabilize it is response, when sensing the target gas to reach some percentage some predefined threshold pre configured value like; 80 percent 90 percent or whatever. So, how much is the time taken to come to that stable point, that is the response time.

Reversibility is whether the sensor resistance can return back to it is base resistance value; if you stop the exposure of the target material to the target gas. And the response percent is the parameter, which is calculated by computing the percentage change in the resistance, when exposed to target gas with respect to the resistance when it is not exposed. So, resistance when it is not exposed verses this thing that is the response percent.

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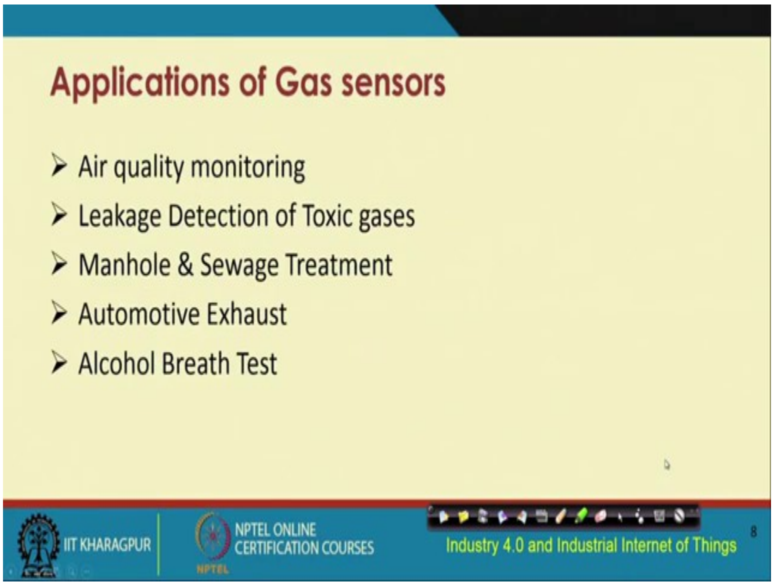


So, gas sensors find different applications; what I was telling you is air quality monitoring. Likewise, it could be used this sensors could be used for leakage detection of toxic gases. If leakage detection of LPG pipes, manhole or sewage treatments plans, gas sensors are commonly used. Automotive exhausts also used lot of gas sensors different types, alcohol breath test also use gas sensor.

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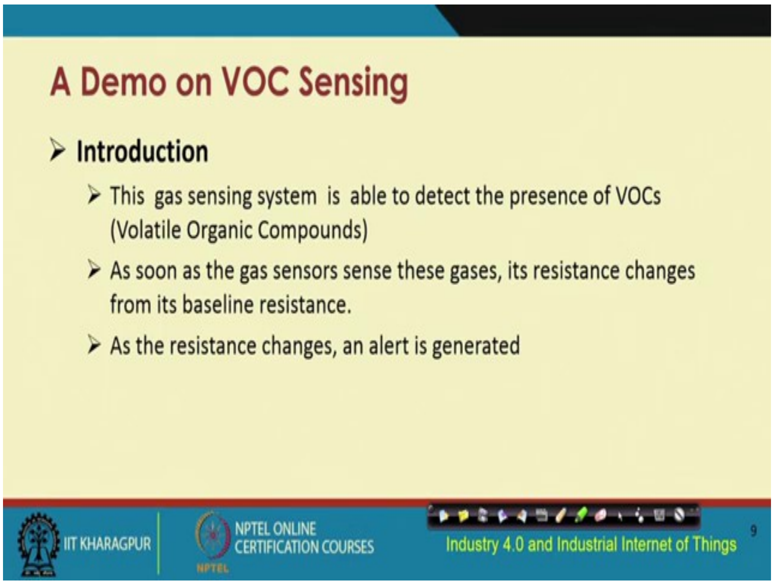


So, I am going to show you the demo of one of this sensors, which is based on it is a gas sensor, which is able to detect the presence of volatile organic compounds. So, as soon as basically in this kind of sensors as soon as the gas sensors senses, this gases, their resistive capacities their resistive properties change with respect to the baseline resistance; that means, when the resistance value when this gas sensors are not exposed the target gas. So, as the resistance changes basically alerts are generated, if a certain threshold is crossed.

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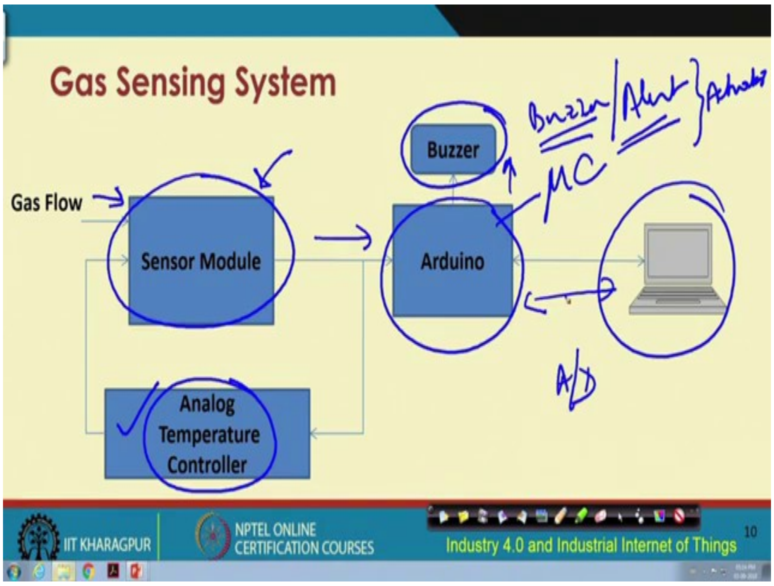


This is the overall block diagram of a gas sensing system. We have this sensor module, which will have this sensing material for a particular target gas. So, gas basically is passed through this particular sensor module and this material is chosen in such a way that it is going to change it is resistive properties with respect to the concentration increase in concentration of the chosen gas.

Then you have the analog temperature controller, which will basically monitor or control the temperature variation. Because I told you that we need to have some heater in order to start this chemical processes of this materials when the gas is pass through them. So, that the controlling of this temperature is done through this particular controller, the analog temperature controller.

Then you have some kind of a micro-controller, which will help in doing some processing of the data the analog or the digital data that comes in to the micro-controller. And then some kind of alert like some buzzer or something could be used in order to generate the alert. So, this will be like an actuator. And then you also have kind of PC, which will help you in the overall monitoring and processing it could be a PC or a laptop or, anything any other computational device.

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We are actually right now in the gas sensing facility lab of the Material Science Centre of IIT Kharagpur. This particular lab is lead by Professor Subhasish Basu Majumder. So, I have with me Professor Basu Majumder; Professor Majumder Basu Majumder would you please tell me what are the facilities in this particular gas sensing facility lab.

In fact, the lab was developed to test a variety of gas sensing materials. So, as that the gas sensing materials are characterized first in terms of it is porosity and semiconducting properties. So, once you have the material ready, then you will have to characterize them in order to know that; what is a gas sensing capability. So, we have fabricated a sensing facility which we call a dynamic flow gas sensing facility, because the gases are flowing.

So, it starts with this kind of different types of gas we actually procure from outside. And the idea is to make say air-quality monitoring that is one of the examples or you can sense various types of toxic gases as well. So, at present our lab is interested to measure the sensing facility of hydrogen that you can see and various toxic gases like carbon monoxide methane, then NOx. And recently we where started working on; carbon dioxide for breathe sensing development, breathe sensor development.

So, it starts with variety of gas and there is a provision for you to mix the gas also. So, gases are transported, so it is having a many fold their. So, you can select that which gas chamber will be connected to the sensing chamber. So, we will have to move from this place to the other side of the lab.

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And so the gases that are coming from the many fold there are four different lines. And one exclusively we use for the carrier gas and in most of the instances the carrier gas is here, which is having 20 percent of oxygen and a variety of test gas. So, this gas controlled this gas they are controlled by this mass flow controller. And at present there are three mass flow controller and we can add 1 or 2 more and this is controlled by this controller.

So, the flow rate of this gases you can controlled either manually or through software. And this past through a hygrometry chamber, so you use different types of solutions to maintain the humidity of this gas. So, either you can test this gas in dry condition or, you can put your own humidity to see the effect of gas plus humidity. And this flows through a several walls are there so it passes, through this kind of line so, which is the input line of the sensor chamber.

So, we put our sensing element inside this chamber and I can just take it off the first part and you can see that there is a small substrate here and this is connected with two probe. And later I will show you the type of sensor that we developed and just at the point of this base we have a thermocouple, we can precisely monitor the temperature of the sensing chamber itself. And by controlling this mass flow rate of these gases we can precisely control that, what will be the PPM level of this gases inside this chamber. So, this is block initially, although it is not being operated now.

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But if you just fix this one so it is a gas proof chamber with a heater embedded at the bottom; so, we can precisely change the temperature and your sensor remains there. And two probe on the surface of the sensor, they take the resistance value as a function of this gas concentration or, as a function of temperature. So, there is a temperature controller. So, in one kind of measurement, I can keep the temperature of the sensor constant, so we call it as a isothermal condition, and then change the gas concentration.

So, that is one set of measurement and we measure the surface resistance of the sensor, as a function of time so this is one type of measurement. The second type of measurement is that you keep your gas concentration constant and vary the temperature. So, as a function of temperature, you can measure the same set of resistance transient. And if you want to make this system complicated, then you can add humidity into it. So, you want to know that at humidity level that how this gas sensing is being performed. So, these three measurements are done for each of these samples and on top of that you can now modify your samples.

For example, you start with zinc oxide, then you can add indium into it. So, see what kind of vacancies are there in inside this material and how the gas sensing is changed by porosity or, by defect concentration. So, there are there is a once you get this resistance transient value, as a function of temperature, as a function of concentration, or, as a temperature of humidity. Then you have a wide full of data, and we do lot of data analysis of the resistance transient, and we have dedicated equipments for those kind of measurement, and the basic measurement that we do with an electrometer.

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So, we have two electrometer here, one is a source measure unit and another one is a very high resistive measurement type electrometer. So, usually we use this electrometer to measure the transient that is the base data that we measure so these are all dc measurements. So, we have the capability to go for AC measurements. So, we can do the impedance spectroscopy, by this impedance analyzer and that will tell us that; what is the difference between; a DC measurement and AC measurement.

And we can analyse our data perfectly, because sometimes we use the data in the time zone or sometime we use the data in frequency zone, so just by Fourier transform. So, this gives us lot of flexibility to understand this gas sensing material and I will show you some of the graphs that typical graphs which we can think of. So, this part is quite useful, both this resistance measurement and this transient measurement.

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And also we have another network analyser, which basically we use for noise spectroscopy, because sometimes are noise inside the resistance transient that also gives lot of information. This is not very frequently used, but this gives very very exceptionally high quality data as per as understanding of the types of gases concerned. Because basically when you measure the resistance versus time the data is more or less very monotonous.

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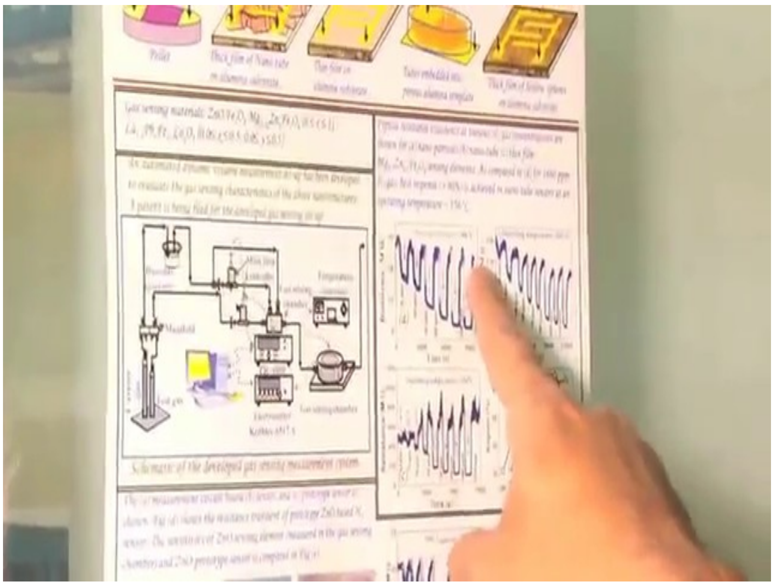

When you pass gas then the resistance changes and depending on the concentration of the gas the resistance changes more. So, you can calculate the response percent from this transient data that how much is this change resistance in air and resistance in gas. So, it is R a minus R g by R a so you can calculate what is the response percent. How much time does it take to this kind of fault typically according the SDM specification?

The fall 90 percent of this resistance at each concentration of the gas so that is your response time. Similarly, when it comes back from this resistance to the base resistance so that is your recovery time. So, this are the basic data of whatever we get that is response time then response percent. So, when you do as a function of temperature, then as you can see that not at all temperature it as similar kind of response percent.

So, depending on the concentration of the gas whatever you are using, and the temperature operating temperature of the sensing material, you have this kind of bell shaped curve and this also gives us lot of information. So, I think we can explain it better, but it is a time consuming process. So, we have to learn lot of things to understand to these basic features.

But once you get this kind of data it will be interesting for you to know, that the type of sample that the morphology of the sample as immense influence on this kind of data, which is one good part because you can do a one to one structure and property correlations. This particular poster you show it is being showed that you have a powder you make a pullet out of it make two electrode and then measure this resistance.

And change your sample configuration from here to a nanotube kind of thing or a basic thin film, or a embedded nanostructure, or a thick hollow frame nanostructure, these are all schematically drawn and one to one correlation you can get in the upper micro structure. You see that this is just like a pallet this kind of powder with having a porosity the tube exactly it forms a hollow tube. And suddenly the gas will defuse inside also absorbed outside so response percent is very fantastically high here.

Similarly, you have nano-rod thin film this is interesting embedded nano-duo structure already the base is some kind of porous material and we packed this kind of tubes inside and put one electrode here and one electrode there. So, in that case it is a parallel kind of plate configuration we are using sometimes we get surface type of electrode we deposit. So, once you do this kind of nano structuring the same material, same gas concentration, same humidity, same temperature, but you get dramatically improved gas sensing performance.

So, the whole idea of this type of dynamic analysis is to understand your material modification of your material for a particular purpose. In order to make it selective we also do another type of material prepare whatever we do that is nothing, but materials engineering. The same zinc oxide it can sense all the gases or by sudden modification, I can make it, selective for hydrogen selective for NOx.

So, this is a tremendous materials engineering we do in this lab and we get a selective sensor. So, once we get the selective sensor then the idea is to pack the selective sensor in the form of indigenous sensing element, that was developed by our M Tech students. So, this kind of sensing element, and then separately we will have to define a electronic circuit module, so that this can be connected with the circuit module. And whatever this all this instruments are doing.

In fact, that will lead to a portable sensor so you can carry this sensor module. So, our job is mostly to manipulate the materials check their sensing properties. But somebody should make this sensor also to make a prototype, so that we can take it outside hang it somewhere so some kind of arrangement was made, so that is quite rudimentary. But this kind of arrangement was made, and you can hang it on your wall, and then you put a room fragrance in the wall and in principle it will do the characteristics. I mean we will do the sensing.

Now, one important aspect of this kind of dynamic measurement is that in real ambient this flow is will not be there. So, the flow whatever we are getting so whether this is say 20 SCCM or 100 SCCM or 500 SCCM. So, you are drawing lot of oxygen on to your sensing surface. And when the gases senses, the sensing product develops, and you are driving get out. So, you get a very characteristic response and recovery plot out of this measurement. But your actual sensor whenever it will be hang somewhere, there will hardly any flow. So, we will have to device we had have a device a static chamber. A static chamber where you just put the sensor put some gas and allow it to sense and then automatically it gets recovered. So, that challenge we took when we understood this material well and this part whatever you are saying. So, much equipment etcetera, everything was by passed and we have our own micro-controller best circuitry and this was also remotely sensed.

So, all this kind of complications came and it was beyond our knowledge to actually address this kind of practical problem. So, we started to collaborate with different faculty members one Professor Misra is one of them that he is taking care of the remotely controlled sensing if you can control the sensing or if you can take the data acquisition. Some other faculty members from Electronic Department Professor Sudip Nag is working on the development because in our knowledge we could only do it, but he is expert in this field. So, he developed a printed circuit board may be in other forum we will show those kind of things whatever has been developed from this lab. So, materially is the art of this kind of activity because finally, we will have to sense selectively a gas you should know what is their concentration. And exactly, which temperature how it is varying. So, if this temperature is too high you need a separate power circuit to drive those kind of sensor so those are the issues.

So, using that feedback we are do something to reduce this temperature this part of our research. And this is a thing I feel it is enough for someone to understand that what exactly is done in this laboratory. Now, you will have to make the sensor as well I mean this is not only the material, but sensor in different forms.

So, we have the facility to deposit a thin film by flugery technique. And mostly we use it in the other lab we have done microwave assisted hydrothermal technique were we can make porous material or different types of nanostructured material to know their gas sensing properties.

Thank you so much for Professor Basu Majumder. So, we are going to have a look at other facility that we have over here where we will see how volatile organic compounds would be sensed. Yeah, that is one of in case of volatile organic component it is difficult to get the cylinders for all those things. But you can easily have your gas lighter and you can put butene gas in it you can easily have some kind of paint, where toluene is there so just we have developed a chamber may be one of our students will explain it better because she is in the way of in the processing of developing it.

So, we will just go there and see that how this evosis are being sensed in this laboratory. So, I am going to now introduce to you Miss Shamistha, who is a PhD scholar, jointly been supervised by Professor Basu Majumder and by myself. So, Shamistha could you please explain the setup that you have for sensing volatile organic compounds like; methanol, butanol etcetera.

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Yes actually the gas sensing setup is broadly classified into two types one is dynamics and statics. Dynamic system is already explained to you by sir. And this is a static chamber through this one we are introducing the gas through this hole. And there is a sensor array data can be taken through this we can take multiple sensor data from those probes that are there we will keep an area of sensors. And we can take data and this is a real times gas sensing system because it is exposed to real time environment.

Here the conditions are isothermal, but here as it is exposed to environment. So, this is basically a miniature miniaturized version of gas sensing system. This is a gas sensing probe, where you can see, we have, this is heater this nichrome wires, you can see with in a mica, mica sheets that is separates provides insulation between that heater and the sensor. This is sensor and this is the NTC that is an negative temperature coefficient material it is a NTC thermistor actually used for sensing for it is for used as a temperature sensor and mostly it also abstract the in-rush flow of current to the sensor.

And then you can see this is a temperature controller, here PID control unit is used, we have designed a PID controlled circuit here. And then through this NTC which I said as a temperature of that resistance of that material is increasing, the resistance is decreasing.

So, that is some way acting as a feedback to the system. So, depending on that the power that is the power transistor, which is there the input to that is varying. And depending on that we are able to control the temperature at particular at a particular point at which we will perform a experiment.

So, now you can see this is the base line the for this sensor first of all this is a sensor, this is fabricated on a glass, the base material is a glass. And then using soil gel technique we have using a spin coating unit we have developed a thin film of copper oxide, this is a p-type MOS, sorry, metal oxide semiconductor sensor. So, I will show you how is it working.

First of all, when at a particular optimum temperature this probe is exposed to the environment the oxygen reacts with the surface of this sensor. So, there is some chemical absorption process taking place on this surface, due to which we are getting the electrons this is a p-type material. So, the minority electrons that are there, those are taken up by the oxygen which have higher affinity towards the electron. So, what is happening the conductivity of the p-type material is increasing.

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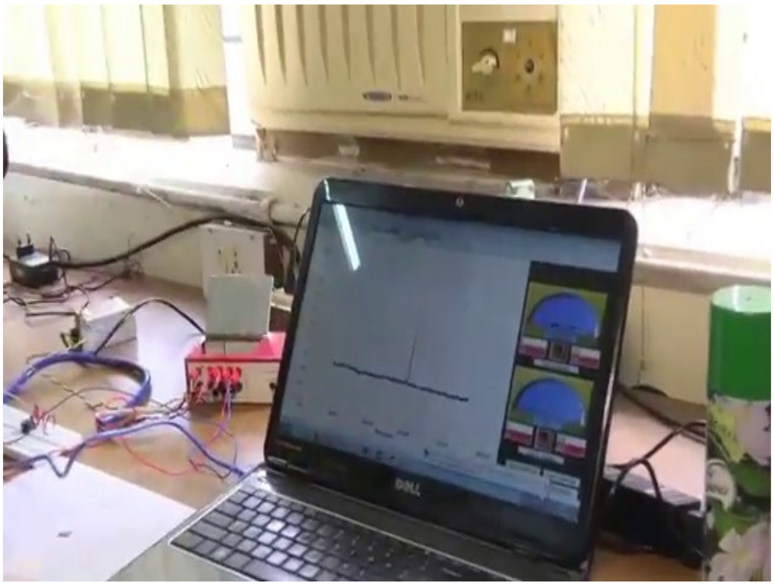


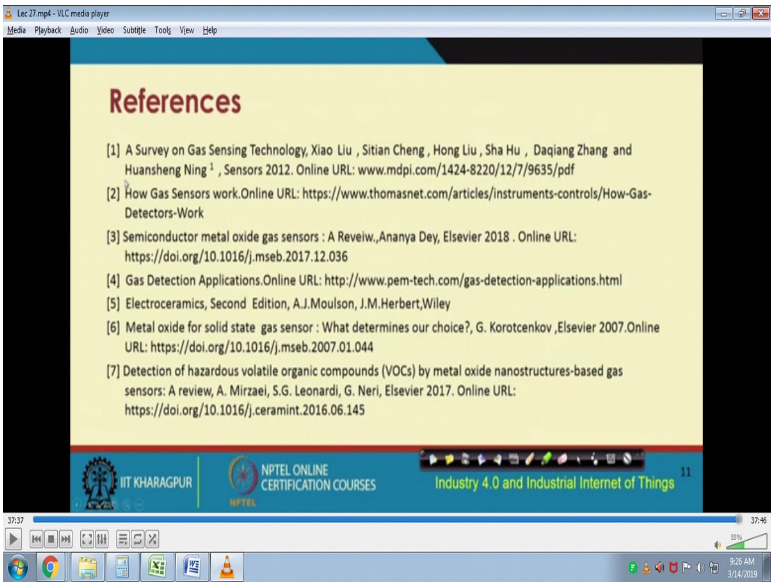
So, we can see whatever the voltage label we are getting here it will be the highest voltage. After a introduce we will see this is having some ethanol this freshener actually has some ethanol content, which is a VOC, so this particular sensor will detect this VOC. So, let us see so you can see the response there it is falling there the voltage is falling it is able to detect that there is a volatile organic compound there in the environment depending.

So, thank you Shamistha, so Shamistha could you tell us now about the different applications of these kind of sensors.

Yes these kind of sensors are widely used in different kind of industries. For example, if you go for oil and gas industry the workers working there are exposed to different harmful gases. There the diesel engines that are used to run the machineries, there in the oil factory those emits such radiation the exerts that are emitted contents very harmful gases like hydrogen sulphides, nitrogen oxides, all those things. And some particular metals those are very much harmful for humans it may cause lungs cancer, respiratory diseases.

Ok.

And also while in bacteria fabrication there you may be exposed to emissions of carbon monoxide and carbon dioxide at those place monitoring the concentration of these gases are very much important. So, there are even more wide scale are used in different kind of industries of these gas senses. Thank you Shamistha. Thank you, Professor Basu Majumder.




So, these are the references finally. And if you are interested about the designs of any of these types of metal oxide gas sensor this is the one that you could go through. And there are many other references as well. So, depending on your interest you can go through any of these references.

Thank you.

**Introduction to Industry 4.0 and Industrial Internet of Things**
**Prof. Sudip Misra**
**Department of Computer Science and Engineering**
**Indian Institute of Technology, Kharagpur**

**Lecture – 28**
**Key Enables of IIoT: Connectivity – Part 1**

If, we are looking at a IIoT holistically, there are different layers, at a very high level, we can think of an IIoT based system, to be comprised of different layers; layers such as sensing, which is what we have already gone through so far. Then, after the data are sensed from these different industrial equipment's, machinery, and so on, the data will have to be sent through some medium following certain protocols.

So, this is this connectivity part, right. So, after sensing the data will have to be sensed over some kind of connectivity. And, after connectivity, the next layer will be the layer of processing, and based on the results of processing some kind of actuation or control or feeding back the control back to somewhere will have to be done. These are the different layers of layers of an IIoT based system, that we can think of.

Let us go through this connectivity part now. So, we have already understood the sensing part now next comes the connectivity part.

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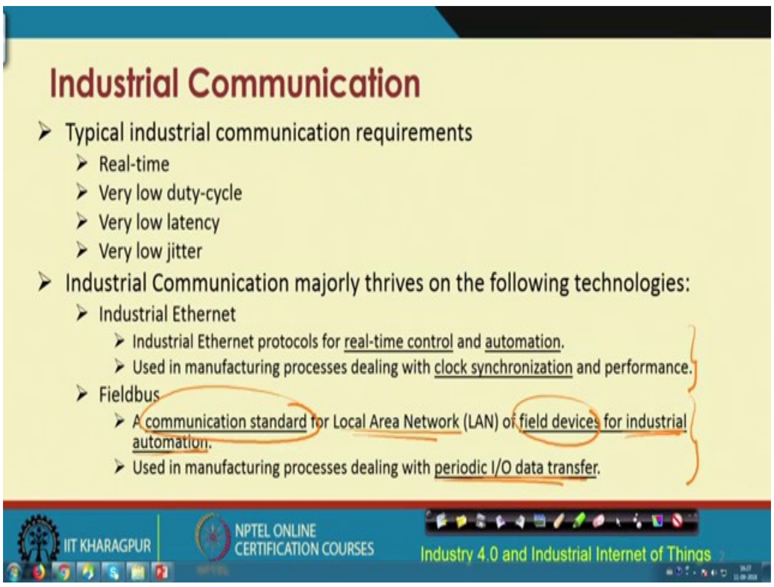

When we talk about industries. Industrial requirements are very specific, industrial communication particularly has certain specific requirements. These requirements are that the communication, the processing, everything will have to be done in real-time, with least delay, whatsoever in all the different respects.

Thereafter, the next important consideration is that there is very low duty cycle; there is very (very) low duty cycle that should be there. So, which basically will ensure that, we need to make our sensors active for only that duration of time, which is sufficient and thereafter put the sensor in the sleep mode; so the duration for the active mode will have to be much less compared to the overall cycle of the operation of the sensor, because of the requirements with the way, the machineries are going to work etcetera. So, there is a very stringent requirement of very low duty cycle.

The third one is that there has to be very low latency. The latency is required to be very low because just consider that you process something and if it does not the processing takes, maybe in the order of few seconds. And, by that time maybe some job will be will which was required to be finished is not finished, and if you do not get that control back to that point where the job is being performed, then that particular job is going to be basically damaged. And, also the latency requirements are very stringent because that can also lead to different types of industrial hazards.

The next one is the requirement of very low jitter. Jitter means the rate of change of delay. There has to be a very low jitter rate, that is required for industrial communication. So, industries so, nowadays, we are talking about IoT. And, consequently, sort of projecting it for industrial requirements we are talking about Industrial IoT, but looking back communication in the industrial sector, let us say, manufacturing plants, and so forth has already been there.

So, there has been different communication requirements, reliable communication for industrial use, those sort of requirements have been there. So, communicating different machines have also been there, but those have been primarily, those have been primarily using the conventional communication mechanisms. And, with the help of guided media wired medium for communication primarily, but gradually the different wellness requirements are also coming into picture. And, also at the same time these sensing enabled, sensor enabled, devices and processing close to the site of sensing and higher degrees of processing, real time processing, real time analytics. So, those kind of requirements are coming into picture and that is what makes this communication interesting in this current perspective. And, that is where this IIoT is coming into picture, but a IIoT is not something new.

So, the only thing is that we have some stringent requirements with respect to the fulfilment of IoT requirements and that is what makes IIoT much more interesting in the industrial context. So, looking back if you are talking about industrial communication; industrial communication legacy industrial communication was primarily, based on two different technologies; one is the Industrial Ethernet, and the second one is the field bus technology.

So, these are the two major dimensions for industrial communication. So, the Industrial Ethernet protocols for real-time control and automation have been proposed. And, also there are different protocols such as the Modbus based protocols have been proposed to which we are going to go through because this is very important. In the context of Industrial IoT, we cannot basically throw away these legacy communication mechanisms that have been there and that are those are still being used in the industry. So, what has to be done, is whatever newer things we are trying to bring in the context of Industrial IoT, we will have to be built on top of the existing, legacy communication infrastructure that is already in place right. Otherwise, it is going to be complete transformation, it is going to be complete transformation, which may not be desirable. So, rather I think what is better is to have an evolution of the existing, industrial, communication, infrastructure, mechanisms, protocols, etcetera and making it much more transgressional to adopt IoT requirements.

So, Industrial Ethernet and the next one is basically the field bus, in the field bus technology we are talking about, some kind of having some kind of a communication standard, for use with local area networks, having connectivity with the different field devices field instruments in the industrial automation sector.

So, these are time in the field bus technology is primarily used for manufacturing processes dealing with periodic input-output data transfer. So, these are the two main technologies, that are being used in the industrial communication sector, so far.

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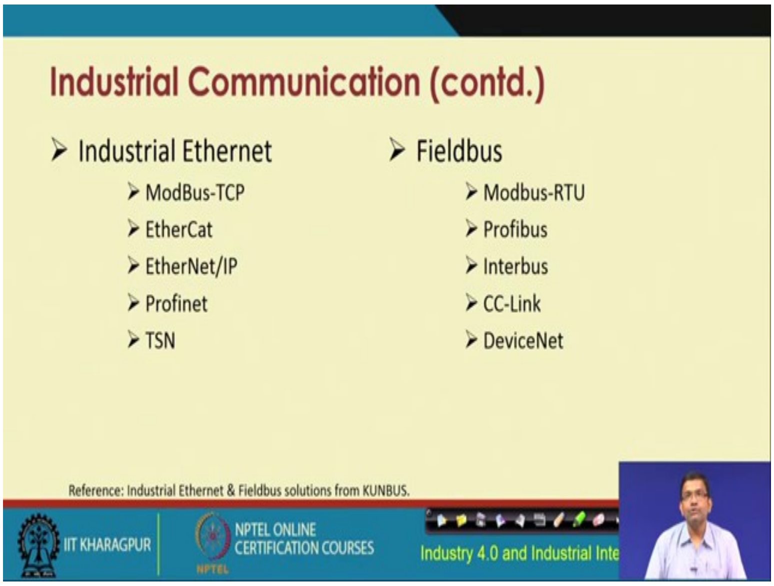


So, for the industrial Ethernet there are different protocols that are there, number one is the Modbus TCP.

Modbus TCP is a very popular industrial Ethernet protocol. Second one is the ether EtherCat, third is Ethernet/IP, next is Profinet, and TSN, Time Sensitive Networks. These are some of the Industrial Ethernet protocols that are used in practice in for industrial communication. Particularly in the manufacturing, industries manufacturing plants and so on.

The other one is the field bus technology, where different protocols such as the Modbus-RTU version, not the TCP version Modbus-RTU. Profibus inter bus CC-link, Device Net; these are some of the different protocols that are used in the field bus in the field bus category.

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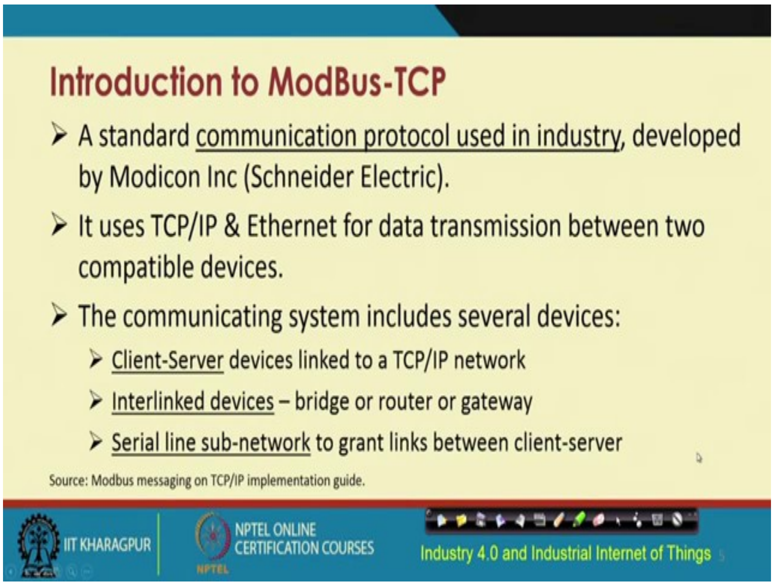


So, we will start with the ModBus-TCP. As this name suggests, ModBus-TCP is built on top of TCP/IP suite of protocols. So, it uses the TCP/IP and the Ethernet for data transmission between different compatible devices. Compatible means, that they have to talk the same language, they will have to talk the same language, both will have to use the same protocol then only the communication can happen.

TCP/IP suite of protocols is used and on top of that the Modbus is used. So, you have TCP/IP Ethernet and Modbus TCP built on top of the existing TCP IP Ethernet protocols. So, incidentally Modbus TCP has been proposed by present day Schneider electric, which was earlier known as the Modicon Inc. And, this particular protocol was proposed to cater to certain industry specific requirements that Schneider Electric or Modicon had you know in their plans. And, to in order to cater to those requirements particularly requirements such as reliable communication, low latency communication. This kind of protocol was required, because the existing TCP IP protocol in its in the TCP IP form was not very suitable.

So, it has to be modified in order to be used for the industrial communication requirements in manufacturing plants. Schneider electric came up with their own protocol, which later became sort of like an industry standard communication protocol for being used. And, what was TCP is a popularly used protocol present. So, ModBus TCP has different types of communication, in the different devices that they have.

So, first of all they use the client-server based mechanism for communication, which is quite well known what is the client-server mechanism? Client-server communication is used and for that a TCP/IP conventional one is used for the communication with between the client and the server.

The next one is the devices such as the bridges, routers, gateways etcetera, which interlink different parts of the network, right. So, that is these inter-linked devices part. And, the third one is basically the serial line sub network that basically grants the links between the client and the server. So, these are the three parts of the communication system, that are used in the Modbus TCP protocol.

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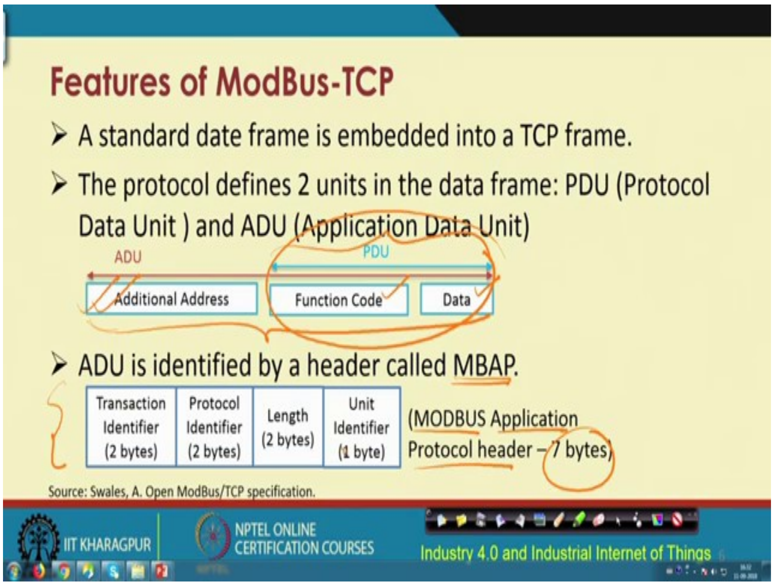


So, these are some of the features there are many many different features I will talk about some of the salient ones. So, here are some of the salient features of the Modbus-TCP protocol. So, the standard data frame is basically embedded in Modbus-TCP into a TCP frame into a TCP frame a standard data frame, which carries the information is embedded into it into the TCP frame. So, the protocol basically defines two units in the data frame; one is known as the application data unit, the other one is the protocol data unit. So, as you can see over here this entire thing is the application data unit and this part is the protocol data unit. So, basically the protocol data unit has the functional code, function code and the actual data. And, the application data unit includes the PDU plus the additional address. So, this ADU application data address, data unit has some header, which is known as the MBAP.

An MBAP stands for Modbus application protocol header, which is of length 7 bytes and this header structure is over here. So, 2 bytes of transaction identifier, 2 bytes of protocol identifier, 2 bytes of actual length, and 1 byte of unit identifier. This is the Modbus application protocol header, the MBAP structure, right.

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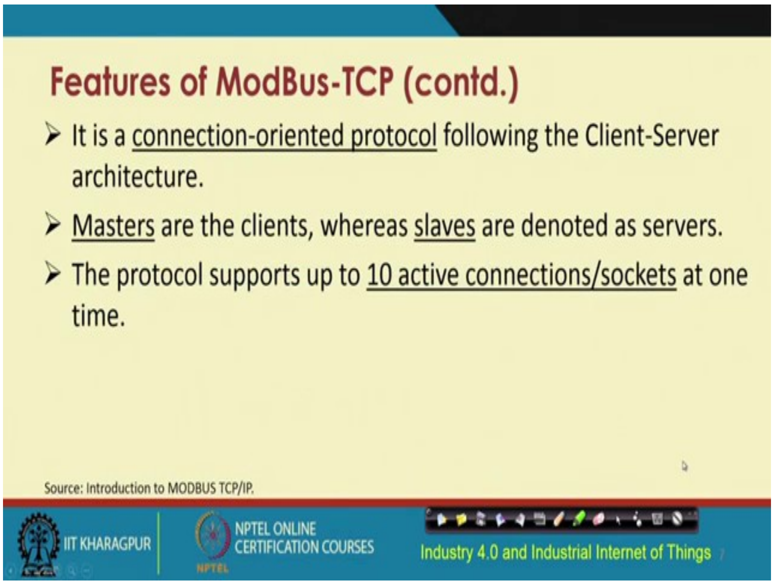


So, we go next and look at the other features. Modbus TCP is a connection-oriented protocol and as I said before, which uses client-server architecture for the client to communicate with the server. And for the server to respond back to the client done on using the TCP protocol of the TCP/IP suite. Now, in Modbus TCP the clients are basically the masters and the servers are the slaves.

So, master slave kind of communication takes place between the client and the server. So, in the same way as the master asks the slaves to, I am not quite impressed with these terms, but this is what is used the term slave or, the master this is not a very comfortable term for use for me, but let us continue, to use the terms that are used in the literature. So, masters basically in the same way as masters ask the slaves to do certain work. Here, also the clients ask the servers to do certain work and the servers respond back. In the same way, as the slaves who do the work and respond back to the masters, here also the servers respond back.

So, Modbus TCP basically supports up to 10 active connections or sockets at one time.

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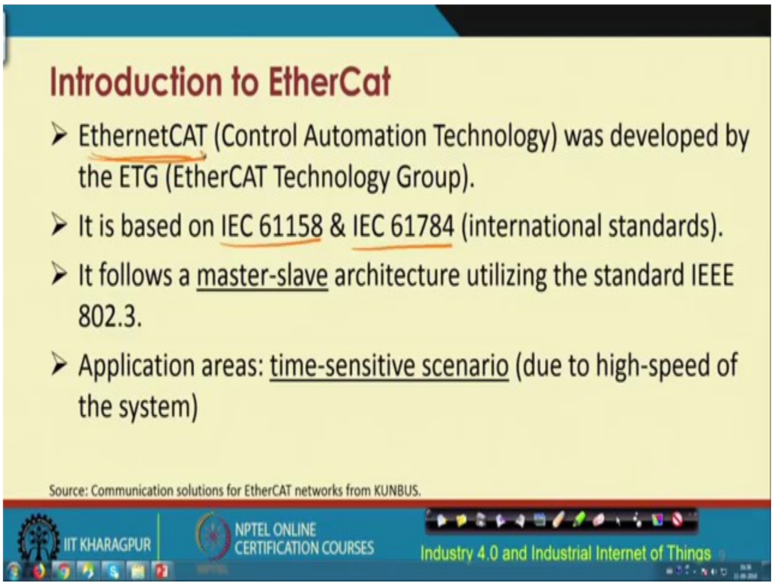


Next, protocol is the EtherCAT protocol and the full form of CAT is Control Automation Technology. And, this was developed this particular protocol, EtherCAT was developed by the technology group EtherCat, EtherCAT technology group, ETG, this developed this Ethernet CAT protocol.

So, this particular protocol is based on two different industrial standards; one is the IEC 61158 and the other one is 61784. These are two industrial international standards and based on which the ether Ethernet CAT protocol was proposed. So, this particular protocol follows a master slave architecture utilizing the standard IEEE 802.3; that means, the Ethernet, the standard Ethernet is used and the master slave communication basically follows this particular standard 802.3 Ethernet.

And, the application areas of for use of EtherCAT are basically systems, where there is a requirement of time sensitivity, where there are time-sensitive scenarios, and basically these scenarios will have to cater to specific times by when the jobs will have to be completed, or certain process will have to be completed. And, this is typically used in systems which are of high speed and industrial machinery typically operate in very high speed, right.

So, there is lot of batch processing and high speed processing by these different industrial machinery takes place. So, that is the reason as you can see, industry specific requirements will have to be taken into account in order to come up with these protocols and EtherCAT is one such protocol, which cater to this particular need.

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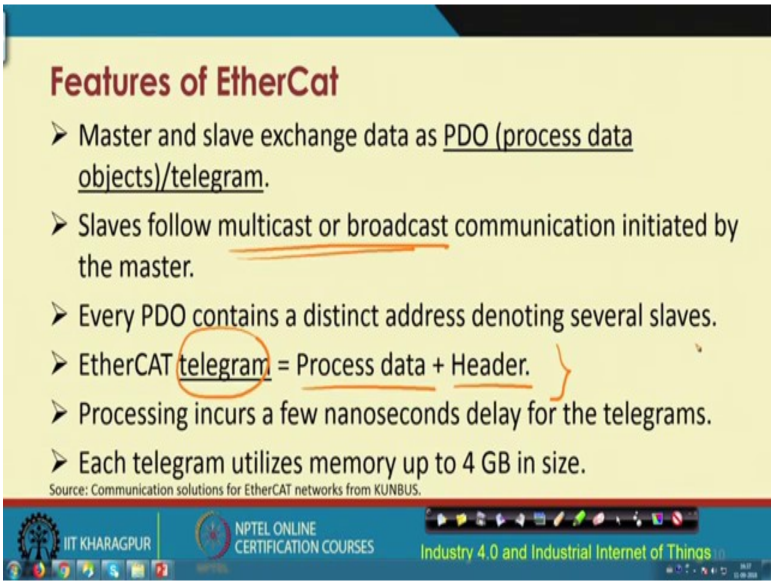


So, here are some of the features of EtherCat, here also it uses the master slave protocol for detects exchange between the client and the server. And, this is done in the form of something known as the PDO, which is the Process Data Object, it is also known as the telegram. Now, in EtherCAT this telegram is defined in this manner, telegram is the processed data plus the header, together it forms the telegram or the PDO in EtherCAT. So, going back the slaves so, I said that it is master slave communication. So, the slaves basically will follow multicast or, broadcast communication and every PDO contains a distinct address denoting the several slaves.

So, every telegram basically utilizes the memory up to 4 gigabytes in size in EtherCat.

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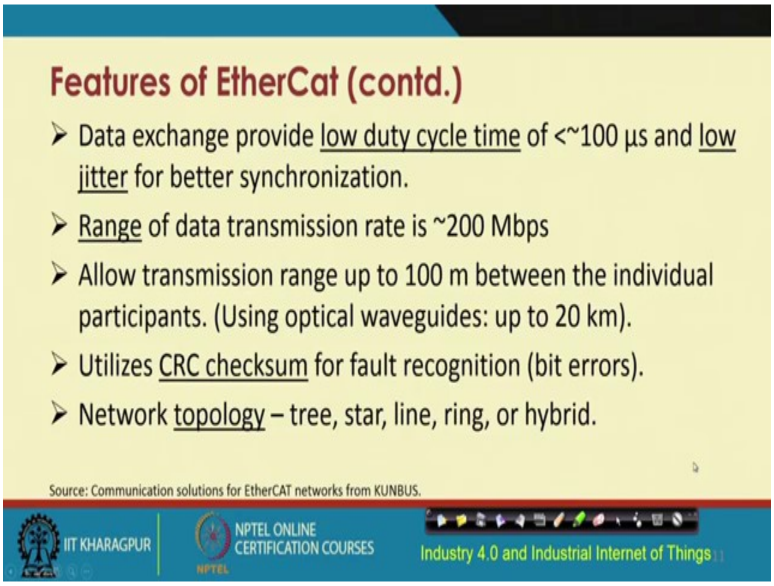


Other features low duty cycle requirement. So, fulfilling to low duty cycles less than less than about 100 microseconds, low jitter, better synchronization so, all of these are requirements for data exchange with EtherCat. And, the range of data transmission in EtherCat is typically in the rate of about 200 Mbps, 200 Mbps in that kind of quarter.

And, in terms of security not only security, but also error correction, error detection, error detection and control etcetera. The CRC checks take some based error detection or fault recognition, mechanisms are used where the, but errors are found out with the help of this kind of CRC based checksum mechanism.

The network topology that is used are the tree topology, the star topology, line topology, ring topology, hybrid topology, different types of network topologies are supported by EtherCAT.

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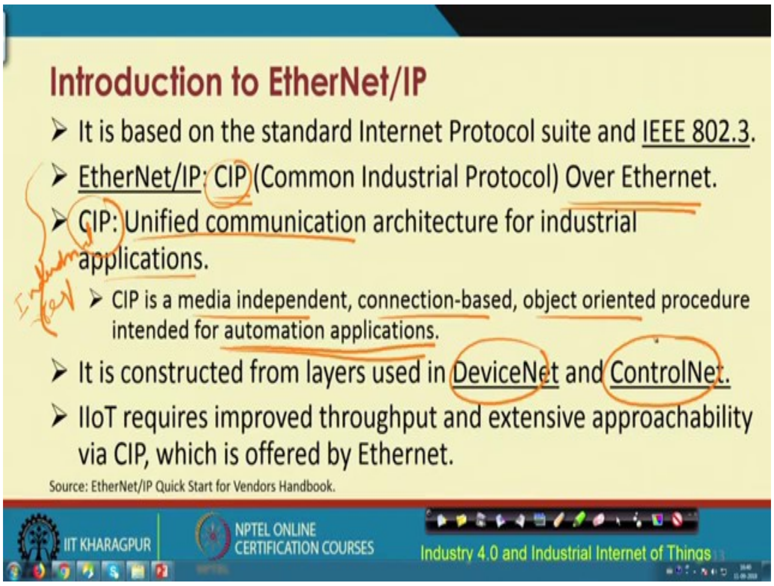


Next comes a protocol Ethernet/IP. So, this Ethernet/IP is based on the standard IP suite of protocols plus the Ethernet, which is IEEE 82.3 compliant. So, this Ethernet IP protocol follows the common industrial protocol, Common Industrial Protocol CIP, common industrial protocol and Ethernet IP basically happens to be like, CIP over Ethernet, CIP over Ethernet.

And, the CIP provides unified communication architecture for industrial applications. So, CIP basically is the Common Industrial Protocol, which is media independent, connection-based, object oriented, and primarily targeted towards automation-based applications. So, as you can now understand, why it is industry oriented. So, Ethernet IP protocol is overall catering to the different industrial requirements.

So, this particular protocol is constructed from layers used in the device net protocol and the control net protocol. We will look at these in more detail, later on, but just for your information device knit and control net together, basically controls the different layers of Ethernet IP.

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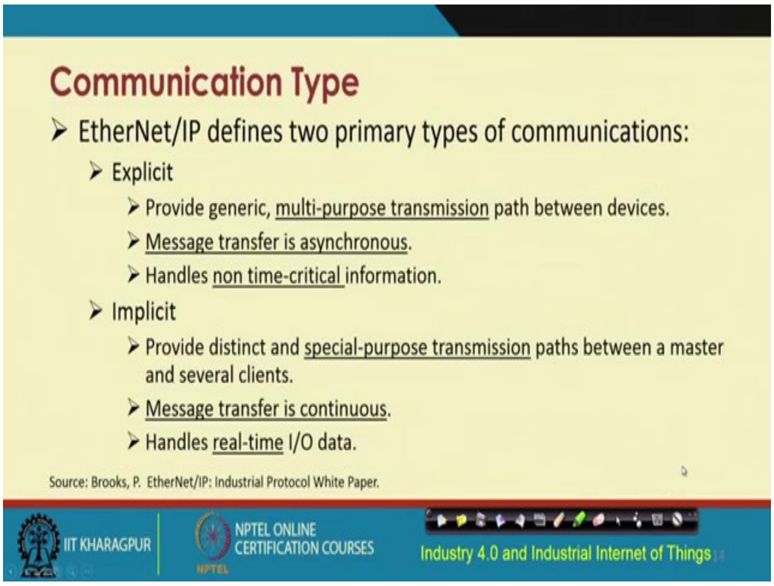


So, in EtherNet/IP there are two types of communications; explicit and implicit communication. Explicit communication provides generic multipurpose transmission between different devices. And, typically the message transfer is asynchronous in this explicit type of communication.

Explicit handles non time critical information. On the contrary, implicit handles real time input output data requirements. Here, unlike in the case of the explicit, where the message transfer was a synchronous, here the message transfer is continuous. And implicit type of communication provides distinct and special purpose transmission between the master and clients.

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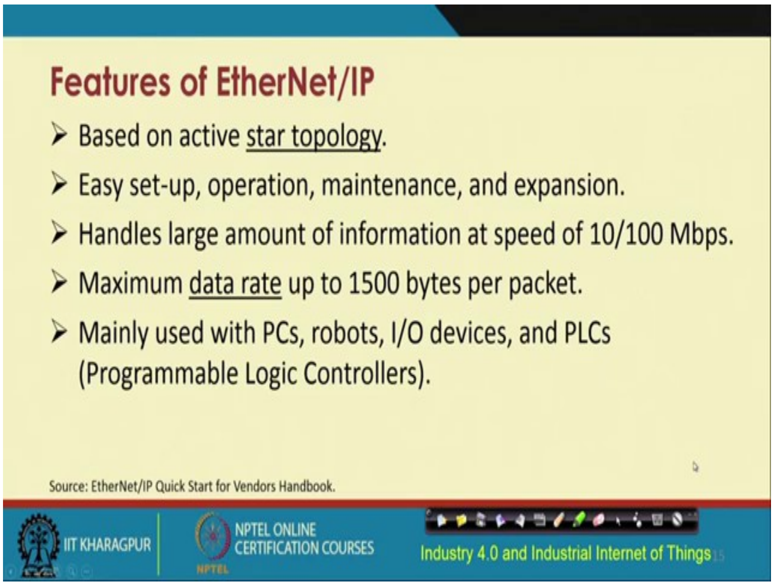


Ethernet IP uses the star topology and (Refer Time: 21:17) it supports data rate of up to about 1500 bytes per second. And, this is mainly used Ethernet IP protocol is mainly used with PCs, robots, input output devices, PLCs and so on and connectivity between them.

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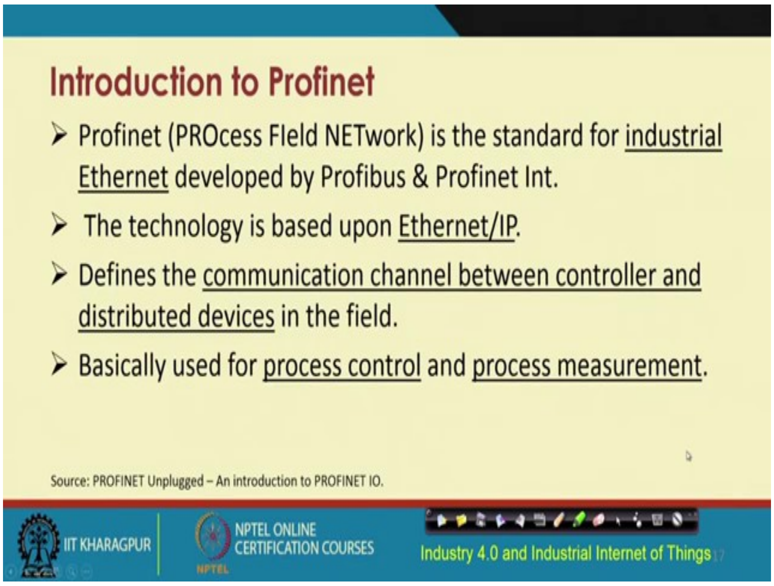


Next, comes the Profinet protocol. So, profinet is a standard for Industrial Ethernet, it was developed by the Profibus and Profinet Int organizations. It is based upon the Ethernet IP protocol, which we have discussed before. This Profinet defines the communication channel between the controller device, and the distributed devices in the field for example, the different sensors and the controller, and so on.

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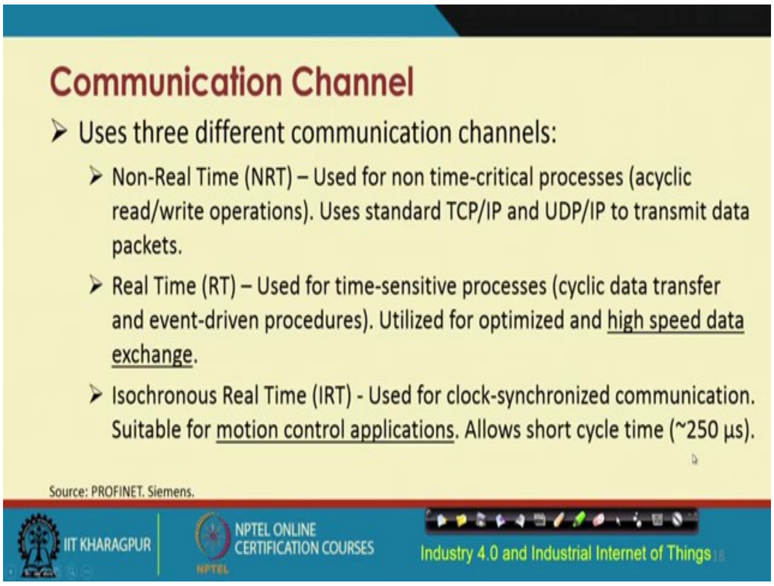


So, profinet will help in this kind of communication between the controller and the field devices. So, basically it is used for process control, process measurement and so on. So, the communication channel supports three types of communication, non-real-time communication, which is used for non-time critical processes. Second is real-time communication as the name suggests used for time sensitive processes, such as cyclic data transfer even different procedures, where basically high speed data exchange is very much required, between different, maybe different processes, different machinery use high speed data exchange requirements are there in those machinery.

So, high speed means like the machine is operating in such a high speed, that the communication will have to happen in real-time. For this real time communication channel will help in it.

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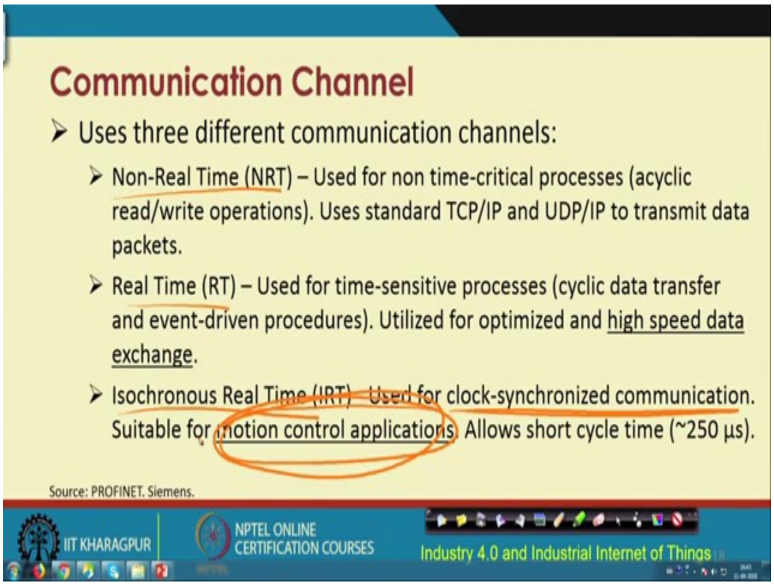


And, then we have so, we have the non-real time real-time, and then we have the isochronous real time requirements. So, this is this isochronous one are used for clocks synchronized communication scenarios, clocks synchronized communication scenarios, and are suitable for motion control applications.

So, as you can understand that clock synchronization is very important in motion control applications. And, that is why this IRT or the; I soaked isochronous real time communication requirements or these channels are important and required.

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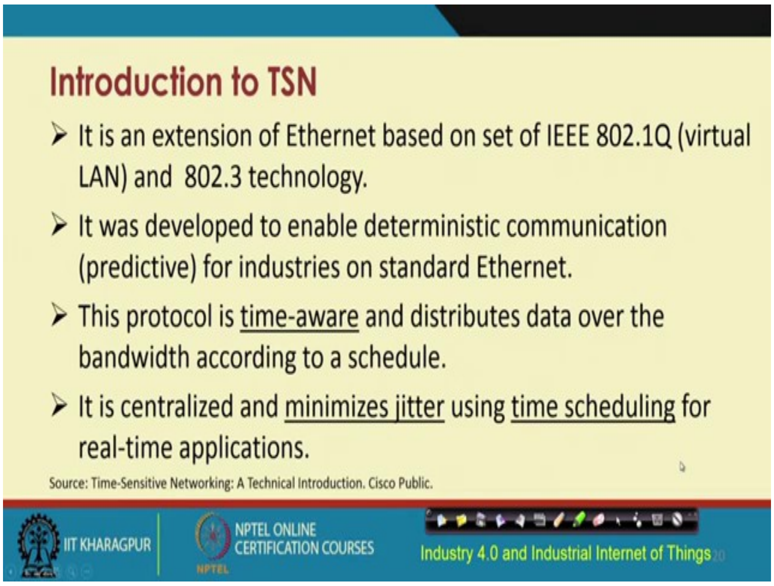

Next, we come to the TSN, which is the Time Sensitive Networking. So, here this particular protocol is based on the Ethernet protocol; rather it is an extension of the Ethernet. And, it uses it is built on top of I EEE 2.1Q 1Q, which is the standard for the virtual LANs and the 802.3, which is the standard used by Ethernet.

So, it was developed to enable deterministic communication, where the communication is going to be deterministic, predictive. So, where beforehand how much time will be required. So, superlative communications and how the process the processes are predictive; so predictive communication scenarios it is used.

So, it is sort of a protocol that is time ever, it is a time-aware protocol, time-sensitive predictive nature of communication is supported in this particular protocol. It is centralized and minimizes jitter, using time scheduling for real time application support.

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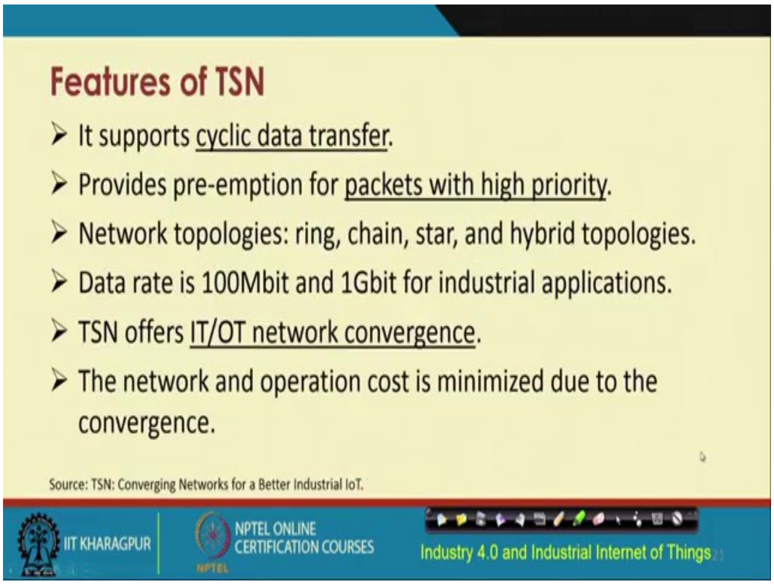


It supports cyclic data transfer provides PM cell for packets with high priority, different network topologies that are supported our ring topology, chain topology, star topology, hybrid topologies.

It supports network convergence of IT; that means the Information Technology. And, the Operational Technology IT, OT, convergence is supported by TSN.

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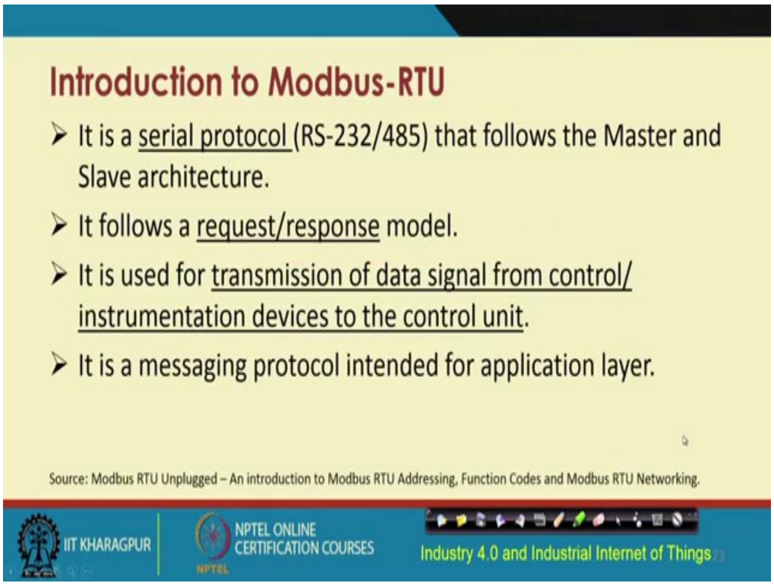


Then, comes the field bus protocol which is the Modbus RTU. This Modbus RTU protocol is a serial protocol following RS 232 and RS 484 standards. So, it provides the serial communication between the master/slave and follows a request/response model.

So, it is used for transmission of data signal from the control or instrumentation devices to the control unit.

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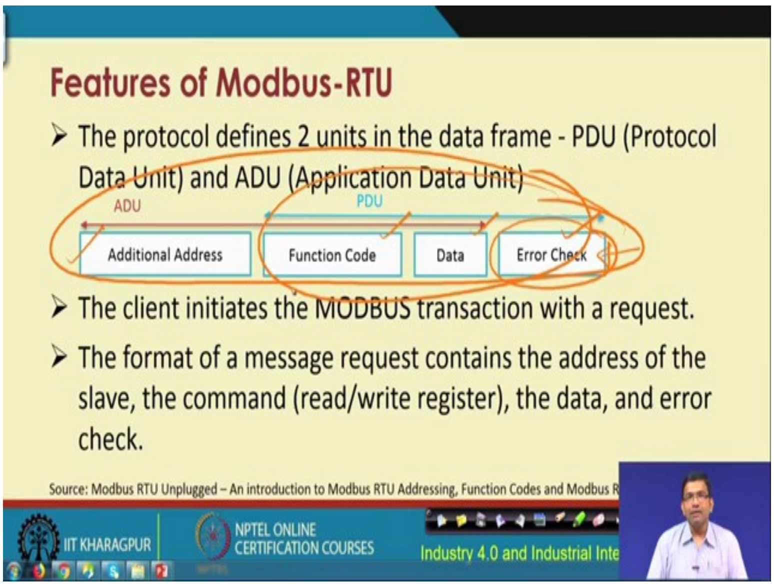


So, here is basically the overall structure of the Modbus RTU protocol data frame. So, as you can see over here, this is this PDU, this PDU consists of the function code data, and the error checking mechanism, and this if you recall earlier in Modbus TCP this error check field was not there. So, here it is in the Modbus RTU and, this is the whole ADU the application data unit, which has the PDU plus the additional address.

So, basically in this kind of communication the client initiates the Modbus transaction with a particular request. And, the format of a message request contains the address of the slave, the read write register the data and the error check.

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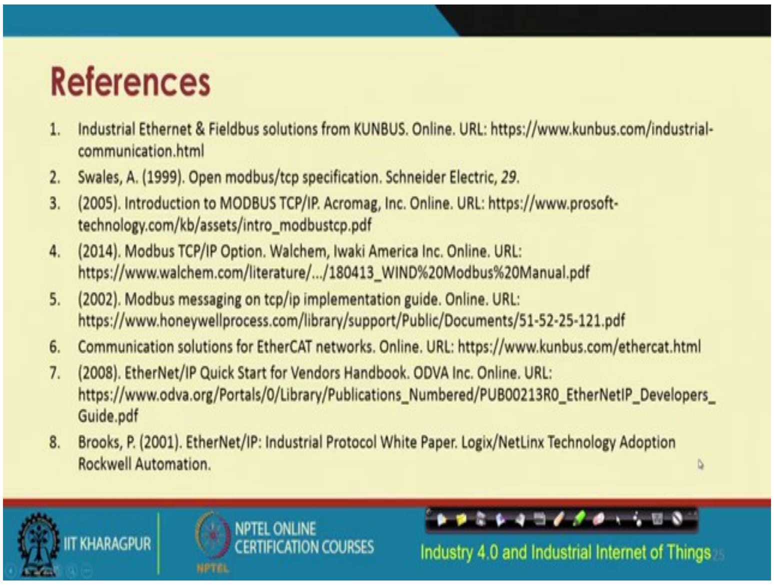


So, before we end I wanted to show you something very interesting. So, we have gone through different protocols. So, let me now give you a holistic picture of connectivity in the industrial context.

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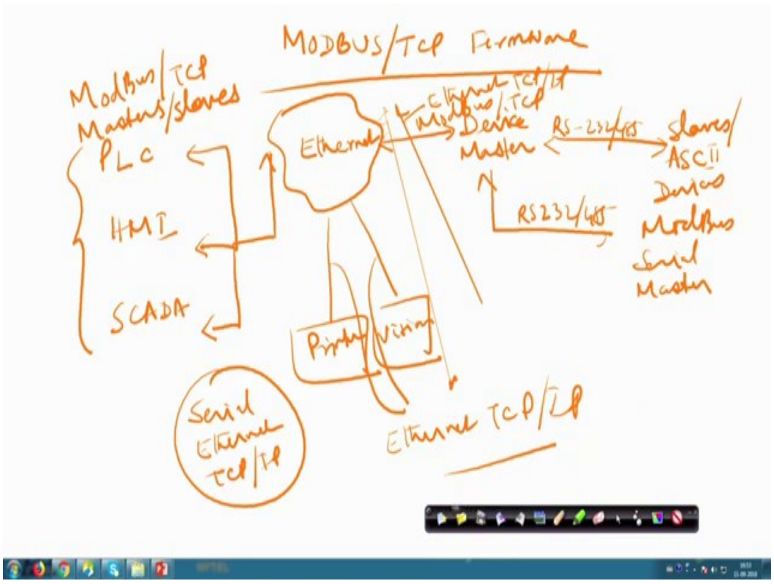


So, I am going to show you, how this Modbus; Modbus TCP firmware works. So, we have different requirements, we have the PLC devices, we have HMI, the HMI devices and SCADA. These are some of the different types of devices that are used in the industrial contexts, right, PLC, SCADA, HMI.

So, these basically would be the Modbus TCP masters or they can even act as the slaves. So, these devices are operating and they collect these different information, and this information is sent through, let us say, this particular cloud we call it as the Ethernet. It is sent through the Ethernet and then this is sent further to it can be two-way communication to the device master, to the device master. And, this is this device master if you recall this is what I was talking about earlier. And, so, we have this device master and this communication will be taking place, with the help of this Ethernet TCP/IP, and Modbus TCP.

Then on the other side this figure looks little ugly, but I am afraid that I am not able to delete these 3 lines. And, so, but this part we can use the serial communication, and we have these different devices such as the ASC II devices or, the slave devices, Modbus slave devices. And, this could be even like, Modbus serial master.

So, these two can use the RS 232/485 standard, right and this is also two-way serial communication. So, this is the overall how these different communications can happen. So, we can have different types I mean this can be extended even further you can have these different printer devices for example, printer devices we can have vision systems connected over here vision systems, and so on.

So, anyway so, holistically we will have in a single industrial scenario industrial communication scenario, we will have serial communication, Ethernet net communication, and TCP/IP, or rather Ethernet TCP/IP connections. So, we can have different links for supporting different communication.

So, and as I said that you can extend this even further and you can have a much more comprehensive kind of communication support. And, as we can see over here this part we have all these PLCS, HMIS, SCADA. You know communicating as either masters or they can be slave typically masters, but they could be slave as well.

Here you would be having this part you could be having all these different master and this part you could be having all these different slave devices and master-slave communication, different parts, different protocols. You know so, different like this part would be Modbus TCP protocol, which will be used this part would be the RS 232 484 could be used between the device master and the slave.

So, like this you could even extend it even further and you could have different other communication, mechanisms in place. And, this part also even could be this one and this one could be Ethernet TCP, IP. So, this is how it is going to work holistically.

So, next we come to the references which you can use for getting a comprehensive overview of the different protocols and getting an in-depth understanding of these different protocols that we have discussed so far, with this we come to an end.

Thank you.

**Introduction to Industry 4.0 and Industrial Internet of Things**
**Prof. Sudip Misra**
**Department of Computer Science and Engineering**
**Indian Institute of Technology, Kharagpur**

**Lecture – 29**
**Key Enablers of Industrial Iot: Connectivity – Part 2**

In the previous lecture, we have gone through the specific requirements for supporting industrial communication. We have seen that the regular protocols that are there for use for other types of non-industrial scenarios are not usable, for say, in the industrial context. And, we have seen, what are the industry specific requirements in the previous lecture.

There are different protocols such as the Modbus TCP the fieldbus suite of protocols, which have been proposed in order to have support for communication between master devices, slave devices, and so on in an industrial communication scenario. So, we will go further and we will have a look at few other different protocols.

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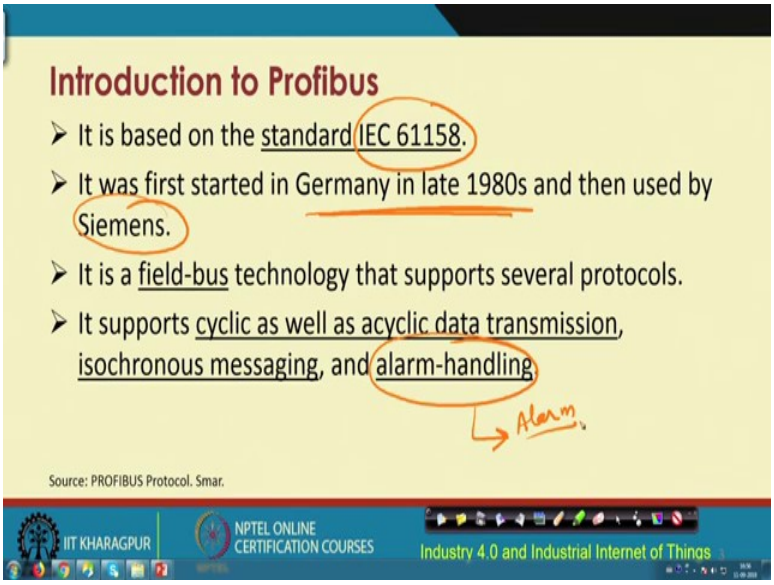


The next one is the Profibus protocol, which is basically the process field bus; this is the full form the process field bus Profibus protocol we are going to go through now.

So, this particular protocol is based on this; it is based on this particular industry standard, the IEC 61158. This Profibus protocol is a field bus technology protocol and supports several other protocols.

So, and incidentally I should mention over here that, this was first proposed in Germany in the late 1980s, and was used by Siemens. So, it supports both cyclic communication and acyclic communication. Asynchronous messaging is supported and is very much attractive for use in scenarios, where alarm-handling will have to be done, the communication for alarm handling will have to be done.

So, Profibus protocol is very much useful, in those kind of scenarios.

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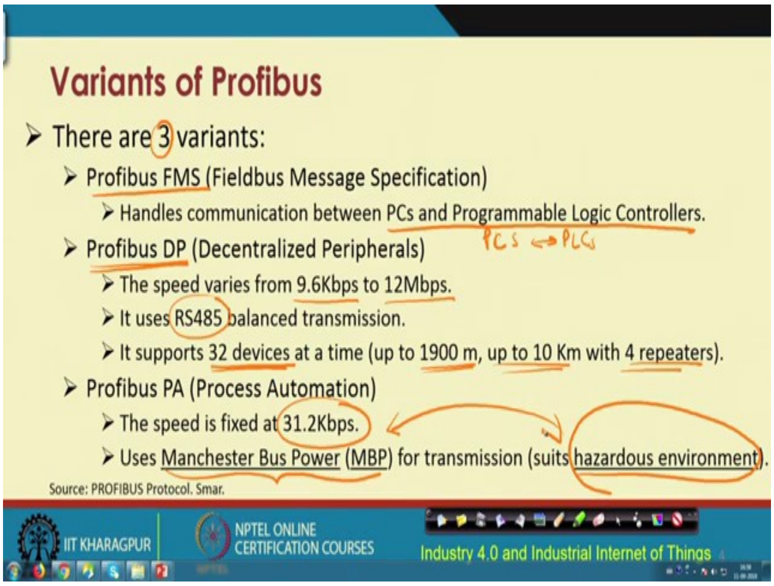


There are three different variants, three different variants of Profibus protocol. The first one is Profibus FMS, which stands for Fieldbus Message Specification. This basically handles the communication between the PCs and the PLCs. This is PCs and PLCs, this particular communication is supported by the FMS variant of Profibus.

Next is the Profibus DP, DP stands for Decentralized Peripherals; it basically supports RS 484 communication, RS 484 communication supporting up to about 32 devices at a time. At the same time 32 devices, up to 32 devices, could be connected supporting about 1900 meters, up to 10 kilometers 4 repeaters this kind of thing can be done, it uses the 484 RS 484 transmission and speed varies from 9.6 Kbps to 12 Mbps.

Then, comes the Profibus PA; PA stands for Process Automation and here this PA basically supports a speed of about 31.2Kbps. It uses the Manchester bus power MBP, this (MB) MBP is very useful for hazardous environment. Because, it has been built in such a manner that, this MBP will still work even if there is a hazardous environment, this MBP will still transfer data in such kind of environment.

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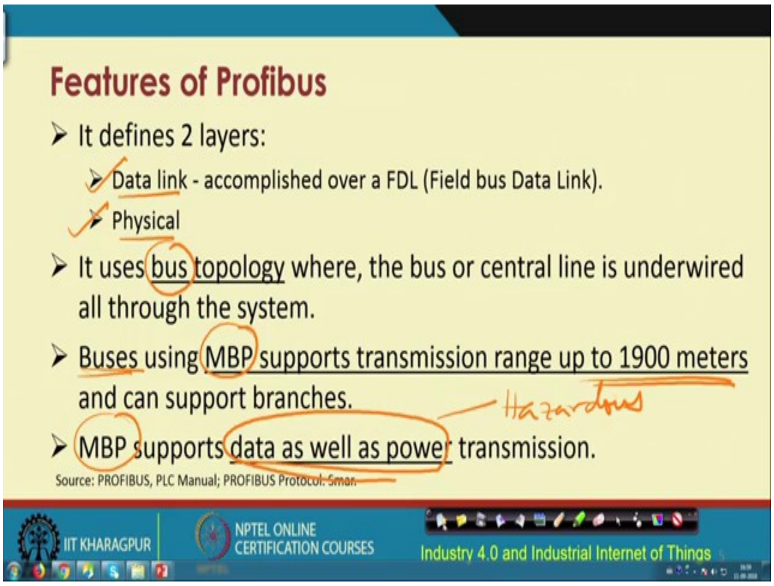


Profibus has two layers; one is the data link layer and the other one is the physical layer. In terms of the topology, the bus topology is very popular in Profibus and these buses use this MBP, that we have seen earlier at Manchester Bus Power Technology, to support communication of, up to about 1900 meters. So, this MBP technology Manchester Bus Power technology supports data as well as power transmission, both can be done in hazardous environments.

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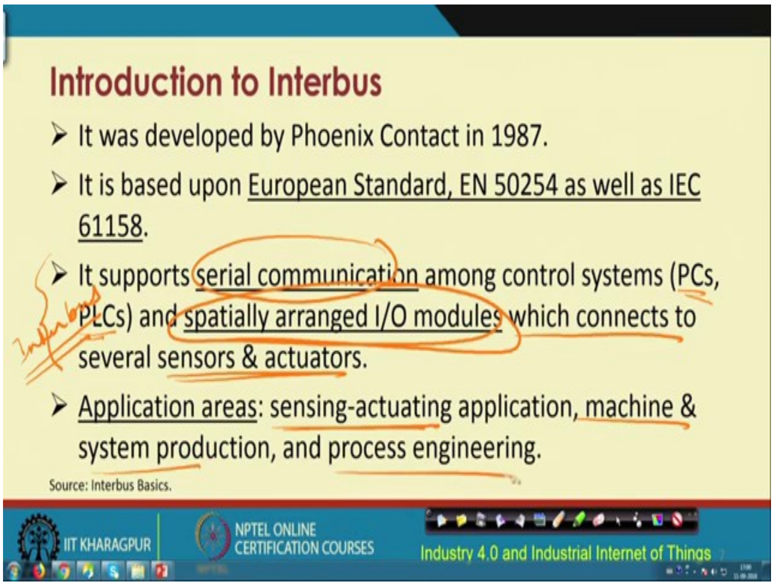


Next, comes the inter bus protocol. So, this particular protocol was developed in 1987 by the company phoenix contact. It is based on the European Standard, EN 50254 as well as the IEC 61158. Supports serial communication, in this case, serial communication between PCs, PLCs and specially arranged I/O modules, and these specially arranged I/O modules will in turn connect to different sensors and actuators.

So, basically the spectrum of communication in inter bus is quite widely varied, so PCs, PLCs, I/O devices, sensors, actuators, and so on. So, all kinds of communication is supported by inter pass. In terms of application areas, sensor actuated applications machine system production process engineering all these sorts of applications are supported.

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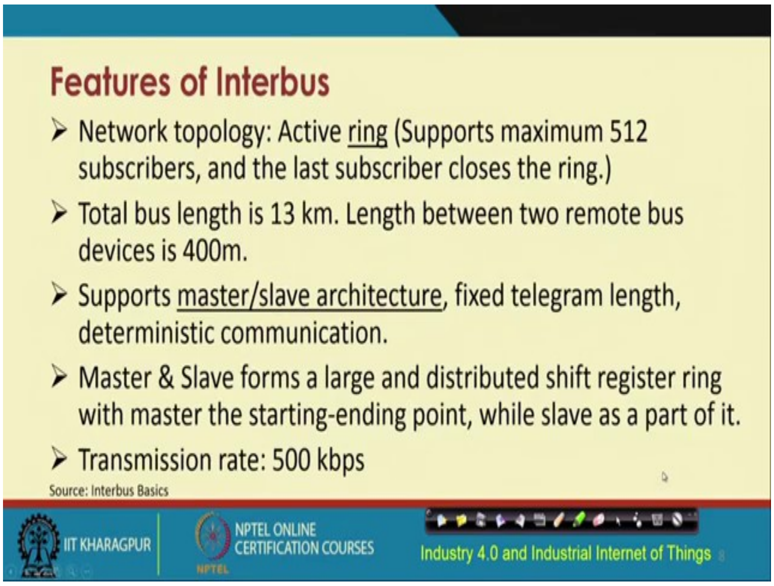


In terms of other features, network topology that is supported is the ring topology, which will provide connectivity to about 512 subscribers. The total bus length is 13 kilometres, which is quite long as you can see. So, 13 kilometres of operation is quite helpful for industrial requirements. Master slave communication architecture like, before is still being used and the transmission rate that is supported by inter bus is 500 kbps.

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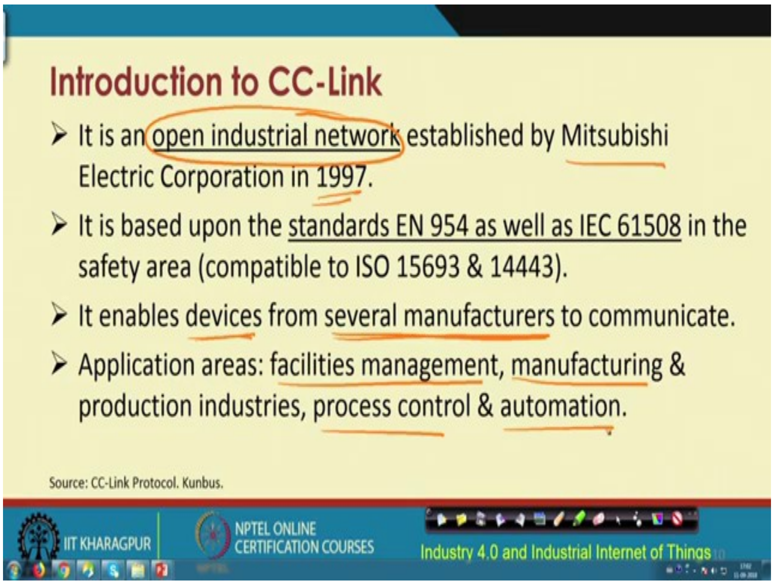


Next comes, this protocol the CC link CC stands for Control and Communication. Control and communication link protocol, CC link. This is basically an open industrial network protocol. So, here actually we are talking about all different types of protocols, different companies came up with Siemens, Mitsubishi electric corporation etcetera.

So, all Schneider electric, all of these different companies came up with their own different protocols to help with satisfying the different specific requirements that they had, which eventually became popular got standardized and being widely used for industrial communication at present. So, this particular protocol was proposed by Mitsubishi in 1997, the CC link protocol. And, it is based upon the standards EN 954 as well as IEC 61508, and is compatible with ISO standards 15693 and 14443. So, it enables the different devices thought that are produced by different manufacturers to be able to communicate. This interoperability between these different devices is supported to a large extent by this particular protocol, the CC link protocol. In terms of the application areas; that are supported facility management, manufacturing production, process control automation, these are the different application areas of support by CC link protocol.

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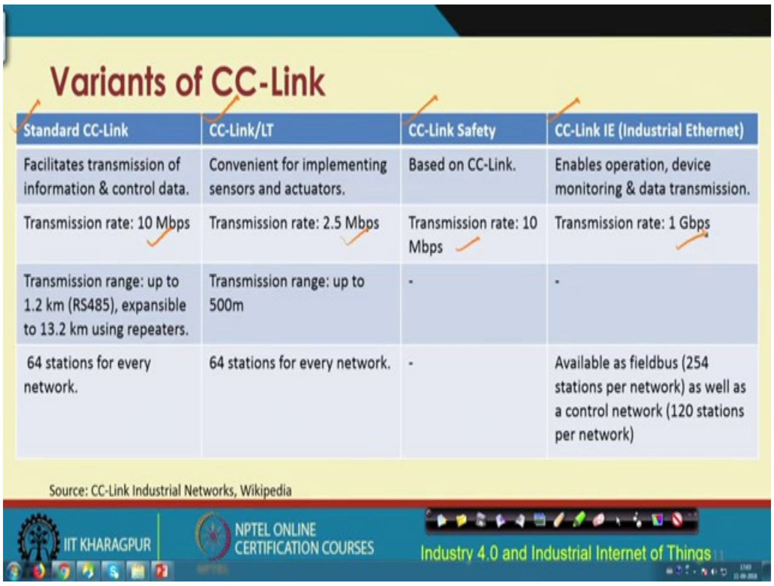


These are the different variants of the CC link protocol, the standard CC link protocol, then we have the CC link LT, CC link safety, and CC link Industrial Ethernet. So, CC link standard facilitates transmission of information and control data. CC link LT provides convenient implementation of sensors and actuators and connecting between them. CC link safety is based on the CC link protocol and CC link IE enables operation, device monitoring and data transmission.

And, the corresponding data transmission rates are given over here 10 mbps for standard 2.5 Mbps for CC link LT, safety is 10 Mbps and industrial Ethernet is 1Gbps, and the other features are listed over here.

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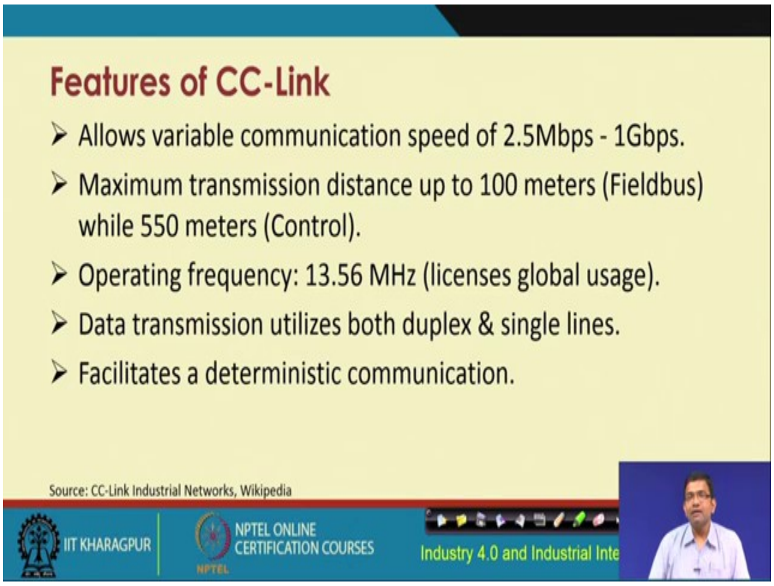


So, overall the communication speed is quite varied in CC link 2.5 Mbps to 1Gbps, transmission distance that is supported is 100 meters for field bus and for control 550 meters, operating frequency is 13.56 megahertz. And, it supports both duplex and data transmission in the form of duplex, and single transmission lines. And, overall the deterministic communication is supported by CC link.

Before we go to this protocol device net we will go through overall how this CC link protocol works. We have in CC link, we have these different devices, let us say the slave devices.

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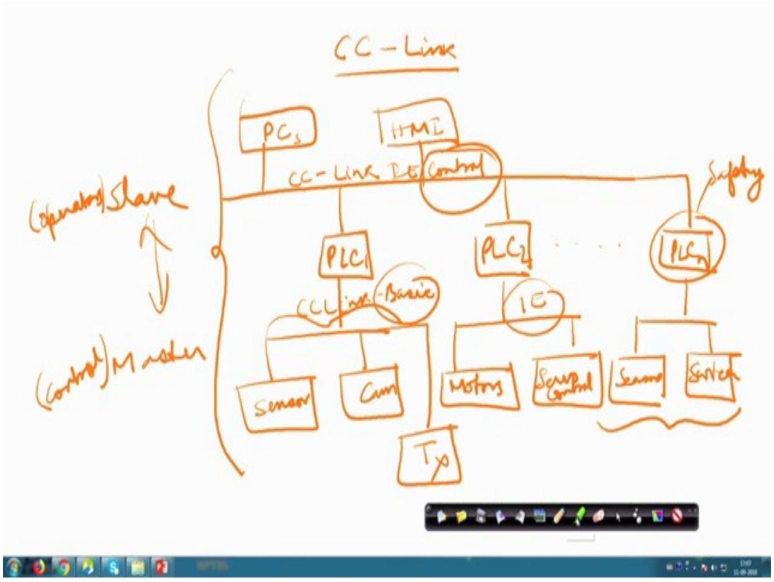


We have the controller devices, the master devices, these slave devices will be operated by different operators and these master devices by the controllers.

So, we have different bus, we have these PLCs PLC 1, PLC 2. PLC n, we could have different PCs industrial PCs we could have HMI devices, HMI and so on. So, we have different PLC supporting different things for example, this one could be for catering to safety requirements, these ones could be for different other things.

So, this protocol would be CC link protocol over here over this particular bus, CC link and CC link IE control. Then, we could similarly have this particular PLC connect to different sensors, for example, sensor 1, sensor 2. Different cameras likewise cameras, camera 1, camera 2, different other may be transmission devices and this part we could use CC link basic.

For this part, we could even use motors connection with motors, motor drivers then different other for example, different types of motors maybe servo control servo control and so on. Here we could have the CC link IE version being used. And, we could even extend it further and we could have PLC n catering to different other kinds of sensors or different switch gears; so different things we could extend.

So, what I wanted to show you over here is different types of this protocol the IE control basic, then this one over here like this would be used in the different buses, connecting the master and the slave like this master in the slave, in this particular manner. So, let us now proceed further and to look at the DeviceNet.

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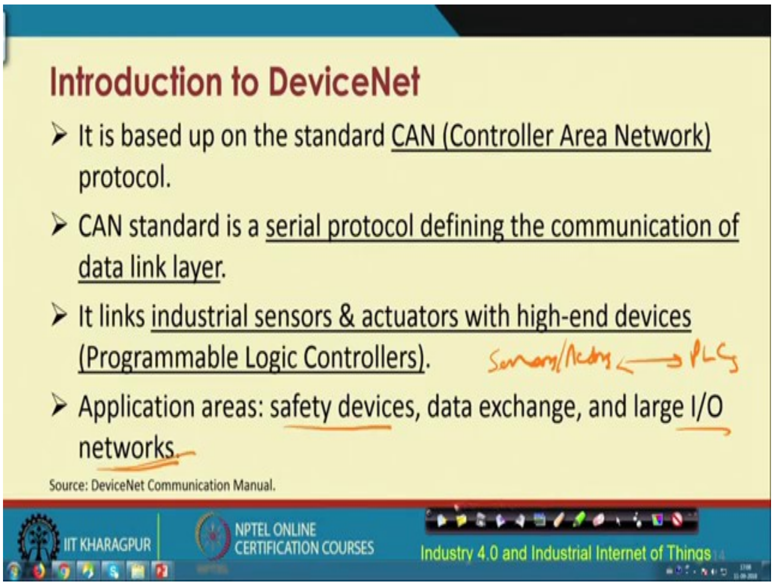


So, Device Net is based on the standard controller area network protocols, CAN protocol. So, it is based on the CAN protocol. And, this CAN protocol provides a standard for serial communication in the data link layer and it links different sensors, actuators, with PLCs and so on. So, device net can help you in this communication between the sensors, or the actuators, and PLCs. This particular protocol could be used and this particular protocol is based on the CAN protocol. So, safety devices, input output networks, could all take help of the devices and DeviceNet protocol.

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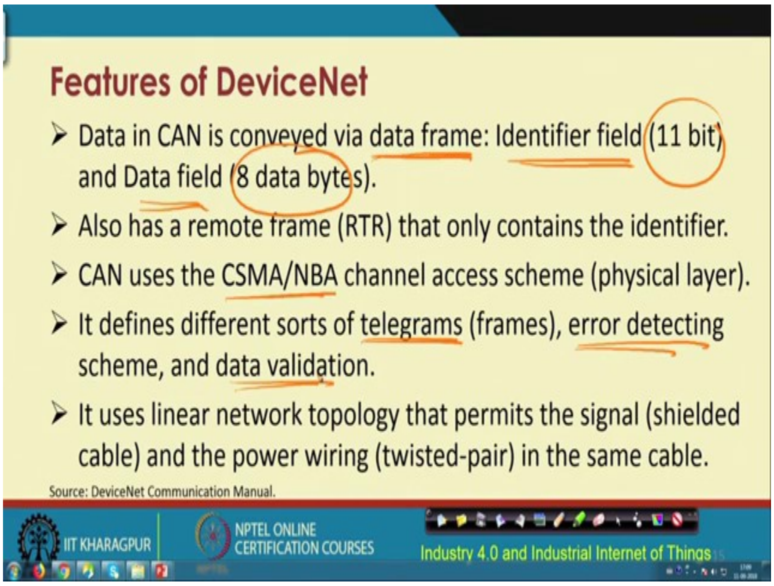


So, there are different features of DeviceNet. The data in Controller Area Network is conveyed with the help of data frame. So, this is nothing new so, in the form of frames. These frames have this id field which is of 11 bits and the data field which is of 8 bytes.

So, this basically uses the CSMA, NBA channel access scheme, in the physical layer and defines different sorts of telegrams, which is basically some something like the frames. Error detecting mechanisms and data validation for supporting different parts of the network topology.

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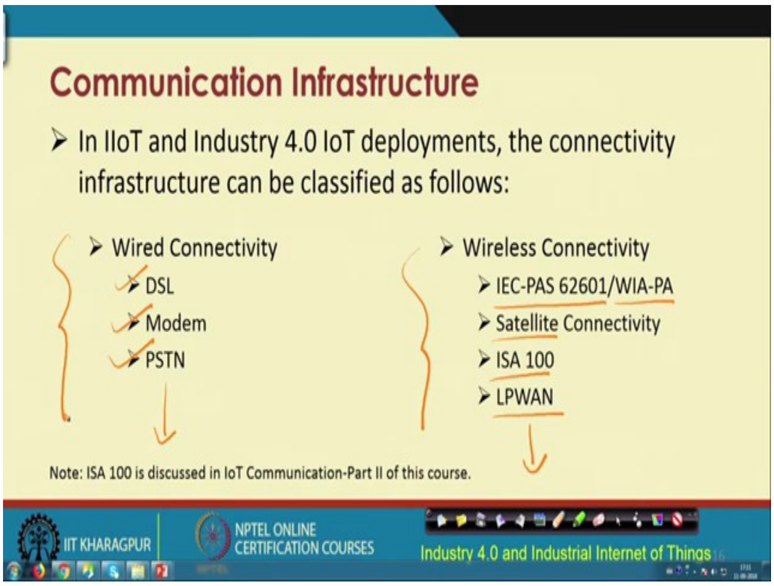

Now, these are some of these popular industrial communication protocols that are used.

There are many other protocols that are also there. We have also discussed if you recall about the ISA 100 protocol, that we did at the time of covering the generic IoT communication protocols. So, at that time the ISA 100 series of protocols was discussed. So, that is basically well is that is for providing wireless connectivity and, that is what we discussed for use with general industrial wireless connectivity, particularly, low power connectivity, support for low power devices, and that can be done with the help of this is a 100, it supports industrial applications that is the interesting part of it.

In terms of wired connectivity; these different technologies are there traditionally. One is this DSL, MODEM Technology and the PSTN for telephone networks. In terms of wellness this IEC pairs 62601 WIA-PA, Satellite, ISA 100, which I just mentioned and LPWAN. These are the different wireless connectivity protocols and these are the different technologies for wired connectivity.

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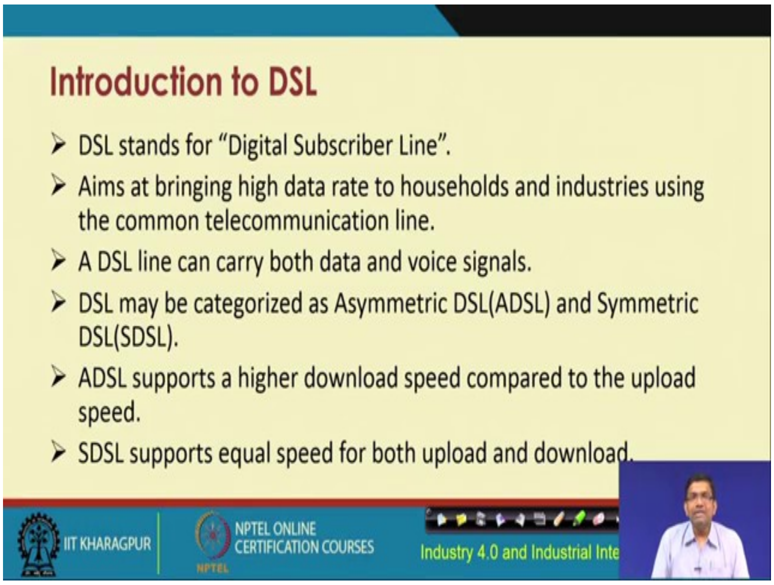


We will look at each of these very briefly. DSL I think many of you are already familiar with DSL, although we tend not to use DSL much anymore. DSL stands for Digital Subscriber Line. And, this particular technology became very popular in order to convert the conventional telephone, analog telephone communication lines. In order to send data over those analog telephone communication lines, this particular technology, the DSL technology was started.

So, this DSL technology can support both communication of voice like, the telephone signals, telephone voice signals as well as the data both can be supported. And, it has two parts the ADSL and the DSL, sorry, SDSL; it can be operated in 2 modes ADSL or SDSL depending on the particular device, that is there. So, typically it will support both.

So, ADSL is more commonly used in the households. Basically, ADSL modems were quite popular. Nowadays, actually people have also, they are not using ADSL based modems anymore, but still it is good to know what are these because some of these industries might still be using these legacy modems. ADSL why it is called asymmetric because, it supports a higher date download speed compared to the upload speed.

So, there is an asymmetry between the download speed, and the upload speed, which is equal in the case of SDSL, equal upload and downloads speeds.

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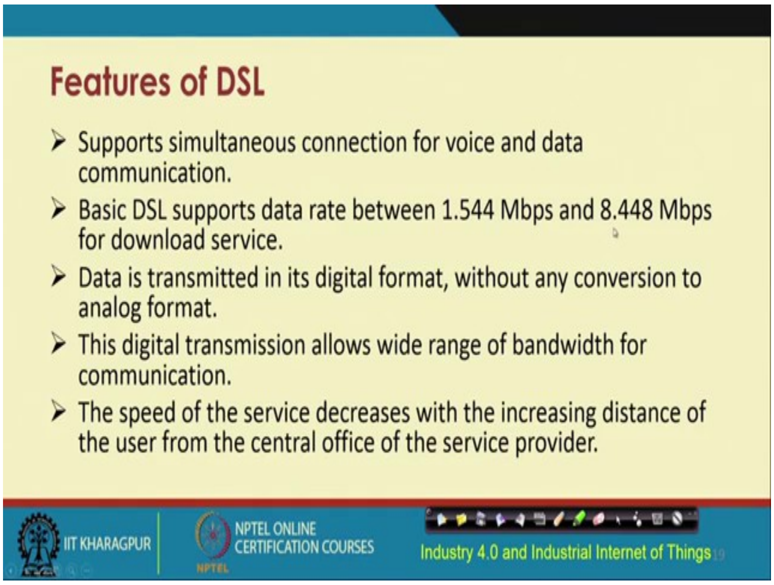


So, the basic DSL supports data rate of 1.544 Mbps and 8.448 Mbps for download surface. Data is transmitted in digital format, without any conversion to the analog format. And, this digital transmission allows wide range of bandwidth for communication.

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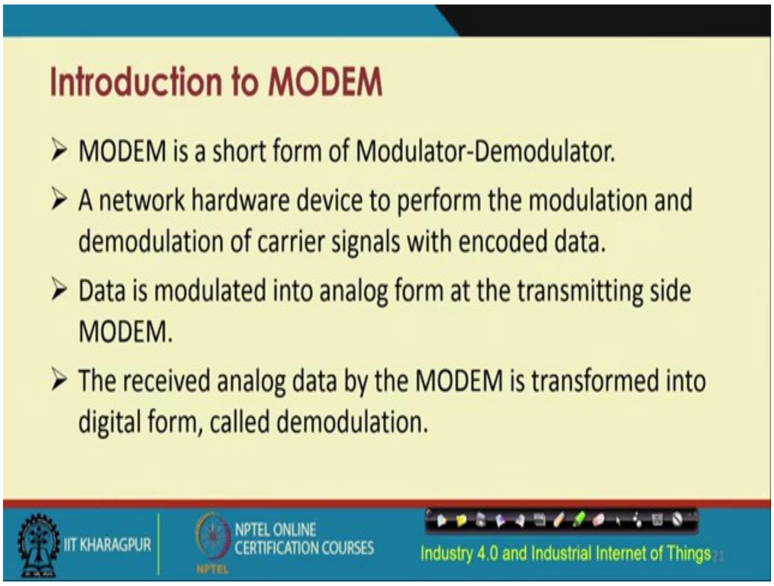


MODEMs are quite popular, MODEM technology, MODEM stands for Modulator-Demodulator, which is basically a device that will do modulation and demodulation of carrier signals, with the encoded data. And, this data is modulated into analog form at it is transmitting site and the received analog data, by the MODEM is transformed into the digital form at the demodulator side.

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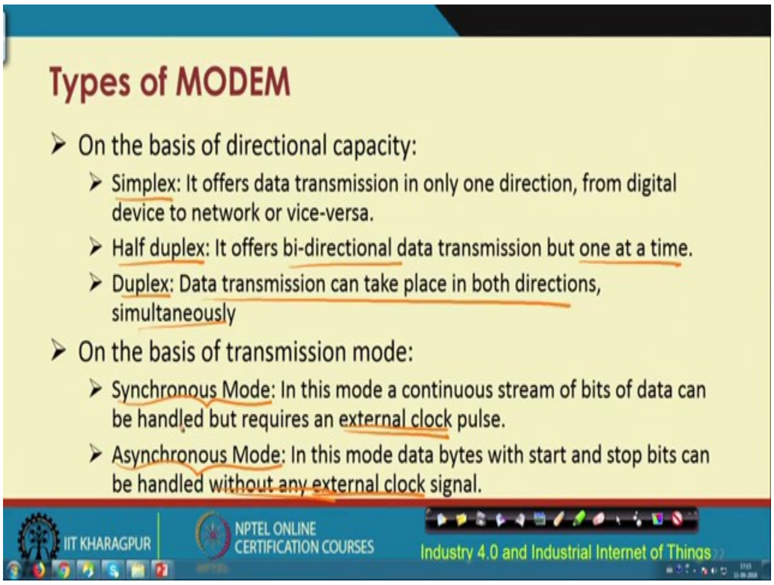


So, there are different types of MODEMs that are supported; simplex modem, half duplex, and duplex. Simplex offers data transmission in one direction, half-duplex bidirectional, but one at a time and duplex bi-directional and at the same time; that means, simultaneously. On the basis of the transmission mode, these modems can be classified as synchronous or asynchronous.

Synchronous meaning that in this particular mode a continuous stream of bits of data can be handled, but requires an external clock pulse. And, asynchronous basically has start and stop bits that can be handled, without any external clock signal. So, here you want to use the external clock, here there is no external clock, without any external clock. So, asynchronous is without external clock and synchronous is with the help of the synchronization is done, with the help of the external clock.

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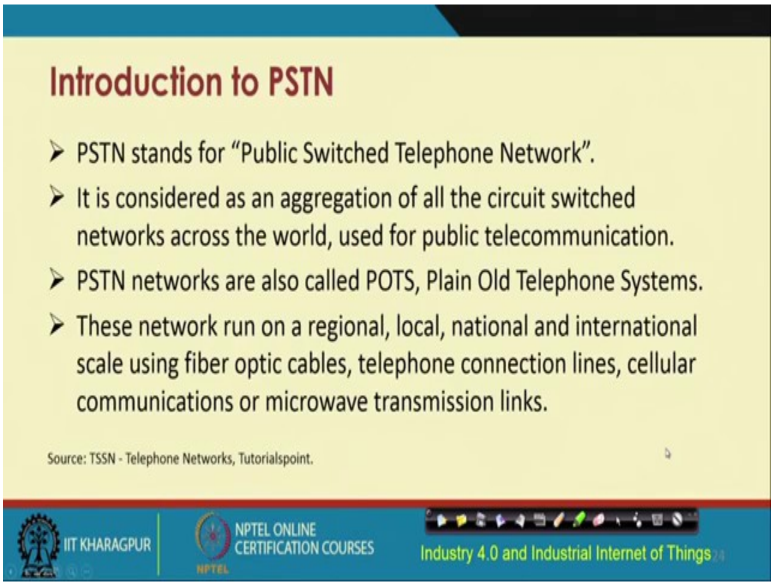


Next, comes the PSTN technology and PSTN basically stands for Public Switched Telephone Network, which is like our old telephone systems. So, this basically technology operates, with the help of something known as the circuit switched networking, which is how the telling the public telecommunication systems work. These networks run on the regional, local, national, and international scales, using fiber optic cables, telephone connection lines, cellular communication, microwave transmission links.

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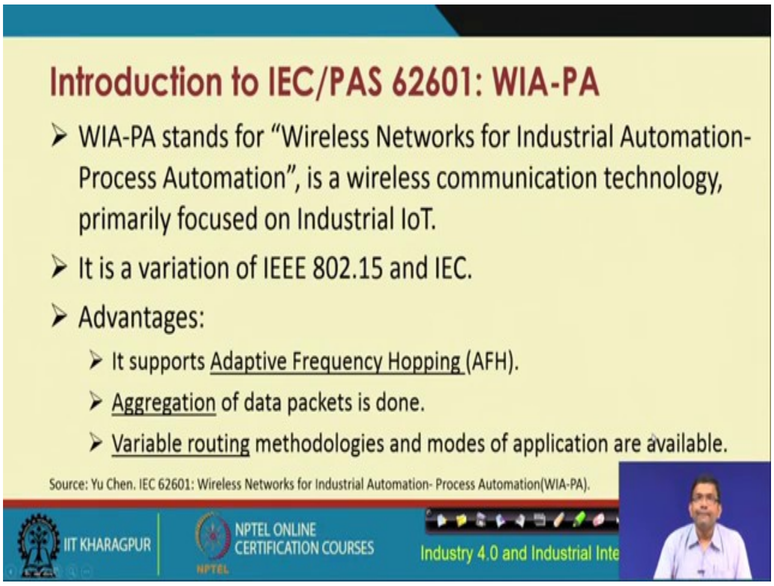


Then, the next one is IEC PAS 62601: WIA PA. So, WIA-PA stands for Wireless Applications for Industry Automation and Process Automation. Industrial automation, process automation, this is a standard wireless communication technology focused on industrial IoT, it is kind of a variant of 802.15 and an IEC standard.

The advantages of this particular protocol is that it supports, adaptive frequency hopping, which makes it more secured, aggregation of data packets, and variable routing methodologies variable routing protocols, are supported by this particular protocol.

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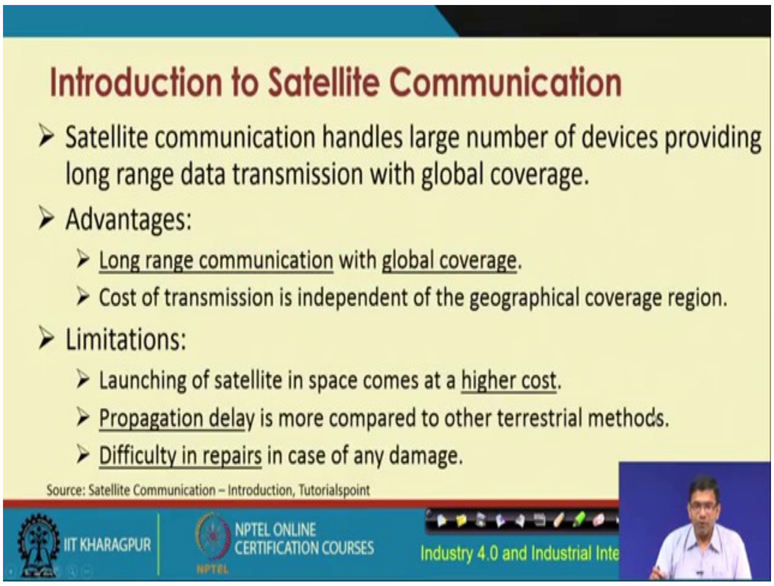

Satellite Communication is a well-known technology, for offering global, long range, communication between different points, but these satellite communication devices come at higher cost. There is higher cost although, it is much more effective in providing global coverage in terms of communication, but the cost of these devices is much higher.

Other difficulties are that there is huge propagation delay compared to the other types of protocols and the communication technologies that are in place in on the terrestrial surface. The last one is that in terms of repairing; that means that if there is some kind of defect that has happened in the satellite communication technology. So, correcting it is much more difficult, because here we are trying to connect the base stations on the earth to the satellite stations.

This kind of error correction and diagnosis is much more difficult over here.

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So, these are some of these references for these protocols that we have discussed in this particular lecture. So, I would encourage you to go through these different references and you could search for even more and try to understand these technologies even further with this we come to an end.

We have talked about different protocols that could be used for industrial communication, we have also talked about the use of different wired as well as wireless communication technologies and protocols, for industrial internet connectivity. And, we have seen that there is much more we could expand even further these are not the only protocols, that could be used; we could even use different other protocols that are out there.

So, large number of protocols are over there. So, we could use them to offer connectivity between these different devices. And, typically it is a client server architecture, master slave kind of architecture, different parts of this overall network supporting, different protocols is what is common across most of these different protocols that we have gone through so, far. But, what is important is irrespective of the architecture, you need to design protocols, you need to use the protocols, which will cater to the industrial requirements of low rate latency, low jitter, and high reliability. These are all very important in terms of industrial catering to the industrial requirements. With this we come to an end of this lecture.

Thank you.

**Introduction to Industry 4.0 and Industrial Internet of Things**
**Prof. Sudip Misra**
**Department of Computer Science and Engineering**
**Indian Institute of Technology, Kharagpur**

**Lecture – 30**
**Key Enables of Industrial IoT: Connectivity – Part 3**

In the previous 2 lectures on Connectivity, we were primarily focusing on legacy protocols, which have been around for offering industrial communication of high quality, high grade, having specific, industry specific requirements of reliability, low latency, low jitter, and so on, but there are many different protocols that could be used in the industrial contexts. Many different protocols have evolved over the years many different protocols have evolved over the years particularly with the advent of wireless communication, low power wireless communication, IoT based communication and so on.

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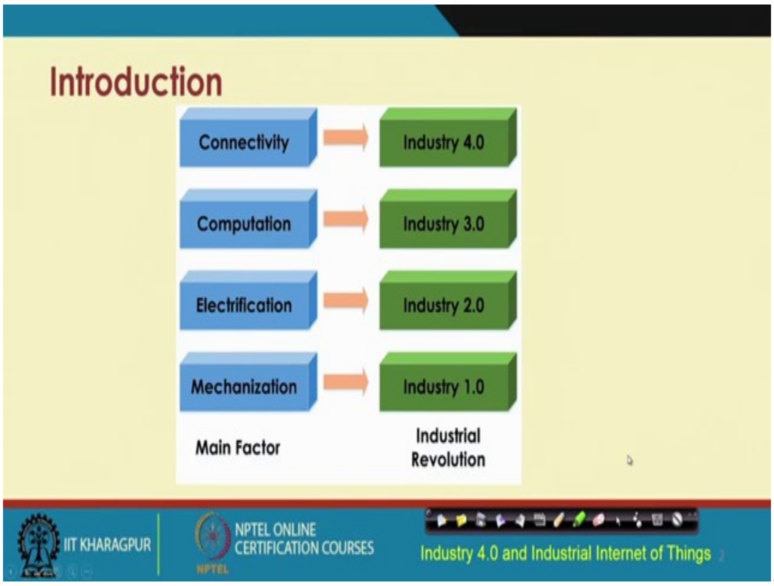


So, if we look at present we are talking about Industry 4.0. So, industrial revolution has happened through different generations of 1, 2, 3 and at present we are talking about 4.0 where the focus is on connectivity.

Now, in this particular context there are different IoT technologies that have come up which can help cater to the requirements of supporting Industry 4.0, protocols such as the ones that we have discussed in the introductory section on IoT at the outset of this particular course we talked about different IoT protocols. Protocols such as AMQP, MQTT, and many others that we have gone through so far could all be used in addition to these legacy industrial communication protocols, that we have discussed in the previous lectures.

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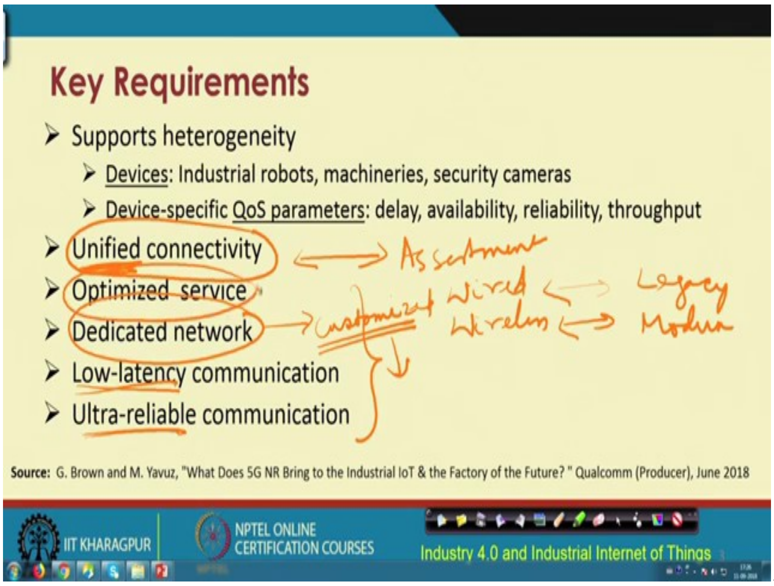


In addition we could use different other advanced protocols particularly protocols belonging to different wireless communication technologies could be used in order to provide connectivity between different devices such as the industrial machines, different types of industrial machines, robotics, robotic machines, robotic devices between the security, cameras in the industry, and so on, and supporting different quality of service parameters of the networks, that are being built in terms of delay, availability, reliability, throughput and so on.

Overall what is desirable is to have unified connectivity even if you are using an assortment of different protocols which may be wired or, wireless or which could be the legacy ones or, the modern ones, what is important is to be able to offer unified connectivity, unified connectivity.

Unified connectivity means what, that seamless connectivity users would not know how which protocol depending on the specific requirements, scenarios, instances, circumstances and so on, which protocols are being used and they are getting shuffled, reshuffled and at the back end. Users basically get the services and behind the scene there is an unified connectivity architecture, that basically helps in sending data from one point to another catering to the specific industrial requirements that are there.

So, these legacy protocols have been there modbus TCP, RTU, these fieldbus, profibus, inter bus and so on. So, all these protocols have been there plus you have new protocols such as MQTT, AMQP and many others which have become popular in the IOT era. Plus there are few others that we are going to discuss now, which are like 5G tactile internet etcetera which have become very popular, in the recent times. They could also be used they could be integrated together to offer an unified kind of platform supporting different protocols they could be used and unified connectivity can be offered.

What is next important is the optimized service, optimized service, dedicated network communication, low - latency communication, ultra - reliable communication, these are the different other industry specific requirements that will all have to be care to. So, this low latency communication is understood, ultra reliable communication is also understood.

What is this dedicated network? customised requirements, basically customized requirements will have to be fulfilled, in addition, to the because different industry, the particularly different industrial sectors have specific in, customized requirements. Those dedicated network solutions will have to be used in order to fulfil to the customized requirements plus optimized, together with fulfilling these customers requirements optimized service offerings will have to be made.

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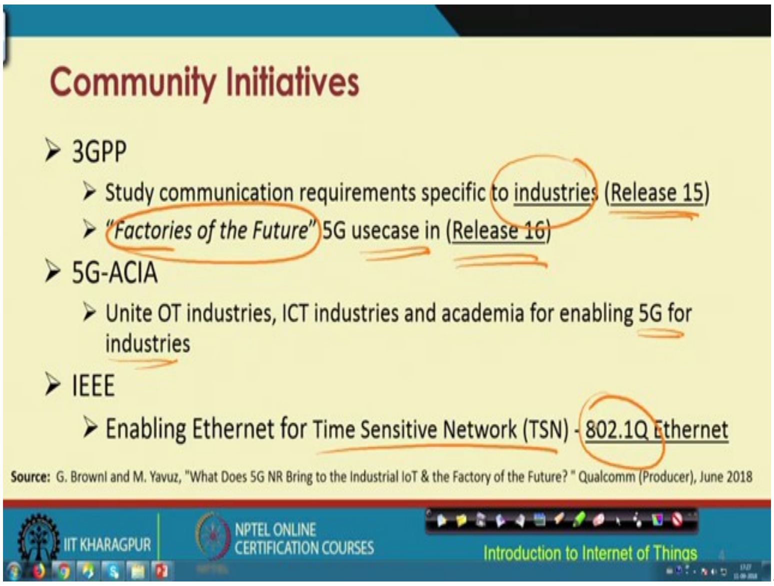


So, we will look at different protocols there have been different community initiatives for example, the 3GPP which has different religious catering to industrial requirements is this release 15, release 15 basically caters to the industry specific requirements.

Release 16 basically talks about the factories of the future so smart factories and so on. So, different use cases supporting the factory smart factory requirements and then you have the 5G – ACIA, which basically unites the OT industry OT means operational technology industries with the ICT industries information and communication technology industries and academia for enabling 5G for industries. So, basically this is talking about 5G for industries 5G- ACIA and IEEE, has different protocols like the TSN supporting the 802.1Q Ethernet protocol.

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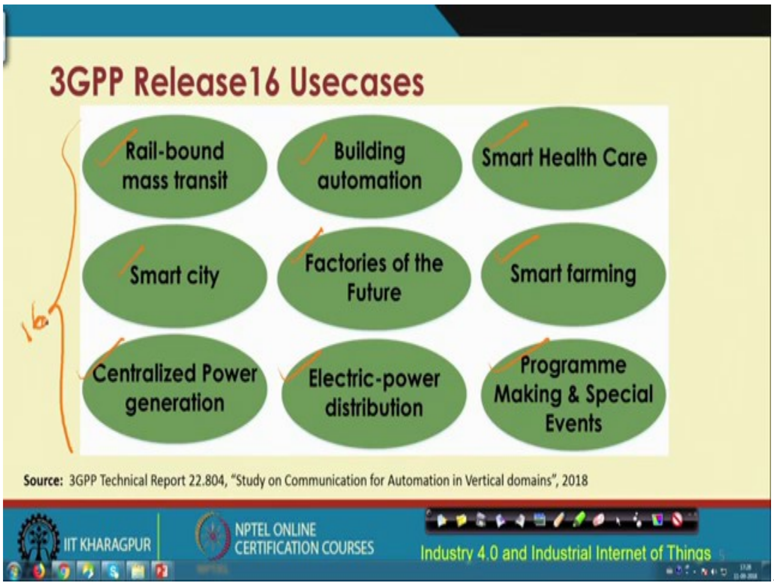


So, 3GPP released 16 has these different use cases has support for different use cases, these are the ones that are basically listed in the 3GPP document. So, first one is the support for support for real bound mass transit, real bound mass transit, building automation, smart healthcare, smart city, factories of the future, smart farming, centralized power generation, electric power distribution, program making, and special events, these are the different use cases, that are supported by the 3GPP released 16.

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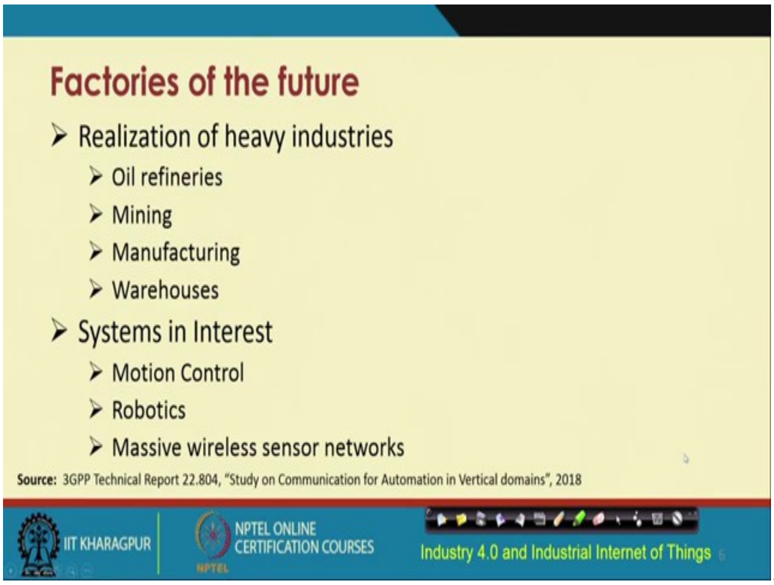

Factories of the future, here basically we are talking about catering to the heavy industries primarily such as oil refineries, mining industry, manufacturing industry, warehouses, and so on and the interests of the different systems for example, motion control this is very important, robotic machinery, sensor networks, massive wireless sensor network deployment. So, all of these are requirements specific to the smart factories of the factories of the future.

So, 5G technology could be used to build different private networks within these different industries. So, there is this 5G in our 5G new radio which has different band specifications this high band, which is basically more than this 24 Giga hertz band is this millimetre, supports millimetre wave communication, supports millimetre wave communication. Then we have this for small scale private network communication, small cell deployments are also there in the form of femtocells, picocells, integrated Wi-Fi. This device to device communication, basically, you are talking about one device supporting one type of cellular communication with another device supporting another cellular communication not another, but the same cellular communication basically device to device direct communication without involving some kind of a centralized controller is going to be performed and that is sometimes required. And this will be very much useful particularly in the industrial context, because the one machinery might want to talk directly to another machinery and you do not want to send the packets from this machinery to the central controller and then from the controller to the other machine. So, device to device communication will cut down on the overall latency of communication in the system.

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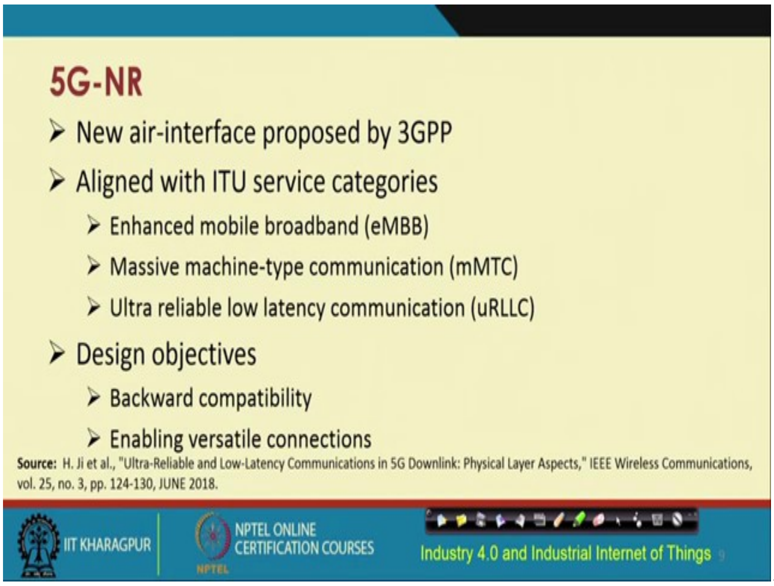


So, let us talk about this 5G- NR. So, now it provides it is a 3GPP protocol, which provides new air interface and is aligned with different ITU service categories such as the enhanced mobile broadband, eMBB, massive machine type communication, mMTC and ultra-reliable low latency communication, uRLLCC.

So, the design objectives are to offer backward compatibility; that means, connecting different devices with the help of these technologies plus the technologies that we are supported in the past backward compatibility will be supported by these different technologies and also enabling versatile connections, connections across different heterogeneous devices, produced by different vendors, supporting different standards, and small device large device devices, has supporting different speed may be PC to PLC, PLC to something different a high motion device with a small, low motion device. All these different types of heterogeneous communication could be supported with the help of this NR.

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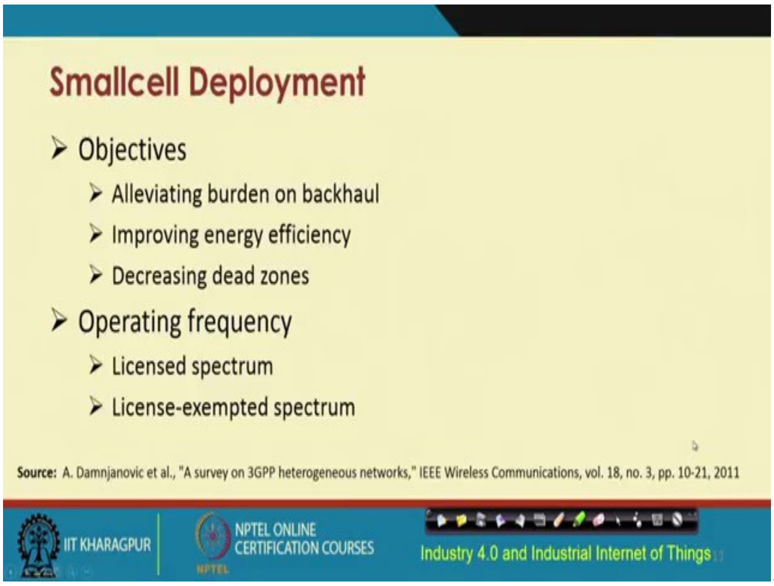


Small scale deployment here we are talking about addressing different objectives such as alleviating burden on the backhaul, improving energy efficiency and decreasing the dead zones. Dead zones are basically the ones where the network, the signals basically do not reach so, if there is if there are some dead zones, where the signals do not reach, the small cell deployment will help in this kind of offering connectivity in those dead zones, where the signals are not able to reach.

So, operating frequency these small cells support both licensed spectrum as well as licensed exempted spectrum. So, it can be supported by both of these types of spectrum.

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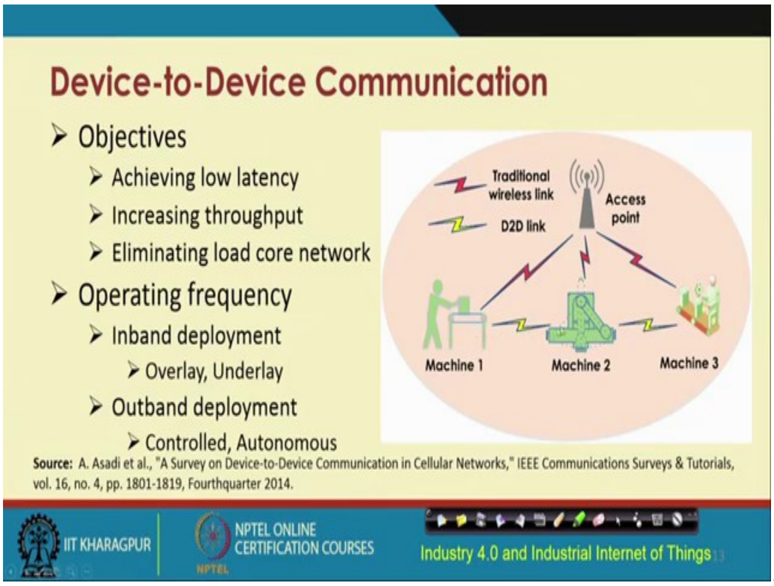


Device to device communication here we are talking about this kind of thing. So, machine 1, machine 2 they can talk to each other D2D link, again machine-to-machine 3 another D2D link device-to-device communication that basically cuts down on the time or the latency of communication and so on. So, these are the D2D links this is one, this is another and we are talking about it in contrast to the traditional links.

Traditionally what would happen is, the machine one would send the data 2 or the packets to the access point and from the access point it is going to come to the machine 2. Instead of doing around about kind of way this direct machine-to-machine communication takes place. So, the overall objective is to reduce the latency increase throughput and eliminate load onto the backbone network, the core network.

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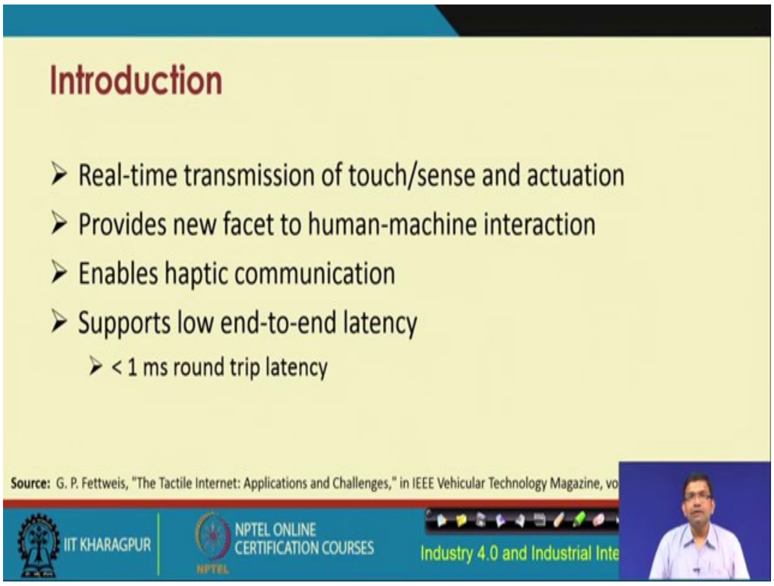


This is very important now a technology, which has become very popular is the tactile internet, which basically supports data transmission in the context of touch, offering real time transmission of touch sense devices and actuating them. So, provides a new facet to human machine interaction, particularly in the context of HCI, BCI, this a tactile internet has become very popular, haptic communication it provides haptic communication enable meant supports low end-to-end latency of less than 1 millisecond RTT.

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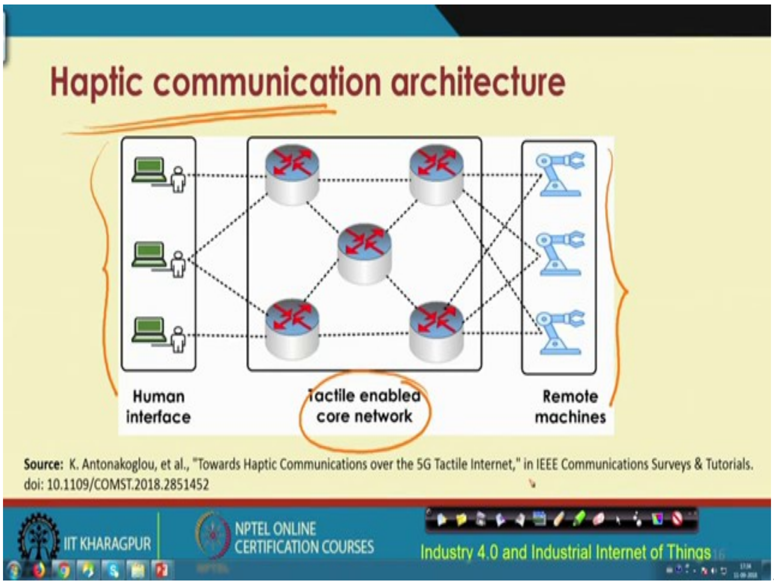

Haptic communication architecture is given over here. So, we have this human interface we have this human interface, this is this human interface we have these remote machines and in between we have this tactile enabled core network and this overall haptic communication architecture is shown over here.

So, for more details you are encouraged to look at this particular paper, which is talking about towards haptic communication over the 5G tactile internet. So, haptic communication over pair 5G tactile internet is talked about in this particular paper. So, I would encourage you to go through this particular paper to learn more details about how this these mechanisms work.

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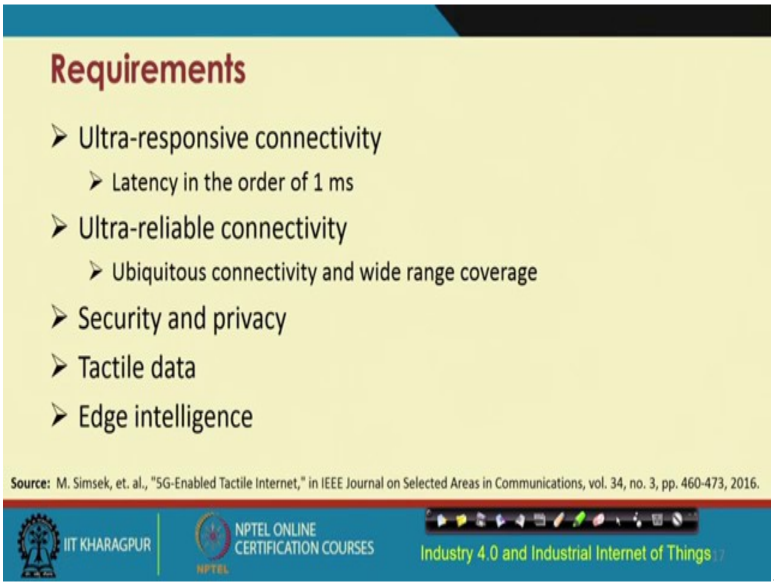


So, in terms of fulfilling requirements, requirements of ultra responsive connectivity, latency in the order of 1 millisecond, ultra reliable communication, ubiquitous connectivity, wide range of coverage, security privacy, tactile data exchange, edge intelligence; that means, close to the source of the data some of these processing is going to be done instead of sending everything to the back end to the servers and so on, for further processing.

Edge intelligence, intelligence close to the edge; that means, the source of generation of the data are going to be performed with tactile internet.

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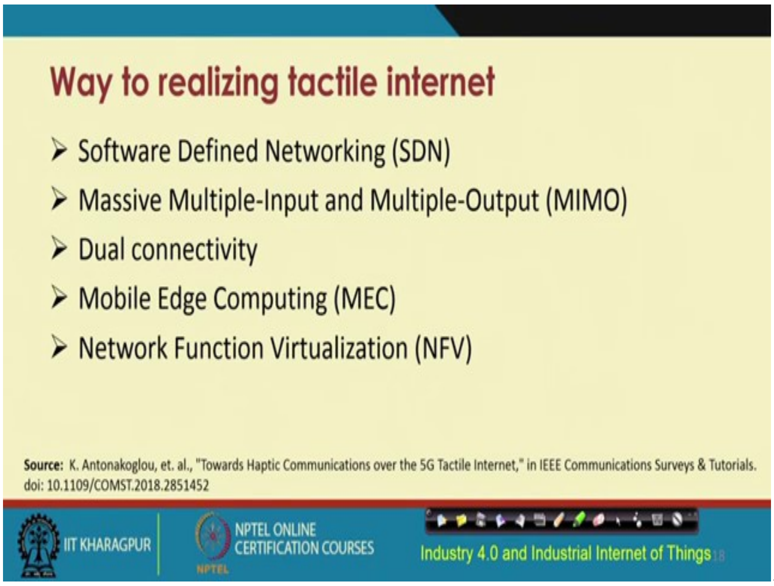


There are different ways to realize the tactile internet SDN is heavily used SDN technology, MIMO, MEC mobile aids computing, and network function virtualization.

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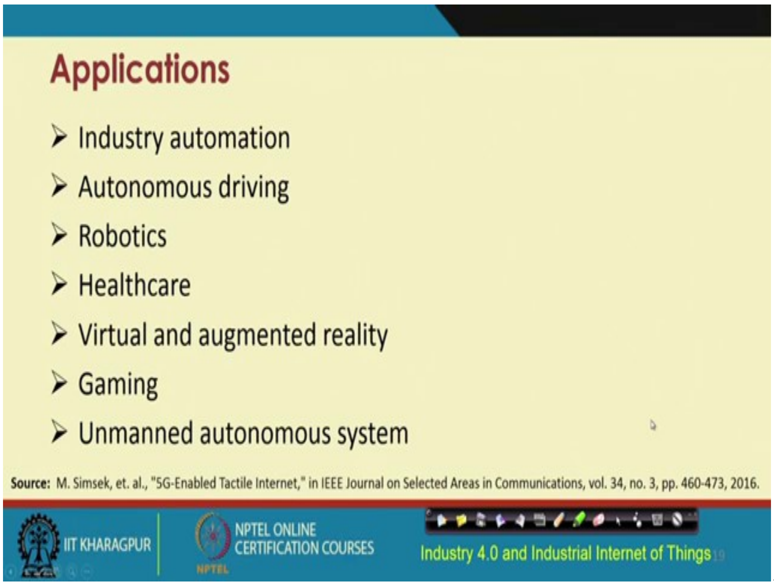


Applications for use industrial automation, autonomous driving, robotics, healthcare, virtual augmented reality, virtual reality augmented reality gaming, UAVs and so on.

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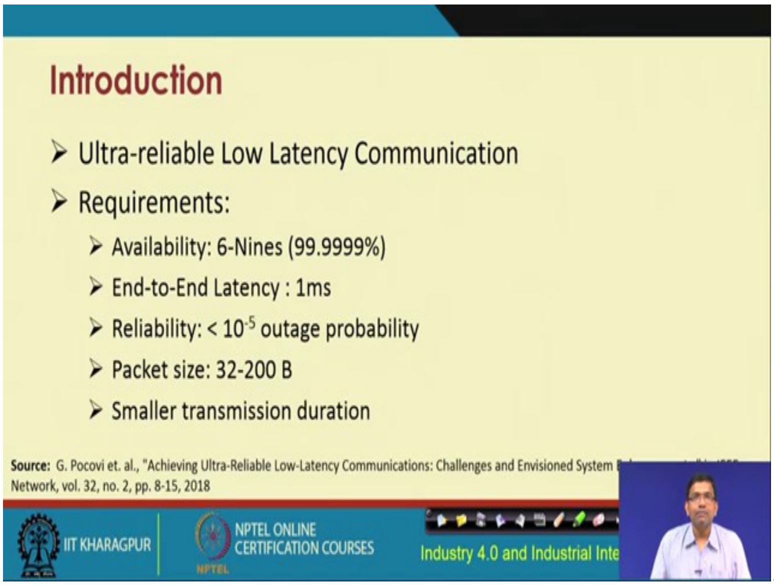


Next comes this particular protocol URLLC which is Ultra-reliable Low Latency Communication. So, as you can understand that this is quite attractive for industrial scenarios. So, here the requirements are to have availability in the order of 99.9999 percent availability. The network is made available in 6 nines 99.9999 percent of the time it is available. So, high levels of availability then into entrance e of in the order of 1 millisecond reliability in less than 10 to the power minus 5 outage, probability packet size of thirty to 200 bytes, and small smaller transmission duration.

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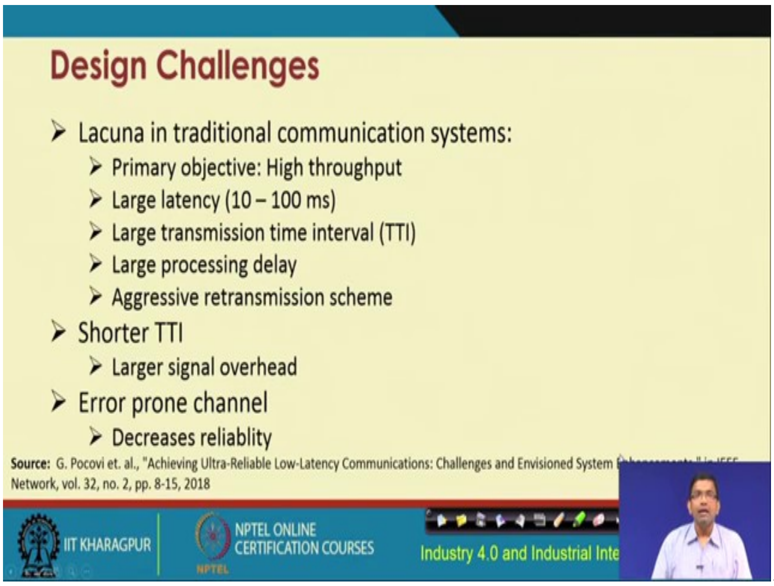

Design challenges, there are different challenges with the traditional communication systems with respect to throughput latency RTT, TTL, sorry TTL and TTL, TTI. So, TTI is basically transmission time interval, TTI then the processing delay processing delay TTI latency these are all quite high, the including the throughput is also quite high, with the traditional communication systems.

Here we need shorter TTI systems, which will provide faster communication, prompt communication, low latency communication with larger signal overhead. So, basically the signal over it is going to increase. Additionally, we have built with the challenges of errors dealing with errors we are talking about error prone challenges, which decreases the reliability.

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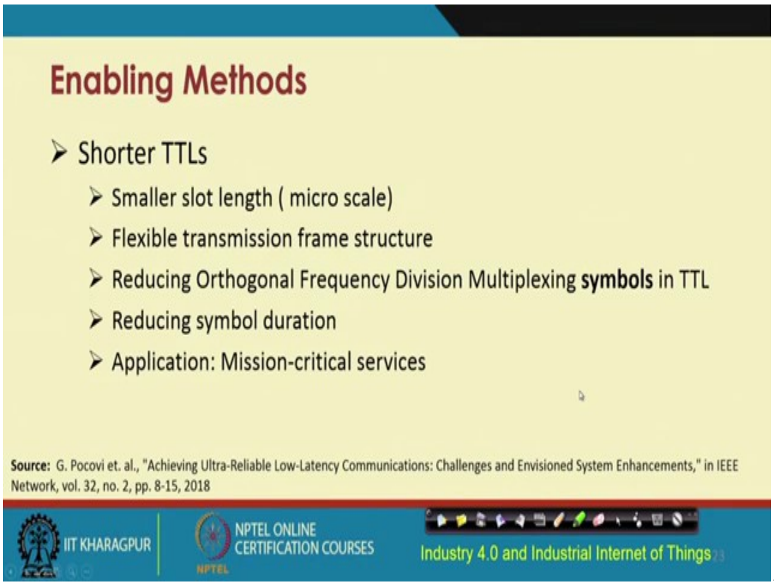


The different methods are there so, shorter TTI's or shorter TTL, whatever weight is the same thing. We are talking about shorter TTL requirements, smaller slot lengths in micro scale, flexible transmission frame structure, then reducing the orthogonal frequency division multiplexing symbols, reducing symbol duration and so on so all of these weak it attractive for use in mission critical applications.

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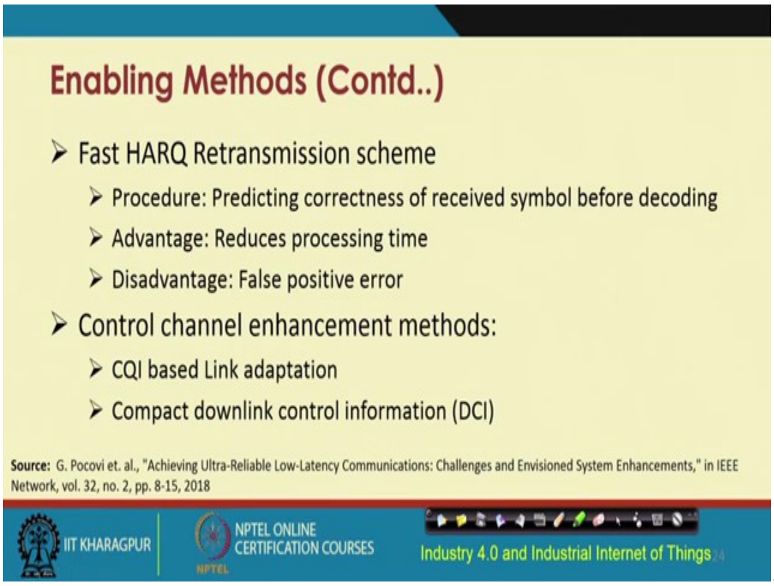


First HARQ retransmission scheme, HARQ stands for hybrid ARQ, ARQ is automatic retransmission request and basically this first HARQ is basically takes care of the retransmission through the procedure of predicting the correctness of the received symbol, before actually decode decoding it. The advantage is that it reduces the processing time and the disadvantage is that it has it leads to false positive errors.

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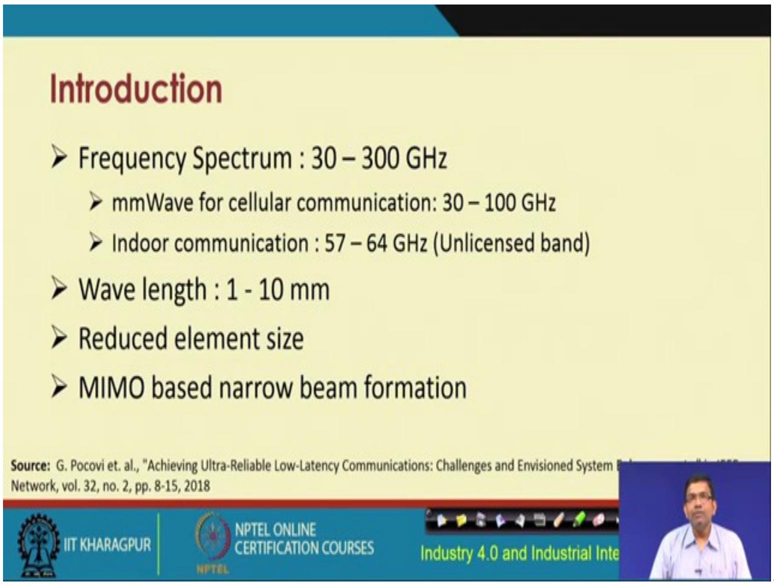


Then comes the millimetre wave communication, where the communication happens in this particular band of the spectrum 30 to 300 Giga hertz band and this basically millimetre wave communication offer cellular connectivity in this particular band, and particularly for indoor communication, where there are dead zones and so on this is also particularly attractive.

The wavelength is typically 1 to 10 millimetre in this millimetre wave communication, and there is a reduced element size, and MIMO-based narrow beam formation in this particular millimetre wave communication.

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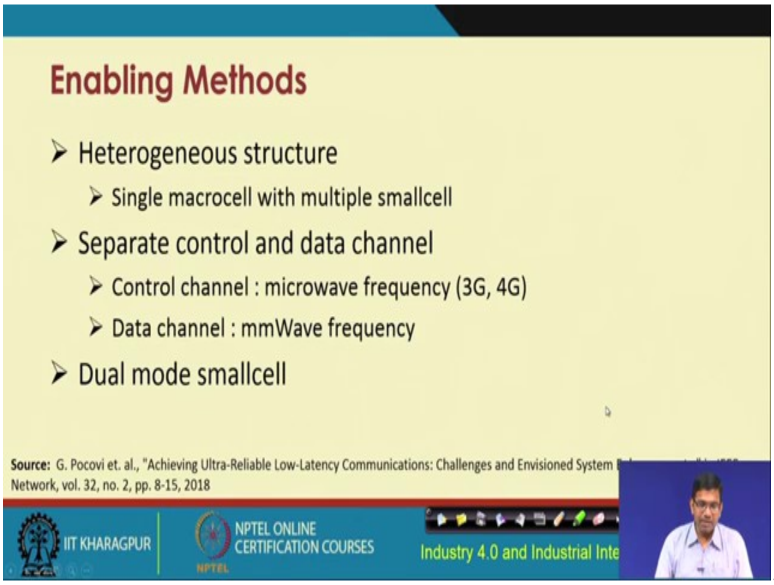


So, for details of these things I would encourage you to go through this particular paper which is the achieving ultra reliable low latency communication paper which has been published in the IEEE network magazine in 2018. So, here basically you would be able to get a lot more different types of ideas in with respect to these methods.

Enabling methods include heterogeneous structure where a single macro cell with multiple small cells would be used or separate control and data channels could be used. So, separate control channel control channel, for microwave frequency data channel, for the millimetre wave frequency, and dual mode small cell via some of these different enabling methods that could be used.

So, I am talking about these in a very high level quite fast I am mentioning these, but if you really have to go through and understand these in detail a lot more time will be required. In case you are very much interested to know about millimetre wave or any of these technologies, in much more detail, I would encourage you to go through the corresponding material, the paper, the source, that is given at the bottom of the slide.

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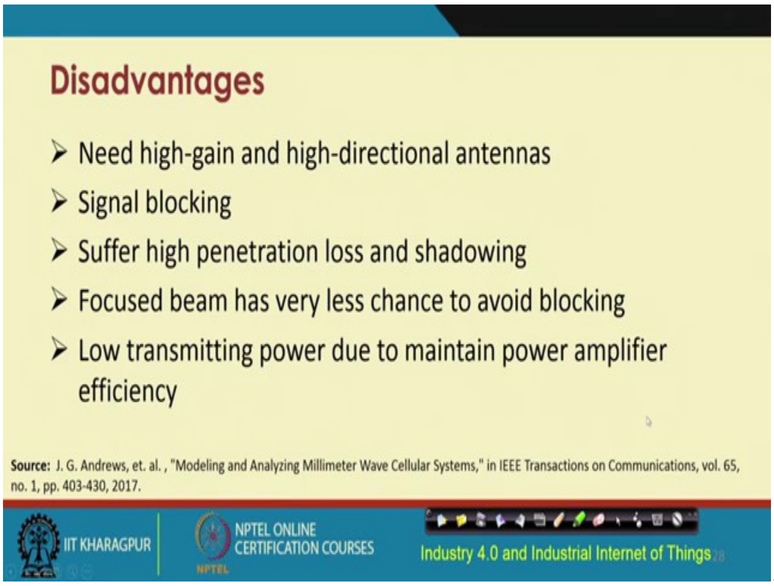


So, disadvantages of millimetre wave communication is that there is a need for high gain, and high directional antennas, and there are different other disadvantages such as have this technology suffers from high penetration loss, and shadowing, and there are many different disadvantages.

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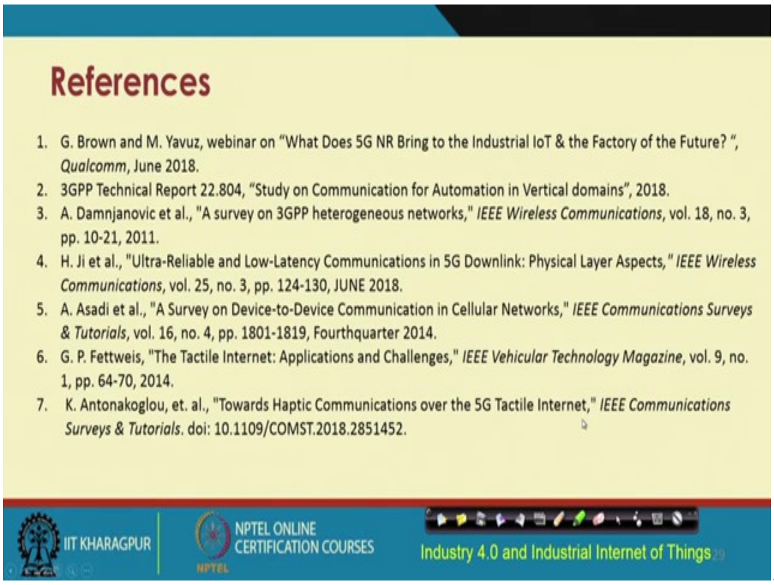

With this we come to an end of this particular lecture and we have looked at some of these different modern technologies that could be used in the context of industrial communication particularly with the help of 5G and tactile internet and so on. So, these different newer communication technologies could be used in addition to the IoT communication technology that we have discussed in the first module of this particular course, with this we come to an end.

Thank you.

**Introduction to Industry 4.0 and Industrial Internet of Things**
**Prof. Sudip Misra**
**Department of Computer Science and Engineering**
**Indian Institute of Technology, Kharagpur**

**Lecture – 31**
**Key Enablers of Industrial IoT: Connectivity – Part 4**

In this lecture, we talked about the 4th episode of Connectivity. In this particular lecture, I am going to focus on two technologies; LoRa and SIGFOX. And then I am going to show you; I am going to first talk about some of these features of LoRa and SIGFOX. And then I am going to show you a real example, a real set up for sending data over LoRa.

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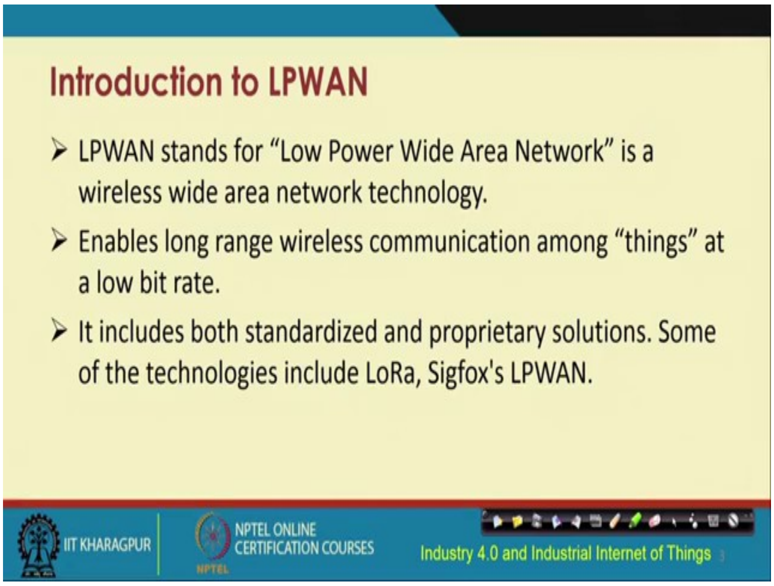


So, low power wide area network sorry double LPWAN; it is a wellness wide area network topology that enables long range wireless communication among different things. Technologies such as ZigBee, which we have briefly understood in the introduction section and also in the next lecture I am going to show you a demo of. So, technologies such as ZigBee do not have too much long range of communication particularly if the sender and the receiver are not too much close to each other.

So, basically they Zigbee is for mid range communication and particularly if they are not the sender and the receiver are not within the line of sight of each other then even this range reduces in Zigbee. So, for long range wireless communication between different things at a low bit rate; that means, low data rate, LPWAN techniques are useful. So, LoRa, SIGFOX these are two different technologies that could be used for long range communication.

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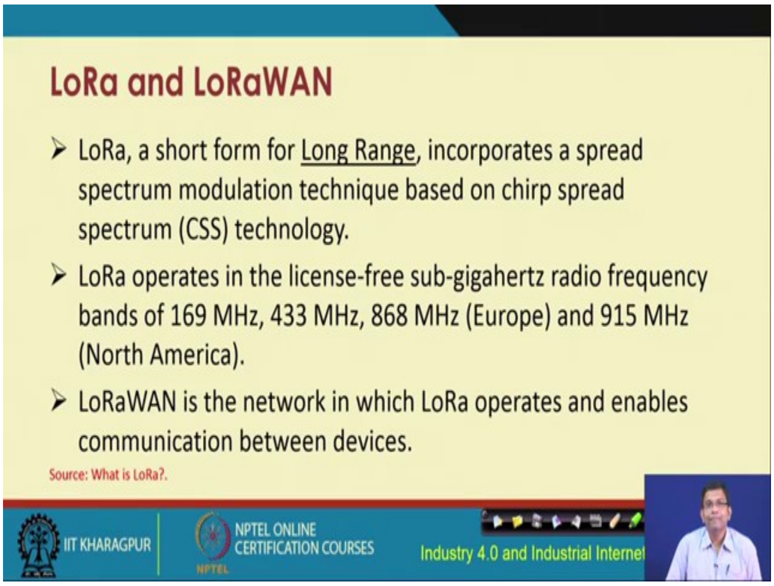


Lora is a short form of long range; long Lo, and range Ra so that is how this LoRa is has been acronymed. So, long range or communication for long range communication, LoRa incorporates a spread spectrum modulation technique, based on something known as the CSS, CSS spread spectrum technique the full form of which is chirp speed sorry Chip Spread Spectrum. C stands for chirp. So, LoRa operates in the license free sub gigahertz radio frequency band.

Sub giga hertz means that it is less than 1 gigahertz. So, all these different bands like 169 megahertz 433 megahertz 868 megahertz and 915 megahertz. These are the different bands of operation of LoRa depending on the territory where it is being used. And LoRa WAN is a network in which LoRa operates and enables communication between different devices.

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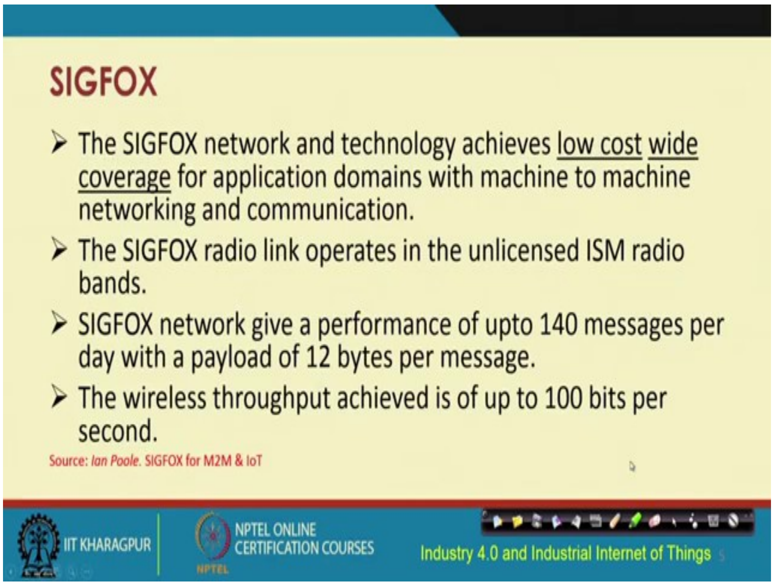


SIGFOX is another technology, which is compared to LoRa low cost, but has wider coverage for application domains with machine to machine networking and communication. SIGFOX radio link operates in the unlicensed ISM radio bands and the SIGFOX network gives a performance of up to 140 messages per day, with a payload of 12 bytes per message. And the throughput is achieved using SIGFOX is up to 100 bps.

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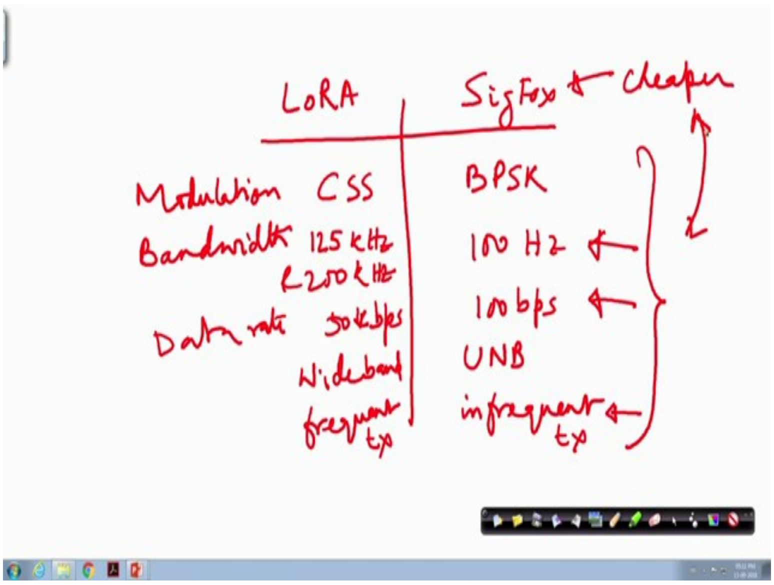


Let us now have a better understanding about how these two technologies for long range communication LoRa and SIGFOX compare with each other. So, basically in terms of modulation technique that is used LoRa as I said uses CSS chirp spread spectrum on the other hand SIGFOX uses BPSK. And in terms of bandwidth, LoRa uses 125 kilohertz and 250 kilohertz.

It offers bandwidth of 125 and 250 kilo hertz. And whereas, SIGFOX basically gives 100 hertz. So, as you can see over here the bandwidth in SIGFOX is much less compared to LoRa. So, basically in low bandwidth scenarios or applications SIGFOX will be more useful, because as I said earlier SIGFOX is overall cheaper compared to LoRa. In terms of the data rate in terms of the data rate for LoRa it is 50 kbps.

Whereas, for SIGFOX it is only 100 bps bits per second; for LoRa, LoRa operates in wide band whereas, SIGFOX in ultra narrow band. The frequency of transmission is frequent in LoRa whereas, in SIGFOX it is infrequent.

So, basically where your requirements are less, where the bandwidth requirement and data rate are less, where infrequent transmissions will suffice your purpose, then it might be better to go with cheaper SIGFOX technology.

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Now, let us talk about how this communication happens. So, I am going to now give you a demo of how communication happens with LoRa.

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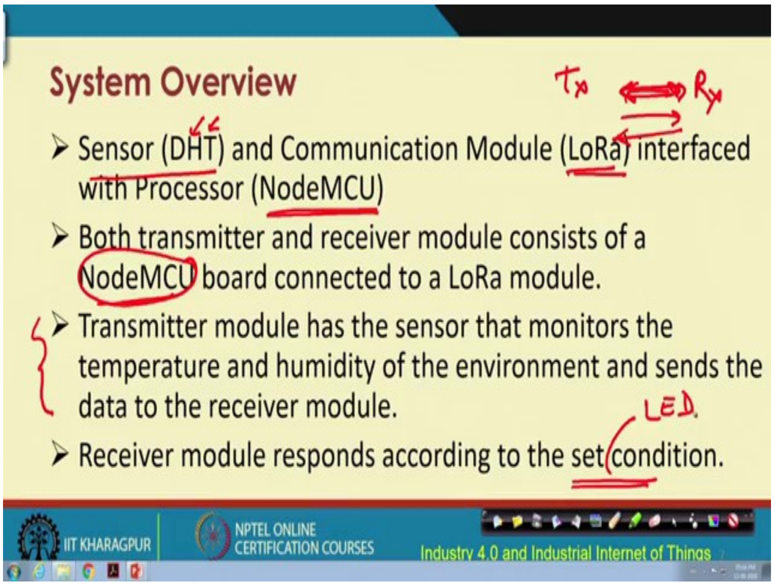


Over here let us look at.

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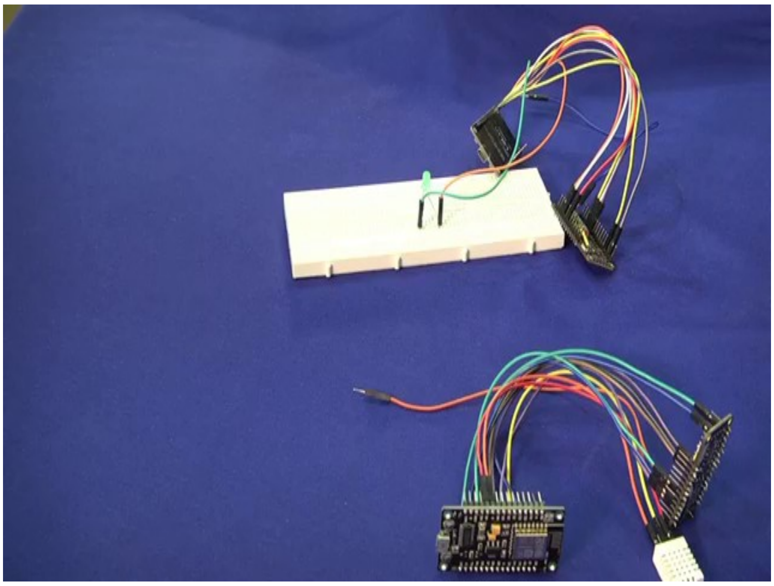

Let us look at this setup here; we have the LoRa module this one is the LoRa module this is this transmitter and there is a sensor the temperature sensor connected to this transmitter. This temperature data from the transmitter are going to be sent to the receiver module, this is this receiver. So, I have this transmitter I will keep it separately and this is my receiver.

The temperature data from this transmitter unit is going to be sent from through this LoRa transmitter to this LoRa receiver, which is this one. And if the temperature crosses a certain threshold, then, basically, this light is going to blink, this is how this setup is done. So, what we have? We have this temperature sensor this one this is the temperature sensor this is this LoRa transmitter module.

And we have something known as the Node MCU which I am going to talk about shortly this is this Node MCU, this is this Node MCU. And then we have this receiver unit with the receiver LoRa this one this is this receiver LoRa, I am pointing through this pen, this is this receiver LoRa. And this is this receiver Node MCU and this is this led, which is going to blink once you send the data, from this transmitter to the receiver.

So, we are going to show this in action and let us try to first get an overview about this system that we talked about. We are talking about a DHT sensor and a communication module, which is basically the LoRa communication model over here interfaced with the processor, which is the NodeMCU. So, we have the DHT digital Digital Humidity and Temperature sensor DHT sensor. We have this LoRa communication module and the Node MCU processor.

So, both the transmitter and the receiver modules consist of this Node MCU as we have seen. And this processor board is required at both the ends the transmitter end as well as the receiver end. So, for this one way of communication, this will be the transmitter this will be the receiver and this could be made the other way as well. So, that is why I have denoted using a double headed arrow like this.

The transmitter module has the sensor that monitors the temperature and humidity of the environment and sends the data to the receiver module and this is what I am going to give you a demo of. So, this receiver module will then respond, according to the set condition. And this I am going to show using the glowing of the led lamp, that I have shown you a while back.

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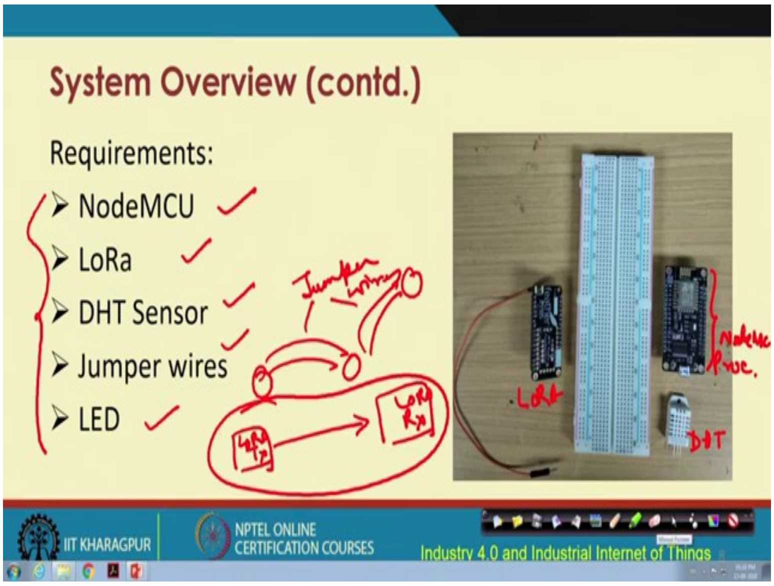


So, let us go further and try to get an understanding first about our setup. I have captured this entire setup in the form of pictures taken, so that it becomes very easier for you to have a glimpse of what how these devices look like and this is these pictures.

And after this basically I am going to show you I am going to switch back and show you the actual setup the demo, that I have for you over here. So, first let us go through these materials to understand, how this setup looks like from a much closer viewpoint. So, what we have over here this is this, I am going to show you this is this LoRa.

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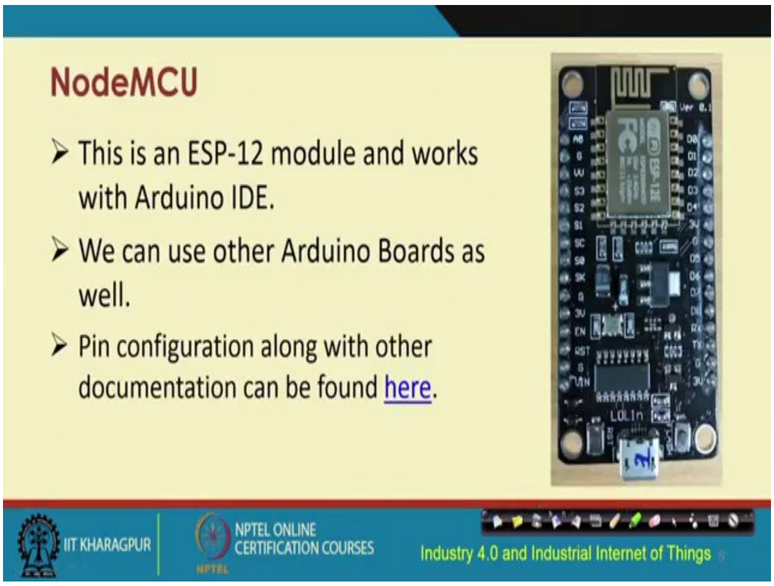

This is this LoRa module and this is your DHT sensor the digital humidity temperature sensor and this is your Node MCU; Node MCU which is nothing, but the processor, this is the processor. So, we need the Node MCU, LoRa, DHT sensor, and some jumper wires those wires, that I was showing you connecting different units like.

So, these were these different wires these are known as the jumper wires and the led. So, these are the components that are required in order to give you a demo of the system that I have just shown you. And here what we are going to show is that we have a LoRa transmitter sending the data to the LoRa receiver.

And so this is what basically is what I am going to show you I am going to show you the corresponding code as well. So, this Node MCU, I think this basically shows you from a very closer this gives you a closer view of how this Node MCU looks like.

So, this Node MCU is basically a cheap Arduino board you can think of that way it is a very cheaper module which does similar kind of function which has similar kind of functionalities like your Arduino and it is basically an ESP 12 module which is compliant with the Arduino IDE. So, basically instead of using Arduino which is a little bit more expensive you could use the Node MCU.

So, this Arduino IDE it is compliant with and we can use other Arduino boards along with this one. So, there is interoperability between the Node MCU and the Arduino IDE and the pin configurations are shown over here this is the pin configuration. And if you go to if I go to this link if I go to this particular link, I can show you how this pin configuration looks like for the Node MCU.

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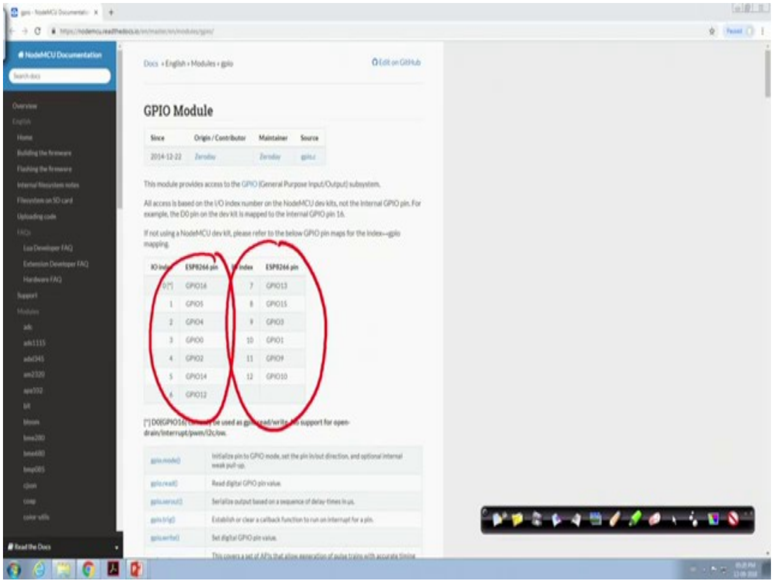


So, these are the different mapping between the IO pins and the GPIO pins. So, this is the basically the pin configuration and the mapping between the regular IO pins and the corresponding GPIO numbers. So, this basically will have to be taken this information will have to be taken into consideration while trying to map between the GPIO and the pin numbering in this Node MCU board. Let me now, close this and go back to where we were.

So, this is this Node MCU pin configuration and as you can see over here these different data pins D0 D1 D2 D3 D4. And this is where we are going to connect our other components of this setup, this is this pin corporate configuration overall. And what are these I am not going through in detail, but you could you could go through yourself through from this particular link, this will give you the complete picture of what each of these different mean.

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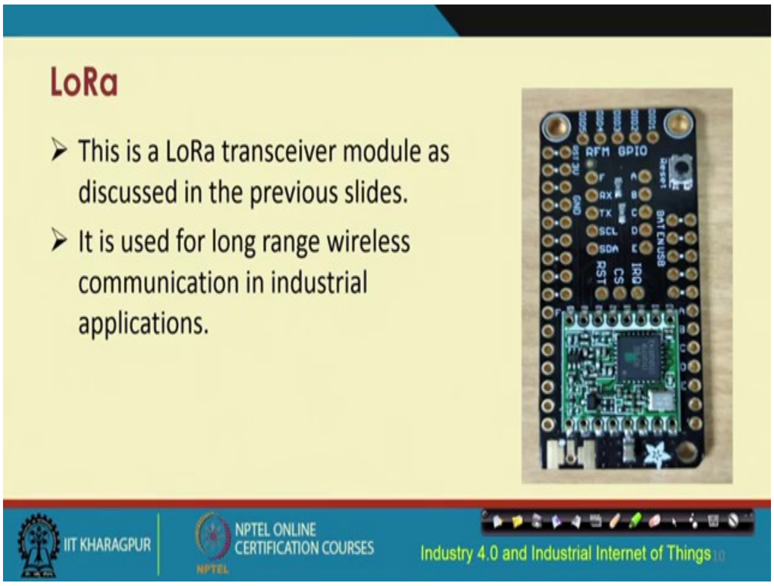


So, now this is basically how the LoRa transceiver module looks like. So, this is this LoRa transceiver and it has different pins like shown over here in this figure, this is the pin configuration. And it is used basically for long range wireless communication and that is very important particularly for Industrial IoT scenarios, LoRa basically is very useful.

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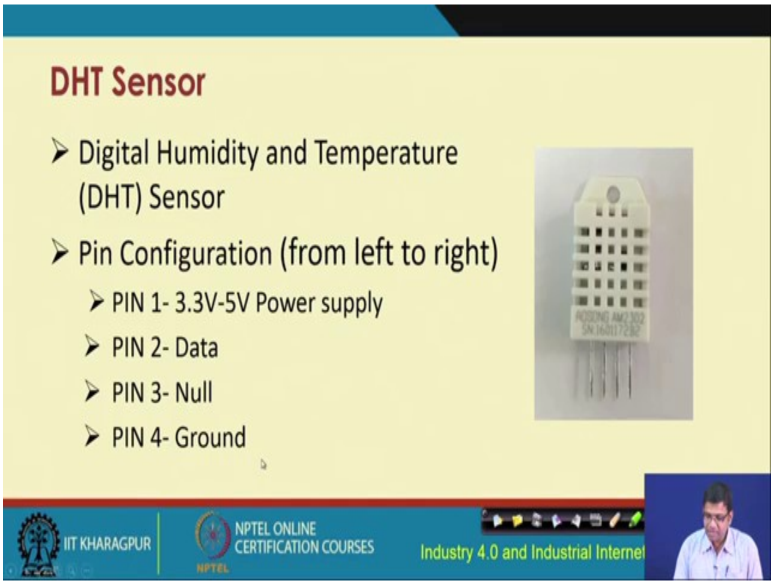


And this is the pin configuration of this DHT sensor. The other component that we are using in our setup so; PIN 1 basically is the 3.3 volt to 5 volt power supply. Then PIN 2 is the data, PIN 3 is the null, and PIN 4 is the ground. So, we have four different pins over here.

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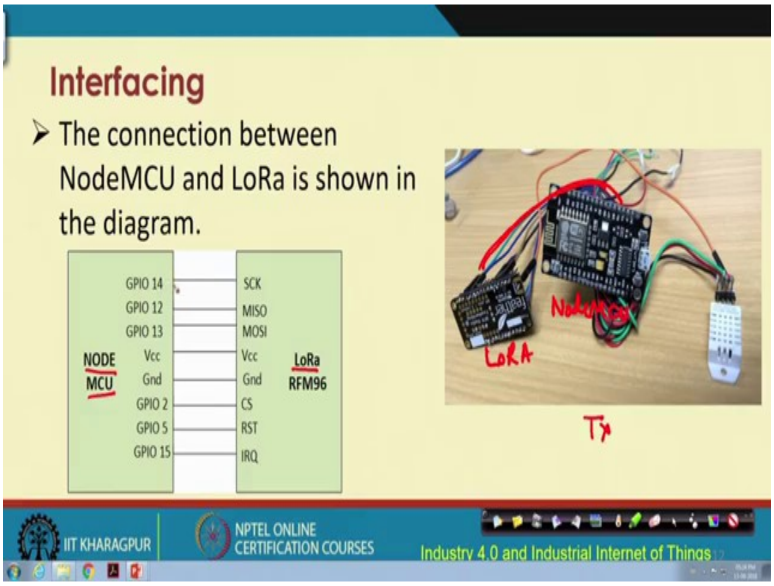


So, this is how this connectivity is going to happen between the Node MCU between the Node MCU and the LoRa. So, Node MCU and LoRa, this is how this connection is going to take place. So, we have this is this LoRa module, this is this LoRa and this is your Node MCU. And these jumper wires if you can see from the figure are connecting from one port of this LoRa to the corresponding port in the Node MCU.

So, we have different (different) wires jumper wires connecting different ports from this LoRa module to the Node MCU. And also you can see over here how these different jumper wires are connecting this temperature sensor, this temperature sensor, the different pins, there were four pins as we have seen in the previous slide. So, these four different PIN's 1 2 3 4 how they connect to this LoRa module is shown over here.

So, this is basically how your connection is going to happen because the temperature sensor will sense. And then it will through this LoRa module it is going to send the data, this will be the overall transmitter and it is going to send the data, and it will be received by the receiver. So, over here this mapping between the different pins of this Node MCU and the LoRa module are given for you, you can try it out yourselves.

So, as you can see over here the GPIO 14 pin in NodeMCU connects to the SCK for clocking. And then GPIO 12 to the MISO pin. So, this is basically multiple input single outputs and GPIO 13 connects to the MOSI. Then Vcc to Vcc ground to ground to GPIO 2 to CS and then GPIO 15 5 to RST which is the reset and 4 this is for the interrupt and so these, if you look, at if you look at this NodeMCU.

Let us look at this over here you do not find any GPIO written, so it is not mentioned over here. So, for that basically this mapping, that I had shown you through that particular link if you remember in that website that I had that linked to from that link you can get mapping between this GPIO to these numbers that are given over here. So, these are the numbers that are given over here.

So, with this mapping between this GPIO and that one will have to be derived. And however, for convenience over here we have shown you that what is this GPIO pin and where to which other pin of the LoRa module it connects.

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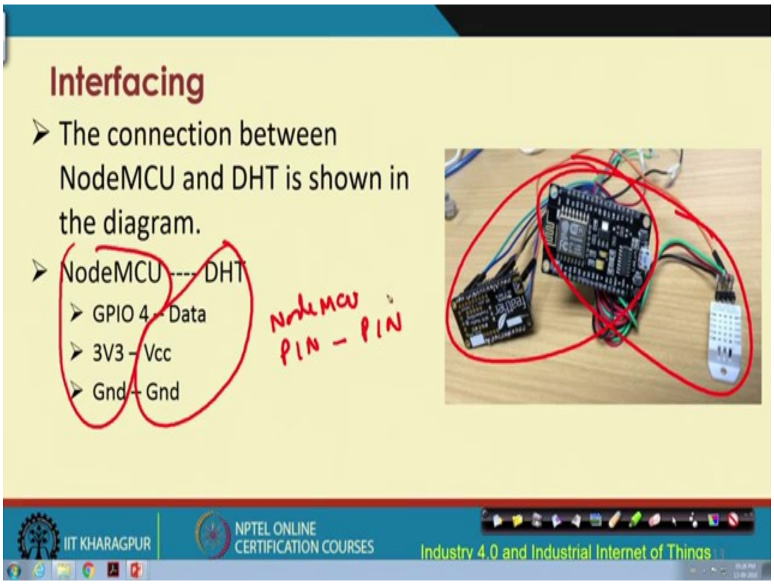


Then then for the connection between the Node MCU and the DHT; so, this part I have already shown you, this part I have shown you in the previous slide. Now, for this part for this part of connection between this GPIO 4 so, GPIO 4 of Node MCU connects to the DHT of data and sorry the data of the DHT.

So, 3V3 is 3.3 volts this one connects to the Vcc and ground to ground. So, this is this overall this is how this mapping between this Node MCU and DHT looks like in terms of the pin configurations in both. So, Node MCU pin configuration with the DHT sensor pin configuration.

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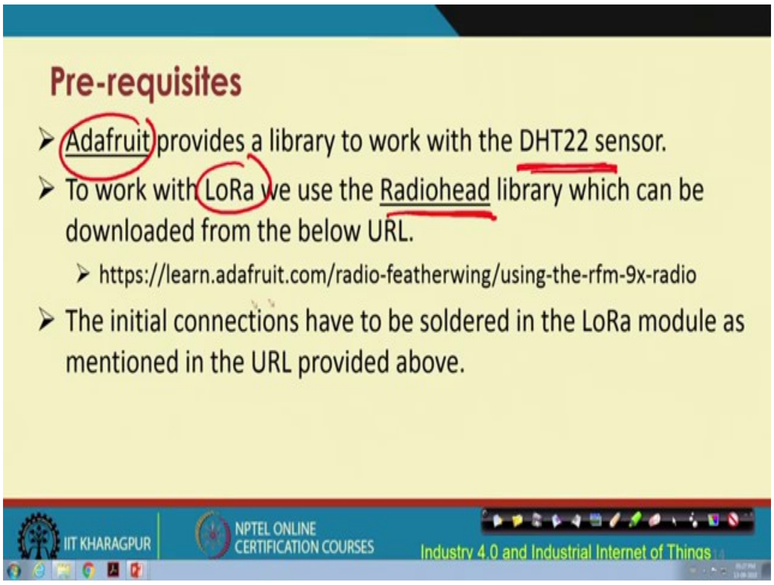


So, I am going to show you all of these in action, shortly. So, the there are some of these prerequisites that are required in order to make this setup run. So, one thing that you need is basically this adafruit library, which will work with which will make this DHT 22 sensor to work.

You also need this Radiohead library for this LoRa module to work and these can be downloaded from here. And the initial connections for convenience have been soldered in the LoRa module as mentioned in the URL over here.

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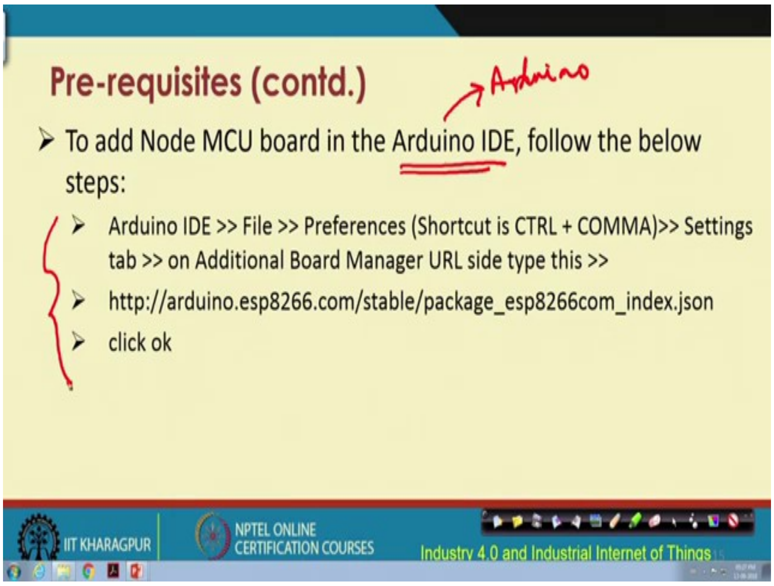


So, this is given here and to add the Node MCU board to the Arduino IDE, because I told you earlier at the outset if you recall that we would be using this Arduino IDE, which typically is compliant with only Arduino. But node Node MCU also works on the Arduino IDE platform. So, for doing that you have to follow these steps.

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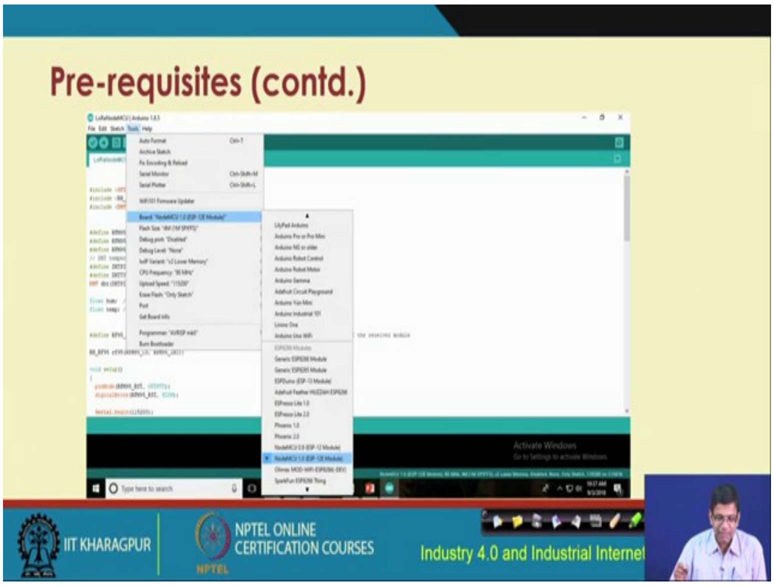


So, you follow these steps and then this is how this Arduino IDE looks like for LoRa Node MCU. And these are the steps that you will have to follow and for just brevity, I am skipping this thing.

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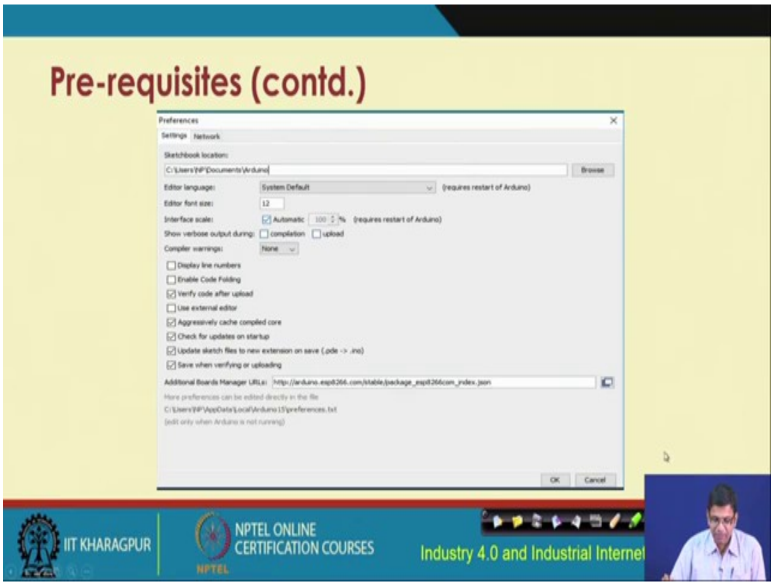


So, these are the steps that you will have to follow as given in the previous slide.

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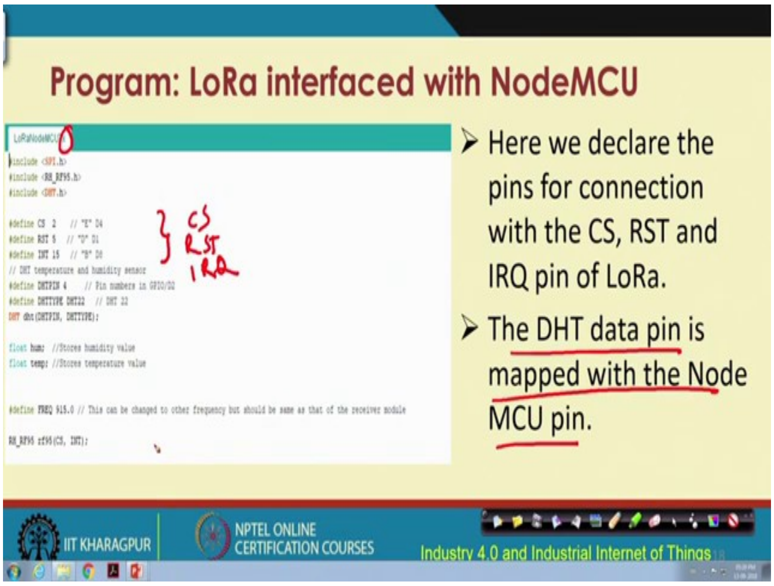


And so finally, you will have to open the programs, the corresponding programs for the LoRa. So, for LoRa interfacing with Node MCU, this is this transmitter program, this is how it is going to look, like this is for the transmitter end. So, as you can see over here we have these declarations for the different pins of LoRa CS RST and IRQ or interrupt.

So, these are the different pins and their definitions are given. So, these are this value the pset values. And this data pin this is also something that you will have to do the DHT data pin will be mapped with the Node MCU pin. And this is a long code and these snapshot basically shows only part of it, but this basically is something that will have to be done.

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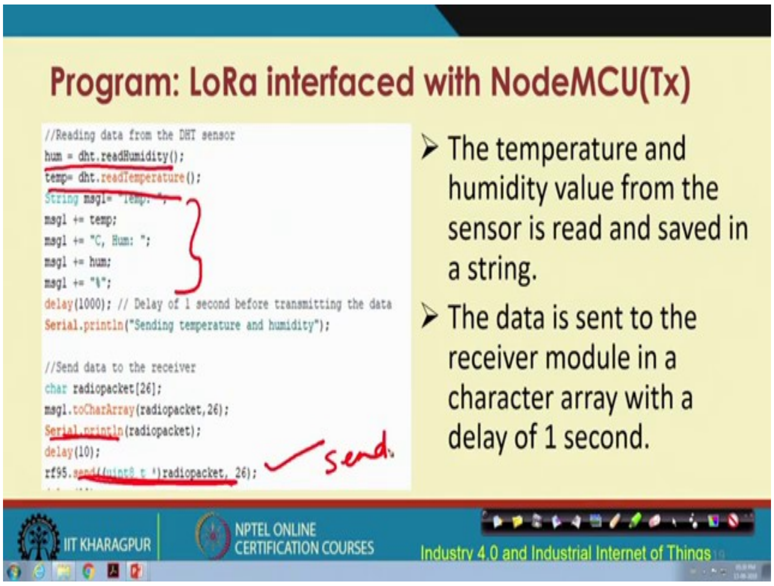


So, for the LoRa interfacing with the Node MCU this is this part of the code. So, as you can see over here the temperature and the humidity value from the sensor will be read and saved in the form of a string. So, as you can see this humidity value is being read, the temperature value is being read, and then through string concatenation in this code this long string msg 1 is being built, which will have the concatenated humidity and temperature values.

And then this will have to be sent through the port. So, this message one, which has been built earlier through this string concatenation, it will have to be converted to a character array and is printed in the serial port. Then it is sent, then it is sent using this part of the code, it is sent using this part. So, the sending will be done.

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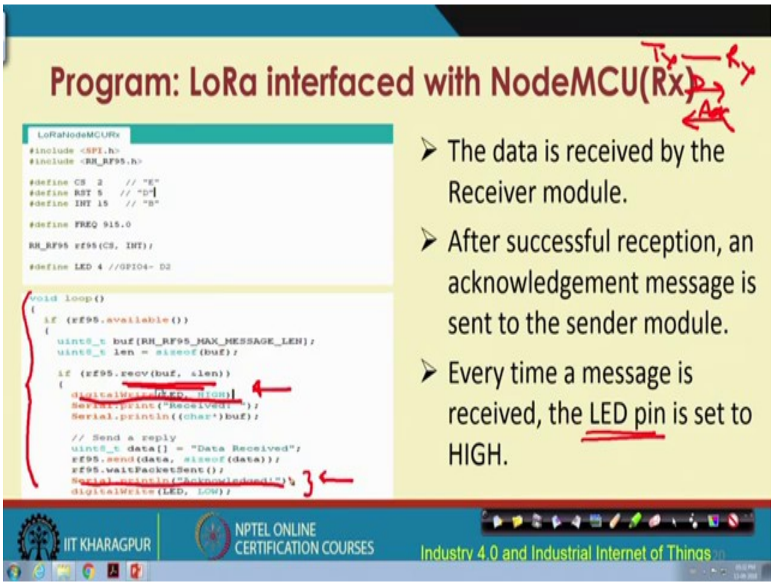


After that for the receiver side, the data will have to program in such a way that the data will have to be received. And after you receive the data, it has been programmed in such a manner that you the transmitter sends, receiver receives, and then it will send an acknowledgment. So, this is this data and the acknowledgment will be sent from the receiver to the transmitter. So, the transmitter knows that there has been a successful reception.

So, after successful reception and acknowledgement message is sent to the sender module. And every time a message is received, the led pin that I am going to show you is going to glow; that means, it is set to high and. So, this is where this led is set to high, through this comment. So, this loop as you can see this is a loop, which runs to receive the data, it is listening over the channel.

This receiver is listening continuously through a loop to see if there is any data being received. And this is this transmitter had sent the message packaged in this manner. So, it receives this message, and once it has received it is programmed in such a way that it is going to glow that led through this particular command high.

So, thereafter it is going to print that it has been received and what has been received is also going to be printed. Now corresponding to the data that is received the acknowledgement will have to be sent and that is done with the help of this code. So, it will acknowledge that it has been sent.

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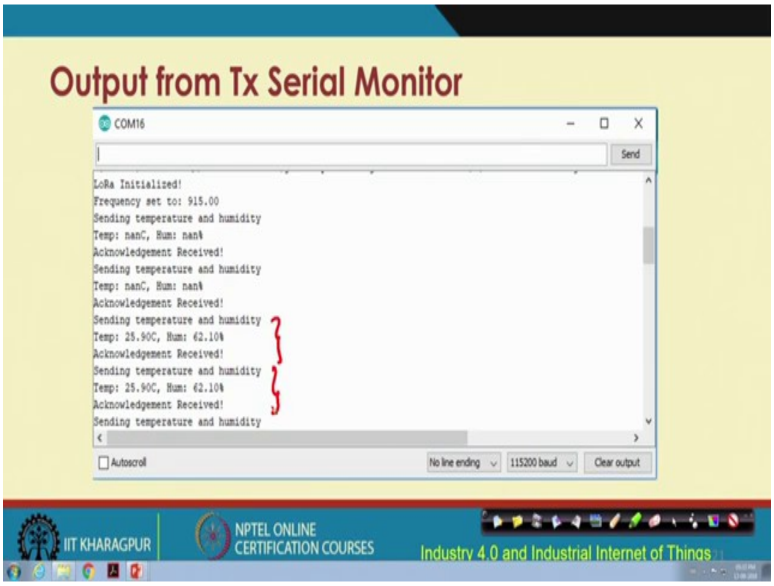


And this is the output from the transmitter serial monitor. So, as you can see over here LoRa is initialized first, frequency set up to 915, temperature sending temperature and humidity values temperature is given so because we are not showing the actual temperature of the humidity values. But this is how this code is going to look like. So, initially it is like that then it starts sensing the temperature and sensor temperature sensor senses the temperature and the humidity.

Then basically it sends it and the receiver basically will send it back, the acknowledgement will be received by the transmitter. And then the process is going to continue further. So, these are basically this part sending temperature humidity temperature equal to this humidity equal to this and acknowledgement received this basically keeps on repeating like this.

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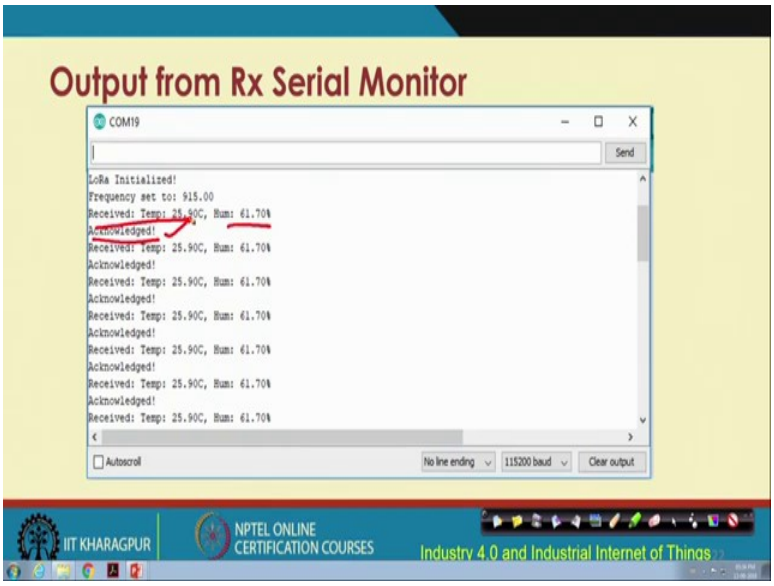


This is how it looks like at the receiver, in their Arduino IDE for the receiver end, basically, as you can see over here. This received temperature and the humidity value is shown. And then this acknowledgement is sent and this acknowledged message is printed.

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Now, I am going to show you the actual working of this particular setup. So, now, let us go back to our original setup. So, if you recall that this is what we have as our transmitter and this is our temperature sensor, the DHT sensor, and their corresponding pins, this temperature sensor is connected to this Node MCU.

And the corresponding pin configuration I had shown you in the slide, and from this Node MCU, there is a connection to this LoRa transmitter, and this connection also I have shown you in the slide, so you can try it out yourselves. So, these are the three different components that are connected at the transmitter site these three components. And so then from this LoRa transmitter this is the transmitter.

And it has this antenna also this is this antenna for from this LoRa transmitter we. So, the data are being sent. So, the data are being sent and the data are being sent to the; are being sent to the receiver and this is this LoRa receiver, this is this LoRa receiver. And this is the transmitter, this is the antenna of the LoRa receiver. And this is this transmitter and also this Node MCU at the receiver end.

So, we have this transmitter sending the data to this receiver. So, from this transmitter LoRa to the receiver LoRa, the data are being sent transmitter to the receiver LoRa, the data are being sent. And based on that and actuation of this led lamp, as you can see over here will be done.

So, the way it has been programmed is that the immediately after receiving the data from the transmitter it is once it is sent it is received and then it is basically whenever it is sent, whenever it is received this receiver, basically will make this lamp the led lamp glow and as you can see that it is glowing. So, this is this small setup that we have.

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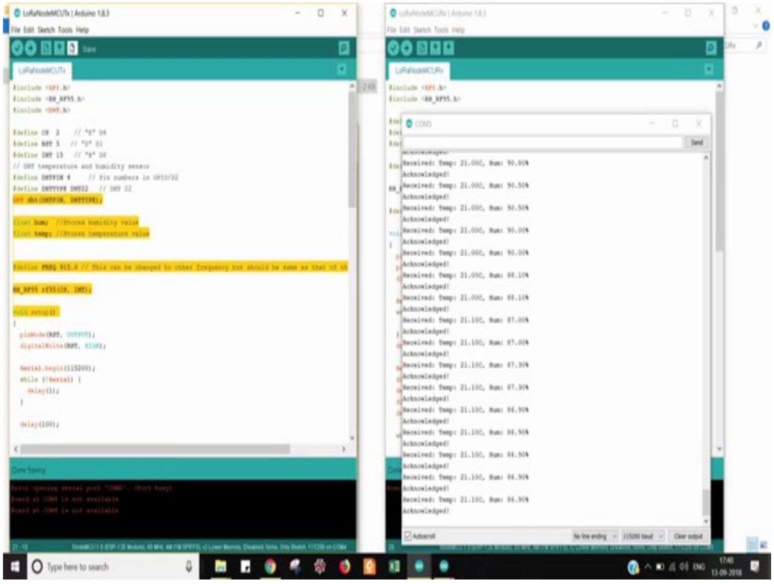
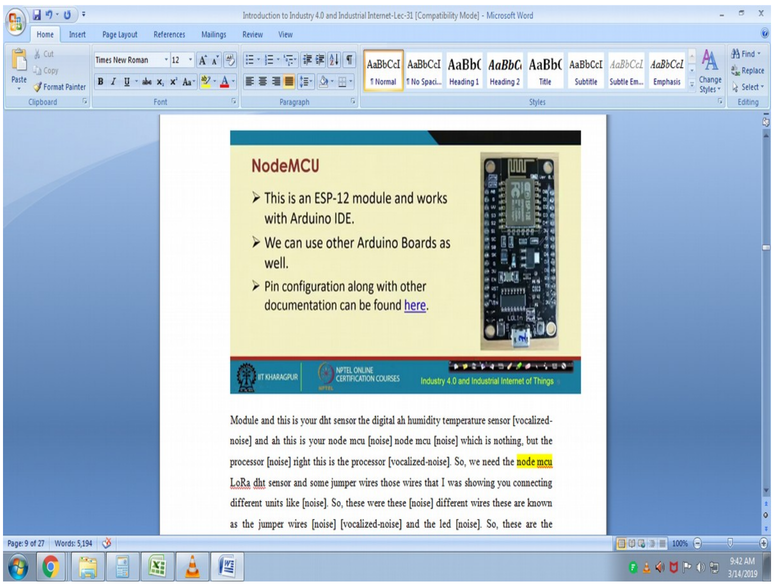


And so let us now go back and look at our screen. So, this is this IDE platform.




And if you recall that there is some configuration that you would have to make and so I earlier in the slide I talked about this configuration. So, let us say that this is your transmitter site in the Arduino IDE.

And this is your Node MCU, LoRa, Node MCU transmitter, and this is your LoRa Node MCU receiver. So, we will look at this code from the transmitter, but before that in the IDE this configuration will have to be made, few configurations will have to be made.

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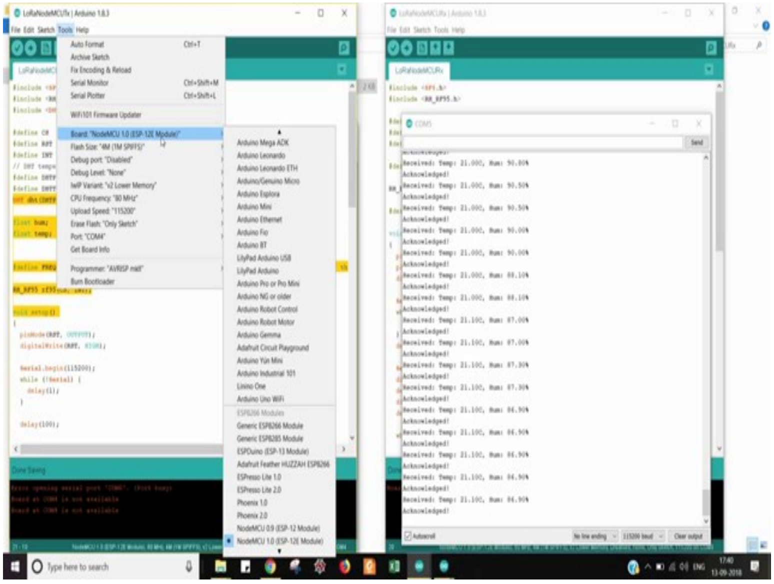

First of all the type of this board will have to be selected and we are using this Node MCU 0.0SP12E module. So, this was selected, we have pre-configured this way. And also for the transmitter, which communication port is going to be used so we have selected COM 4 for it so, this is done and thereafter. So let us go back.

And so so this is basically how this code looks like. And already I told you how you preset each of these different pins and their corresponding values. And basically there after this message is sent it is composed and it is sent through this serial port and is being received at the other end.

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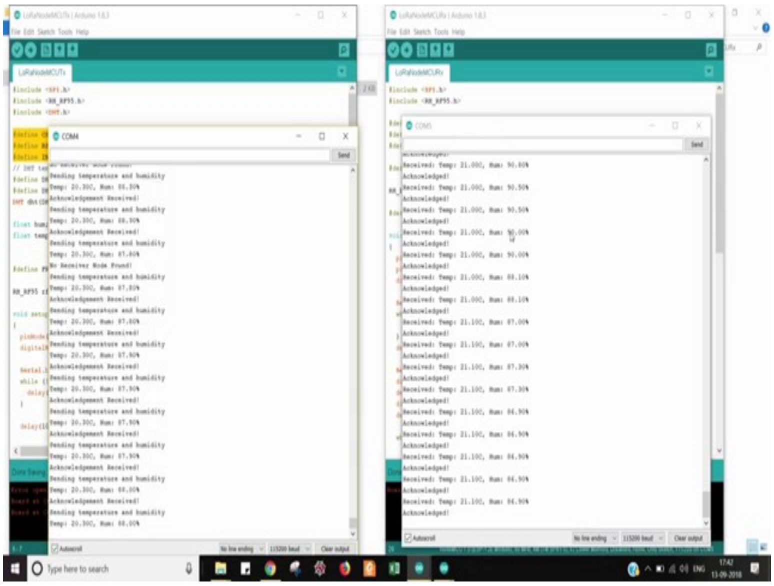

So, for the transmitter sending part, this is as you can see over here. The temperature value let us start from somewhere this temperature value, and the humidity, and the acknowledgment received continuously, it is showing the corresponding values, so this is basically how it looks like at the at the transmitter panel.

And at the receiver panel likewise these are basically what is being received and the corresponding code is also shown over here. So, this is how the receiver window looks like and this is the overall panel and. So, this is the way we have programmed that we have programmed, in such a way, that once the transmitter sends and it is received the data is received by the receiver it is going to show, it is going to blow that led.

And you could basically program the way you would like you do not have to glow an led you could actuate something maybe turn on the refrigerator or turn on the air cooler or something like that. So, these are this is the overall setup and you try out by doing this coding in the Arduino IDE platform yourselves, with this very small setup.

And then once you are confident you could try out with different other setups, where through the use of LoRa module you would be sending the data from 0.1 to another point. And that between that the spacing between the transmitter to the receiver could be more than even 100 meters in LoRa. And finally, we come to an end and these are the different references, if you are interested you could go through these references.

Thank you.

**Introduction to Industry 4.0 and Industrial Internet of Things**
**Prof. Sudip Misra**
**Department of Computer Science and Engineering**
**Indian Institute of Technology, Kharagpur**

**Lecture – 32**
**Key Enablers of Industrial IoT: Connectivity – Part 5**

So, this is going to be the last lecture in the series on connectivity for IIoT. So here, basically I am going to give you a demo of the ZigBee. So, before I do so, let me just try to go through some of these basics of ZigBee how it works and how you can configure ZigBee for working. And thereafter, I am going to show you this ZigBee in ZigBee communication in action. So, basically we will have a ZigBee transmitter and a ZigBee receiver. And I am going to show you how this transmitter sends and the receiver receives and basically shows the sent information from the transmitter.

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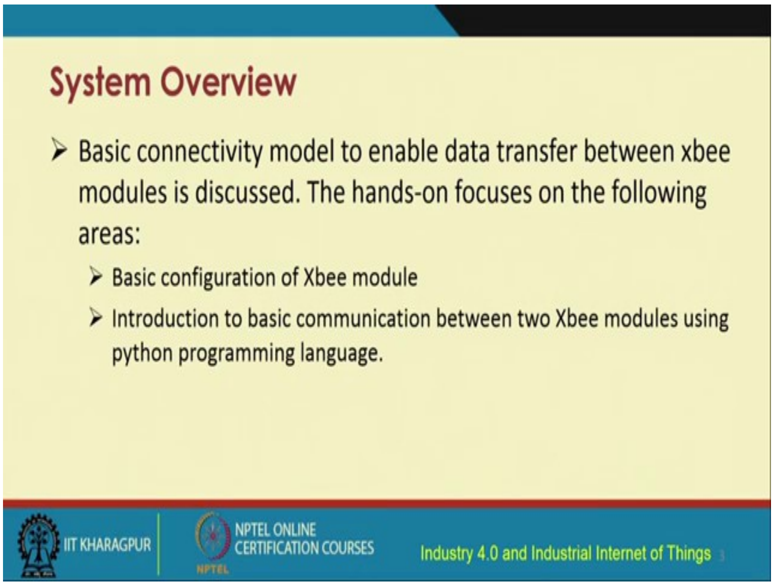


So, for ZigBee connectivity, the basic connectivity model that will be used for data transfer between the ZigBee modules is discussed. And particularly we are using the Xbee for doing it. And basically we are going to focus over here, this Xbee, which is basically also pronounced as ZigBee, but is a product from one of these companies a specific company, specific product which follows the ZigBee protocol. This Xbee module and its configuration I am going to show and thereafter I am going to introduce the basic communication between 2 Xbee modules, using python programming language, that I am going to do next.

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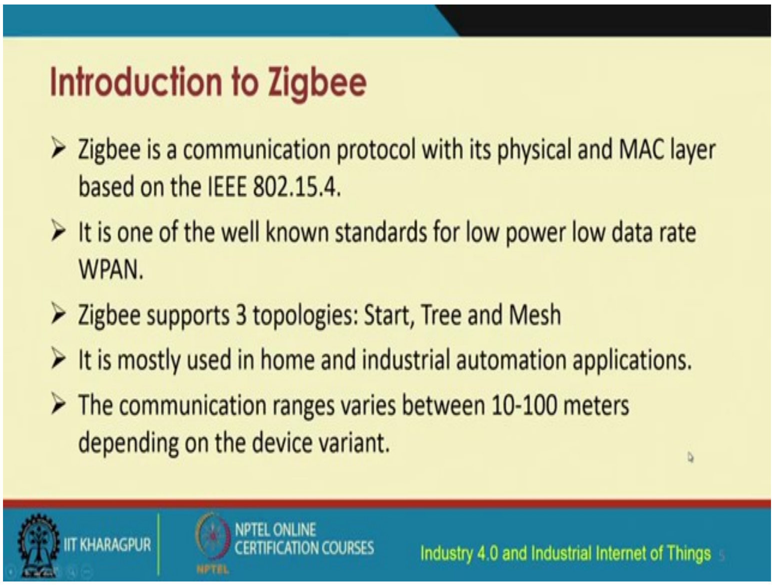


So, just a recap, ZigBee is a communication protocol that is used for mid range communication and its it follows the specification of IEEE 802.15.4. And it is one of the very well known protocols for IoT, for whether it is for home based applications or for industry based applications, ZigBee is a very popular technology. And it is very popular for low data rate, low power communication in wireless personal area networks. There are different topologies that are supported by ZigBee, star topology, tree topology, and mesh topology. Particularly, the star and the mesh topologies are the most common and are widely used for home and industrial automation applications.

The communication range in ZigBee varies from 10 to 100 meters. It becomes more, if that the receiver and the transmitter are in the line of sight of each other.

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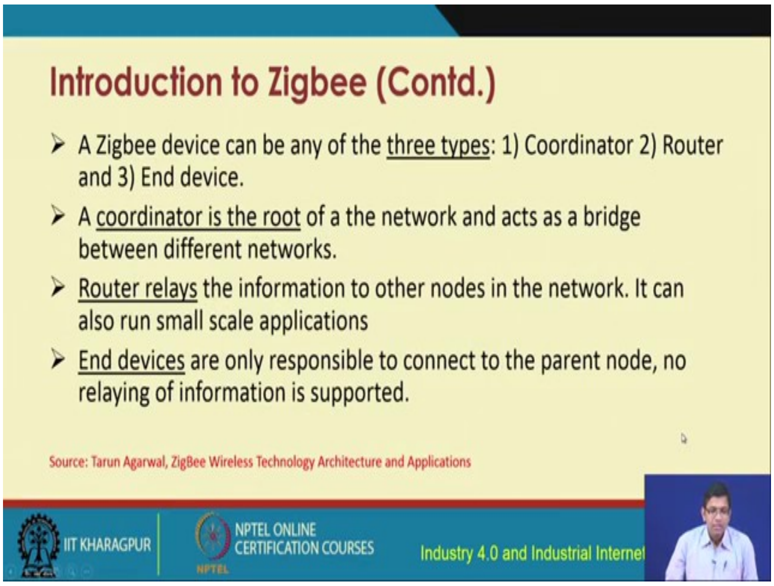


So, a ZigBee module basically can be of 3 types. There can be a coordinator, a router, and an end device. The coordinator is the root of the network and it acts as the bridge between these different networks. The router basically relays the information to other nodes in the network, and the end devices are only responsible to connect to the parent node, and no relaying of information is done by the end devices.

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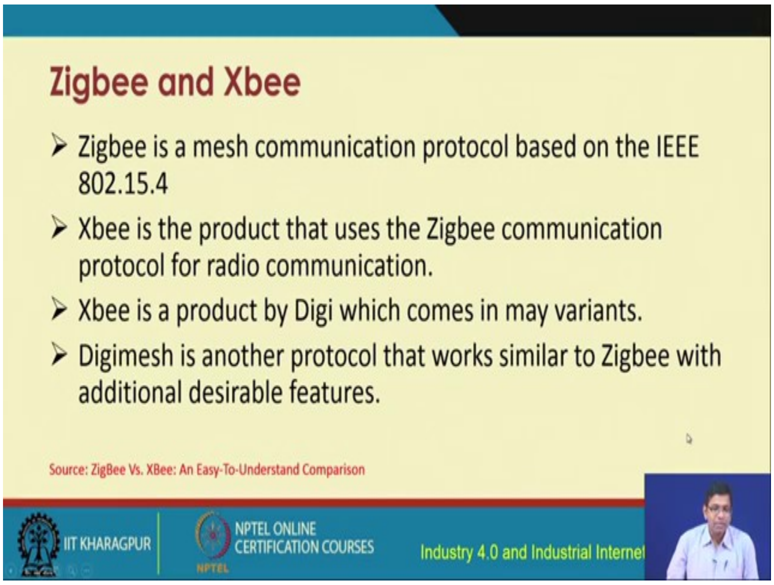


So, these are the 3 different types of devices that are supported by Zigbee.

So, ZigBee and Xbee, although these terms are used interchangeably, but they are different. So, ZigBee protocol is a mesh communication protocol which is based on IEEE 802.15.4 standard specifications. Whereas, Xbee is a product from this from this from the company Digi, and it comes in different variants. It is available commercially in different variants. So, Digi-mesh is a protocol that basically is similar to Zigbee, but has certain additional features. So, Digi-mesh is basically supported by Xbee and it has certain features that are similar to ZigBee, but certain additional desirable features are also their Digi-mesh.

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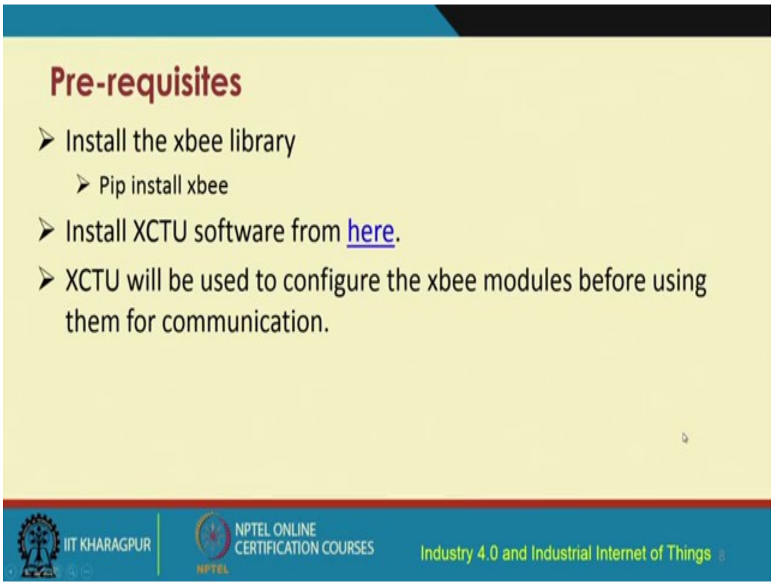


So, these are the prerequisites. Initially, you have to install the Xbee library, using this command pip install, Xbee and then install the XCTU software from this particular link that is given. So, you can click on this particular link, and you would be taken to that. From this link you would be able to get the download and the installation of this software XCTU and that is required to be installed even before you can do this configuration.

So, XCTU will be used to configure the Xbee modules before they can be used for communication; that means the ZigBee center and the transmitters could be used.

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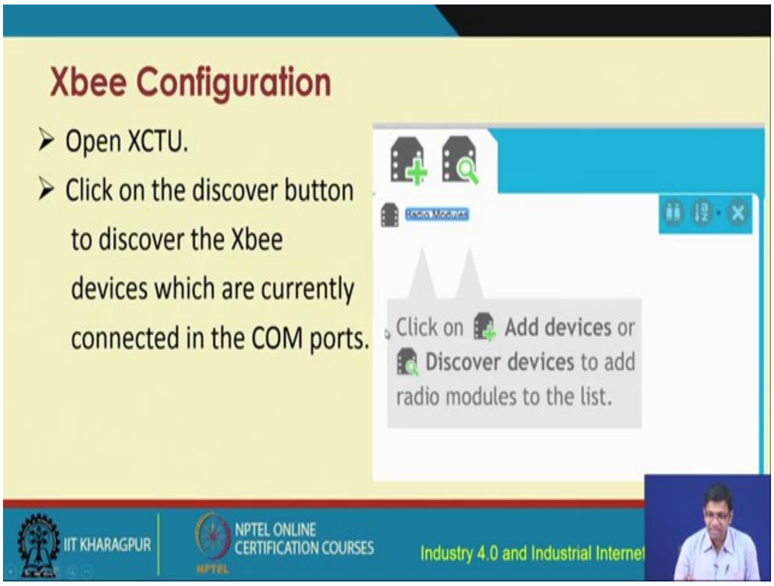


So, for configuration, after you have installed XCTU you open the XCTU window like this and then you click on the discover button to discover the Xbee. So, basically once you do that, you would be able to add the different devices and discover devices. For adding devices, this is the button that you will be using and for discovering this is basically the button that you are going to use.

So, once you click on this particular button it has discovered different modules and this is this module that has been discovered and has been found. So, there could be many different other modules, that could be discovered through this discovery process.

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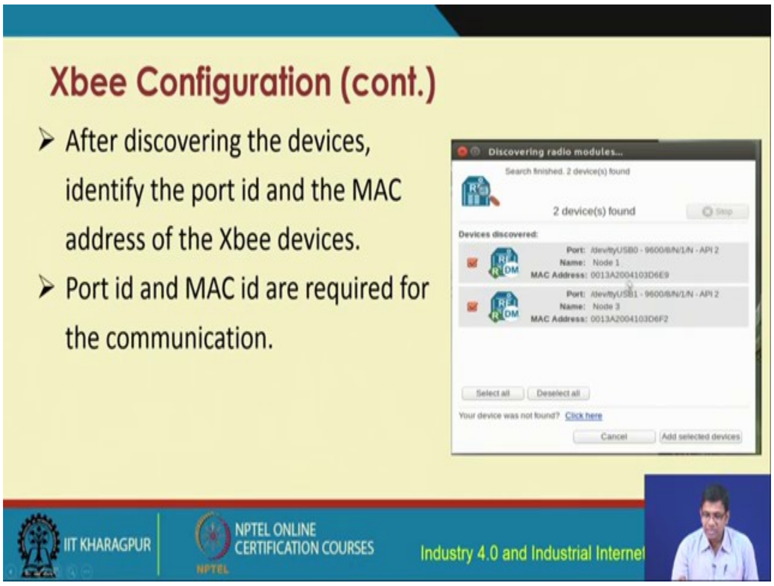


So, after discovering that this devices, it is required to identify the port id and the MAC address of the Xbee devices. And this port id and the MAC id are required for this communication. And this is quite obvious and here as you can see based on these different devices that are discovered the corresponding port id and the MAC id, will have to be assigned, will have to be found out. And the names of these devices will also have to be assigned and so, here the names are node 1 and node 3, but you could change, you could over here, you could change the names of these devices.

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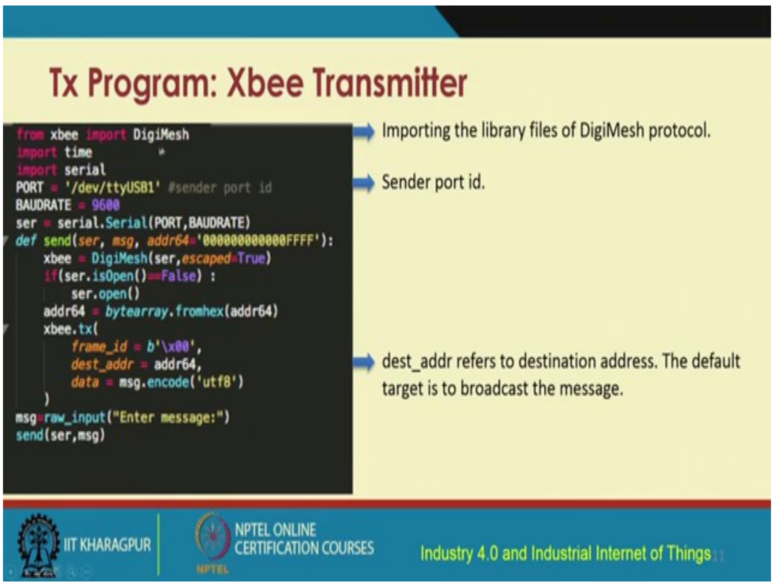

So, in that for the transmitter program, for Xbee this is basically a screenshot for the transmitter. this part basically talks about importing the Digi-Mesh library. This is the Digi-Mesh library, the sender port id is sent is set basically through this particular comment line. And for the destination address this destination address is set through this particular line of code in python and the default target is the broadcast mode of communication.

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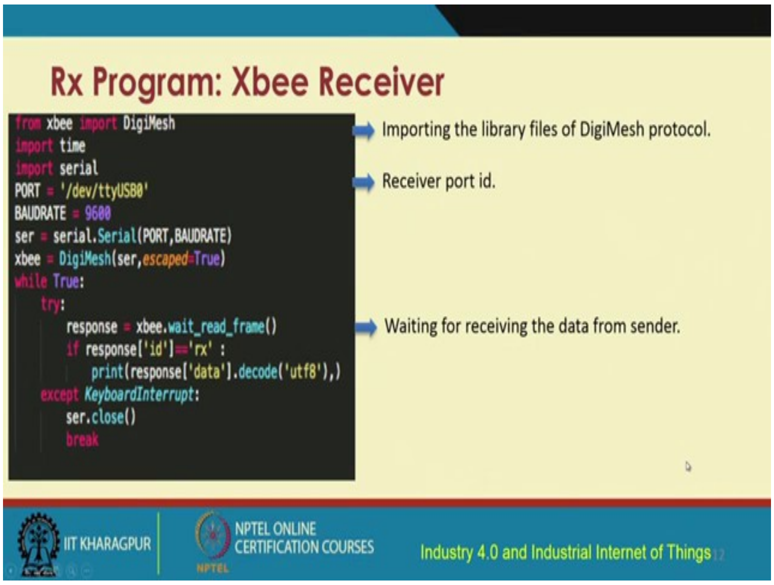


This is the receiver side program. again you import the Digi-Mesh and because this Digi-Mesh library is the backbone the enabler for supporting this communication. So, it is very important to imp import for the transmitter as well as the receiver Xbee modules, it is imp it is important to import this Digi-Mesh library. And then the port is set the receiver port id is set over here and this try block if you look at it is looking for, it is waiting for the receiving of the data from the that is sent from the sender. So, it is waiting for reading the frame and.

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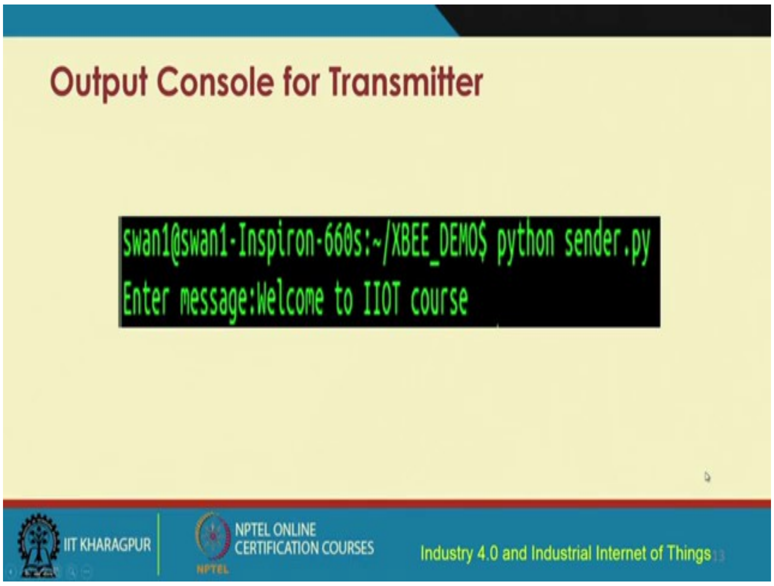


So, this is basically this block and this is the python code and so, output console for the transmitter is going to look like this. So, you can enter the message that you want to send from the transmitter. Let us say that we type in welcome to IIoT course.

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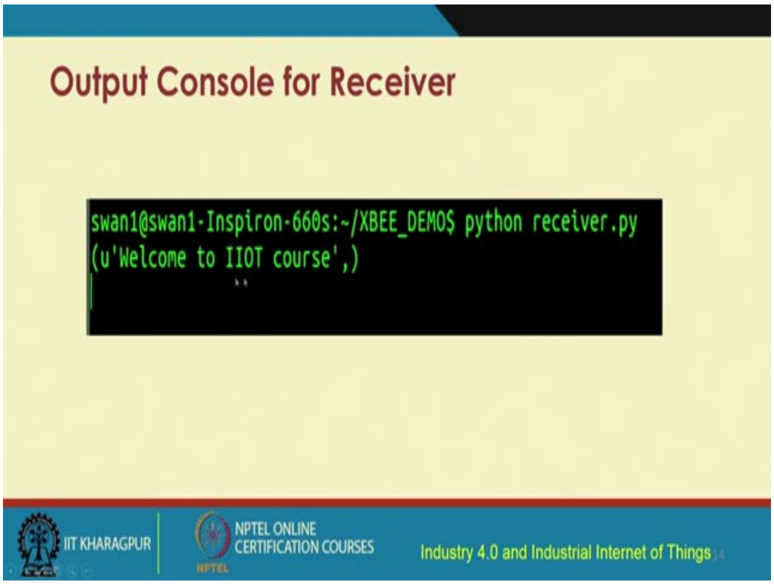


And then at the receiver, you are going to receive this message ‘welcome to IIoT course’ and u stands for unique code. And so let us not worry about it and this is basically this message that is received at the receiver end.

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So, with this, we come to an end of this particular lecture we have seen the configuration of ZigBee, and the sender and the transmitter module configuration, their corresponding code, and how the data can be sent from the transmitter to that receiver. So, now, I am going to show you whatever I have explained so far, the XCTU configuration and also this python code for the ZigBee transmitter and the receiver, I am going to show it in action.

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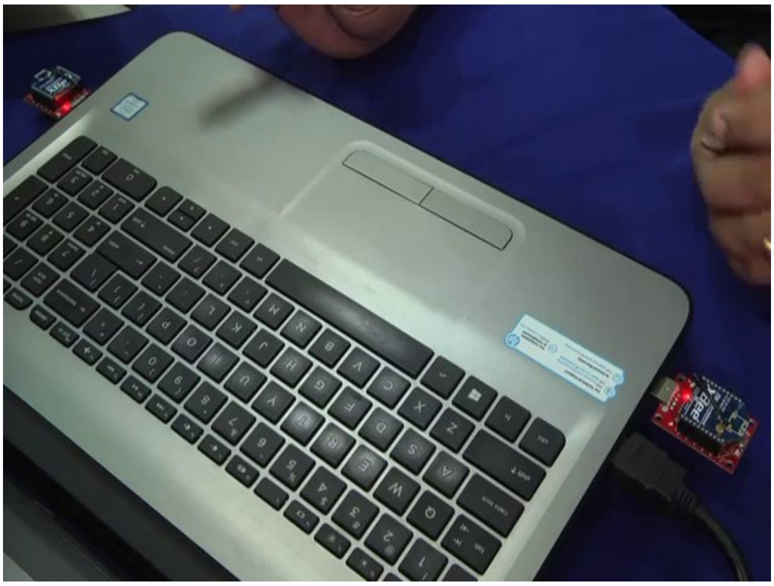

So, as you can see over here we have these two ZigBee modules. this one, is the transmitter a ZigBee module, and this is the receiver ZigBee module, which have been com connected to the laptop, because ZigBee modules can connect over USB. So, for convenience we have connected over laptop.

So, this is the transmitter module and this is the receiver module and we will show that how this communication is taking place. Right?

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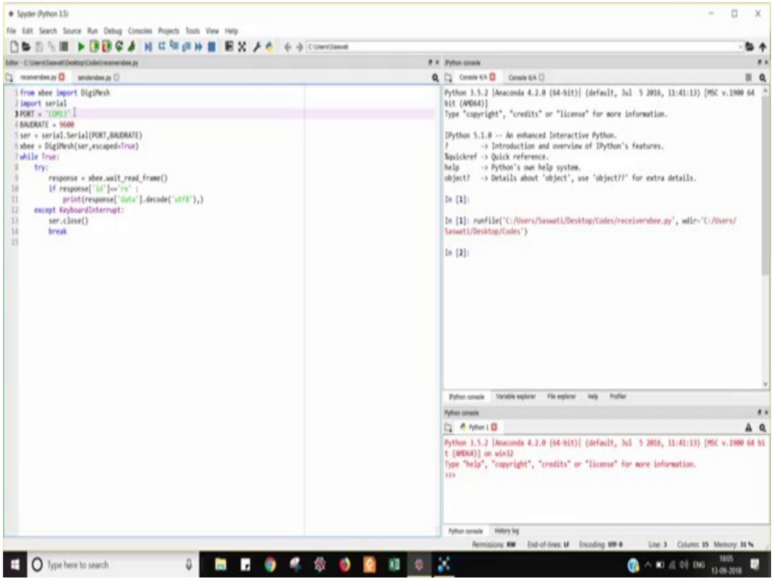


So, we have already written the code that will be required for it, but before that let me show you. let me show you, this XCTU configuration windows.

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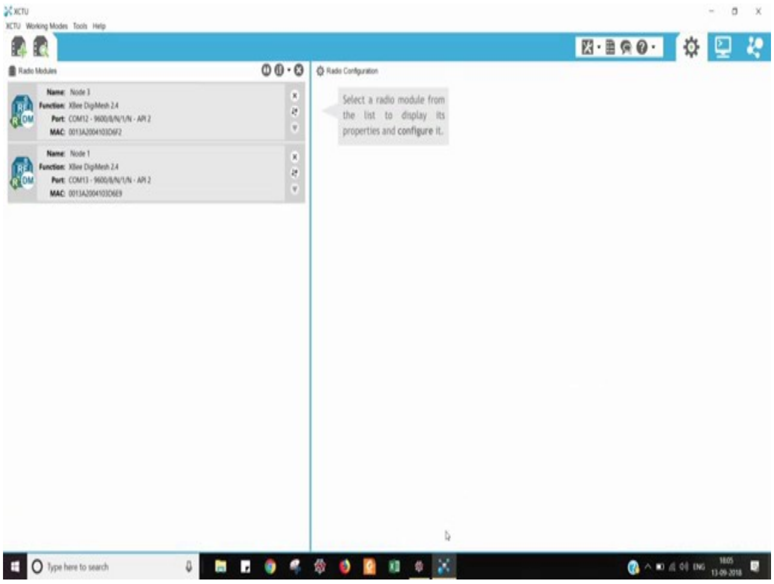

So, this is basically this XCTU configuration window. And if you recall, that in the slide I had shown you that you will have to first configure these different nodes regarding, which port they are going to work, which one will be the sender port, which will be the receiver port, what will be the names of these different nodes? The MAC ids and all these things will have to be configured. Many other configure configurations you can do, but those can be done in the XCTU configuration screen.

So, after you have done that basically, you can then transmit the data and then also receive it. So, this is basically the receiver code in python we have this receiver code receiver Xbee dot p y. and this is basically there is a while loop trying to read the data frame as I was showing you in the slide earlier. And it is trying to look for whether any there is any data that has been sent and this is this imported Digi-Mesh library this is required as I told you already.

And so, let us execute this one over here, and thereafter let us go to the other code which is the sender x b dot pi. this is the other code here, also we have imported the Digi-Mesh library and we have set the port and also we try to form this message that is going to be sent. this message is sent through this command send acr mes msg, and msg is this message that is built and is being sent. So, after this we go to this console to see that how it looks like from the sender side.

So, that was the receiver one and this is the sender console. We execute over here, we run, and we send a message. So we can type in any message, let us say, hello world, hello world, and then we send it. So, it is being sent from the transmitter side. We send it, and we go back, and we can see whether it has been received or, not. So, as we can see over here, it has been received. Hello world has been received at the receiver side. This is the receiver console and that was the sender console. From the sender console, it was sent and from the receiver console, we are able to receive this.

So, you can try it out yourselves, and see whether things are working for you or, not. It is very simple and there are lot of open source code available for supporting ZigBee programming and so on. particularly with python and you can try out this particular setup that I have demoed you today.

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So, these are these references that you could go through and if you are interested. You could go through any of these references, and I would encourage you to try out this particular setup, that I have just explained. And try to send some data from the transmitter and see whether it has been correctly received at the receiver or not, because that is the basic building block for ZigBee communication.

Thank you.

**Introduction to Industry 4.0 and Industrial Internet of Things**
**Prof. Sudip Misra**
**Department of Computer Science and Engineering**
**Indian Institute of Technology, Kharagpur**

## Lecture – 33
## Key Enablers of Industrial IoT: Processing – Part 1

In this lecture and the next, we are going to talk about the processing of the data, that are received through the IIoT systems, that are deployed in the companies. Let us go back and think about what we have covered so far, in this particular module. We have talked about the deployment of different types of sensors, in industrial scale. In different parts of the manufacturing plants, different industries, the different types of sensors that could be used.

We started with that then we talked about in length, we talked about the different types of connectivity mechanisms, that could be used. We talked about the different protocols, the communication protocols, the network infrastructure, and so on the different types of topologies that could be used, and so on.

We have talked about all of these connectivity issues. So, what happens is these different sensors and the actuators are all connected. Through this particular network that we have gone through, in the last few lectures. So, the data basically are received at somewhere, it is received let us say in the cloud or in some server or somewhere it is received, and this data will have to be processed.

So, it has to be processed as quickly as possible in most of the cases. So, how this data has to be processed and what are the different mechanisms in place, what are the different research works that are going on in terms of processing of IoT data and so on is what we are going to look at in this particular lecture and the next.

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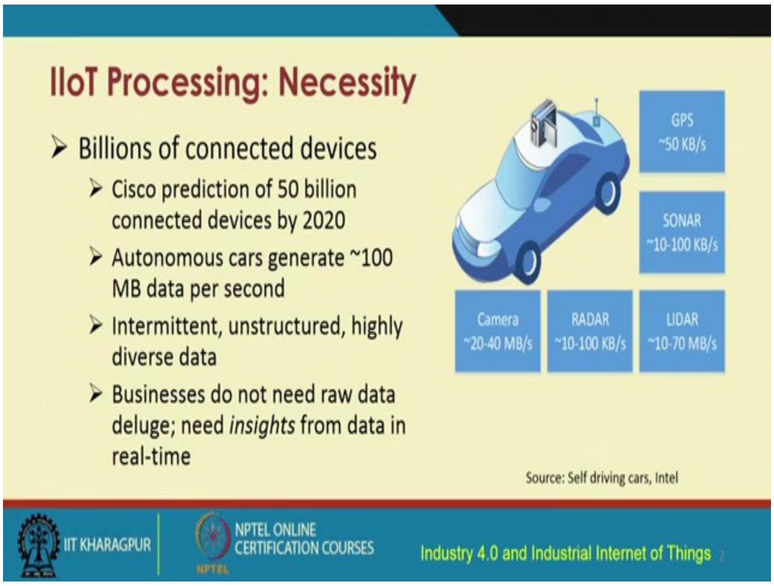


Let us take a look at the self-driving cars, which has very become very popular in the recent times. So, these self-driving cars or forget about the self-driving cars, if we are talking about the smart cars, in general. These smart cars are equipped with different sensors and different communication devices. And these different cars it is expected that we are going to have these connected cars in huge numbers in the next few years. These cars they will generate large volumes of data and it is estimated as per one of the estimates, it is estimated that these cars and particularly the autonomous cars; they are going to generate data at 100 MB per second. At 100 mbps, it is estimated that this much of data is going to be generated per second. So, this data will have to be dealt with. If, we take the case of the self-driving cars, the self-driving cars are equipped with GPS. The GPS transmits data in these cars at the rate of roughly 50 kbps, sonar these cars could be equipped with sonar modules and which could be sending data at the rate of 10 to 100 kbps. LiDAR 10 to 70 mbps, radar 10 to 100 kbps, cameras 20 to 40 mbps, and so on.

So, as we can see that individual components of these autonomous cars, they are going to throw in lot of data at huge rates. So, you have to deal with this kind of data and in order to get proper meaning out of this particular data that is collected, there has to be some kind of processing engine, that is going to be executed, and that will derive the meaning out of the data, that are collected and received.

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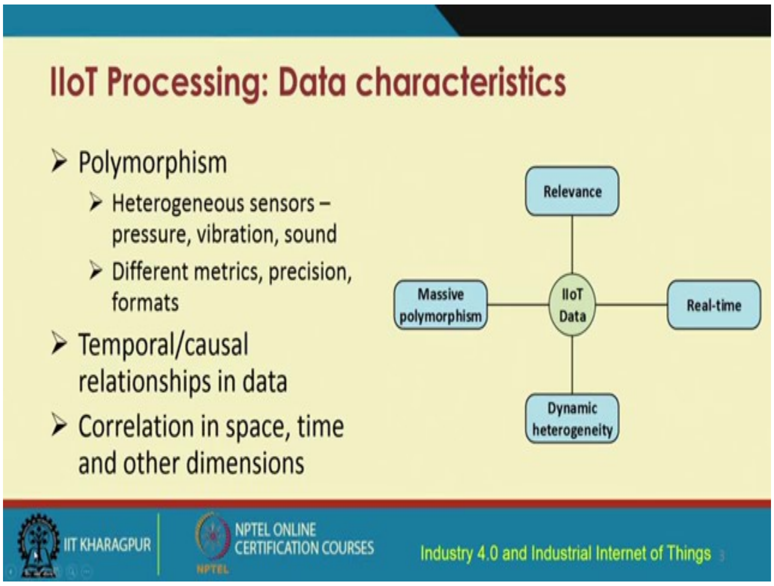


How we can deal with this data, we need to first understand the type of data, that we are receiving. The type of data, that we receive can be characterized in different ways. First of all this data has massive polymorphism in place. Massive polymorphism means, we are talking about the use of large number of different types of sensors, pressure sensors, vibration sensors, sound sensors, and large number of different types of sensors could be used.

This heterogeneous say data from these different types of sensors will have to be dealt with, because they come in different rates, they are of different types their data types are different and so on. So, they have different varieties, different types of data coming through a single pipe. Additionally, this data will come in different formats their precision levels will be different; the metrics that characterize this data are going to be all different.

So, this kind of variety of data having different forms, of having different types of varieties, will have to be dealt with. The next thing is that you have to deal with data in real time, to be able to make most value out of the received data. So, this real time dealing of the data will have to be performed. So, the data will have to be dealt with in real time and we have already seen that there is heterogeneity in the type of data that is received through this common pipe, conceptually, if we can think of that way. And this heterogeneity itself is going to be dynamic with respect to time.

The type of heterogeneity is also going to change with over time plus this relevance of this particular data. The relationships--the causal relationships, the temporal relationships between these different data components, these are also very important and will have to be understood in order to make this data useful. There has to be some kind of correlation, which will have to be established in space in time and other possible dimensions of the data that is received.

So, these are some of these different attributes or the characteristics of the data and we have seen that these this type of data will have to be dealt with appropriately.

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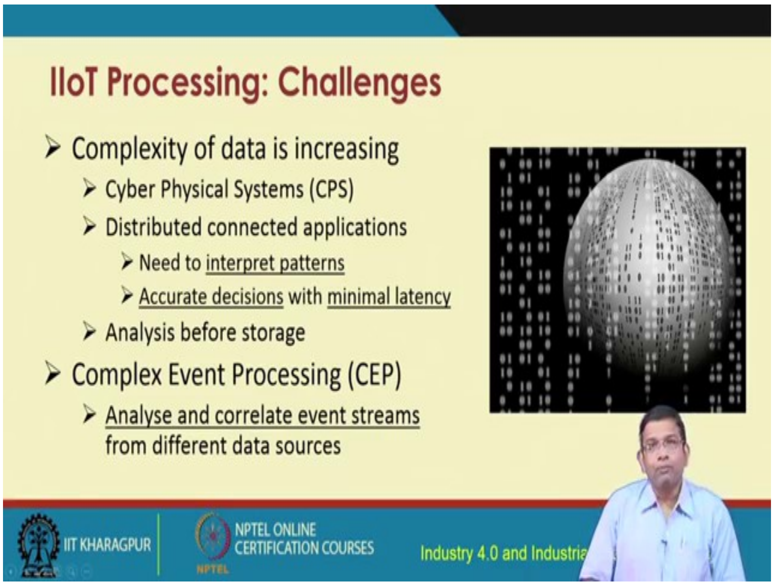


Now, the so, we have to process the data, but there are different challenges with respect to this processing. The complexity of data in industrial systems is increasing day by day. These industrial systems exhibit the behavior of cyber physical systems, where there is an intricate relationship, that is there between the cyber component and the physical component of the different machines and there and the interconnected ones.

So, what is required is to interpret through different applications, it is required to interpret the patterns that are there, out of the data that are coming from these different cyber physical systems. Accurate decisions will have to be taken and these decisions will have to be taken with minimal latency; that means, in least possible time, this decision will have to be taken about decision means like what is the the data that are coming, what it is going to do what if there is any kind of thing that is going to happen in the future. So, those kind of decisions will have to be taken.

So, even before the storage so, first of all, the data will have to be stored. And one can analyze, the data after storage, but before storage also the in many cases the data may need to be analyzed. And this is particularly true for real-time applications, where there are real-time decisions will have to be taken in real-time. So, there is some kind of complex event processing, that will have to be executed, the data will have to be analyzed correlations between different event streams will have to be found out from these different data sources.

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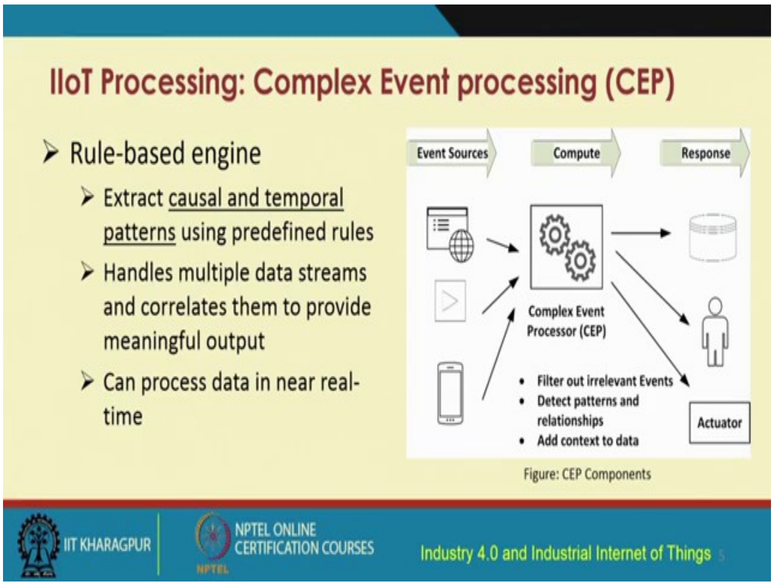


So, let us look at this complex event processing. So, one of the ways to do it is with the help of a rule based engine and this is shown over here in this particular figure. So, let us look at the complex event processing, one of the ways to implement it is using rule-based engine.

So, let us look at this particular figure, we have this complex event processing mechanism, which does the computation. Data come from different event sources and this data will have to be processed, with respect to filtering out irrelevant events, with respect to detecting patterns and relationships, and adding context to the data.

So, all of these things will have to be done appropriately in this compute engine. And, based on that either there would be some kind of an actuation or, this data will have to be sent appropriately to certain actor or, it has to be stored. So, a complex event processing will have to be performed. So, it is very important to extract the causal and temporal patterns causal and temporal patterns, will have to be found out, through complex event processing in this particular component.

So, it is very important to process the data in real near real-time; that means as much real-time as possible in order to be able to have value out of the decisions, that are made out of the processing of the data.

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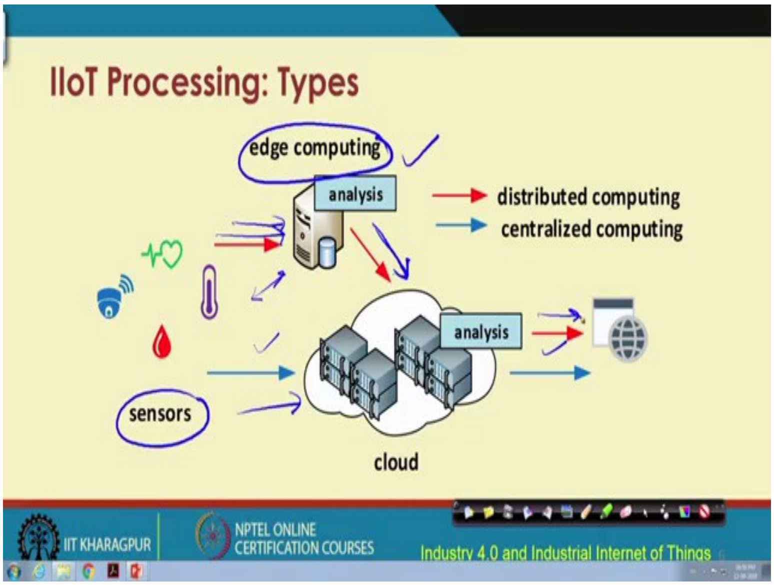


So, if we are talking about this processing, where do we do this processing? So, let us say that we have different sensors like the ones that are shown in this figure.

So, this these sensors will be sending lot of data. This data will have to be processed. This processing can be either done through some server's small servers or, something of that type, close to the sensors, as much close as possible to the sensors, in order to reduce the latency in processing or, the data could be sent to the cloud. It is also possible that partially some part of the data will be processed at the edge over here, and the rest of the processing would be done at the cloud.

So, this is the flow of distributed processing or distributed computing the red colored arrow shows it and the centralized processing pathway is shown, through the blue colored arrow. So, this is basically the centralized processing, and this one is the pathway for the distributed processing of the data.

So, what we see that the data that are produced from the sensors, will either have to be analyzed will have to be sent completely to the cloud, and will have to be processed at the cloud, or it could be sent to the edge partial processing, will take place at the edge. And the rest of the processing will be done at the cloud or it is also possible for small jobs, the processing will be done completely at the edge.

So, all the 3 different possibilities are possible to be implemented. Now, what is important is to identify which type of processing, what computation will be done at the edge, which processing, what computation will be done at the cloud? And more importantly, if you have to distribute the processing between the edge and the cloud, then how do you make that differentiation and correspondingly the distribution.

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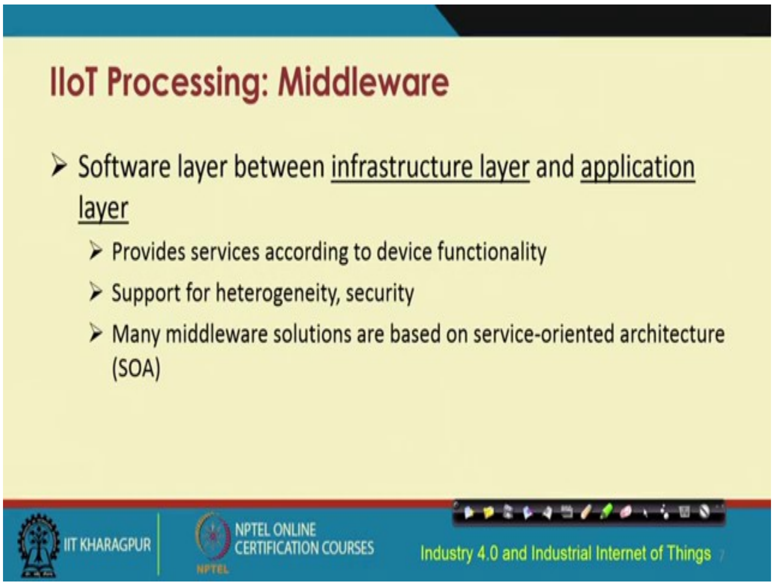


So, it is proposed that we could use some sort of a middleware. Middleware means it is a software layer, which will be standing between the infrastructure layer and the application layer. So, this particular middleware software will provide different services according to the device functionalities. This middleware could also implement security mechanisms; it could also handle device heterogeneity and correspondingly data heterogeneity.

So, there are different middleware solutions, that are proposed and many of them are based on the service orientation, service oriented architecture based middleware.

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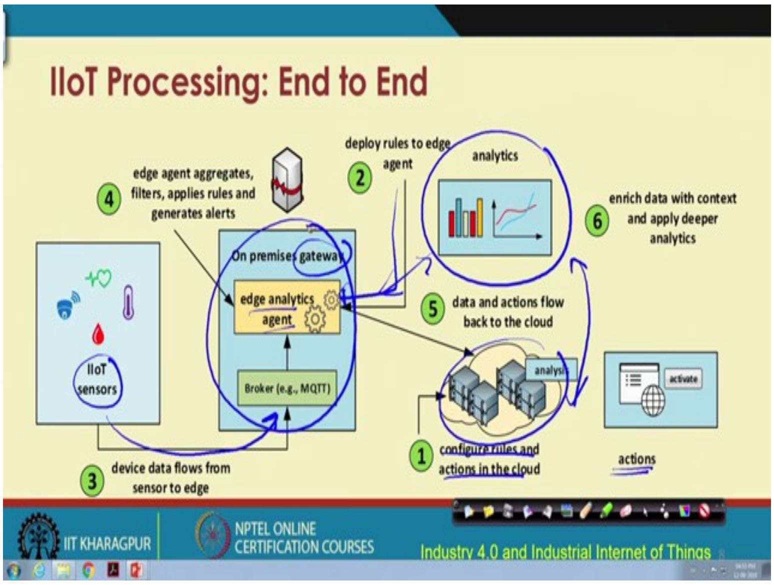


So, let us look at this end to end mechanism and let us try to highlight stepwise, how this processing is coming into picture and its importance. So, let us look at this particular figure and as shown over here. We are talking about; we are talking about different steps; step one is configuring the rules and actions in the cloud.

So, after this configuration is done at the cloud, it is required to deploy these rules at the edge. This deployment will have to be done. Next, the device data will flow from these sensors these IIoT sensors, these device data are going to flow from the sensors or, the end devices to the edge device. Let us assume, that this is the edge device or the gateway, which is doing partial processing.

There after this edge agent analytics agent will do things like aggregation filtering applying the rules generating alerts. There after the data and the action flow are sent back to the cloud, for further processing, where initially we had started with the configuration of the rules and the corresponding actions, that are going to be taken. And thereafter, the actual actions are going to be taken. And also it is important to analyze the data based on this analysis, basically the data, the actions will be taken.

So, basically this analysis of the data will have to be performed and this will have to be done mostly at the cloud, but partly this analytics could also be done at the edge; that means the gateway device.

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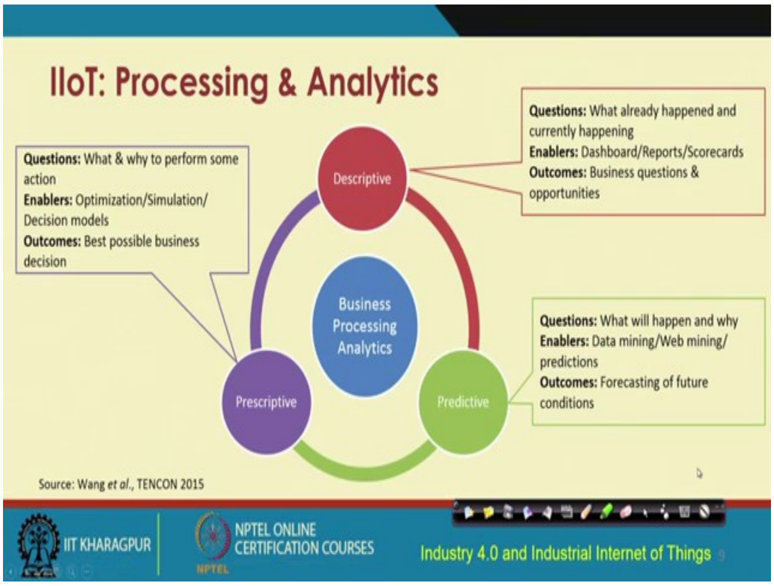


So, we talked about processing, we talked about analytics. So, some business processing analytics will have to be performed. So, this business processing analytics could be of 3 different types, it could be prescriptive, descriptive or predictive.

Prescriptive basically questions things like, what and why to perform some of the actions. And the enablers for doing it, are some optimization techniques simulations, use of different decision models, and so on. And finally, the outcome is the best possible business decision and this is prescriptive. As this name suggests prescriptive means that it will prescribe, that what is the best possible business decision.

Descriptive talks about what has already happened and is currently happening. And based on that coming up with outcome such as the business questions and the opportunities, the enablers for descriptive analytics are dashboards, reports, scorecards, and so on. Prescriptive analytics questions, what will happen and why it will happen? The enablers for it are data mining different data mining techniques, web mining techniques, and predictive techniques. The outcomes from predictive analytics are forecasting for future conditions

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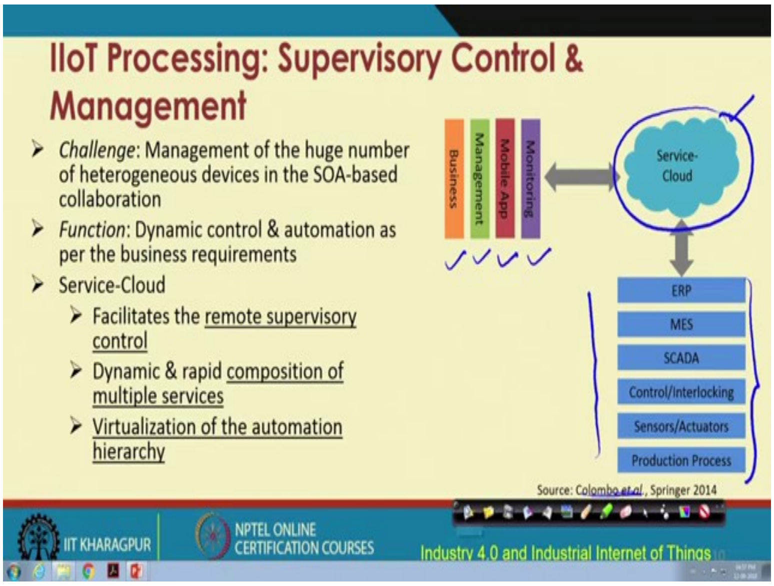


So, there are different solutions, that are placed that are in place, with respect to analytics and processing. So, one of the solutions the source is given over here. So, this particular solution was proposed by Colombo et al, talks about supervisory control and management in the context of processing. So, as we can see over here its 3 different components in this particular solution mechanism.

At the center is basically the service cloud and at the bottom are a stack of different layers. So, it starts with the production process; production process, then the sensors and the actuators control and interlocking SCADA, MES, and ERP. So, these are the different things, that are implemented as per their solution. And at the same time different functionalities such as monitoring having mobile apps, running different mobile apps, management strategies, business logic implementations, are also performed.

So, this service cloud that we talk about over here, as per the solution by Colombo et al, facilitates some kind of supervisory remote supervisory control. It also does service composition. Service composition means like we will have multiple different services, which will be aggregated together into different clusters of services. So, this is the service composition. And the third component of the service cloud or this or its functionality is the virtualization of the automation hierarchy.

So, these are the 3 primary functionalities of the service cloud as per the proposal by Colombo et al.

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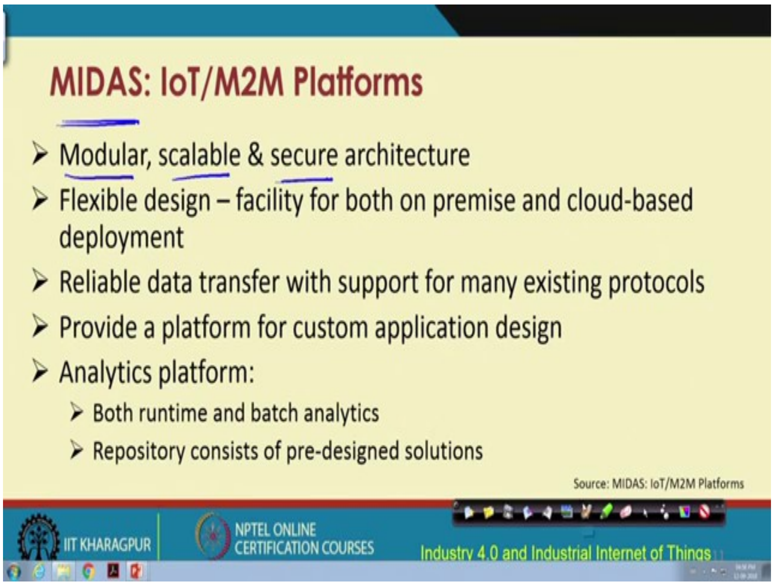


There is another solution named as MIDAS, which provides some kind of IoT/M2M platform. So, this MIDAS platform is a modular, scalable, and secure architectural platform. It provides a flexible design and offers a facility, for both premise and cloud based deployment. So, there are different types of analytics that can be performed through the MIDAS platform, runtime analytics could be performed or batch analytics could be performed and the repository in MIDAS consists of different predesigned solutions, that have been implemented

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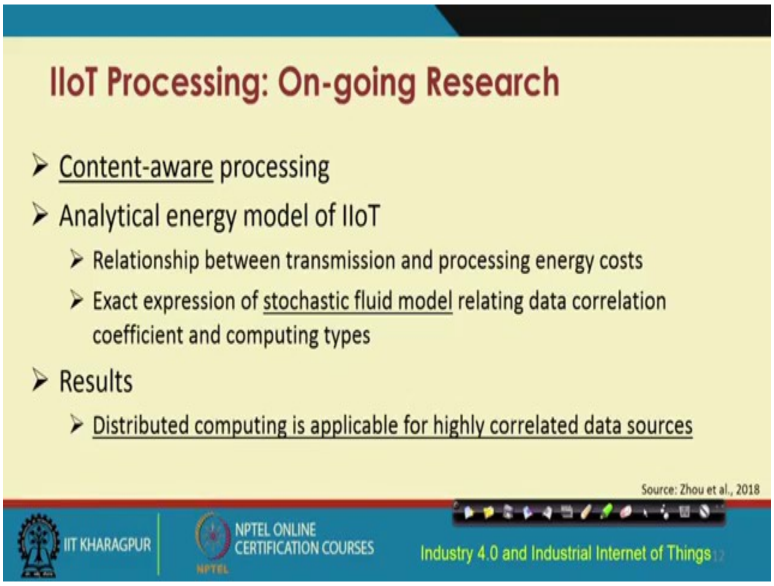


Now, let us look at some ongoing research works with respect to processing, with respect to processing one of the important research works by Zhou et al. the corresponding complete reference is given at the end of the slides. So, this particular work talks about content-aware processing. So, the processing is done in a content-aware. So, what is there the content the processing is done, content aware.

So, they talk about an analytical energy model for IIoT, where the relationship between the transmission and processing energy costs are established. And some kind of a stochastic fluid model is used to correlate the data and try to infer the correlation basically try to infer the decisions, based on that particular correlation.

So, the results of this particular system is to enable distributed computing, for highly correlated data sources. So, that was content-aware. The next one is context-aware. And this particular mechanism was proposed by Akbar et al., and they talk about the use of contexts, different context the information about these contexts are used in order to do the processing. So, here they are talking about stream processing.

So, different streams of data coming from different sources tagged with different contexts are going to be used for processing. So, the limitations of the current CEP - based systems; that means, the context-aware systems is or the traditional systems I am sorry that limitations of the traditional systems are that they use some kind of manual thresholding. So, some kind of a threshold is specified beforehand manually and based on that the decisions are made, and those are not context-aware. So, Akbar et al they proposed some kind of context aware engine which they have named as the micro-CEP engine, which uses adaptive clustering techniques to dynamically detect the boundaries, between the CEP values and find optimal rules.

So, that they do with the help of different rules, which are adaptive in nature, and which are able to extract the causal and contextual relationships between these different data.

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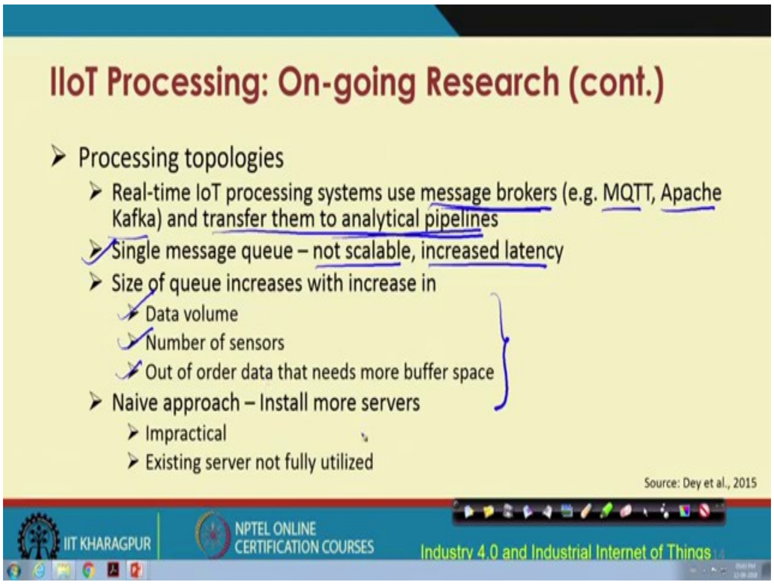


Another work by Dey et al. they talk about the use of different processing topologies. So, here they are talking about real time IOT processing systems using some kind of message broker. Message brokers such as MQTT, which we have studied before or similarly Apache Kafka could be used as message brokers in their system. And those could be used to transfer the data to different analytical pipelines.

In this work, they are talking about the use of single message queues and which may not be scalable and single queues; obviously, will increase the latency. Alternatively, if you are using single message queues, that increases the data volume, the number of sensors that are connected to them, the number of sensors could be reduced, and it is also possible that out of order data will come because the buffer space is very limited. So, all these problems could be dealt with appropriately.

So, a naive approach to deal with this kind of single message queue based system is to install more servers, but installing more servers is impractical, and it might also lead to not proper utilization of this existing server infrastructure.

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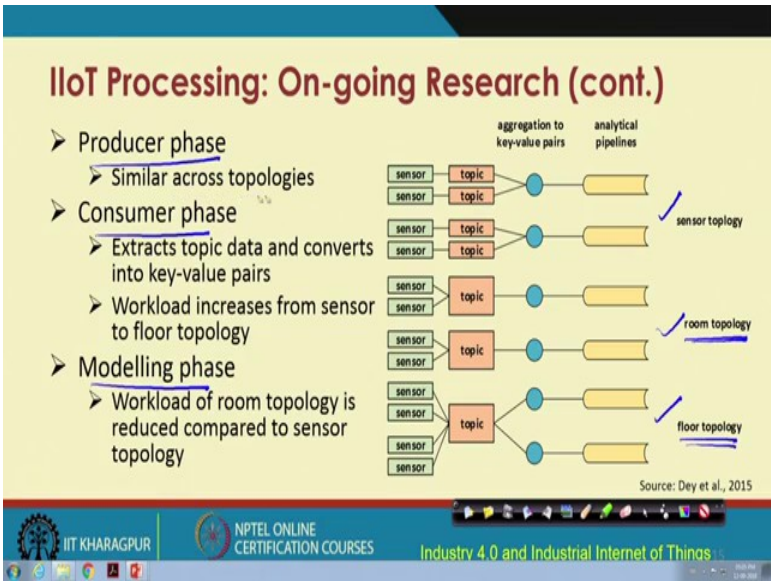


So, Dey et al. they came up with their architecture to deal with this particular problem. In their architecture they have the producer phase, they have the consumer phase, and the modelling phase. The producer phase is similar across different topologies and as we see over here. These are the different topologies that they have analyzed, they have the sensor topology, where we can see that individual sensors are connected or, mapped with individual separate topics, in this manner. And those data are basically aggregated at this junction.

So, this is the sensor topology, they have also analyzed the room topology, room topology basically, what it does is that the topic level this aggregation is performed. So, in a particular room with different sensors this data are going to come and topic wise this aggregation is going to perform in the room level. They also analyze the flow topology, in the flow topology as we can see over here different sensors are installed in the different floors of the building and so, all these sensor data are analyzed and aggregated topic wise, in the floor level.

So, these are the different types of sensor topology, room topology, and flow topology, that they have analyzed. So, in the producer phase the producer phase, basically, is similar across all these different topologies. The consumer phase extracts the topic data and converts them into different key value pairs. And the modelling phase basically does this workload modelling of the data, that are received.

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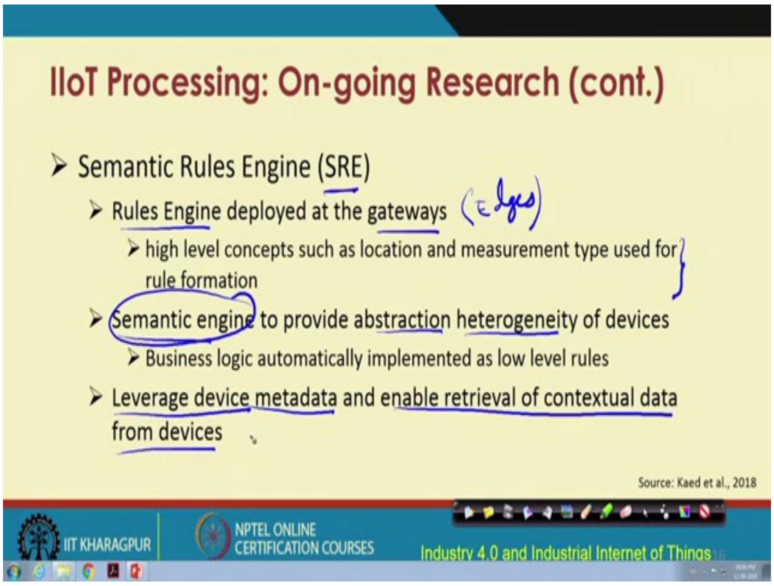


Kaed et al. talked about the use of semantic rule engines SREs, Semantic Rule Engines. These rule engines are deployed at these different gateways or the edges. So, these rule engines are going to do some kind of high level processing, with respect to the location and the measurement type, that is used for rule formation. So, this preliminary level processing is going to be done by the rule engine.

The semantic engine is going to provide abstraction heterogeneity of the different devices, business logics will automatically be implemented as low level rules, in this particular component of semantic engine. And this leveraging, the device metadata and enabling the retrieval of contextual data from these different devices, will be done by the semantic rule engine.

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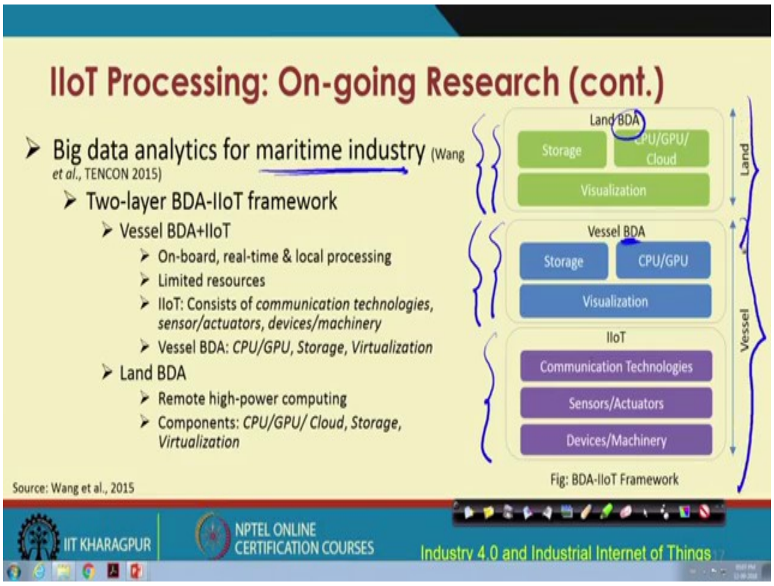


Wang et al. came up with the BDA-IIoT framework, where they are talking about the use of they are proposing a BDA; that means, the Big Data Analytics IIoT framework, for use in maritime industries.

So, in this they came up with this architecture, where they have these components the IIoT component the vessel BDA component; that means, a big data analytic component vessel; that means that the vessel level it is going to be done and the land BDA component, which does the analytics at the land level. So, part of the data will be processed at will be analyzed at the vessel and part of it will be sent to the land, and corresponding engines for vessel level processing, and land level processing are going to be done. So, this is this vessel component and this is this land component.

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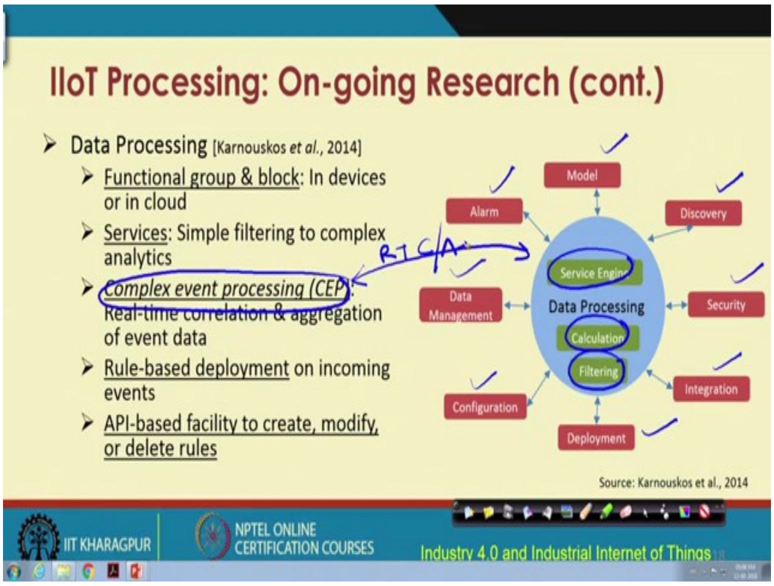


Karnouskos came up with another solution for data processing. So, for data processing they have different components, they have the service engine, a calculation engine, and filtering component. So, all of these things are going to be done at the data processing engine. Service computation, calculation of different types of computation etcetera and filtering all of these are different components of this data processing engine.

So, here basically this particular engine, they have considered to be interacting with alarms different models, discovery component, security components, integration components, deployment components, configuration components, and data management components. So, as we can see over here complex event processing will be performed by this particular service engine over here, which will take care of real time correlation and aggregation of the event data.

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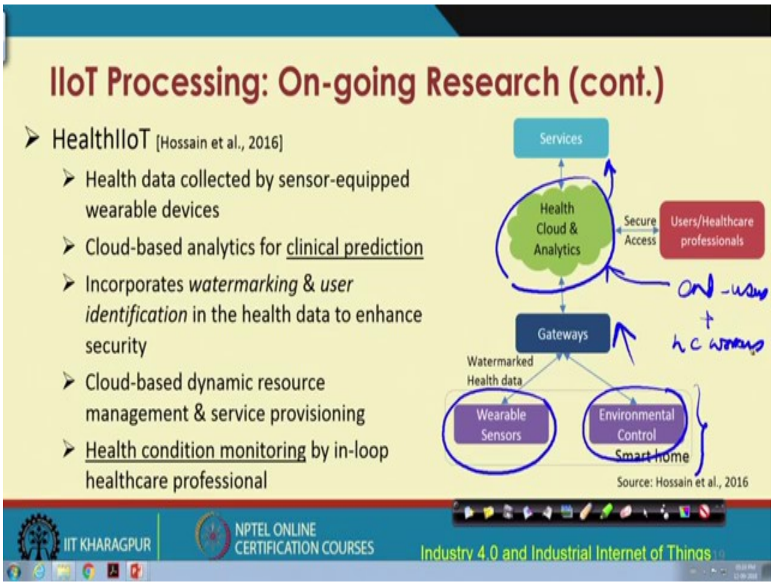


Hossain et al. came up with the health IIoT solution. And this is this solution they came up with, in their architecture they are talking about smart homes. They consider the smart homes, they consider the use of different wearable sensors, which could be owned by different humans, and also the use of different environment control sensors at homes.

So, this data from these environmental sensors and these variable sensors like different health monitoring sensors like spo2, temperature sensor, blood pressure sensor. These are all going to send the data to the cloud for analytics, but it is they are going to send through this particular gateway. And based on these analytics different services are going to be offered to the different users. And these users can get access users means it could be the end users like the people, the residents of the home, end users or, it could be the different health care workers.

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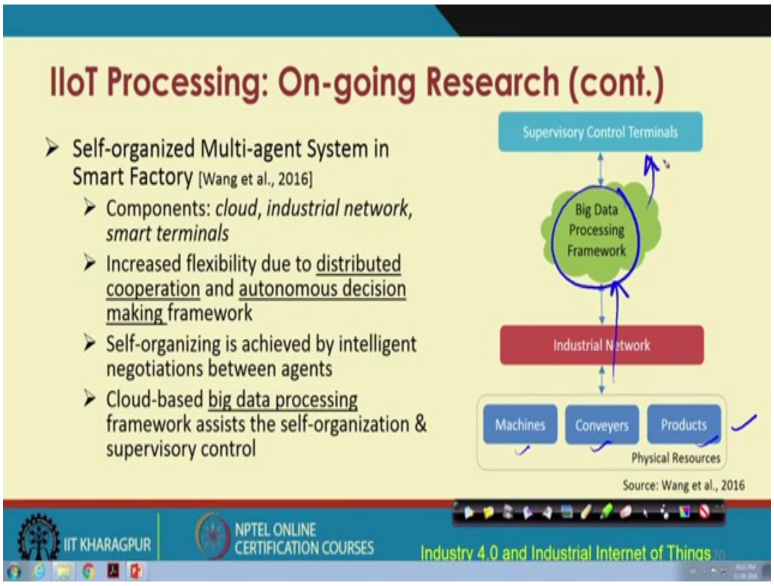


So, in another work by Wang et al. they came up with a multi agent system for smart factories, where they are talking about use of physical resources at the very bottom layer. These physical resources like machines conveyors and the products they are going to be sensor-equipped and are connected to one another. So, through the industrial network the data are going to be coming for centralized event, centralized processing.

These data are typically of the nature of big data and this big data processing is going to be performed. And based on that supervisory control of the different terminals are going to be supervisory control, is going to be performed.

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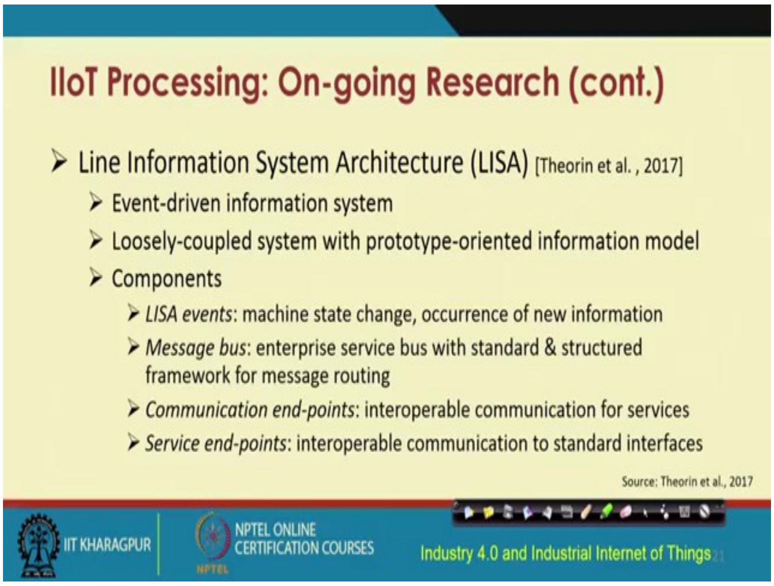


Another work a recent one is by Theorin et al. in 2017, where they are talking about the use of Line Information System Architecture LISA, which is an event-driven information system, which has different loosely coupled components, such as the event component, the message bus, the communication endpoint, and the service endpoint. So, this is this architecture that they have come up with these different components.

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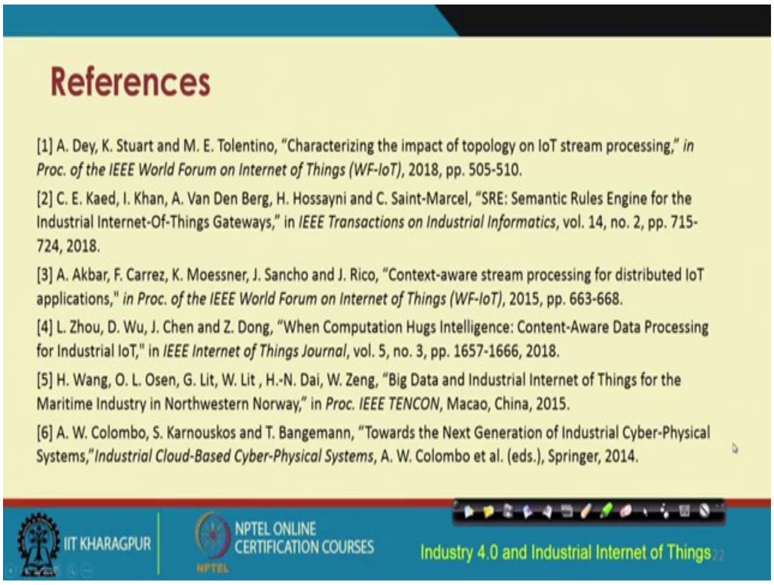


With this we come to an end of this part of the lecture. Here, what I have shown you is initially I talked about the importance of processing of the data. The characteristics of the data, that are received in these IIoT based systems. And then we worked through different solutions, that are talking about installations in different IIoT contexts installations of IIoT systems, in different contexts and their processing.

So, these different references some of which we have gone through so, far will help you to get an idea about how processing is important and how industry scale processing could be implemented, in practice. So, these are all these different references and with this we come to an end. In the next lecture, we are going to talk about a few more case studies, a few more different solutions that have been proposed in recent times focusing on IIoT processing of data.

Thank you.

**Introduction to Industry 4.0 and Industrial Internet Of Things**
**Prof. Sudip Misra**
**Department of Computer Science and Engineering**
**Indian Institute of Technology, Kharagpur**

**Lecture – 34**
**Key Enablers of Industrial IoT: Processing – Part 2**

In the previous lecture we talked about the importance of analysis of the data that are collected through these implementation of IIoT systems. We looked at the data characteristics and thereafter we went through the different research works that are being undertaken. And the different proposals correspondingly that are there; in order to implement effective efficient processing systems to be implemented and deployed in practice.

So, let us look at few more solutions. We have gone through quite a few of them, but let us look at a few more solutions and see how this processing component is becoming important in all of these different solutions that are being proposed. So, FarmBeats is a solution that is proposed by Vashisht et al in 2017.

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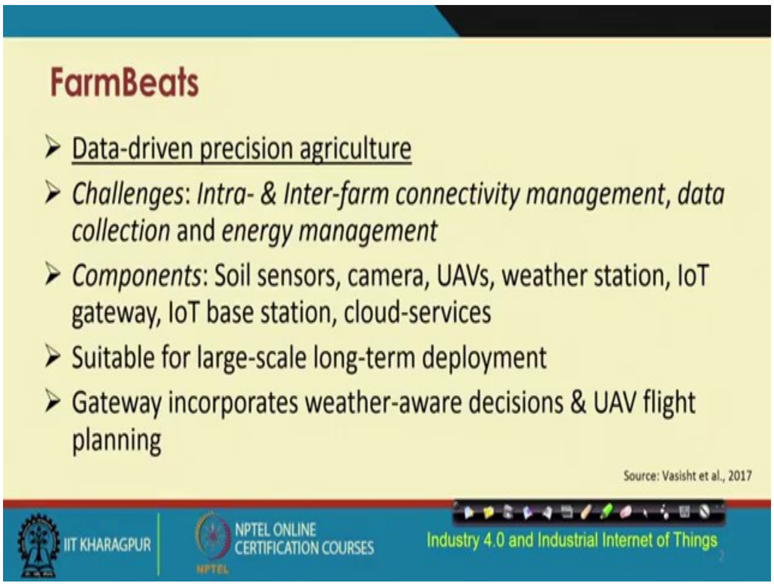


So, there basically this particular work is talking about the use of data driven architecture for; precision agriculture. Precision agriculture talks about that through the use of different sensors and autonomous systems how the precise decision making can be done for different agricultural problems.

So, in this particular work FarmBeats they talk about the use of different sensors such as; the soil sensors, cameras, UVAs weather stations, IoT gateways, base station, cloud services etc. And together they come up with an integrated architecture which can be used for deployment in agricultural farms in order to have an efficient mechanism for collecting data. And also correspondingly processing of the data as soon as possible the data are collected as quickly as possible the data are collected processing of the data and eventually feeding it back to the user for further use.

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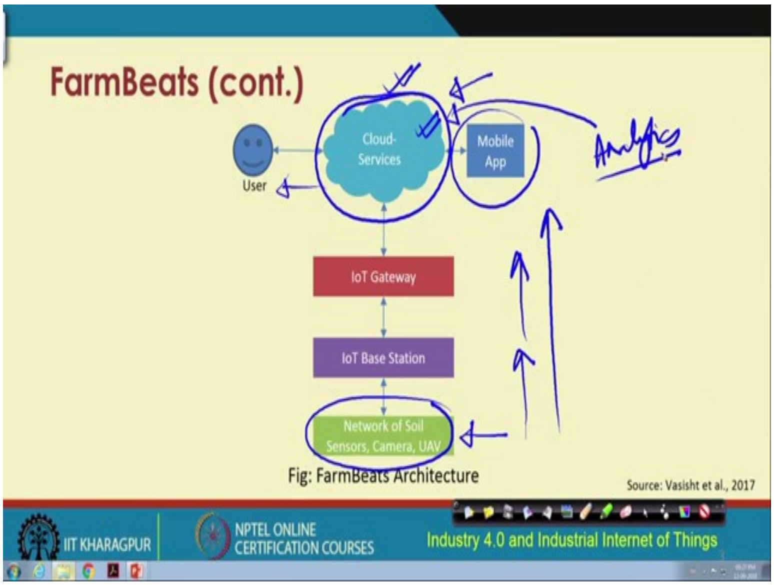


So, this is this FarmBeats architecture that they talked about Vashisht et al. And here as you can see at the very bottom what we have are the different sensor such as the soil sensors, cameras, UAVs and you could talk about different other sensors. And as we go higher up we have the base station the gateway and so on. All of these data basically that are collected from these different in devices will go through this particular network hierarchy.

And will come to the cloud and at the cloud this different analytics will be performed and through different apps or through websites and so on this data are going to be made available to the users. So, as we can see over here this is the integral part in this particular architecture. Here we are talking about this cloud surfaces. So, precision agriculture talks about precision agriculture talks about making meaningful inferences out of the data that are collected as quickly as possible.

Using a processing engine typically in the form of cloud-based architecture use of cloud-based architecture for prompt efficient effective mechanism for decision making is what precision agriculture basically talks about. And this is implemented in this particular lecture the processing part and the analytics part is implemented using this cloud-based services. So, this analytics is performed in this particular component of this their architecture.

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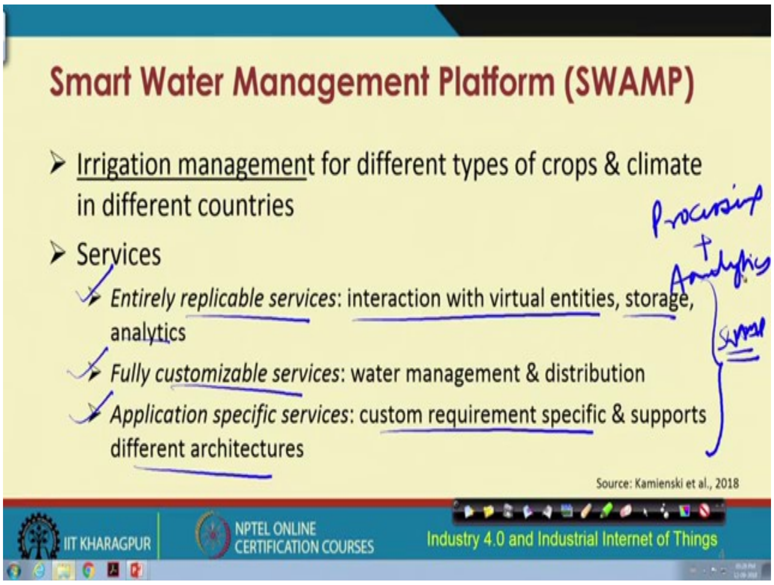


Next comes another work again with respect to in the in the domain of agriculture. So, the SWAMP is a Smart Water Management Platform. Here basically they are talking about the authors they are talking about the irrigation management. Irrigation management based on the different types of; crops, climatic conditions, different regional variations and so on.

With the help of different types of sensors which will be again collecting different types of data from different locations and so on. And this data will be analyzed and different services are going to be offered to the end users replicable services which will give interaction with virtual entities storage and analytics. Different other services such as customizable service for water management and distribution and application specific services for custom requirement specific support and support for different architecture.

So, these are the different types of services that this particular work by Kamienski et al in a very recent work talks about. And this is part of the SWAMP architecture. So, as you can see over here processing and analytics for precision agriculture is basically emphasized through these different works.

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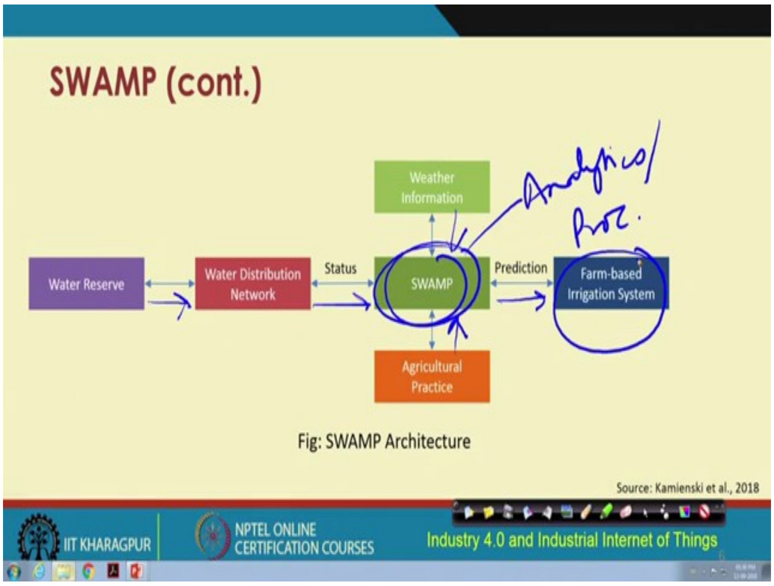


So, this is the SWAMP architecture and in this architecture as I mentioned already. So, as we can see these are the different components which are interacting with SWAMP agricultural practice weather information status about the water distribution. And data about data from the water reserve water distribution network their data everything fed together at SWAMP and decisions being made.

That means, decisions means that again analytics use of analytics and processing and these will help in making different predictions. So, predictions with respect to farm based irrigation when to irrigate what to irrigate which equipments will be better and so on. So, all of these things can be done with the help of SWAMP and similar other architectures for precision agriculture.

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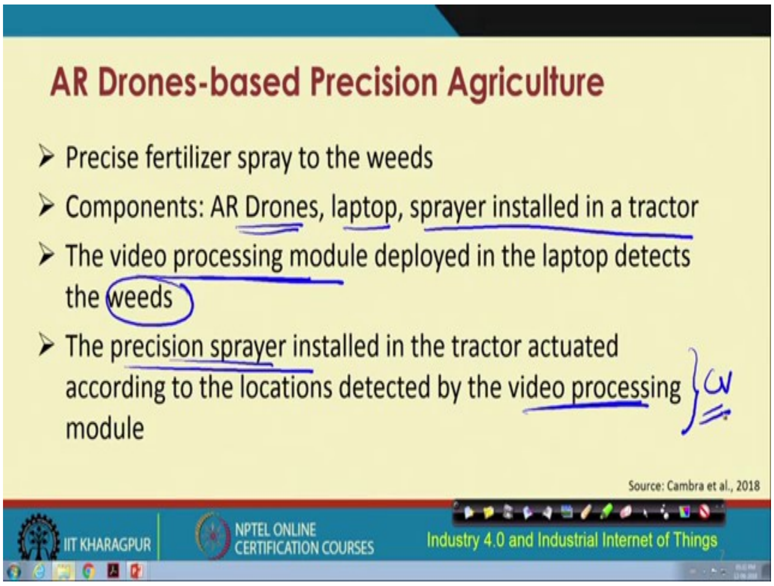


AR Drones basically the parent drones and so on. So, these drones can also be used for precision agriculture and nowadays use of drones has become very common. And in our research lab the SWAN research lab in the department of CSE at IIT Kharagpur we are also using drones along with our colleagues from agricultural department at IIT Kharagpur we are using drones of different types for precision agriculture.

So, we have different applications, but let us look at this particular work by Cambra et al and it is a very recent work published in 2018; that means, very recently it has been published. And here basically they are talking about precise fertilizer spray to the weeds. And this is a very important and a challenging problem. Because the problem is that you need to have precise spray of weedicides in such a way that only the weeds will be sprayed and the other places will be minimally affected right. So, this is a very important and a challenging problem as well.

So, complex event processing mechanisms will have to be implemented if you want to address this kind of problem. So, here in this particular solution they are talking about the use of AR Drones, laptops, a sprayer installed in the tractor, video processing modules. And this video processing module basically helps in this spraying of the weedicides on the weeds.

And also the use of the precision sprayer which is installed to the tractor. And is actuated according to the locations that are detected by this particular video processing module.

So, here actually this particular solution they are using computer vision mechanisms for the decision making and analytics.

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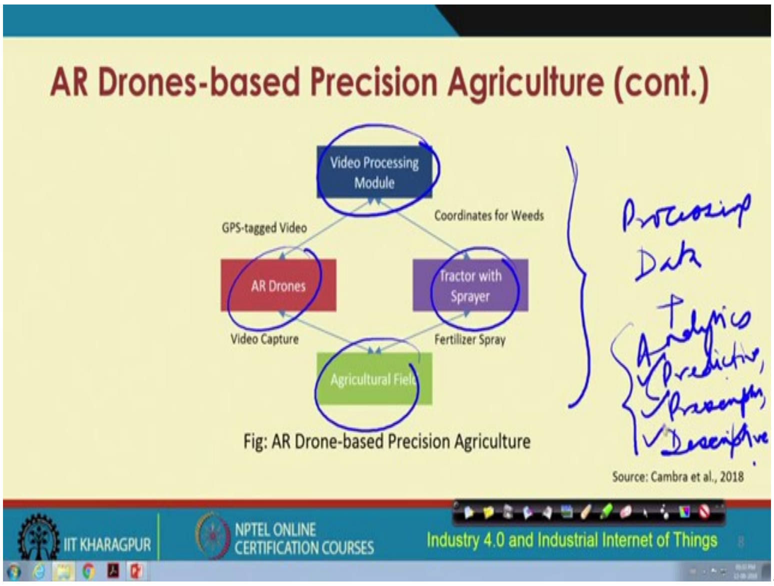


So, this is this overall architecture pictorially it is shown over here. So, we have these different interactions between these different components. This is this video processing model that I was talking about earlier. So, drones, video processing module, tractor with sprayer which can be actuated, and agricultural field and the overall flow of data between these different components are shown over here.

So, data and the processing of the data again is very important and suitable analytics will have to be performed. These analytics could be again predictive or they could be prescriptive or descriptive. So, this architecture basically does not talk about so many different things of analytics. But gives a common architecture where we could extend to implement all these different types of analytics using their solution.

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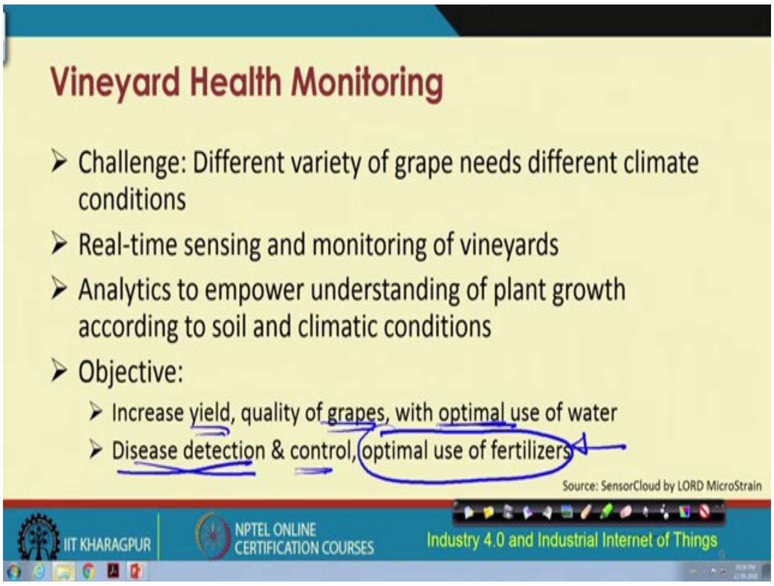


Another one again from agricultural application domain this is for; vineyard health monitoring. So, the challenge in vineyards is that there are different varieties of grapes which will have requirements for different climatic soil and different conditions. So, it is very important to have real time sensing and monitoring of the vineyards.

So, the objective is to have to increase the yield, quality of grapes and optimal use of water. And at the same time decrease the incidences of the plant diseases and control them and consequently based on the predictions optimally use the fertilizers and spray them.

So, this is the vineyard health monitoring solution and the corresponding source for this particular work is also given over here. In case you are interested you are encouraged to go through this particular literature.

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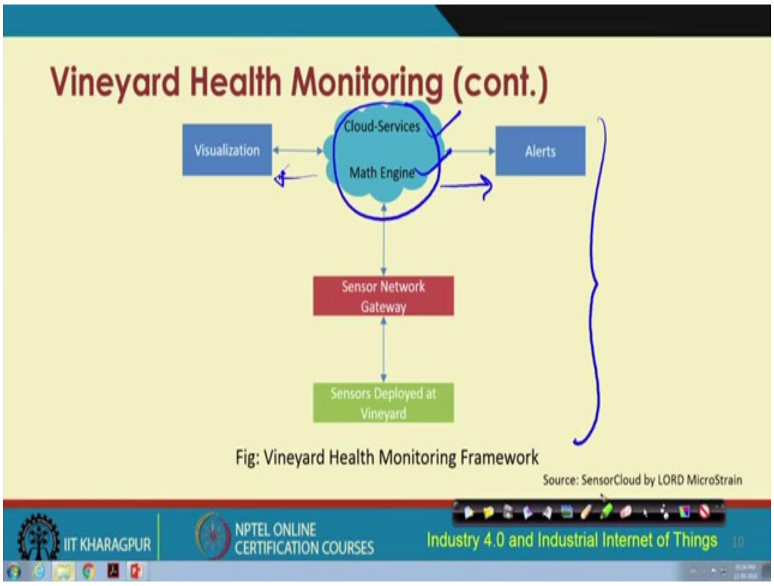


And this is this overall architecture and as you can see over here. This is also this processing engine which consists of the cloud as well as the Math Engine. So, this is what this particular work talks about. And so interaction with the visualization component and generation of alerts this is what is supported in this vineyard health monitoring solution by micro stream.

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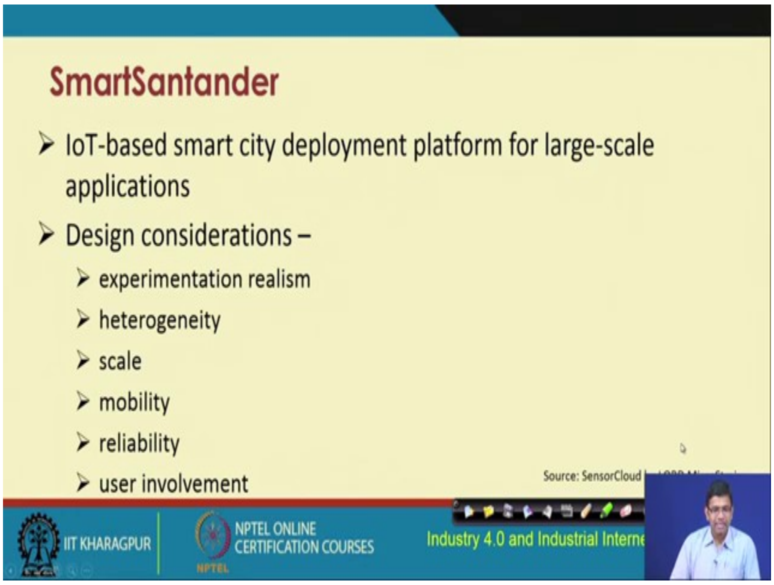


Another work is the SmartSantander. So, this is an IoT-based smart city deployment platform for large scale applications where; the design considerations are with respect to the experimentation, realism, heterogeneity, scale, mobility, reliability user involvement and so on.

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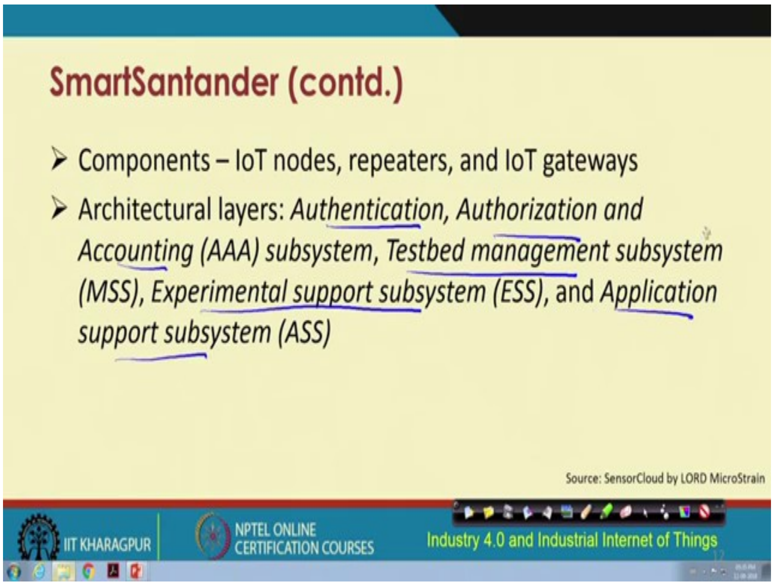


And they have come up with an architecture which uses different components such as the different IoT nodes the sensor enabled IoT nodes the repeaters IoT gateways and so on. And it has different architectural layers such as; authentication, authorization, accounting, testbed management subsystem, experimental support subsystem, and application support subsystems. So, each of these subsystems they have their own different functionalities.

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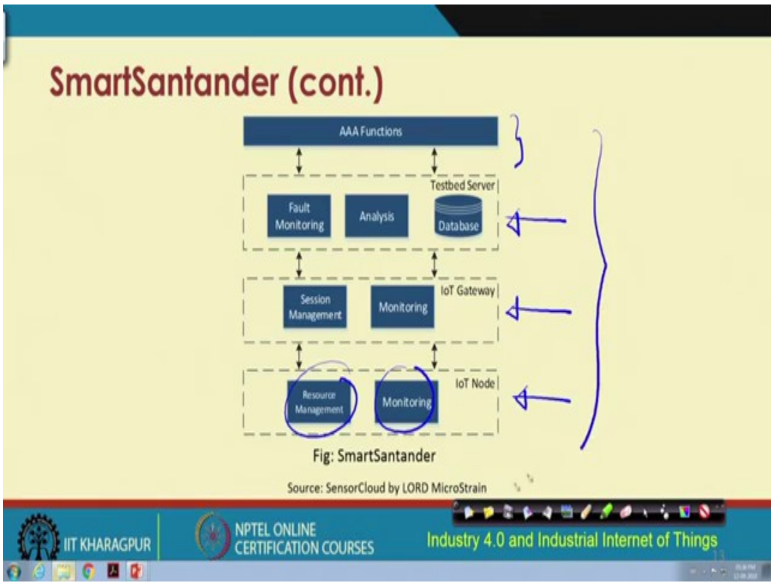


And this particular work they talk about the involvement of all of these different components to arrive at a common solution. So, at the very bottom is the IoT node, then is the gateway and the testbed server. And these different functionalities that are going to be supported on this particular architecture. And the corresponding different components are also shown over here in this particular figure.

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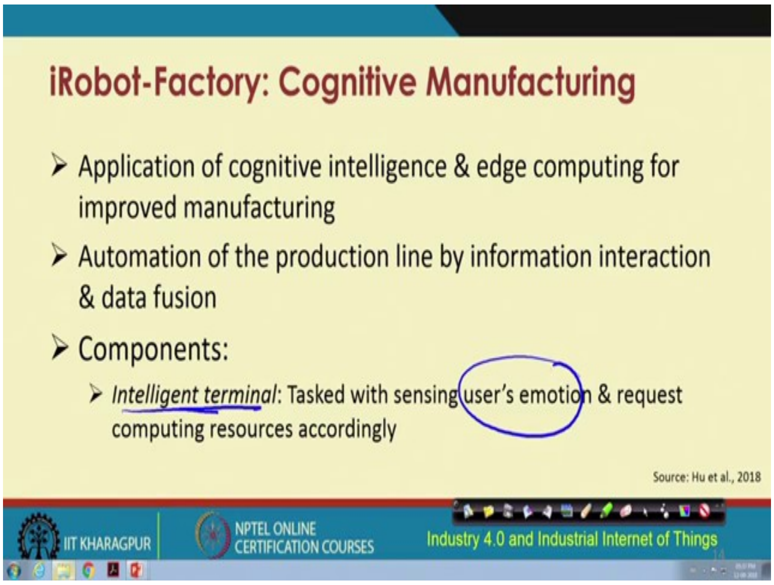


iRobot factory is a solution that is proposed very recently by Hu et al and here they are talking about cognitive manufacturing. So, cognitive means intelligence, intelligence means computation, computation means like lot of processing we will have to be done lot of processing. And if we are talking about cognitive processing that basically is computationally intensive.

So, analytics is very important in this kind of situations or this kind of scenarios. So, this is the work which uses different components such as the cognitive or the intelligent terminal which is tasked with the sensing of the users emotions and requesting computing resources based on the perception of the emotions of the users and different other components.

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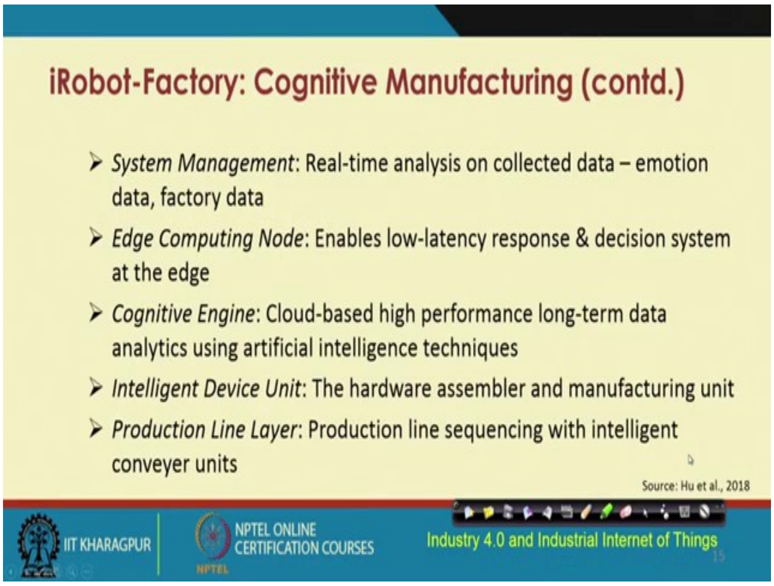


Such as the system management, edge computing node, cognitive engine, intelligent device, unit and production line layer. So, all of these are different components of this iRobot factory. And I am not going through the individual descriptions of each of these components. And it is already given to you and it is very similar actually all these different types of architectures they are conceptually they are very similar.

And the only thing is that there is some application specific problem specific requirements which have been implemented through the different use of different components and so on. So, I am not going to go through each of these, but is given to you, if you are interested you can go through and understand in further detail.

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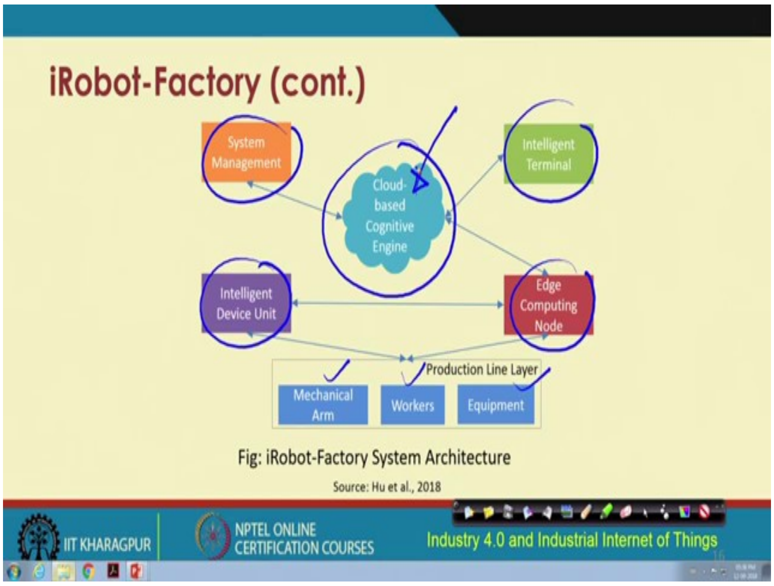


And this is this iRobot factory system architecture and here as we can see we have this production line layer which has the mechanical arm workers and equipment components. Then comes this layer of intelligent decision unit and edge computing, and the intelligent terminals, and system management components.

All of which are interacting with this cloud-based cognitive engine. So, as we can see a time and again that for these different architectures different solution. This cloud-based cognitive engines are being used.

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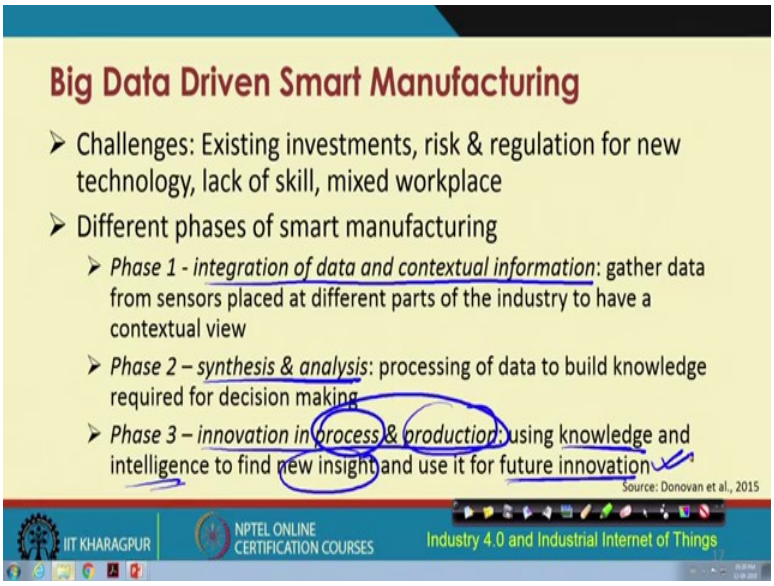

Another work from 2015 by Donovan et al it talks about big data driven smart manufacturing. So, the challenges that they have addressed are that there is existing investment, risk and regulation of new technology, lack of skill, mixed workplace, and so on. So, all of these are different challenges in the manufacturing sector.

So, you want to address these challenges with the help of some kind of a smart manufacturing system. So, there are different parts of the smart manufacturing system. One is the integration component of integration of data and contextual information. Second is the component that deals with the synthesis and analysis of the data. And the third component talks about innovation in the process and the production.

So, process component and production; innovation will come through the use of knowledge and intelligence for deriving different new insights and correspondingly making different predictions which will lead to different innovations in the future.

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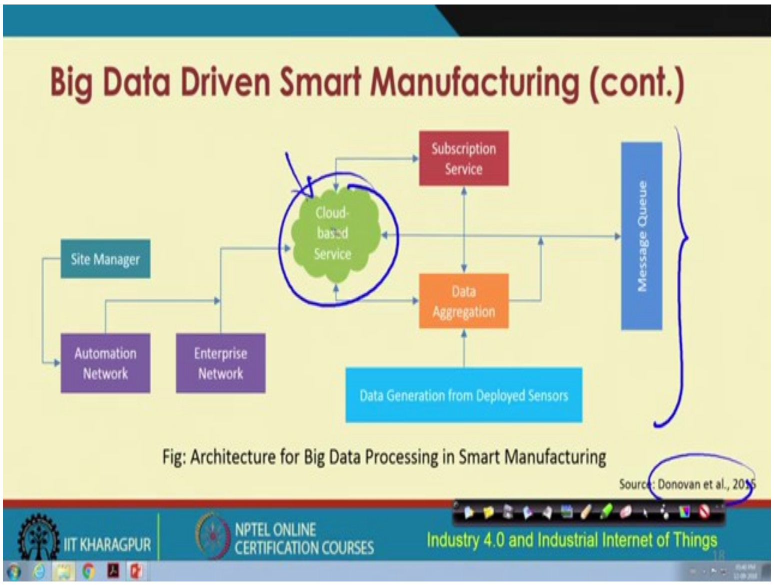


This is this big data driven smart manufacturing architecture. So, all these different components that we talked about and different other components additionally have been shown over here. So, again I am not going to go through, but this is quite self explanatory.

And if you are interested you can go through the corresponding literature the source is given over here. But again as we can see over here this is again data intensive, knowledge intensive, analytics intensive, and so on. And all of these kinds of processing are done at the cloud.

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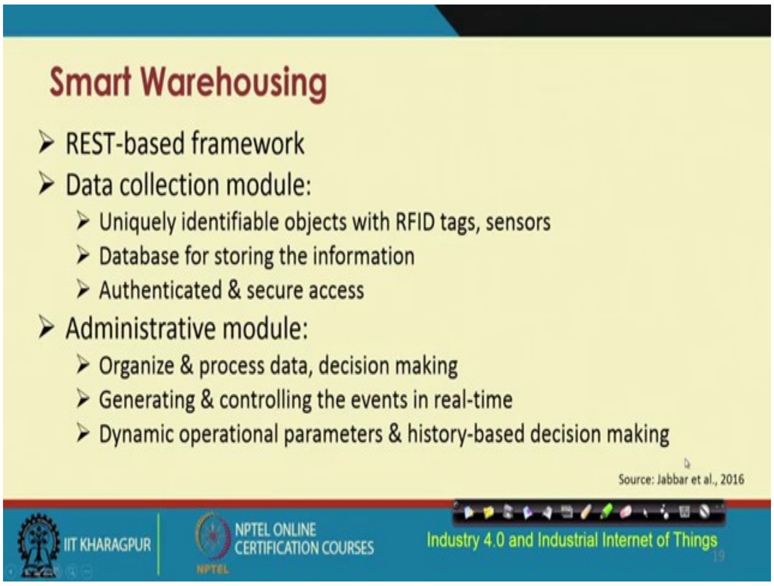


Smart Warehousing, here the authors are talking about Jabbar et al they are talking about the use of a rest based framework. This framework collects the data the data collection module is there which uniquely identifies the different objects with RFID tags and sensors. There is a database component for storing the information and for authentication and secure access. And there is an administrative module which talks about organizing organization of the data processing of the data decision making and so on.

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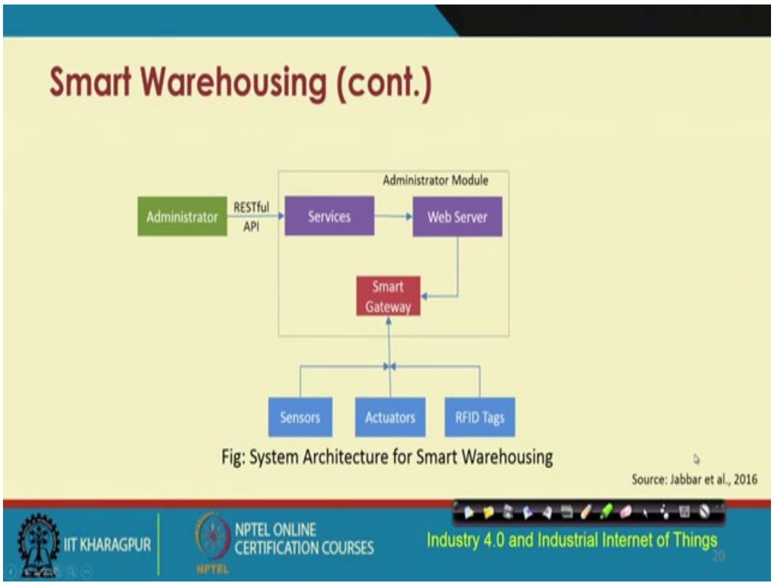


This smart warehousing architecture is shown over here. So, here also as we can see there is this smart gateway that is used, the web server, a service component all of these are going to do different types of processing and analytics. So, which analytics are going to be done this might be a question that might come to your mind. So, what type of analytics?

So, this is where basically we can take help of the different types of analytics and AI techniques that we talked about in one of the previous lectures. So, these solutions which basically make it keep it open about the type of analytics that could be implemented. But any of these analytics like the predictive, prescriptive, descriptive any kind of analytics could be implemented in most of these architectures and the specific solutions that could be used are left open.

But one could use any of the different types of computational intelligence mechanisms based on may be fuzzy logic, neural networks, deep learning and so on. So, any of these could be used different optimization techniques could be used. And different predictive techniques such as game theoretic techniques and so on could also be used to come up with some optimal solution to a particular problem based on the data that is received.

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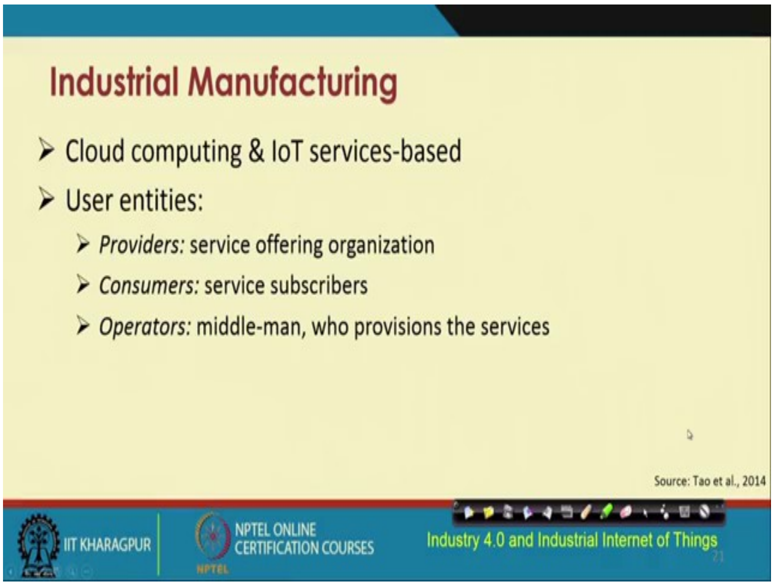


So, like this there are different other solutions industrial manufacturing solution by Tao et al., in 2014. Here they are talking about a cloud and IoT based solution for industrial manufacturing where they are using different entities such as; the providers the consumers and the operators. I do not need to go through the meaning of each of these different entities because it is quite self explanatory.

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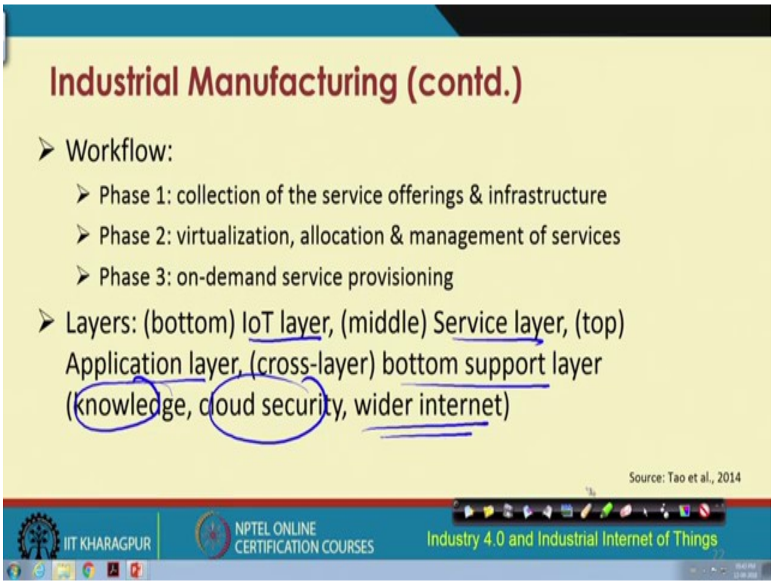


They are talking about workflow in different phases. Phase one collection of the service offerings and the infrastructure, phase two is the virtualization, allocation and management of the services, and phase three is on-demand service processing. So, in their architecture they have all these different layers and the layers such as the IoT layer, service layer, application layer, the bottom support layer. That means, the knowledge cloud security, internet and so on so all of these different layers are used.

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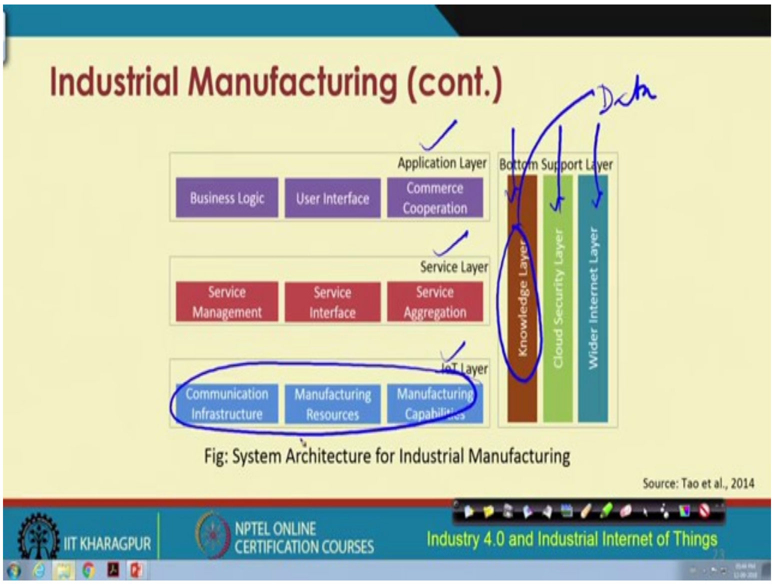


So, this is this overall integrated architecture. So, we were talking about all these different layers. Application layer on the very top, service layer, IoT layer, and the bottom support layer, which cuts across all of these layers of application service and IoT. The knowledge layer, the cloud security layer, and the wider internet layer.

So, each of these layers so knowledge layer particularly is quite data intensive. And in order to get the knowledge out of the different data that are collected from these different IoT devices that are deployed in this particular layer; you need to have different advanced forms of analytics in place.

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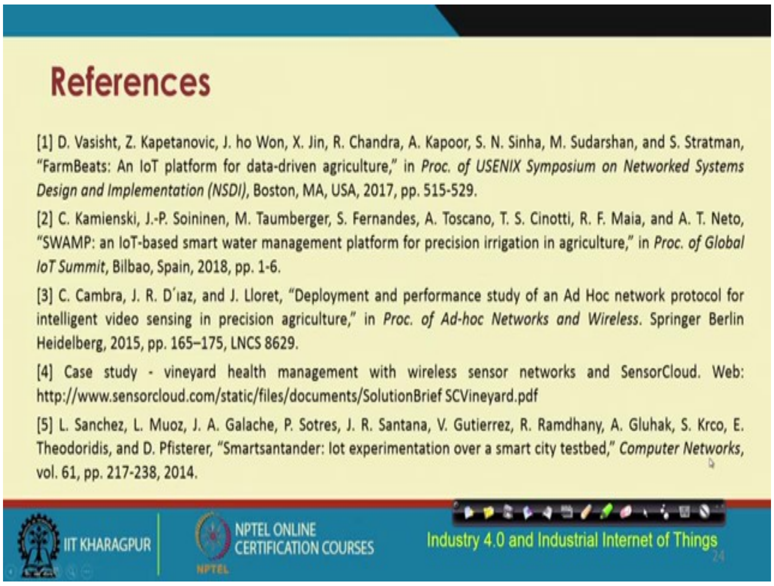


So, like this there are different solutions that are there. So, these are some of the ones that I have just explained. The corresponding references are given to you at the end over here. And if you are interested you can go through whichever is more applicable to you whichever interests you more if you are from if you have interests in agriculture the ones that I discussed at the very beginning you can go through the corresponding literature in further detail.

If manufacturing is one that interests you more you could go through the corresponding literature. We talk which talks about the smart manufacturing solutions and so on. But what is very important in this lecture and the previous one is to understand that we can deploy whatever sensors are required for addressing a particular problem. We can also place the connectivity solutions, the communication infrastructure, networking infrastructure and so on.

But thereafter how do you have to deal with the data that is coming through these different layers from the sensor layer through the connectivity layer the data that are coming will have to be processed adequately. And for this particular processing different solution architectures I have shown you will which will give you a hint about the particular solution architecture that you are going to implement and are going to come up with for your specific problem that you have in hand. And the different types of analytics processing means analytics.

So, different computational techniques will have to be implemented, different optimization techniques, game theory, neural networks, genetic algorithms, or fuzzy logic or anything you know. So, what is more important for you; so those will have to be implemented and then just mere implementation is not sufficient you will have to from the data you will have to gather the information.

Further gather the knowledge at an even higher level of abstraction and it is that information and knowledge which is going to be useful. So, with this we come to an end of the processing part.

Thank you.

**Introduction to Industry 4.0 and Industrial Internet of Things**
**Prof. Sudip Misra**
**Department of Computer Science and Engineering**
**Indian Institute of Technology, Kharagpur**

**Lecture – 35**
**Key Enablers of Industrial IOT: Process Control**

So, far in this particular module, we have talked about different layers; layer such as sensing. It started with the sensing, connectivity which took care of communication networking and so on. Connectivity, processing, so the data that are collected will have to be processed; so, processing we have talked about and then, comes the control. So, basically based on the processing may be some kind of a feedback will have to be given back, some kind of a control. So, for this actually there are different process control mechanisms are there particularly, in automation industries.

Industries which support different automation technologies such as PLCs, SCADAs etc. are used. So, we are going to have a brief look at each of these technologies PLC, SCADA and so on and at the end, I promised you to show you the use of this PLC, SCADA kind of system in a case study that we have used for implementing a certain application with the help of this PLC, SCADA kind of system. So, I will show you that at the end.

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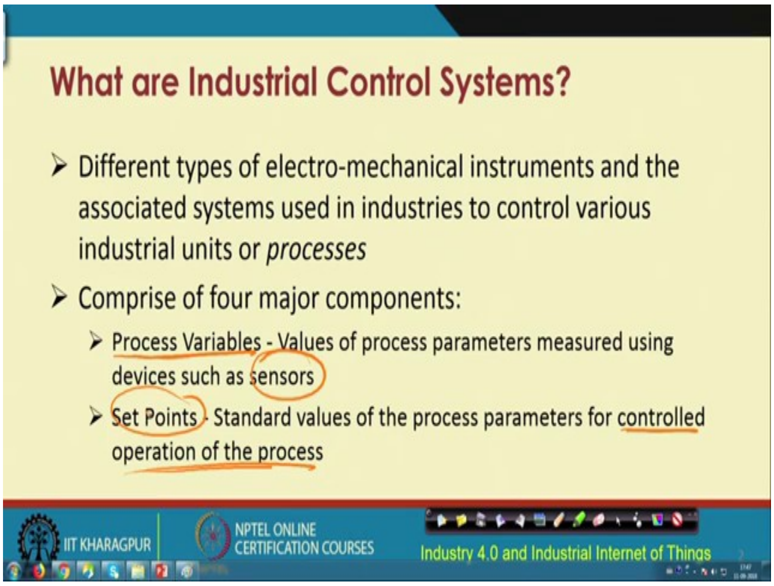

So, let us start with at the very beginning we need to understand this control part in the industrial scenario. So, there are different processes which control this in industrial instruments, the way they work and so on. So, there are different electro-mechanical instruments that are there and this their associated systems are used in the industries to control and offer feedback to the machinery that is used the process that is being implemented that is in process that means, it is being executed and so on.

So, there are four major components. The first one over here is we need to understand, the first one is the Process Variable. Process variable are basically the values of the process parameters measured using devices such as sensors. So, this process variables or the values of this process parameters would be measured with the help of sensors.

Then, comes the Set Points; set points are basically the standard values of the process parameters for controlled operation of the process. So, this is very important, this is for feedback control. So, controlled operation of the process for that we have this concept of the set points, which are the standard values of the process parameters.

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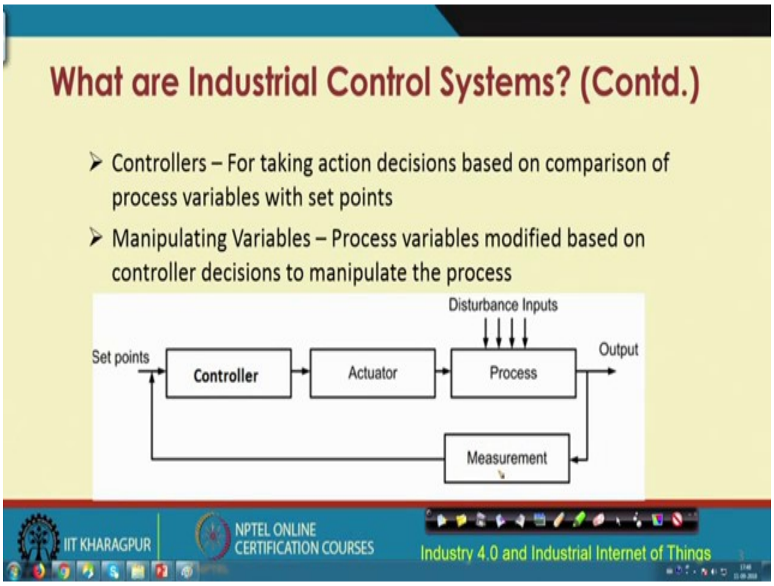


Next comes the concept of the Controller. So, the controller basically takes certain actions. So, based on the process variable based on set point value and so on, it takes certain decisions it or actions and it compares the process variables with the set points before it takes the action. So, this is what this controller does and this is what you see over here in this picture as well.

So, we have this controller, we have the actuator, the process and the measurement. So, the based on the set points basically this controller. So, this controller does this controlling, then comes the actuator. The processing is done over here and then, based on the measurements of how things are. So, this there is a feedback back to the controller. So, this feedback cycle where based on the measurements of the current process parameters and so on, there is a control loop back to the controller and then, we have the manipulating variables which are basically process variables modified based on the control decisions to manipulate the process.

So, this is important part, the manipulation of the variables is the most important part in this particular process and for that this measurement is very important.

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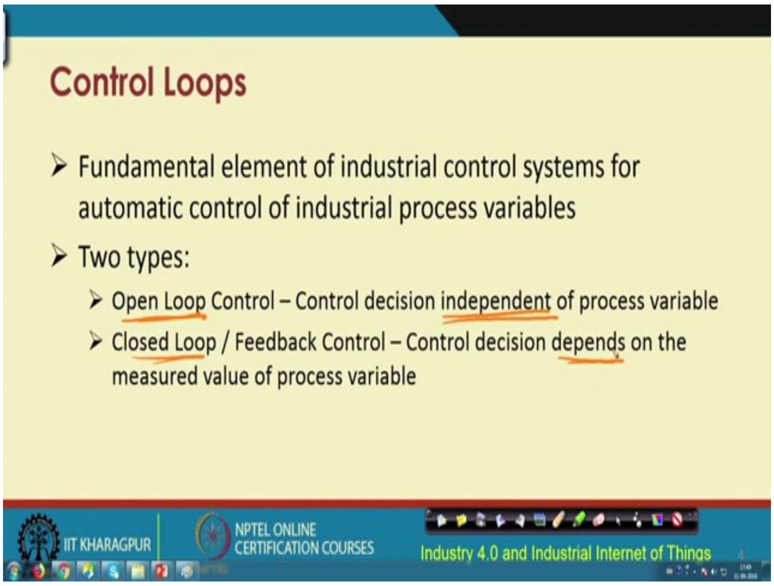


So, we let us look at this Control loop because it is this control loop which is the attractive part in the whole process control automation and so on. So, this control loop is the fundamental element of industrial control systems and this basically these control loops help in automatic control, unmanned autonomous control, automatic control of industrial process variables is offered with the help of this control loop.

So, there are two types of control loops; one is the Open loop control rather and the other one is the Feedback control or the Closed loop control. So, open loop control; open loop here the control decision is made independent of the process variable, control decision independent of the process variable whereas, in the feedback mechanism of the closed loop mechanism, the control decision basically depends on the measured value of the process variable. So, there are two types of control.

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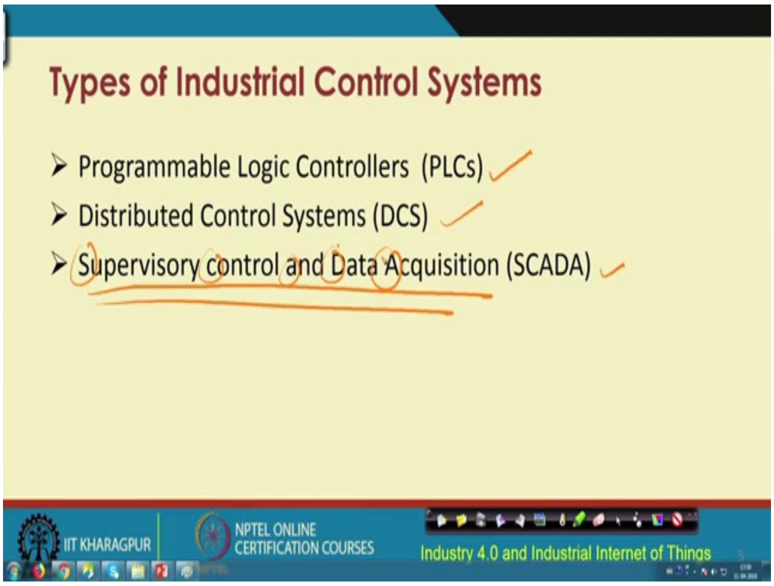


So, there are different industrial control systems that are used for process control. One is the PLC, the Programmable Logic Controller; second is the DCS, the Distributed Control Systems and the third is the SCADA which stands for Supervisory Control and Data Acquisition; Supervisory Control and Data Acquisitions S C A D A. So, this SCADA and SCADA in turn basically use the concept of the PLCs.

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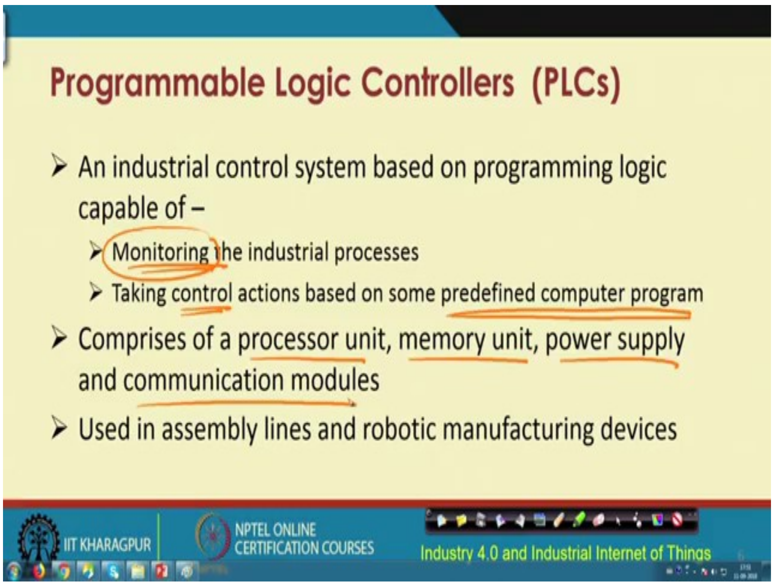

So, what is this PLC? So, basically PLC is the industrial control system. So, it is the industrial controller in control system and this is based on the programming logic of monitoring the industrial processes and taking control actions based on certain predefined computer program. So, the computer program has a predefined set of instructions is provided to the system and based on that the control actions are taken and for that first the monitoring will have to be performed.

So, it comprises of a processor unit, a memory unit, and power supply and communication modules. It is used in assembly lines and robotic manufacturing devices a lot. So, all assembly line things nowadays where there is automation, robotic manufacturing facilities mostly you will find that what is used are these different PLCs in different forms.

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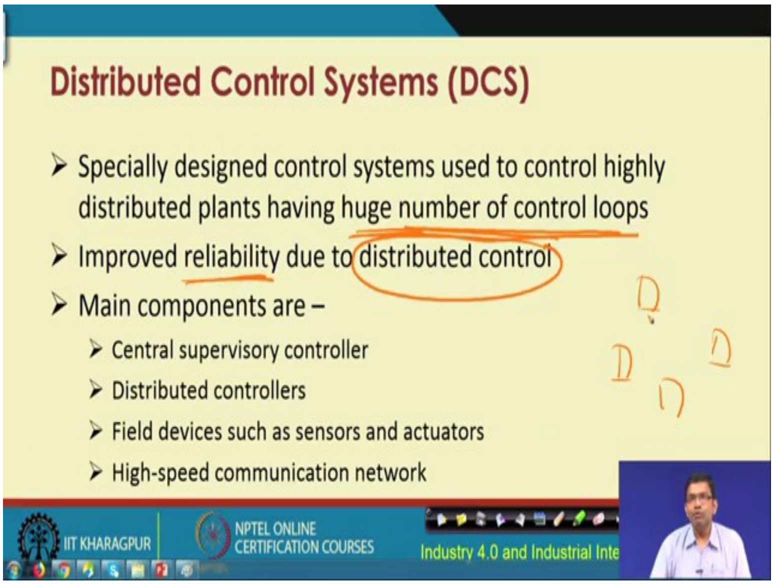


Distributed control systems are specially designed control systems that are used to control highly distributed plants having large number of control loops; large number of control loops is basically the characteristics of the use of DCS and DCS basically provides an increased reliability because there is distributed control. So, if you have distributed control, then that basically offers large reliability because so the control itself has been distributed. So, if one element fails you are going to still have improved reliability.

The major components in use in DCS are the central supervisory controller, distributed controller, field devices such as the sensors, actuators and so on and this communication backbone, the high speed network communication and it has to be high speed. That is the requirement for serving the different communication requirements in the industrial sector, particularly the manufacturing process plant and so on.

So, we will now have a look at the SCADA which is very popular. SCADA is very popular in industrial automation plants and this is very attractive in the industry 4.0 context, because these are the building blocks basically. Because in the industry 4.0, we are talking about a lot about automation, connectivity between these different machines autonomously, autonomous monitoring, control feedback and so on.

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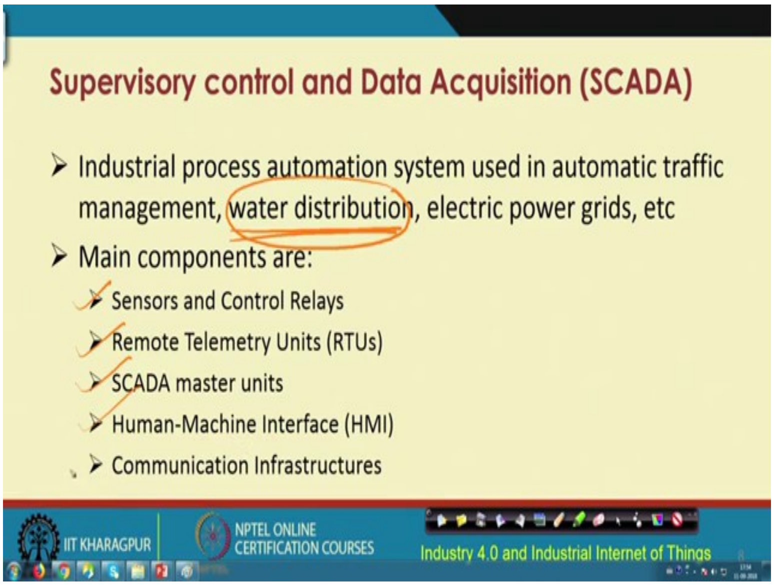


So, this kind of device SCADA based device basically is helpful in order to achieve the requirements of industry 4.0. So, industrial process automation systems are used in automatic traffic management, water distribution then, electrical power grids and so on and in this particular lecture, I am going to show you the case study of use of SCADA in water distribution system, but it could be used in other plants also.

So, water distribution system, I will show you where we are using SCADA based control system for monitoring the water distribution in test bed scale in one of our facilities in our campus at IIT Kharagpur. So, these are some of these different components. Sensors, Relays, Telemetry Units, SCADA master units, HMIs that means, the Human-Machine

Interfaces and the Communication Infrastructure. These are the different facilities that are used and that are the, these are the different components that are used.

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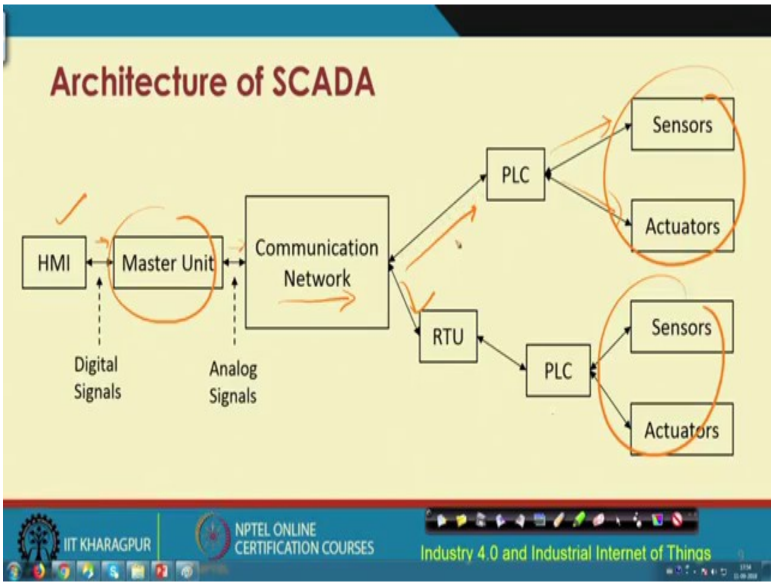


So, here is the Architecture of SCADA. So, here we have as you can see we start with the HMI which is the Human Machine Interface. Then, comes the master unit which takes the digital signals from the HMI and then, converts to the analog signal. So, this basically these master units sits in between the HMI and the communication network and converts the digital signals to analog and analog to digital and vice versa.

Then that particular signal after conversion flows through this communication network and goes to the PLC, to the RTU. From the PLC the sensors, actuators, the different field devices are controlled like this and so on and these communications are two-way communication as we can see over here the double headed arrows basically represent the that there is double sided communication SCADA systems.

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So, right now I am going to show you one of the applications of the use of SCADA and PLC. So, this application I have chosen from the water sector; water distribution particularly and this is basically a facility that we have in IIT Kharagpur in the school of water resources. So, this is a kind of lab test bed setup for water distribution monitoring particularly with respect to leakage and autonomous and continuous monitoring and so on. So, of a water pipes monitoring with respect to leakage and it can be in even extended for other types of monitoring of water quality and so on and so forth.

So, I have with me Professor Manoj Kumar Tiwari, who is a faculty member in the school of water resources and also Miss Deena, who is a PhD student in this particular department. So, I would request you to talk about little bit explain about this particular facility that you have. So, Professor Tiwari, could you explain like what is this setup all about?

Thank you Professor Misra. So, actually what you are seeing here is as Professor Misra suggested it is a test bed for water distribution. So, it is kind of a prototype for water distribution network, what usually we see in the fields. There are pipes of different sizes which represents mains, sub mains and the branch or distribution pipes and this network is nicely equipped with the various pressure meters.

Right now, I am going to show you a practical demonstration of the use of PLC and SCADA based system. So, this specific system is about water distribution monitoring and so, we have a system in the school of water resources in IIT Kharagpur and this particular system basically has end-to-end monitoring of water distribution and it would be also extended for water quality monitoring.

So, we have with us Professor Manoj Kumar Tiwari, from the school of water resources and also Miss Deena, who is the PhD student over here. So, I would request them to explain more about this particular facility that they have and then, we will also look at the applications of SCADA in water distribution.

So, Professor Tiwari, what is this facility that you have would you please explain?

Thank you Professor Misra, So, actually this is a prototype of a water distribution network, the kind of networks that we see in the real field. So, there are if you can see there are different pipe sizes. So, some are simulating kind of mains then sub mains and branch pipe.

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So, the idea of developing this network is to test the things that actually occur in real field.

So, this network or this system is equipped with various pressure sensors, flow monitors and actuators in order to control, monitor and operate it in the real time, through a SCADA and PLC-based systems. Deena is a working on this system. So, see will further explain the details of the system.

So, Deena could you please explain?

Yes.

Like how things work over here?

Thank you sir, as already it has been explained that this is a prototype of a real water distribution network and we all know that water distribution networks expand over vast areas. Hence, its manual monitoring is a pretty challenging task. So, the aim of our work is to devise a methodology of a remote monitoring of these systems through the use of SCADA and PLC. When we come to a water distribution network, both quality and quantitative parameters are important and right now we are monitoring only the quantitative parameters which are essentially the pressure at intermediate locations of the system and the flow rate at the demand nodes of the system.

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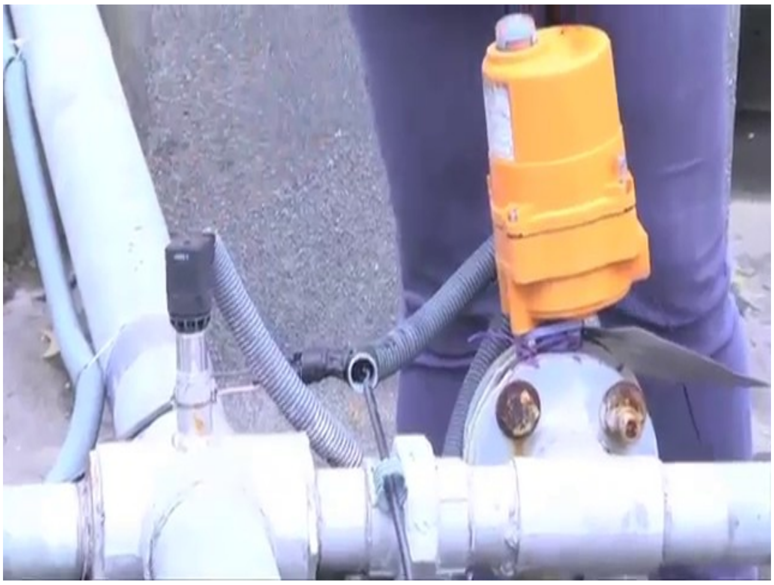

So, here for example, we have a pressure sensor installed at the junction of the pipe network to give us the pressure at this point. Likewise we have the pressure sensors at many locations of this network.

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Again, we here have actuators which are installed at different locations of the network. So, these actuators are actually control devices where we can control the rate of demand from the locations itself.

So, here we have the actuators which are located at different locations of the network and these actuators are basically control devices, where we can increase or decrease the demand flowing through these locations in the network.

So, if I may add actually it is a there are the amount of opening how much flow is to be maintained from this outflow junction can be controlled with such actuators. So, these actuators that way will be able to control the flow in a distribution network or a distribution pipe from a junction that way and these further, these actuators can be controlled remotely; can be monitored remotely. So, with the like in the real time system, we always need not to go to the field in order to control the flow in a pipe or in order to sort of maintain the distribution or the demand from one particular sector.

So, the next component that, I am going to show are the flow meters. Flow meters in a pipe network is essentially the demand node from where consumers can take the water for their necessity. So, here we have a manual paddle wheel flow meter which is connected to an electromagnetic flow meter for knowing the flow through the paddle wheel flow meter here. So, the electromagnetic flow meter is monitored remotely through the SCADA system and the data will be available to us in our system.

Ok.

So.

So, Deena what is this flow meter all about; what does it do?

Sir, basically the flow meter is installed here. So, that we know how much demand is consumed at the consumer point.

And this data is required to actually in real systems this data is required to bill the customers on the amount of water that the customer is using.

Ok. So everything can be monitored in real time.

Yes sir.

In that SCADA.

Yes sir.

SCADA based systems.

So, actually this flow meter essentially records the quantity of water flowing at a given instance and then, it has a totalizer also.

Ok.

So, over a period of time how total water has passed through this pipe will be known to us.

Excellent.

And that is what actually is used while billing the consumers.

Ok.

Because how much water has been passed to their homes and what consumption they have made. So, based on that the billing for water can be done.

So, Deena, so could you explain little bit further about this particular instrument?

Viscometer.

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Yes sir, yes sir. So, this paddle wheel flow meter needs to be a pull and so, this is how we open the paddle wheel flow meter. As soon as this paddle wheel flow meter is opened and the water flow is stabilized.

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The reading for the flow rate of the through this paddle wheel flow meter will be displayed here and also the total amount of water passing through this flow meter over a period of time will also be displayed here.

So, like right now although the there is no flow. So, it is showing 0 meter cube per hour the instantaneous flow. But the totalizer is saying that it is, it has been basically over 1300 meter cube flow has been passed through in a given span of time. So, from (Refer Time: 18:33) this like the operation was installed or reset at 0 point.

Ok.

From that point forwards 1345 meter cube of flow has already been passed throughout there.

Ok. Wonderful. Is there anything else that you have over here other instruments that you might have?

Other instruments as such like there is a weather monitoring station.

That can be seen here ok. This also basically collects the data and transports in the real time the weather data and from this network the other interesting work which we are doing is because one of the major challenges in the real field network is in terms of water losses.

So, in India the urban distribution network, distribution networks only faces losses of the order of say 40 percent.

Ok.

That is a huge amount.

Right.

And there is no mechanism over there to basically detect these losses in real time or and then, because until unless we detect.

There is no rectification possible. So, first challenge is the detection.

So, with this the kind of actuators we have we artificially create leaks in these networks and then developing a system for the real time detection of the leakages from the distribution network.

So, Professor Tiwari, earlier you said that at present what you have is the water monitoring particularly with respect to distribution, control over the distribution over the network and can it be extended for monitoring the water quality as well at different points of the network?

Absolutely, Definitely. So, like whether we are monitoring a quality parameter or a quantity parameter all we need a sensor. So, like we have pressure sensors which are monitoring pressure in the distribution line. We can of course, install water quality sensor like residual chlorine, PH, ORP, TDS. So, there are sensors available for this and if we install those sensors in this network which eventually we might do we have some idea of that.

So, when we installed these sensors in these things; so, we will be able to getting the real time water quality parameters as well. So, we can basically make the consumers assure that the water quality they are getting through their distribution network or through their water supply systems are of the portable quality or domestically usable quality.

So, this the different sensor values these are also tagged with the specific location from where this particular value is coming. So, whether it is with respect to the quantity or quality. So, the specific reading that is coming. So, one can know that this is from this particular point or location from where this sensor value has come?

Absolutely, Professor Misra. So, all these devices, sensors can be geo tagged also ok. So, let us go downstairs and there we can see that how these sensors located at different places are tagged in this thing.

So, that you can know specifically.

Yeah.

From which location.

Absolutely.

The data has come.

From which location how much reading or like we can monitor, these specific locations in real time with the help of quality or quantity sensors.

Ok. Thank you. So, what we have seen so far is basically the water distribution network, the physical part of it. How the test bed showing the different water pipes, their branches and so on; how they have been structured; how they have been organized; how they have been located so we have seen that. We have also seen that there are different sensors, IOT devices like water pressure sensor and different other water monitoring sensors are located at different points and these values the sensor values also come tagged with the specific geo location from where that particular value has come.

So, all of these things can be monitored from a central point where basically one can sit and monitor have a look at the complete picture of the water distribution system. So, we are going to go downstairs at the other location from where this particular facility has been installed and we can have a look at how things are being monitored from that, that particular location. It is enabled with SCADA, it is enabled with PLC. So, we are going to see how this SCADA and PLC-based system will help us to monitor centrally the overall water distribution network.

So, we are at the control room the monitoring point from where the water distribution system that you have seen so far can be monitored and centrally controlled. So, on my back is basically the PLC controller.

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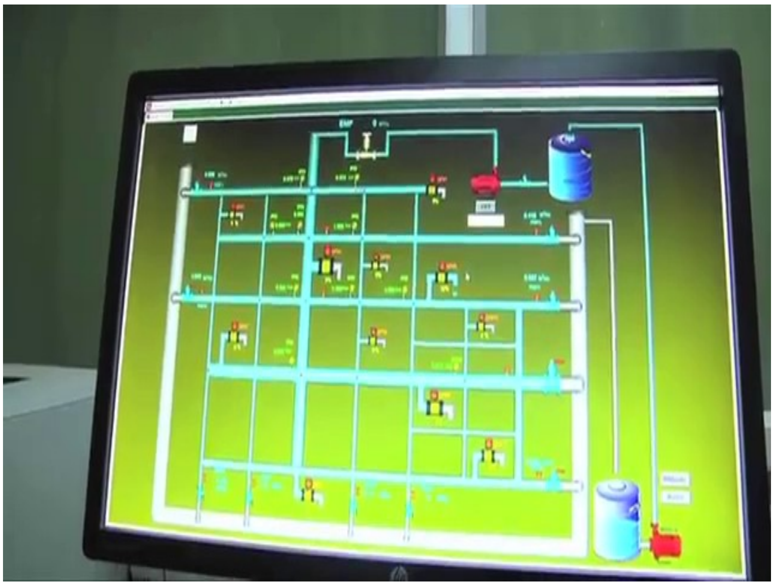

And on my left is the SCADA-based system that can help in the supervisory control and monitoring.

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So, what we have I will just show you what is inside this particular panel. So, this is the PLC control panel.

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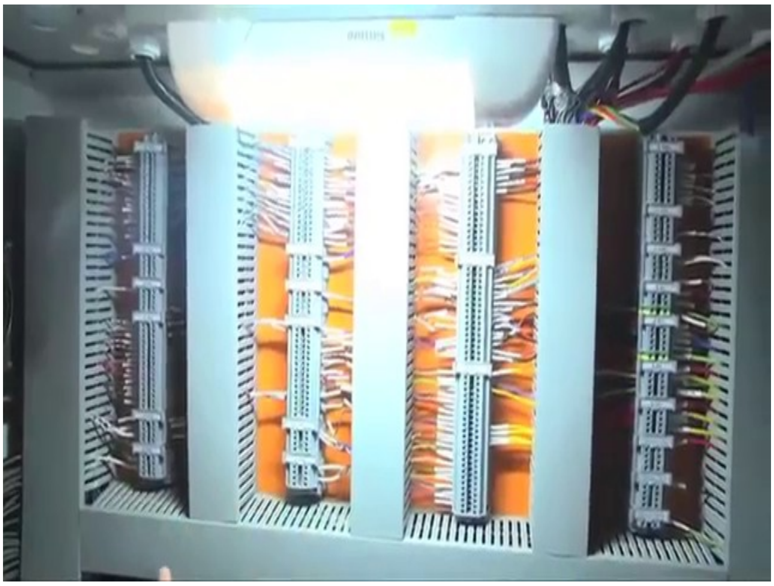

So, as you can see over here there is lot of electronics and so on.

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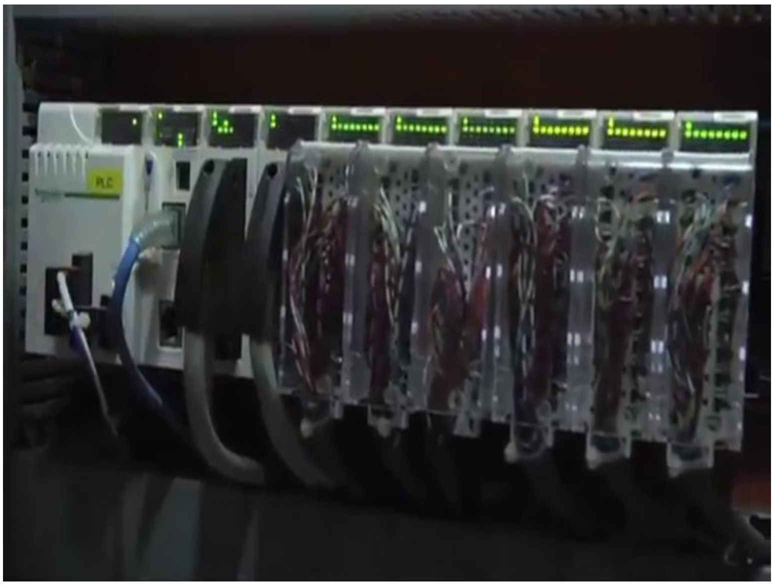


So, this is the main thing the PLC controller. This is the main PLC controller and Deena, can I now request you to explain the different other functionalities that we have over here.

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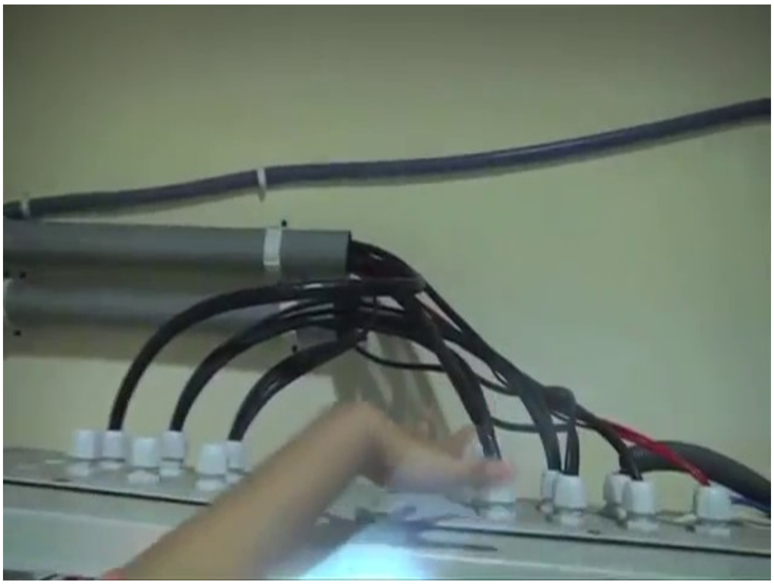

Sure sir. As you can see here sir, the system of wires here are connected to the sensors on the top floor, where we had already seen the system. So, all the pressure signals and the flow signals are in analog form.

And it is transferred to the system of wires to this location.

So, all these components here are basically to change the analog signals to digital form.

Ok.

And these components are for that purpose.

Right

However, this is the main part of this system, where these are the analog input signals.

These are the two analog outputs.

Right.

And these are the digital outputs.

And as you have already mentioned, this is the PLC.

So, I will add a little more onto this. So, because we have the network installed right over the rooftop of this one building. So, we are getting the signals or which are monitored from the sensors through these wires, but what happens in the real fields these SCADA systems or real field systems when we apply it to the let us say larger distribution network and there are system is actually there at few places.

So, it becomes very difficult.

To get the wired signal from far off points.

Right.

So, what we can use is we can use wireless technology.

So, the sensors that record the data and through wireless communication it could be directly sent to the PLC.

Excellent. So, basically what you are saying is that instead of using the wired technology, we could use wireless communication technology in order to send the data from the real sensors to this particular controller.

Absolutely and it is actually in place and like it is already in installed at few places.

And as you were saying that, it is more useful and more convenient basically because wireless technology you do not have to really the dig wires and through that.

Absolutely.

You do not have to connect through the different cables.

Yes. So, that becomes much more handy because you need not to basically control the need not to install such a long wired system to bring all the information to the PLC.

Ok.

You can just the sensor records it and through wireless communication, it directly sends to the PLC system and the rest of the process then becomes easier.

Right.

Thank you. So, on my right is basically the SCADA HMI which basically helps you to graphically have a look at the entire water distribution system and basically to have complete knowledge of from which point how much water is flowing through and also if there is any leakage at any of the points that also can be detected through this particular interface. So, can you show us how we can monitor leakage in this particular panel?

Sure sir. Sir, for an experimental purpose if I want to create a leakage at a location I will be using the actuators where I have control from the HMI. So, here as you can see it is zero percent now that means it has no leakage at all.

Right.

So, I just click here and I click the desired percentage of leakage that I want to create and the same percentage of opening will be done in the actual system and the water will flow through as it is shown here.

Ok.

So, this leakage is actually monitored like the detection of leakage what we were discussing.

Is because this is an experimental network. So, here we artificially create leakage.

Alright.

And then, through a software simulation we are which we are developing, we will be able to identify the location and some extent the quantitative volume of the leakage.

Correct ok. So, Professor Tiwari, so you have a wonderful facility over here. So, SCADA-based systems are available everywhere and so this is an example of the use of SCADA-based system in for water distribution monitoring and so on and so, this has been developed by one of the private farms what it can you speak little bit about?

It is actually a Chennai based company PLC systems private limited.

Ok.

So, they have done this installation and this is as far as I know of this is the first such facility in the nation.

Ok.

Where, on a lab scale we can basically monitor control and try to operate a water distribution network.

Alright and so, basically with the help of this kind of installation, you are able to emulate the behavior of water distribution in a reals real kind of environment?

Absolutely, absolutely.

Thank you.

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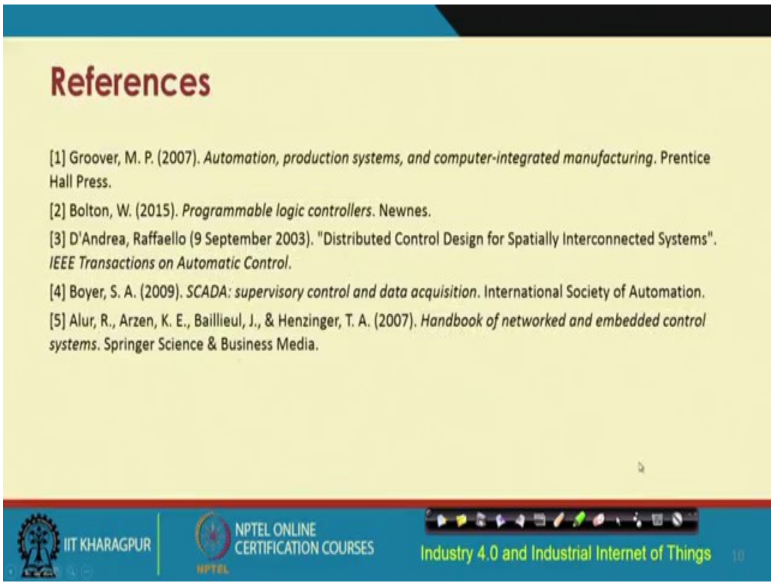


So, these are the differences that one could go through in this particular context and these are some of these references if you are interested to know about SCADA, PLCs, process control and so on; these are some of the ones that I would encourage you to go through. With this we come to an end of this particular lecture.

Thank you.

**Introduction to Industry 4.0 and Industrial Internet of Things**

**Prof. Sudip Misra**
**Department of Computer Science and Engineering**
**Indian Institute of Technology, Kharagpur**

**Lecture – 36**
**IIoT Analytics and Data Management: Introduction**

This particular module of this course on IIoT and industry 4.0 focuses on the analytics and data management. Particularly, in this particular lecture we are going to focus on knowing some of the introductory concepts of how to analyze the data that is received. In the previous lectures we have seen that IIoT based systems generate lot of data. And some of this data will have to be processed as soon as or as close as possible to the point of generation and the rest of the data can be sent for further processing at a later point in time. But, the analysis of the data is very important because otherwise there is no point in installing different sensors and actuators to make these different industrial machinery smarter.

So, what I would like to emphasize is we need to understand; how things go on with respect to the analytics.

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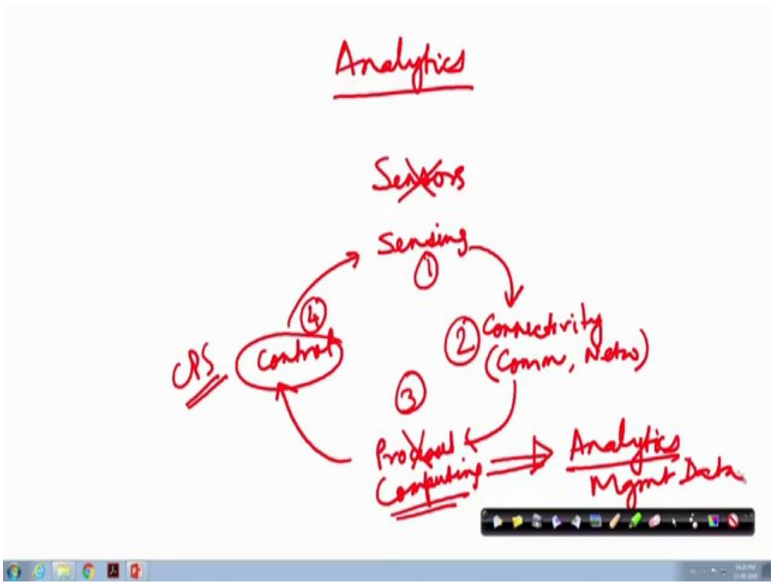


So, first let us start with a recap of what goes on with the end instruments, the end devices and so on. These end devices are fitted with different smart sensors. These smart sensors basically sense and they are going to generate the data. So, instead of sensors if we call it sensing; I think that will be more appropriate, so, we start with the phase of sensing. From sensing we have to send the data over a network. So, let me call it connectivity. So, connectivity and in the previous module we have seen a lot about the different possibilities of connectivity; that means, talking about communication protocols network topologies and so on and so forth.

Thereafter, the data that is sent over the network will have to be processed; that means, computing. And, based on this processing in most of the industrial applications a feedback control will have to be created for feeding the signals to the source of the origination of the data; that means, these machinery fitted with the sensors.

So, this is more or less kind of a loop that continuously gets executed in a real industrial setting. So, basically it goes on like this that it starts with sensing; sensing, connectivity, processing or computing and here we have the control in most of the cases particularly with Cyber Physical Systems this control feedback is very important and most of the industrial you know industrial equipments for IIoT are CPS equipments, so, basically where there is a lot of interaction between the cyber component and the physical component and so, this control is very important.

Now, let us talk about this computing part. This is where things are very interesting. So, we have to talk about the analytics and the management of the data.

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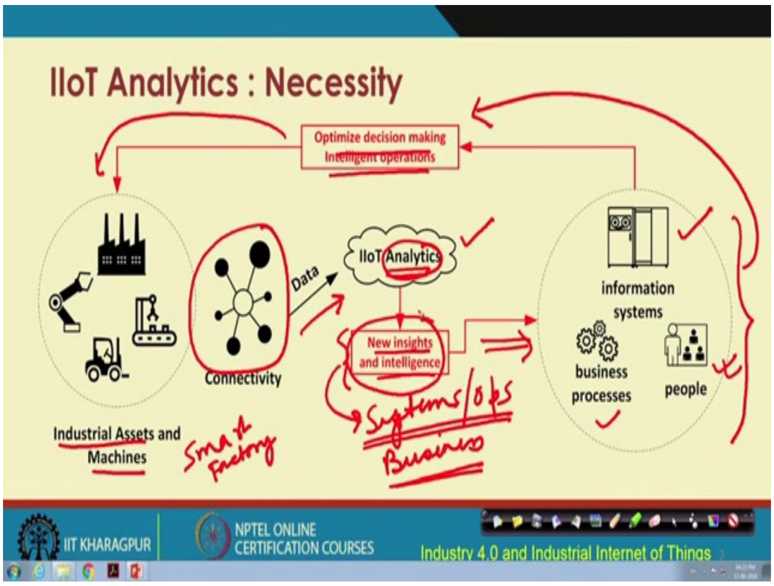

So, let us now go back and have a look at what we have in terms of analytics with respect to IIoT scenarios.

So, as I was telling you earlier we have in an industrial setting we have industrial assets and different machinery. For example, in a smart factory where there is smart manufacturing; that means, the equipments themselves are fitted with different smart sensors and so on, which continuously access the data from data of different types from this machinery. So, these industrial assets and machines these are fitted with different sensors.

Data over a particular network are going to be sent for further processing as I was telling you earlier; the data are going to be analyzed. How it is going to be analyzed, what are the different techniques, tools and so on is what we are going to talk about in this particular module and in this particular lecture, I am going to introduce to you about the different broadly the different methodologies that are there for the analysis.

So, the purpose of this analytics is to generate new insights and intelligence, and this is this intelligence which helps in terms of the systems or the operations and business. So, overall business intelligence and operational intelligence can be derived through different types of analytics and running different analytical processes in these analytics engines is very important.

So, finally, these results are going to be all sent to either different other information systems like ERP-based systems or business processes other business processes it could be sent or to different people. So, these are the different possibilities where the new insights and intelligence that are derived through these different analytics could be made useful. So, any of them could help further to feedback and provide optimal decision making and intelligent operations and those decisions are again fed back through these machines for improved operations improved decision making and further intelligence and so on.

So, this is more or less this cycle where analytics finds lot of use and the core thing over here is to derive new insights and intelligence for which these different methods of analytics are going to be used.

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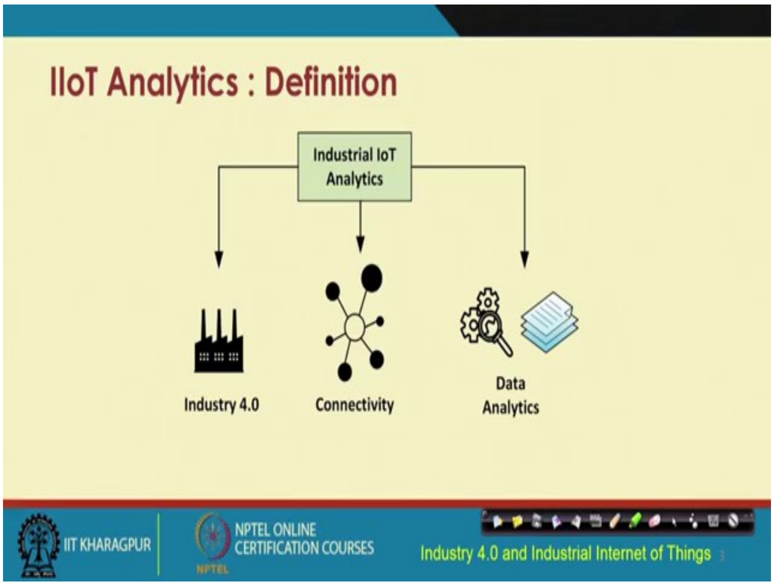


So, talking about IIoT analytics; analytics basically is a core component for industry 4.0. In industry 4.0 we are talking about connectivity. So, basically what we see is there is an interplay between the connectivity, the machinery, the Cyber Physical Systems and this analytics.

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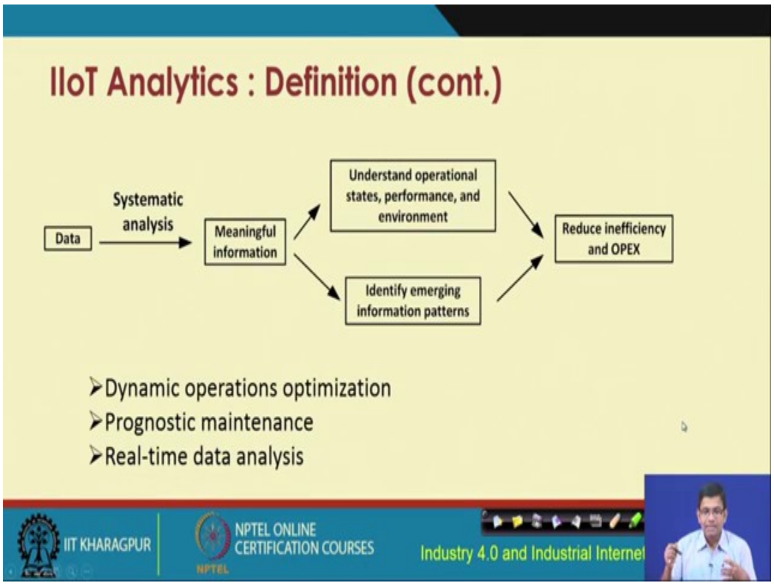


Now, this analytics can be performed in different places for getting different types of insights. The analytics could be performed close to the point of generation; that means, at the gateway node or at the edge or the analytics could be performed completely at the back end, in the cloud, the server, the server firm and so on or it could be a mix of both.

So, let us look at this particular diagram. So, as we can see here; we have the raw data that are generated by the different sensors. These raw data are have to be analyzed because these raw data are going to be all useless, if meaningful information cannot be generated out of the data. So, basically this transformation of the data through the different analysis, a systematic analysis, transforming the data raw data into information has to be done, it is crucial otherwise it is that the data becomes useless. This meaningful information will help us to understand the operational states, the performance and the environment in the industrial setting; that means, the operational states of the machine, the performance of the machine and the environment in which the machine operates.

It also helps, this information also helps in identifying different information patterns that emerge out of this execution or the running of the system. Overall the idea is to reduce the inefficiency and also to reduce operational expenses that might otherwise get incurred if you have a bare bone kind of system deployed for the firm for manufacturing and process execution.

So, the overall idea is we need analytics for reducing inefficiencies of all sorts, overall inefficiency of the product, the process; the process that is being used in order to manufacture the product and the operational efficiency and the expense reduction of the expenses. These are the different considerations that are taken into these are the ones that are taken into consideration in order to motivate the use of analytics in that particular loop which I stated at the very beginning which basically collects the data from these different machinery fitted with different sensors, these IoT devices and send the data over the network.

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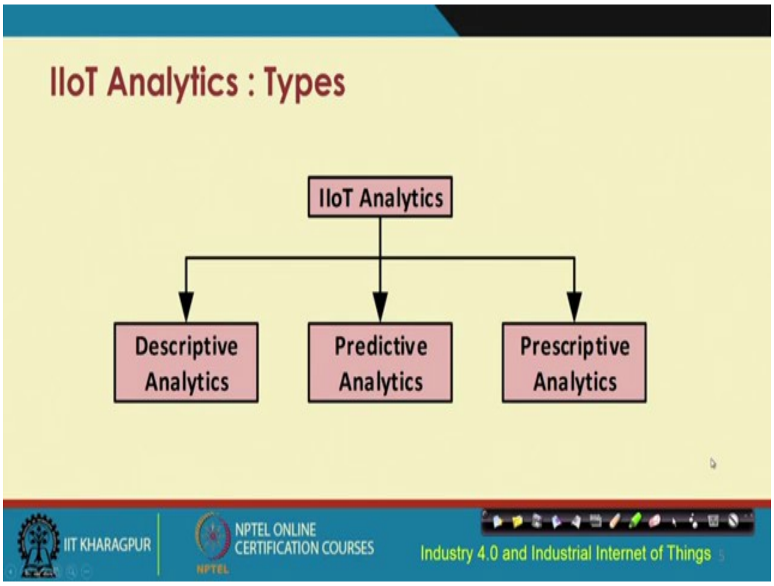


So, I think we have so far a fair bit of idea about why analytics is important. Let us now try to understand and get an over overview of the different types of analytics that could be executed. We could have analytics of different types which can be classified into three; first is the descriptive analytics, second is the predictive analytics and the third is the prescriptive analytics.

Descriptive analytics is about analysis in the current time scale. So, basically the data that are received will have to be analyzed in order to basically improve whatever is being executed at present to get more insight, to get more meaning of the data that is being received from this different machinery to get a descriptive idea of what is going on at present that is descriptive analytics.

The predictive analytics on the other hand talks about use of different tools and techniques in order to predict in the future what is likely to happen because if we can predict what is likely to happen, for example, a part of a machine component might go down in the future, maybe after 1 hour and if that information is obtained beforehand then that will be very much useful because that way you could prevent that particular component from completely going down and consequently the process or the machine that is being operated will also be autonomously taking care of the complete down time and will improve upon the overall efficiency. So, the predicting what is going to happen in the future is what predictive analytics talks about.

Prescriptive analytics basically is related to the predictive analytics. So, here we are going little bit further. In prescriptive analytics we are talking about that we predict that what is going to happen, but then based on that prediction of what is going to happen in the future, you prescribe the different actions that needs to be taken. So, that is this prescriptive different actions that need to be taken in order to maybe you know control a particular scenario a disaster from happening or something of that sort.

So, there is a link between the predictive and the prescriptive; prescriptive goes beyond what predictive does and so, there are different tools and techniques to be used for each of these descriptive, predictive, and prescriptive and so on. Descriptive analytics pair basic we could use different statistical methods for the descriptive analytics. Predictive one could use different machine learning techniques and so on and prescriptive could be a combination of machine learning statistics and different other AI techniques. So, these are the different types of analytics that could be used in an IIoT scenario.

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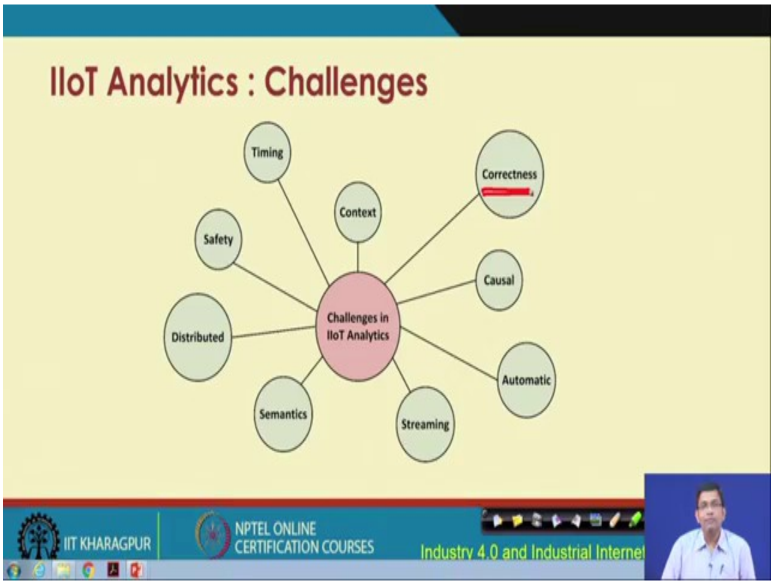


So, there are different challenges in implementing analytics in an industrial scenario. Here are some of these challenges that are mentioned. I would start with the first one which is correctness. Correctness is very important. We are talking about machines which typically operate in high speeds where precision is very important; precision of a job that is being done is important. If precision, correctness, accuracy is not taken into account then that might lead to machine failures, process failures and including hazards.

So, safety; safety issues come into picture if correctness, position and accuracy are not taken into account.

So, your analytics that you implement will have to do the things correctly based on what is actually required and is suitable for improving the operations. Causal relationships are very important; understanding the causal relationships, the cause-effect. So, what causes something that is very important if you do not have that causal understanding of the cause-effect and the causal relationships between different events then that will not help you to implement analytics properly. Automatic with minimum human intervention everything should continue, the analytics and the different processes that get executed without any human intervention ideally should be able to control and communicate with the different parts of the system.

Streaming is a very important thing in industrial machinery, IIoT scenarios, Cyber Physical Systems we are talking about machines which run continuously; which because of the continuous operations collect lot of data, stream those data, that will send those data continuously over the channel and such kind of data coming in huge streams, large streams continuously in real time will have to be analyzed and that is not a very trivial task. Semantics and getting more insights meaning out of the data and trying to relate these meanings of one component with another and their interrelationships is also very important and should be taken into consideration while proposing an algorithm to be used for the analytics.

Distributed nature is very important. Nowadays we are talking about not centralized systems, but distributed systems which have certain parts or components in one location and other parts are geo distributed located in another geographic location. So, you need to have distributed analytics; analytics which will take into account the differences in the geo-locations and their corresponding executions of the different parts of the same system or maybe of a different system, but are synchronized together that has to be taken into consideration.

So, distributed analytics is also very important because certain parts of the analytics might have to be done close to the component located in one location, certain other parts close to the component located in another location and certain analytics will have to be done in synchrony putting together the bigger picture all the components together and making an overall idea about what is happening or what is going to happen and making certain prescriptions if it is required.

Safety is very important in industry scenarios and I cannot emphasize this more. Safety analytics is very important because you know talking about plain bare basic ergonomics safety to safety from different disasters machine failures or consider something like if the operator of a crane makes certain mistake what might so happen is basically there might be some disasters underneath. So, people might die, right. So, there might be deaths that might be associated with certain mistakes.

And, all of these can happen in autonomous systems where things are happening due to certain algorithms that are implemented behind the scene and are getting executed and if some something goes wrong or is imprecise then basically that might lead to certain failures which can lead to accidents in the industrial settings. So, starting from ergonomics safety to accidents etc. safety is very important and paramount in most of the industries particularly in industry 4.0. So, safety is a very important consideration. So, safety reliability and so on are very very important and so, analytics considering safety issues are very important.

Timing is very important because if a particular process gets delayed in execution and that particular signal coming from that particular routine or that algorithm under execution gets delayed by even a millisecond that might also lead to disasters. So, timing is very important and the context. Context is very important taking into account taking into account the different contexts in which the operations are going on and holistically trying to have the analytics that is very important. So, these are the different challenges with respect to analytics for IIoT scenarios.

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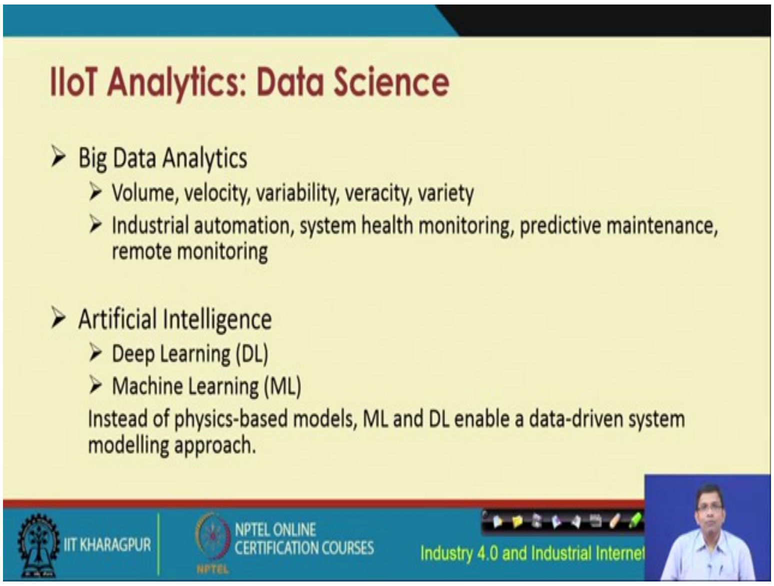


So, we have IIoT analytics; the concept nowadays people are talking about data science, right. So, basically data science is nothing, but trying to derive meaning or insights from data, insights that may not be very apparent and so on. So, this is a new trend in terms of trying to gain meanings out of the data. So, big data analytics is very popular. Big data we are talking about data coming in huge volumes, coming in high velocities in real time streams of data; data of which have high variability and veracity, variety of data and so on. So, all of these are different attributes of big data.

So, big data analytics is a huge challenge, but is a reality and analytics of these types of data, data which are unstructured, data which cannot be stored in relational tables. So, that you could use the relational methodologies for extracting meaning out of the data. So, those things are not available. So, in the absence of that for a data which is unstructured and bearing these kind of characteristics which is a reality in the industrial settings, how do you analyze the data in order to have insights or meaning out of the data as soon as possible; that means, as close as possible to the time when this data gets generated.

AI techniques such as machine learning, deep learning etc. are becoming very popular. So, these techniques together can help in getting more insights about the data.

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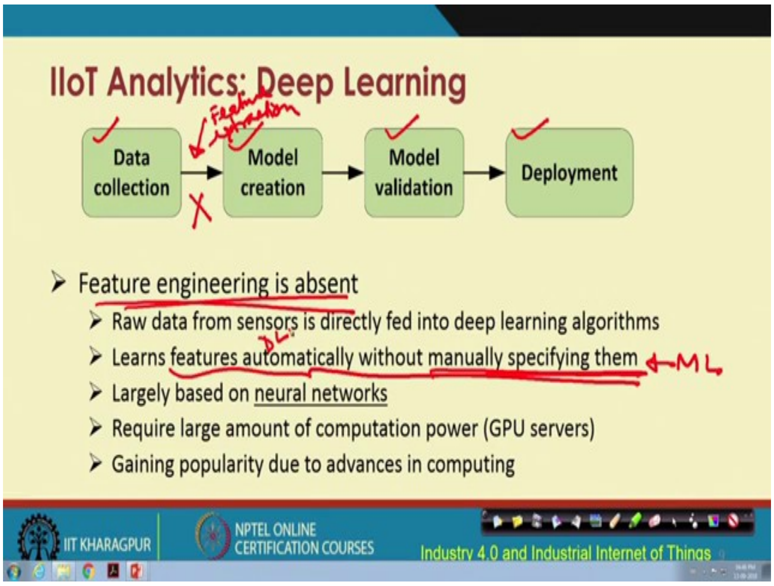


So, now we are talking about a world where machines are data driven, systems are data driven. Systems are data driven means like; you have lot of data and data is controlling. The data has become so important in the industry 4.0 world that it is so important that data itself is driving about the course of actions that have to be taken in terms of the manufacturing processes, the products that are being made and also the business operations.

So, let us talk about machine learning. So, I talked about machine learning and deep learning. So, machine learning basically it is a field of AI and this machine learning basically what we are talking about in machine learning is to derive some kind of intelligence to be derived, right. So, it starts with a collection of data if you look at which comes from different machines, the sensors in these different machines typically. Then there is something called feature extraction which is very important in machine learning.

So, feature extraction methods basically what they do is they convert the raw data into information that relates to the physical state of the asset. So, the feature extractions are performed and feature extraction itself is a task that requires lot of work. So, there are different algorithms that are available for feature extraction. So, once these features are extracted these are the features which will have close resemblance to the actual state of these machines and their operations.

So, following which feature extraction which is very important in machine learning. So, in machine learning feature extraction is very important. So, following feature extraction there is this model creation and model validation. So, models have to be created and then these models will have to be validated and thereafter these models will have to be deployed for further use.

So, there are two types of machine learning. Machine learning means that you are learning, you are learning from this data. The data that are collected from this you are doing certain things, certain activities, feature extraction, model creation, model validation etc. and from that you try to learn from the deployed models, you try to learn and about what is going to happen in the future. So, this is what machine learning talks about at every cross level.

So, this machine learning could be of two types supervised or unsupervised. In supervised in a nutshell I can tell you that supervised algorithms of machine learning are the ones where there is some kind of training data of different sets already available and you use that past historical training data in order to come up with your models. So, models will be created based on this training data and then these models could be also validated using other sets of data.

So, supervised learning basically uses training data. If training data is not available and if the feature extraction will have to be done in the absence of training data unsupervised machine learning algorithms are useful. So, there is no label data in unsupervised methods and these unsupervised learning methods basically extract a structure in the input data on their own. So, this is the main difference between the supervised and the unsupervised learning methods.

We will talk about this in little bit more detail in another lecture, but let us now talk about deep learning which is another thing that people are talking about a lot in the present day. So, people are talking about machine learning, deep learning in the industrial settings. Now, deep learning is like machine learning. It is another discipline of, we can think of that deep learning is another way of machine learning we can think that way. But, in deep learning unlike in the case of machine learning where feature extraction etc. was done; in deep learning you do not have that provision; so, there is no feature engineering aspects present.

So, if you look at this overall block diagram. So, we have the data collection, model creation, model validation and deployment. So, what is absent over here is unlike in the case of machine learning, this feature extraction which was there in machine learning is not there in deep learning. So, feature engineering is absent. So, essentially what happens is the raw data from the sensors are fed into these deep learning algorithms and from that different features will automatically get learnt without actually manually specifying those features which used to happen in the case of machine learning. So, learning different features automatically without manually specifying them this is basically the deep learning.

So, most of these deep learning methods are based on traditional neural networks; techniques such as, methodologies such as deep neural networks are quite popular and because of the structure of these deep neural networks and so on and the similar kinds of methodologies that are present what is required is to have large amounts of computation power of these different computational infrastructure which run these algorithms. So, deep learning algorithms will require GPU servers and the like.

So, these deep learning methods are getting very popular due to the fact that nowadays we have cheap computing power unlike in the previous times, cheap and much more efficient advanced computing at a very reduced price we are able to have at present and that is where deep learning is getting very popular.

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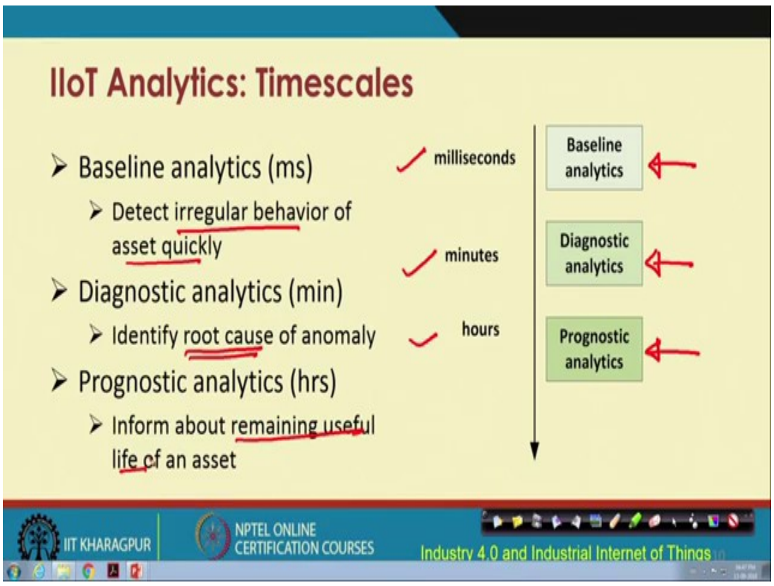

In terms of the time scales for analytics; analytics will have to be performed in milliseconds, in minutes, in hours. Milliseconds basically the baseline analytics, in minutes are diagnostic analytics and in hours our prognostic analytics. Baseline analytics detect irregular behavior of assets quickly; diagnostic analytics identify the root cause of any anomaly; and prognostic analytics basically inform about the remaining useful life of an asset.

So, these are the different types of analytics and their corresponding time skills of operation.

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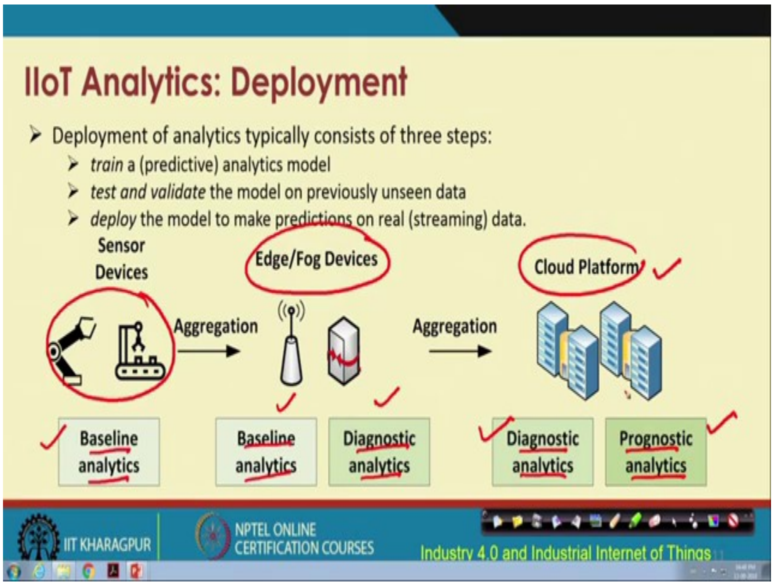


Talking about the deployment; deployment of analytics typically consists of different steps first you have to train if we are talking about some kind of predictive analytics you have to train a particular model. You have to train a model and then test and validate that particular model on some previously unseen data and thereafter deploy that model to make predictions on an actual data set which is being streamed in real time.

So, this is what is going to happen. You have this baseline analytics, from these different machines, these sensor devices this baseline analytics will be done over there that will be done very fast data will be aggregated and then at the gateway devices or edge or fog devices which are basically network equipments that are close to this machinery some baseline analytics and a combination with diagnostic analytics will be performed and again this data are going to be further aggregated, sent to the cloud and in this cloud basically diagnostic analytics and prognostic analytics will be performed.

So, starting from baseline analytics at the source to a combination of baseline and diagnostic at the edge to the diagnostic and prognostic analytics at the cloud we have these different phases of operations of analytics.

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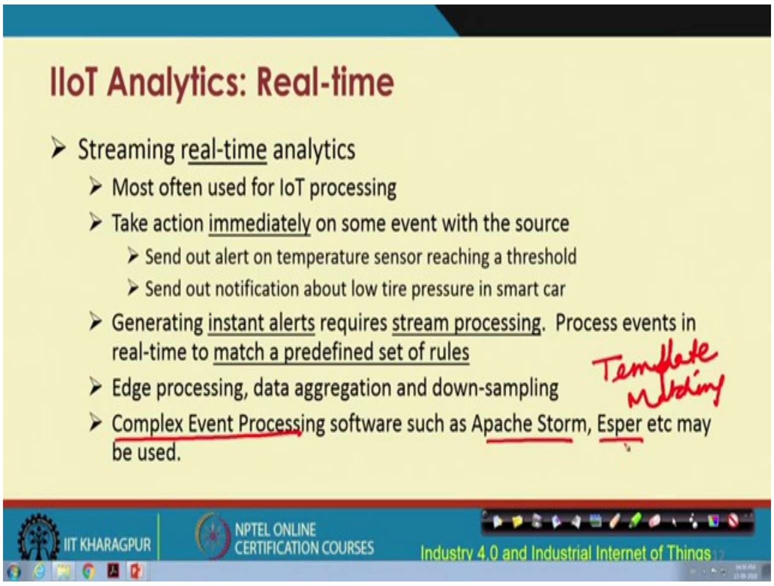


So, analytics will have to be done in real time. We have machines sending data, streaming data in real time. So, the streams of data will have to be processed and actions will have to be taken immediately as close as possible, as soon as possible and to the source of the data because based on that useful alerts can be sent. For example, if a particular machine is crossing or become coming close to a particular temperature threshold then an alert could be sent in a particular machine in operation.

Different notifications about tyre pressures for example, in a smart car could be sent immediately. So, certain baseline real time analytics could be performed and it is also very important to instantly send these alerts through different stream processing and so on. So, how that can be done? Because execution of different processes will take some time. So, that can be done with different techniques something such as matching a predefined set of rules in real time. So, you have a predefined set of rules and some kind of matching can be done. Techniques such as template matching, in machine learning could be used for doing it.

So, template matching is a useful technique that could be used for some kind of necessities like this template matching. Edge processing, data aggregation, and down sampling these are very important in analytics particularly for streams of data coming in real time will have to be processed in real time and so on.

So, complex event processing software such as Apache Storm, Esper etc. may be used for this particular purpose.

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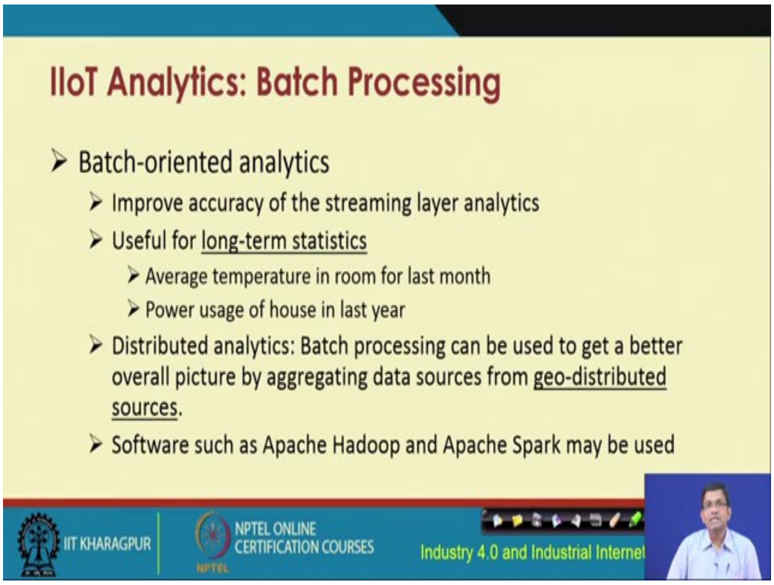


Batch processing might also be a requirement. Batch processing basically you know talks about getting lot of data, executing those data, analyzing those data for long term statistics in batches, right. For example, the average temperature of a room for the last one month that is some kind of batch processing which will give you some kind of long term statistics or the power usage of a house in the last year.

So, this is very important. Distributed analytics is very important because as I said earlier we are talking about industrial scenarios where different machines and their components are all geo distributed and some kind of data aggregation and intelligence will have to be performed as close as possible to these different components and their sources of origination.

So, software such as Apache Hadoop, Apache Spark etc. may be used for these purposes.

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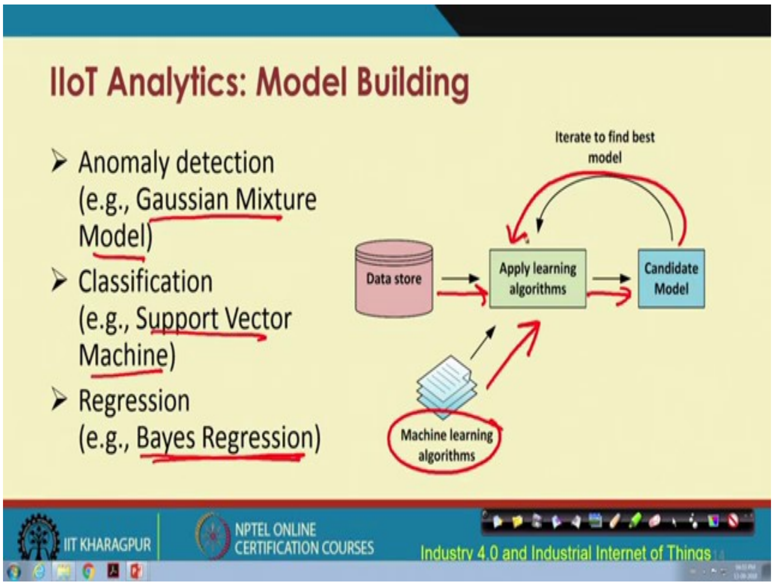


Model building: for model building, so, I told you earlier that for machine learning after feature extraction model building is very important. So, for model building different-different methodologies are there. For example, for anomaly detection GMM models are there – Gaussian Mixture Models, for classification SVM or Support Vector Machines are there, for digression Bayesian regression techniques are there.

So, basically machine learning algorithms could be implemented those algorithms could be applied on the data that comes from the data store and then these candidate models are basically built and then are fed back to these different learning algorithms to improve upon their course of action.

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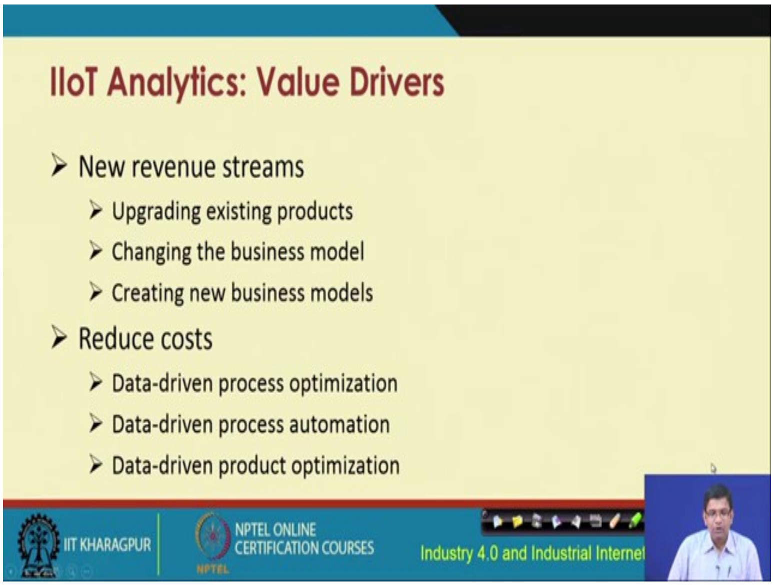


The different value drivers for IIoT analytics are like this, that it is required to derive new value streams, new revenue streams. For upgrading the existing products analytics is going to be useful, for changing the business model analytics would be useful, for creating new business models analytics would be useful. So, these are all valuable for doing different-different stuff in different business and industrial settings.

Analytics is also valuable for reducing the cost, for data-driven process optimization, for process automation and for product optimization. Data-driven process optimization, data-driven process automation and data-driven product optimization for everything we need different suitable analytical techniques to be implemented.

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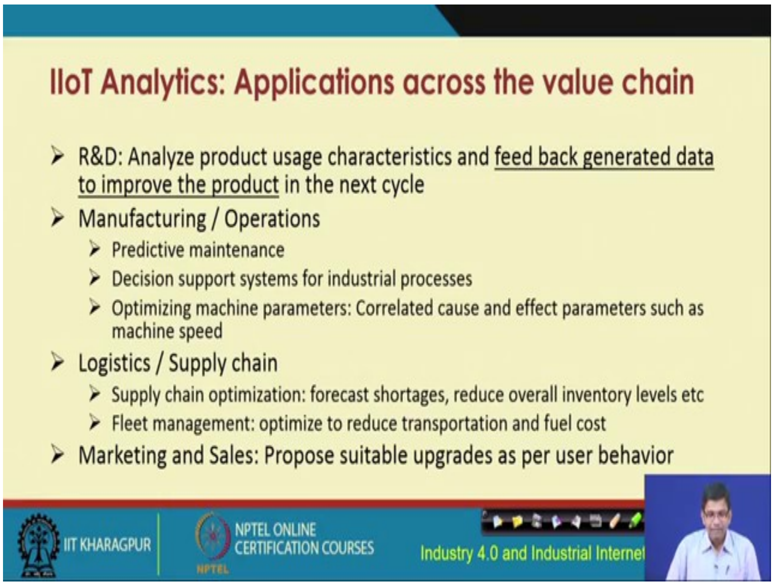


Different applications across the value chain. For R and D analytics is useful to basically understand the usage characteristics of a particular product. And, then feedback those intelligence those insights generated from this analysis to the next cycle of the product that is being manufactured. So, for R and D also analytics is useful. For manufacturing and operations, predictive maintenance, decision support systems for industrial processes and for optimizing machine parameters based on the collected data from the current operations IIoT analytics is important.

For likewise for logistics and supply chain, supply chain optimization, fleet management optimizing the reduction, optimizing the transportation and fuel costs in fleet management you need to derive intelligence out of the data. And, similarly for marketing and sales also to suggest suitable upgrades of a particular product based on the user behavior you need analytics. So, analytics is important in different fronts.

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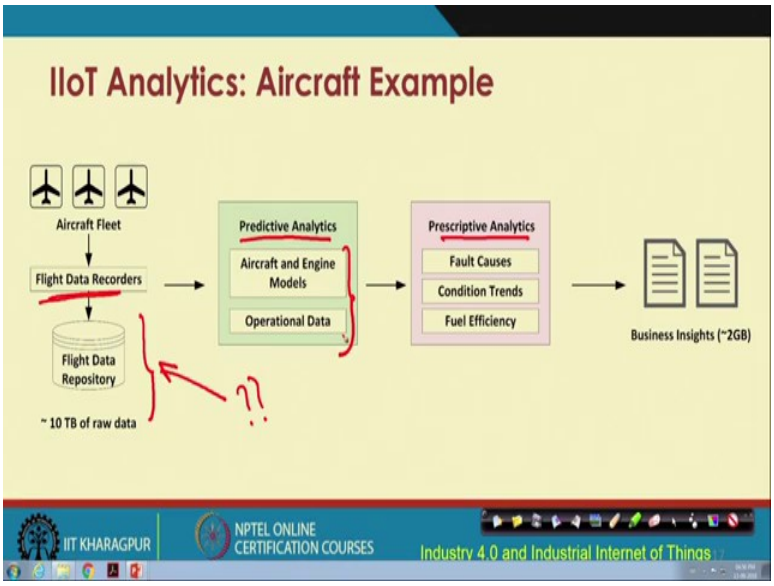


So, let me just take an example of aircrafts. So, aircraft fleet; each aircraft as you know is equipped with different flight data recorders. These flight data recorders they are going to record the data that are coming from the flight, from the different parts, different components of each of these different flights and are going to be stored in these data recorders. These data could be sensor data and different other data that are coming would be all stored in these flight data recorders. These are going to be stored; these data for every flight terabytes of raw data are produced for every flight, right terabytes.

So, huge volumes of data are stored. So, this data will be useless if you do not get meaning out of if you do not derive intelligence out of this data. So, what is done? Different types of analytics like the predictive, prescriptive, analytics, predictive analytics dealing with you know based on the aircraft and engine models and the operational data predicting about what might be happening in the future. So, that some emergency landing could be taken and a disaster would be avoided for a particular aircraft by the captain.

So, prescriptive analytics basically deals with fault causes, condition trains, fuel efficiency and so on. So, both predictive and prescriptive analytics can help in getting business insights and so on. So, this is very important and this is just an example where analytics is very important.

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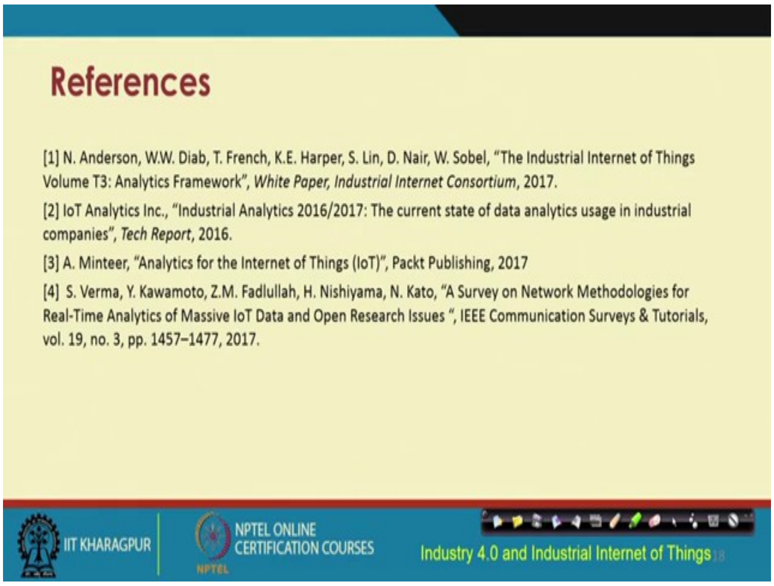


So, with this we come to an end of this particular lecture. These are some of these references that you could refer to. Here in this lecture we talked about the importance of analytics. We talked about the classification of different types of analytics and the different methodologies for analytics; we talked about machine learning, deep learning methods and that are available; we also saw an example where analytics would be very much useful.

So, these are the references that you could go through and with this we come to an end.

Thank you.

**Introduction to Industry 4.0 and Industrial Internet of Things**

**Prof. Sudip Misra**
**Department of Computer Science and Engineering**
**Indian Institute of Technology, Kharagpur**

**Lecture – 37**

**IIoT Analytics and Data Management: Machine Learning and Data Science - Part 1**

In the last lecture, in this module I had given an overview of analytics for IIoT and in this I am going to give you the overview of machine learning. So, we are going to talk about what machine learning is, what are the different types or methodologies in machine learning which are very popular and thereafter I am going to give you little bit of more idea about some of the different popular techniques that are there.

In this, I am going to give you only an expository view of machine learning. We are not going to go through any of these methods of machine learning in detail because the whole purpose of this course is just to expose you to what is out there with machine learning which can be applied for solving some of the problems in IIoT.

So, the purpose of this course is not to really get into the depth of machine learning and if anybody is interested and wants to have knowledge of machine learning and the different techniques that are there for machine learning. There are dedicated courses; courses in NPTEL which could be referred to for getting in-depth understanding of machine learning and the different methodologies for machine learning including deep learning, AI and so on.

So, in this course we will be at a very higher level and we will try to get just an idea about what is machine learning; what is what; what are the broad techniques that are there in machine learning and so on.

So, let us first try to get the ideas of the basics of machine learning.

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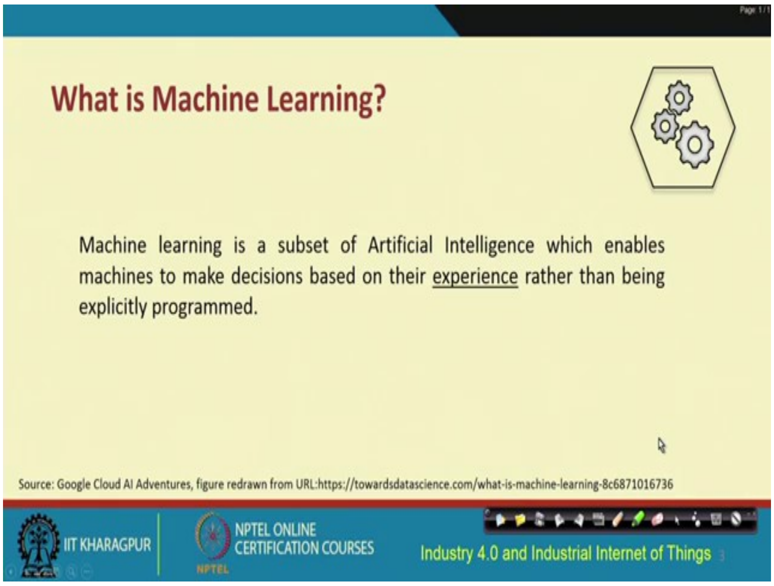


So, what is this machine learning all about? All of us we have heard about machine learning nowadays. Machine learning is very popular. Machine learning being used for analytics. Analytics very attractive for IIoT industrial, IoT applications; so, machine learning is nothing, but it is a subset of artificial intelligence. So, artificial intelligence is a branch of computer science which talks about how to basically imitate some of the natural intelligence that is there and create an artificial scenario of intelligence with the help of different computational devices with the help of different software and so on.

So, we have spoken about artificial intelligence briefly we have got an overview of artificial intelligence in an earlier lecture and so, machine learning is nothing, but it is a subset of artificial intelligence. So, machine learning talks about that how you can try to harness the experience from the past and try to make decisions for the future. So, machine learning basically will enable the machines to make different decisions based on the past experience rather than having the machine perform the actions based on what it is explicitly programmed to.

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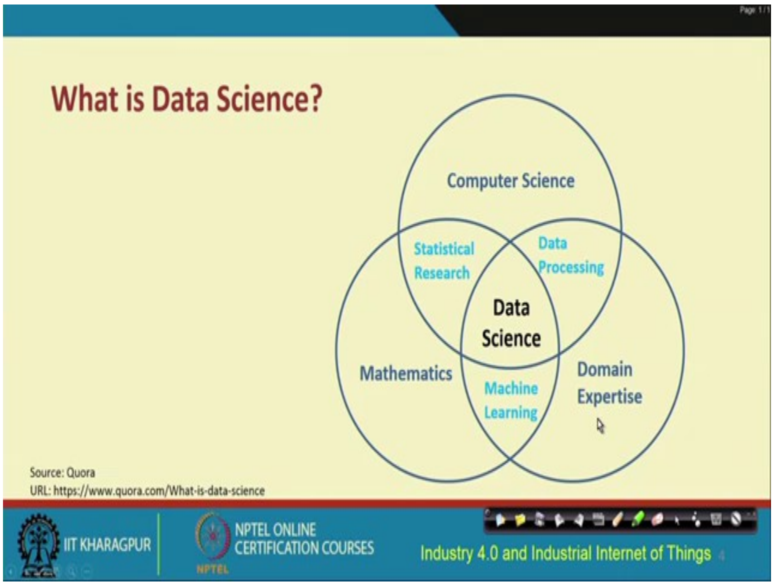


Data science; that is another term that is being used popularly at present. So, everybody is talking about machine learning, data science and so on. So, how do they position each other with respect to the overall knowledge? So, this is the overall scope of machine learning and data science with respect to branches such as mathematics, computer science and so on. So, basically data science combines the knowledge from mathematics, computer science and domain expertise. So, it is an overlap of each of these the domains. It uses techniques from each of these; it uses statistical techniques, data processing, machine learning techniques and so on.

So, we can think of data science to be at a higher level which is convergent, which is basically an intersection of the disciplines of mathematics, computer science and also the knowledge from the domain expertise. So, this is the overall positioning of machine learning and data science.

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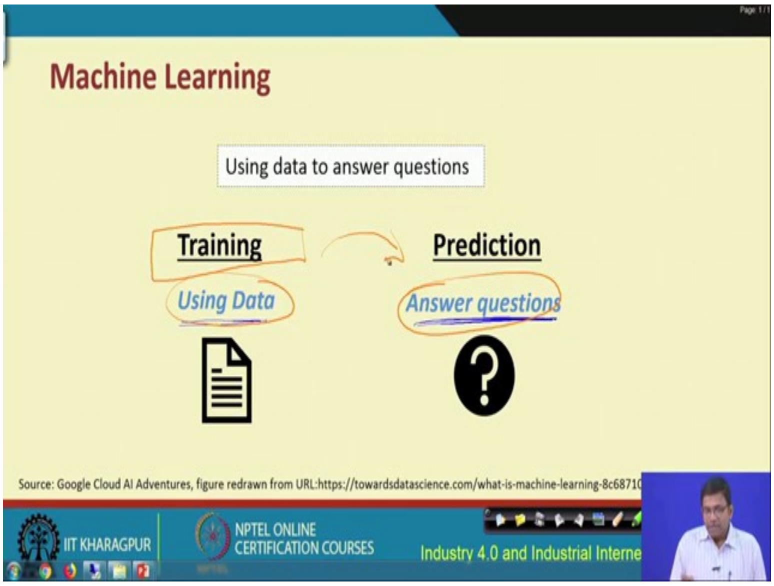


So, what is machine learning? As I told you earlier that we are talking about predicting something in the future based on the past history, past knowledge and so on. So, the whole idea is that you use the past data, existing data you use and then you try to make predictions or answer certain questions for the future, right. So, this is the whole idea behind machine learning.

So, in machine learning basically what you are trying to do is based on the past data you are trying to predict or answer questions for the future. So, what we have is that we need some kind of a training data set which will basically be the data of some observations that were taken from the past and based on that past experience try to predict the future this is what machine learning is all about.

So, this is one view of machine learning, a popular view of machine learning. There are different-different other views of machine learning as well, but making predictions in the future is something that is central to the theme of machine learning. How you make these predictions; what kind of data how much of data; whether data will at all be required or not. So, there are different-different questions people ask, people who are working on the different research themes of machine learning they try to address all these different types of varieties of questions.

So, let us move forward and try to understand a bit more about machine learning.

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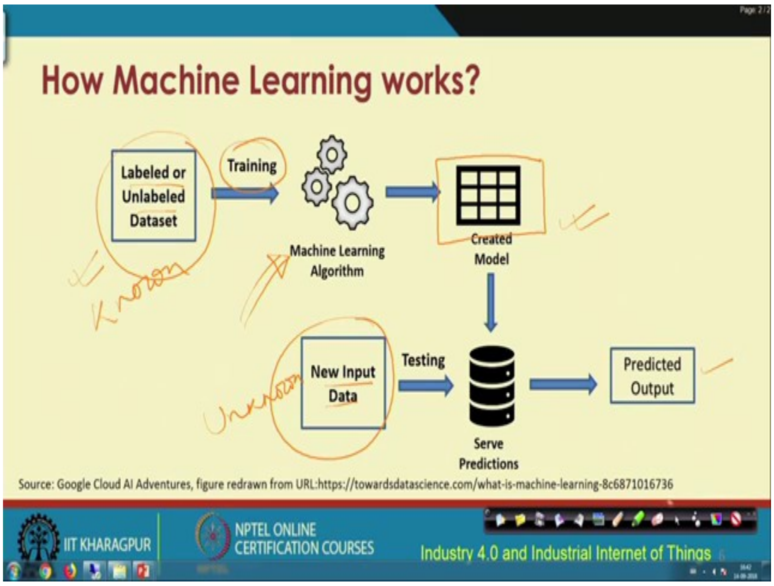


So, how does machine learning work? So, for machine learning what has to be done is that you need some kind of training data. You need some kind of training data this is basically the past historical data for instance which are labeled or unlabeled data and you design certain machine learning algorithms which will take this data, train the algorithms based on this data and will create certain models. And, will create certain models and those models are the important ones.

So, these were known data these models that have been trained and created will be used to predict something in the future for unknown data. This is the unknown data, this was known data. So, this created model that has been created based on the known data will be used for predictions for the new input data which is the unknown data.

So, this is basically how this prediction is done in machine learning.

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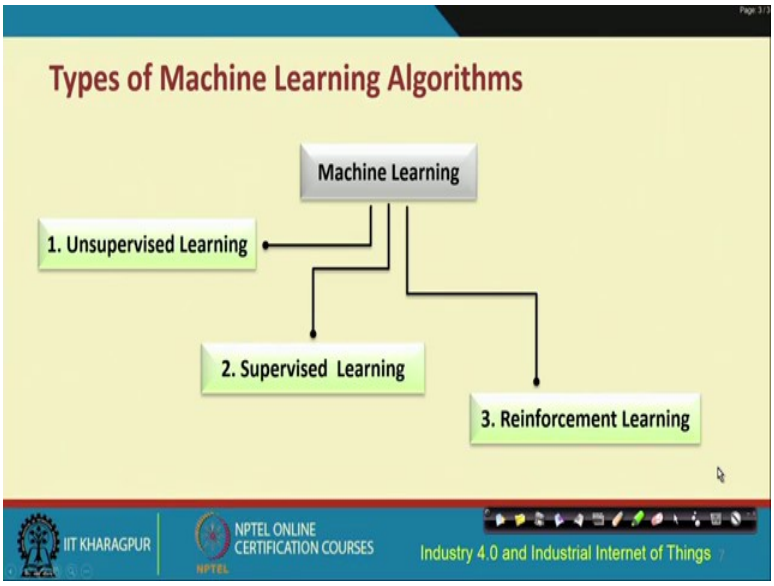


So, there are different machine learning algorithms they can be classified broadly into different types. These are the three main classifications that are very well known unsupervised, supervised and reinforcement learning which is kind of a semi-supervised kind of learning. So, we have unsupervised, supervised and reinforcement learning machine learning algorithms.

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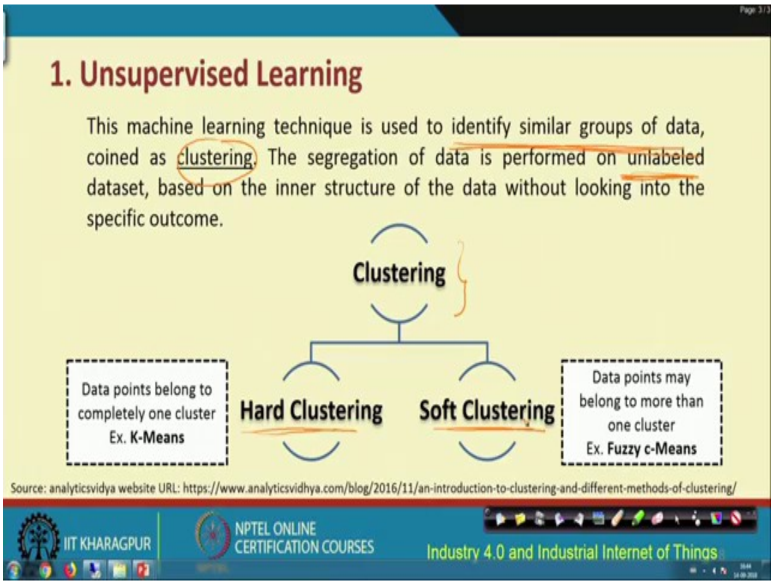


So, unsupervised learning; in this the machine learning happens in this way. So, there are similar groups of data which will have to be classified. So, in unsupervised machine learning what you try to do is you try to identify similar groups of data and this process is known as clustering. This is one popular unsupervised learning; clustering is a popular unsupervised learning technique and this basically will help you to classify the data into similar groups.

So, this classification or segregation of the data is performed on unlabeled data set based on the inner structure of the data and here basically this is very important unlabeled data set, right. So, this is unlabeled data set on which this unsupervised learning works and that is based on the inner structure of the data without looking into the specific outcome.

So, there are two main classifications of clustering algorithms one is known as hard clustering and the other one is known as soft clustering. Hard clustering basically what it does is it clusters into different distinct groups. Soft clustering on the other hand may have overlaps of clusters. Certain points may belong to two or more clusters together whereas, that cannot happen in hard clustering.

Algorithms; popular algorithms such as the K-means is a hard clustering algorithm, where the data points will belong to one cluster completely or another. In soft clustering, soft computing techniques such as fuzzy logic are used in order to come up with faster classifications, faster clustering, extremely faster clustering, but the classification is not hard, and techniques such as fuzzy c-means which is based on the concept of fuzzy logic is an example of soft clustering where the data points may belong to multiple clusters, right. So, these are the two main techniques.

Now, let us talk about this K-means. You might be wondering that what is this K-means all about. You know even though I do not intend to give you a definitive idea of all these different machine learning algorithms in this half an hour course, but I think in order to keep things in perspective and to motivate you enough one of these basic algorithms the K-means clustering algorithms I can give you little bit of idea about how it works. So, this is how this K-means algorithm works.

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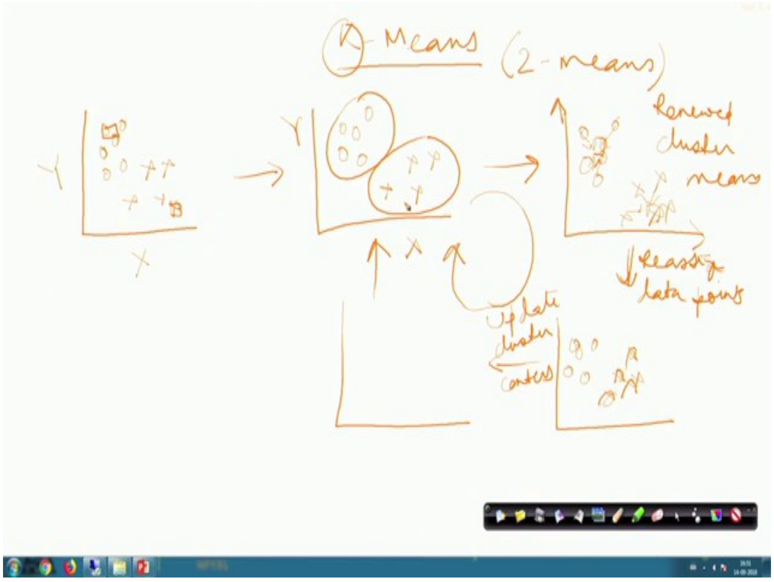


So, K-means basically the way is that you want to let us say that you have certain points and you want to classify these different points. So and let us say that this is your X and this is your Y. So, K refers to any integer.

So, let us say that we will talk about the 2-means algorithm. So, 2-means would mean that we are talking about two clusters, two centroids. So, we will start with two centroids which will be initially like the anchors to start with. These are kind of anchors to start with. And, so, you start with this you randomly select these anchors, the points and then you proceed further. So, then what we do we take each of these points 1 2 3 4 etc. 5 6 whatever and we measure the proximity of each of these points to these anchors.

These anchors are like the seeds. So, we start with these seeds or the anchors, we try to measure the proximity of each of these points in this space in this 2D space to each of these anchors. So, let us say that finally, we get something like these circles are the ones which are closer to this particular anchor whereas, these cross marks are the ones which is closer to this particular anchor or the seed.

So, then what we do is we will in the next pass we will have like this and this one will be like this. So, what is essentially what has happened is that two clusters are formed based on their proximity to the centroid. So, two different clusters will be formed. Then, the next step you need to perform this one once again whatever we have done here needs to be performed once again.

So, we had these points, we again choose a centroid like this; we do exactly the same thing that we have done and we get a better centroid through this. So, we will have the renewed cluster means and thereafter we reassign the data points and we get these; the cross ones. So, we had started with five points. So, we have to have one more and same goes here as well.

We repeat the same thing we update the cluster centers and we repeat this process likewise and we reassign the data points and repeat this step in circles. So, how long do we repeat? We repeat until for two passes we get the same centroid. So, that is when this algorithm is going to converge. So, same or similar centroid if we are getting in two different passes of this algorithm when we are repeating this process. So, that is when this algorithm will stop execution.

So, basically this is how this K-means unsupervised learning technique for clustering works. So, like this there are many different types of other algorithms that are also there in fuzzy actually what is happening is you do not have hard clustering like this. So, you do not have hard clustering. So, in Fuzzy c-means or FCM, so, what you are doing is that you may have because it is based on fuzzy logic one point can belong to both the clusters. So, that is how you will have some kind of a soft partitioning, soft clustering kind of approach and the same point can belong to multiple clusters in FCM. Unlike over here where you have definite distinct clusters to which one point is going to belong to.

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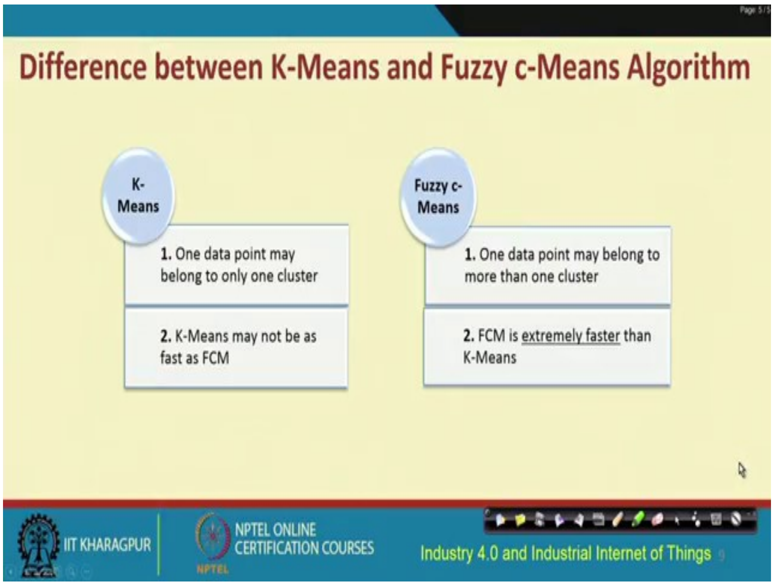

So, we will proceed further. So, this is this K-means where one data point may belong to only one cluster whereas in Fuzzy c-means one data point may belong to more than one cluster K-means algorithm is based on pure machine learning whereas, Fuzzy c-means is based on soft computing approach fuzzy logic. So, that is why it is known as Fuzzy c-means. So, because it is based on fuzzy logic FCM is extremely faster, much faster compared to the K-means algorithm.

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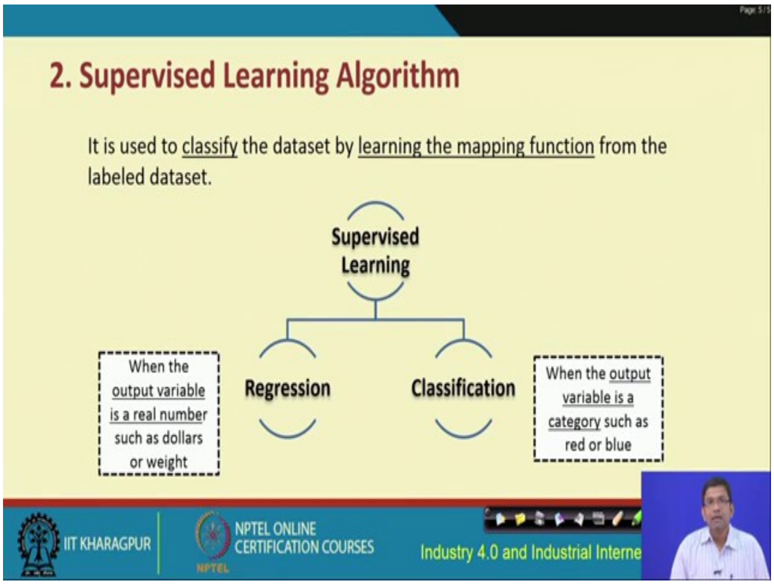


So, next comes the supervised learning algorithm. So, in supervised learning algorithm, primarily we are talking about classification of data sets. Classification of data sets by learning the mapping function from the label data set. So, supervised, supervised means that there has to be some kind of label data set and based on the data set you are trying to make certain classification. So, supervised learning you know one technique is to basically classify the other one is to do regression. So, classification basically is when the output variable is a category; is a category such as red category or blue category whereas, regression is when the output variable is a real number such as the dollar values or the weight and so on.

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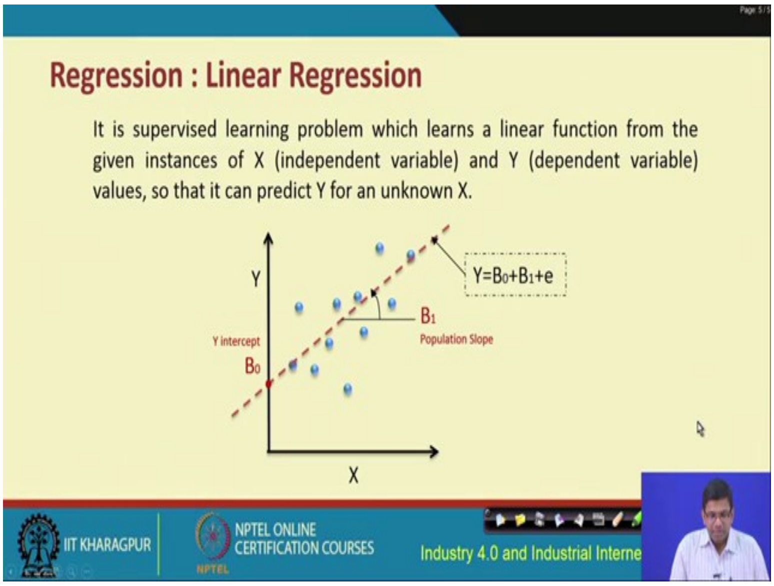


So, this is how this regression or linear regression looks like it is a supervised learning algorithm which learns a linear function from the given instances of the X and Y values, so that it can predict the Y for an unknown X. So, it is some kind of you know given a set of data points you want to basically fit line so that that will become the best fit .

So, that is the linear regression. So, that is the; we have all learnt in statistics also and that is the supervised learning technique and. So, basically this line over here. So, $Y = B_0 + B_1 + e$; $B_0$ is this intercept here, Y intercept; $B_1$ is basically this slope and e is basically the error. So, you have this kind of best fit kind of thing for linear regression.

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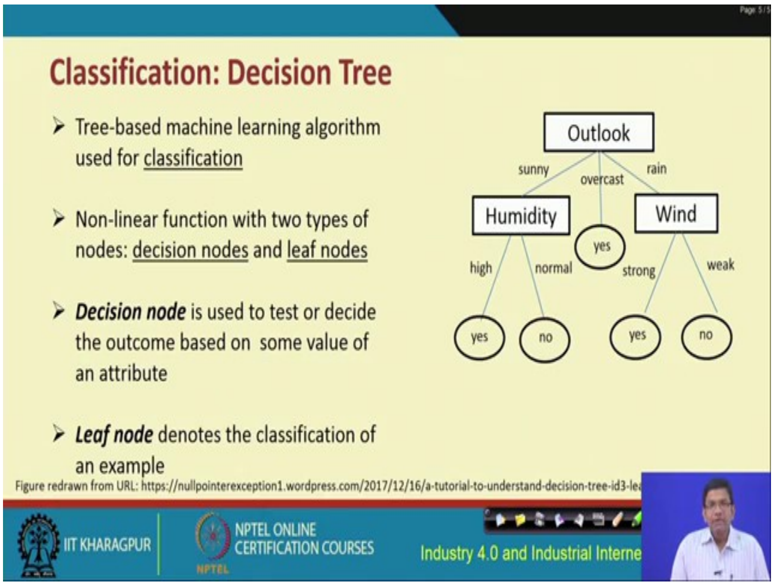


For classification techniques such as decision trees are quite common and decision trees basically as this figure suggests over here you are running some kind of a tree-based classification. And, so what is going to happen is there are two different types of nodes in this tree and these are basically the decision nodes and the leaf nodes. So, these nodes the white colored ones are the recent nodes and these nodes are the leaf nodes and so, this is a node basically will be used to test or decide the outcome based on some value of an attribute, whereas these leaf nodes will denote the classification of an example. So, this is how the decision tree looks like.

So, decision tree is also a very popular supervised learning technique.

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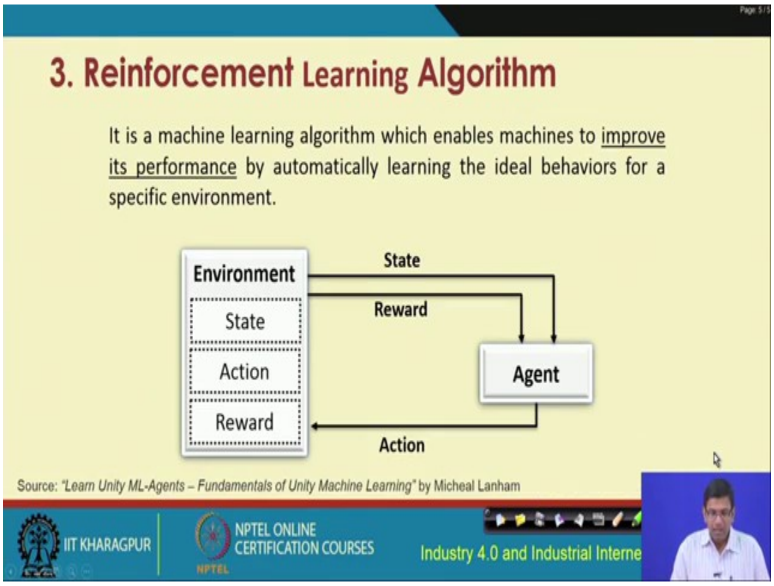


The third category is the reinforcement learning. So, it is basically a machine learning algorithm which enables machines to improve its performance by automatically learning the ideal behaviors for a specific environment. So, the way it proceeds is like this that we are going to have two different entities this agent which wants to learn and this environment on which or with which this agent interacts.

So, typically is going to happen is the agent has to learn by interacting with the environment. So, agent basically learns by interacting with the environment agent does not know that what is best action that it has to take. So, it starts like this that the agent will first take an action, and based on this particular action this environment basically is either going to reward or is going to penalize this particular agent for that chosen action.

So, a reward-penalty kind of mechanism, a feedback from the environment to the agent flows back and also the information about the change in the state is also fed back to the agent. So, with that information based on the reward-penalty value and the state information the agent makes its next choice and this is very important. So, you see even if we have a loop over here it is it we have to keep in mind in reinforcement learning that the next course of action that the agent will choose has to be dependent on these two; if that is not done then you do not have the reinforcement learning. So, sometimes that is a mistake that people commit.

So, so you have to choose the next course of action based on the reward-penalty and the state information.

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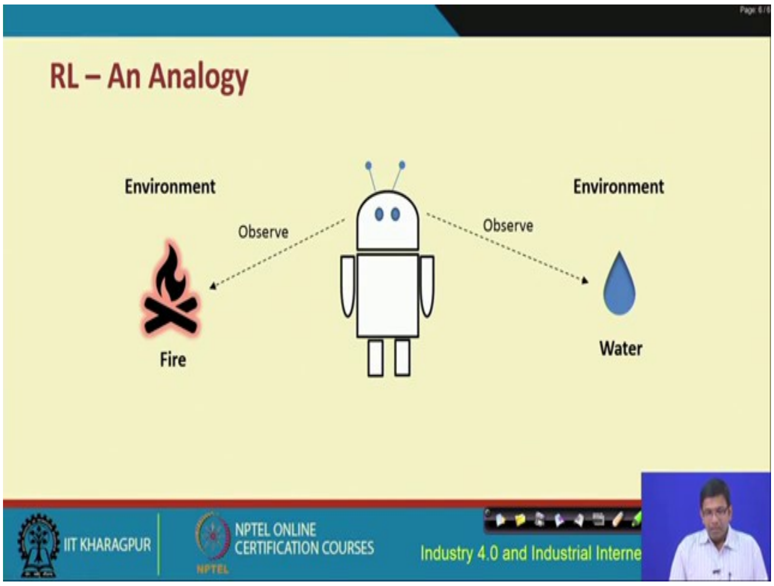


So, it is something like this that you have some kind of a robot or a human. So, in the same way as humans we learn through interactions. A robot also can do the same robot through it is interactions, observations, feedback from the environment and so on will know that what is what. So, basically the robot can through observations interactions with the environment robot will know that this is fire whereas; this is water.

So, this is basically how this reinforcement learning in practice is going to work.

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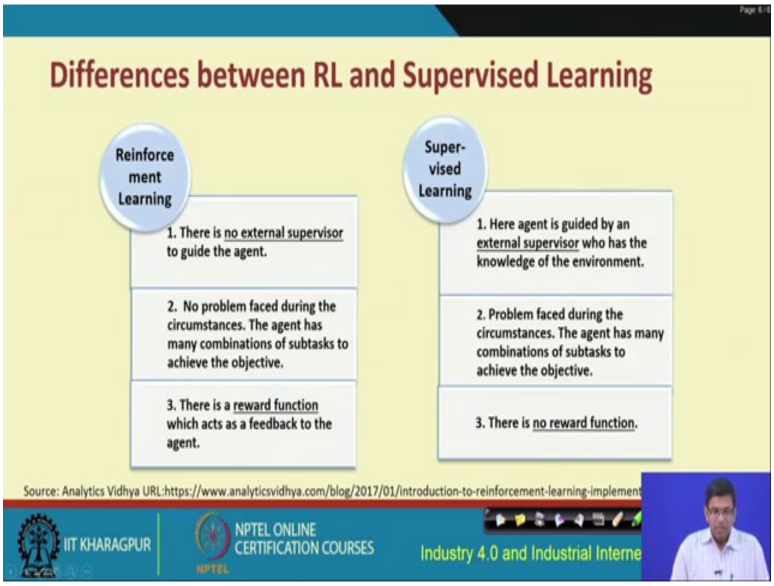


So, what are the differences between reinforcement learning, supervised learning and unsupervised learning? So, let us take up reinforcement and supervised learning first. So, in reinforcement learning there is no external supervisor whereas, in supervised learning there is some external supervisor who has the knowledge of the environment. So, that is where this training data set becomes useful. In reinforcement learning there is a reward-penalty structure that has to be in place whereas, because the external supervisor with previous knowledge is already used in supervised learning you do not need a reward function in supervised.

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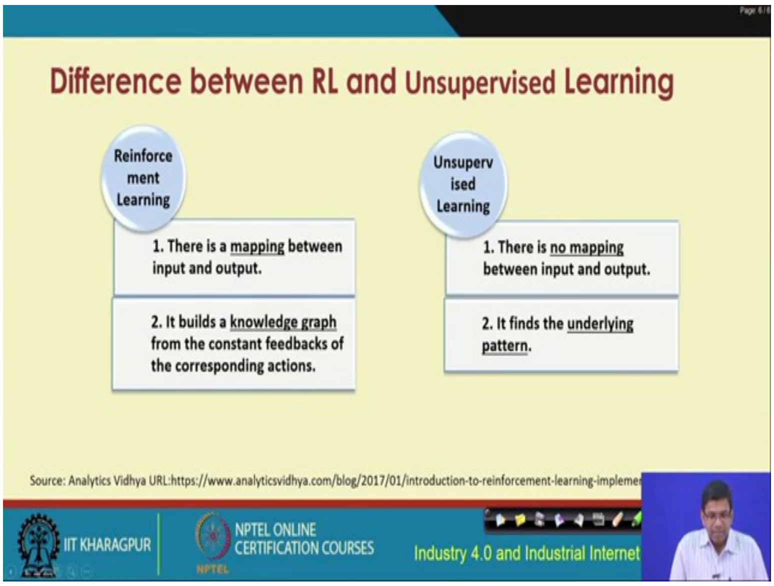

Comparison between the reinforcement learning and unsupervised; in reinforcement learning there is a mapping between the input and the output whereas, in unsupervised learning there is no such mapping. In reinforcement learning the agent basically builds a knowledge graph from the constant feed backs of the corresponding actions whereas, the unsupervised learning in that the agent finds the underlying pattern because here it is different. So, it basically tries to uncover the underlying pattern. So, that is the difference between the reinforcement learning and unsupervised learning.

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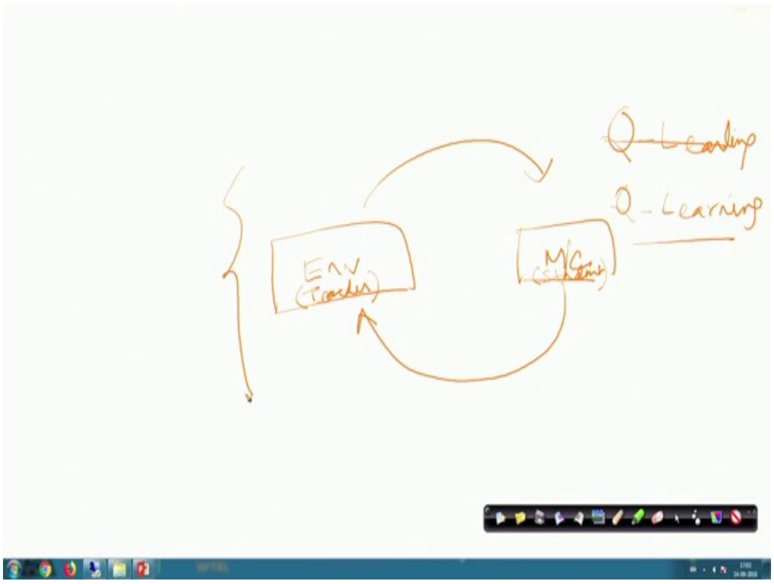


So, basically what is happening in reinforcement learning is that I will give you an analogy in reinforcement learning what is happening is that you have a machine. You have a machine and you have this environment. This environment we can think of to be like a teacher whereas, this machine we can think of to be like a student.

So, basically it is a learning kind of mechanism between the student and the teacher initially the student does not know anything, teacher knows. So, basically that knowledge has to be transferred to the student, but the student will not get that knowledge just like that. The student will have to ask questions; the teacher will say yes or no with a certain marks or penalty value and based on that the student will keep on interacting making different choices, student takes an action, the teacher asks let us say the teacher shows a color and the teacher asks that is it white then the student basically who does not know whether it is white black or what whatever it is will say that it is grey with certain probability.

So, it chooses an action and the teacher basically will then teacher knows that no, it is not grey, but it is white then the teacher basically will penalize the student with a certain penalty probability. And, then based on that the student is again going to make a choice and then the student who is going to gradually converge towards the correct value by interacting with the teacher this is also known as Q-learning. There is a specific reinforcement learning mechanism which is known as Q-learning. This is more or less the overall idea and analogy with Q-learning. This is a specific type of reinforcement learning and this is how it works.

So, for IIoT there are different machine learning techniques in place.

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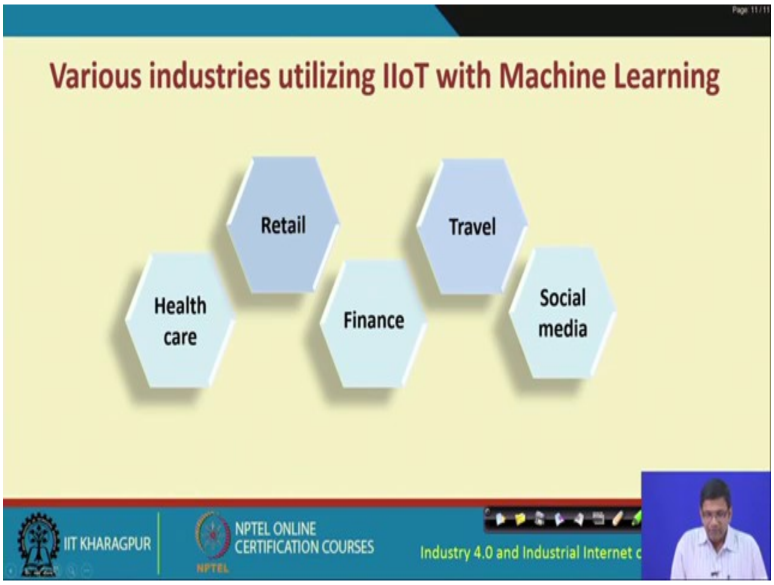


So, you could use machine learning in IIoT in order to harness the benefits, utilize the benefits of machine learning and make IIoT much more efficient and useful. Different industries such as healthcare industry, retail, finance, travel, social media and many more use IIoT with machine learning in order to improve their products their processes and so on.

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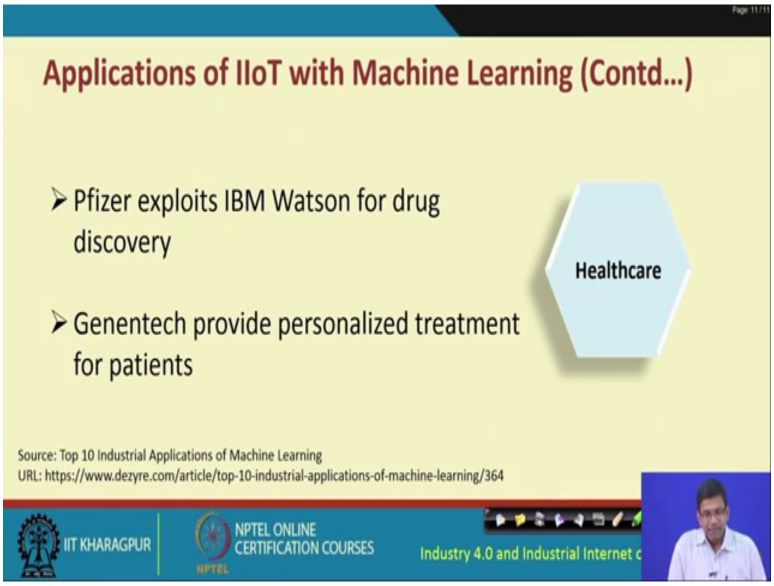


So, the company Pfizer which is in the medical space the healthcare domain they exploit IBM Watson for drug discovery. So, that is where they use different machine learning techniques for drug discovery. Another company Genentech provide personalized treatment for patients there also machine learning is used.

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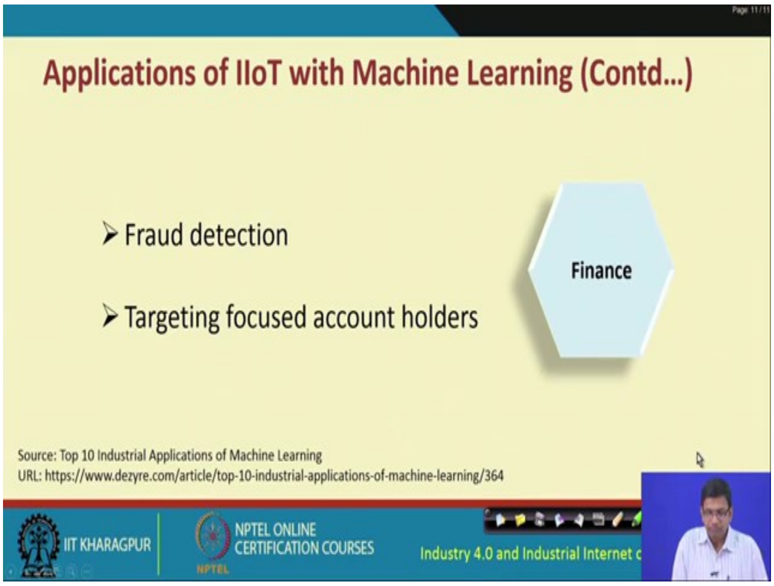


In finance, for fraud detection and for targeting focused account holders IIoT with machine learning techniques could be utilized.

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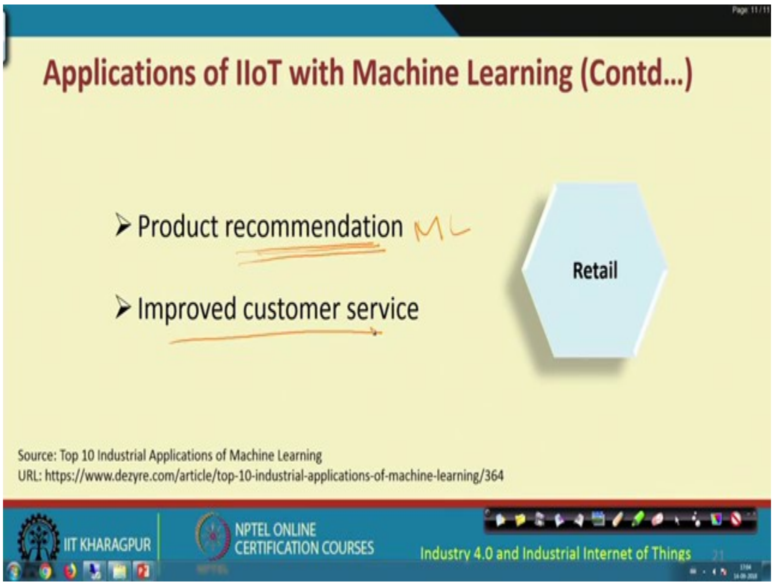


For retail, product recommendation, any recommendation basically this recommendation is something where recommender systems etc. are heavily based on machine learning. So, for product recommendation in the retail sector or for improving the customer services there also machine learning techniques could be used.

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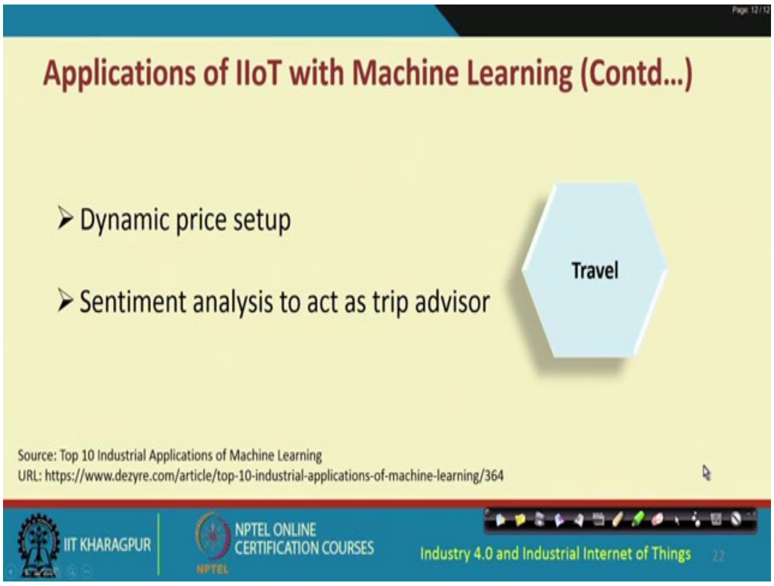


In the travel sector also IIoT with machine learning for dynamic price setup, for sentiment analysis to act as trip advisor IIoT with machine learning combined can be used.

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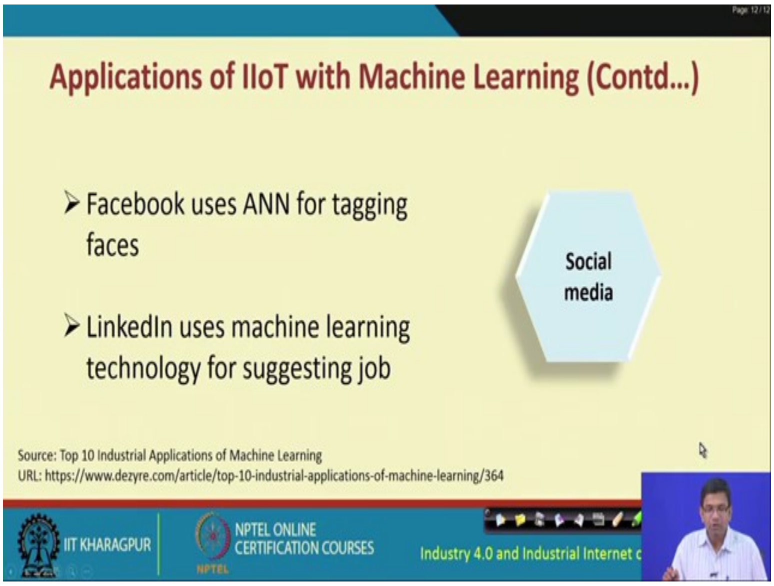


For social media, Facebook uses artificial neural network for tagging different faces and this is what most of us have already experienced. So, behind the scene we see that Facebook basically does lot of these tagging, but that is based on ANN – artificial neural network which is a popular machine learning technique. LinkedIn uses machine learning technology for suggesting jobs.

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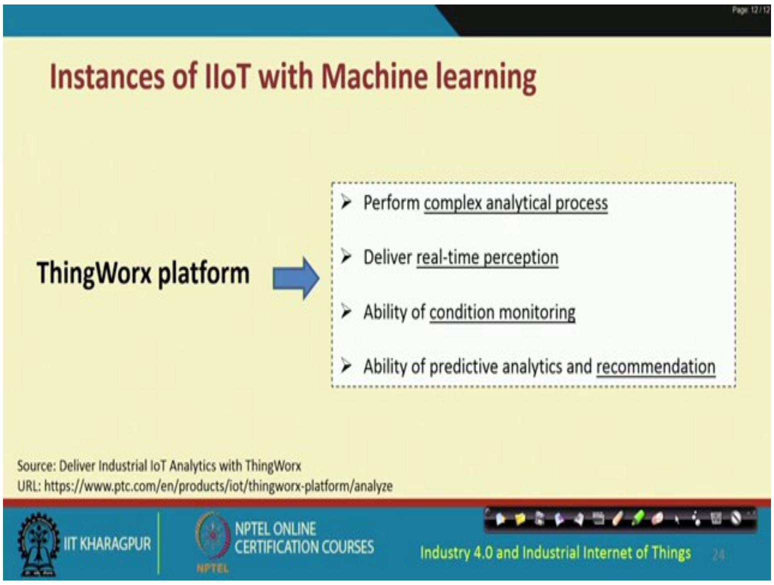


ThingWorx platform is another example which performs complex analytical processes, deliver real-time perception, offers the ability of condition monitoring, offers the ability of predictive analytics and recommendation with the help of different machine learning techniques.

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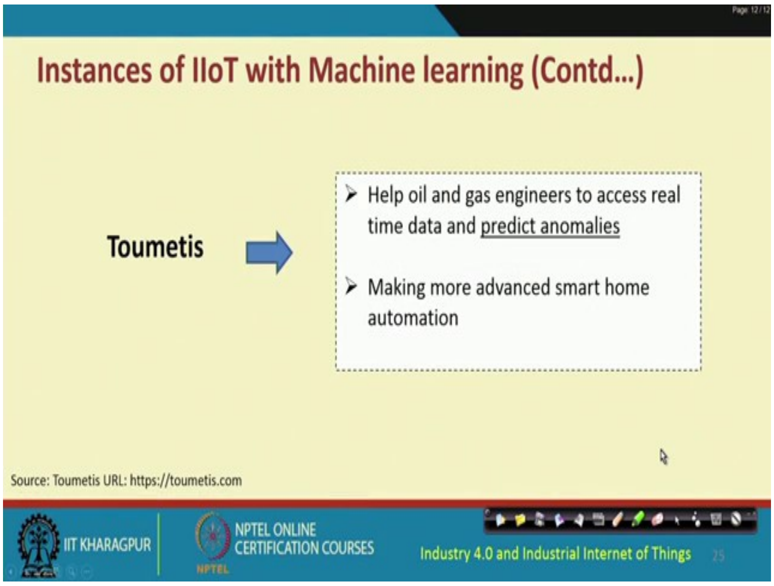


Another company Toumetis, they are in the oil and gas space. So, they help the oil and gas engineers to access real time data and predict anomalies.

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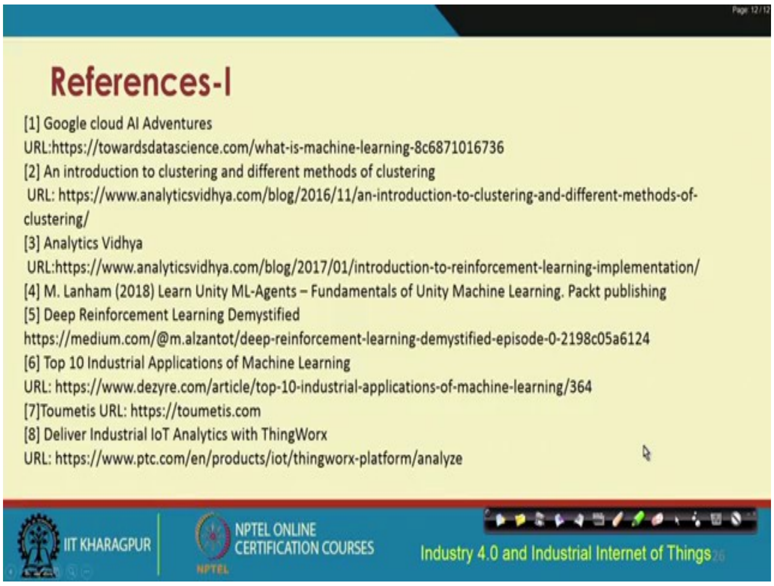


So, these are some of these examples of the use of machine learning and often machine learning combined with IIoT. So, this is where machine learning combined with IIoT can be useful in different industrial settings and machine learning so far what we have understood in this particular lecture is that machine learning can be of broadly three types. One is the supervised, unsupervised and reinforcement learning and there are different-different other machine learning techniques that are also there.

So, these are some of these different references that can help you to get a little bit more in-depth understanding of machine learning. If you are indeed interested to get more understanding of machine learning you are encouraged to go through some book on machine learning, but unless you have real curiosity and curiosity to know the different algorithms and methodologies that could be used in machine learning only this much of information should be sufficient for you. And, in case you are more interested you are encouraged to go through different literature and particularly the machine learning books.

With this we come to an end of the first part of lecture on machine learning introduction for IIoT.

Thank you.

**Introduction to Industry 4.0 and Industrial Internet of Things**
**Prof. Sudip Misra**
**Department of Computer Science and Engineering**
**Indian Institute of Technology, Kharagpur**

**Lecture – 38**
**IIoT Analytics and Data Management: Machine Learning and Data Science - Part 2**

In the previous lecture, we got an overview of machine learning. We have also seen what data sciences and how it relates to fields of computer science mathematics and machine learning. So, here in this particular lecture, we are going to go little bit further.

We have already understood in the previous one, what are the different techniques for machine learning, the broad classifications of machine learning? And how it could be used for IIoT scenarios? And we have also seen a few examples of the use of IIoT and machine learning combined for addressing some real life problems in industrial settings we have already seen that.

So, in this, we are going to continue further. And first we are going to start with understanding how machine learning compares with something also very popular nowadays which is known as the deep learning. So, how machine learning compares with deep learning and how machine learning, deep learning; they compared together with artificial intelligence.

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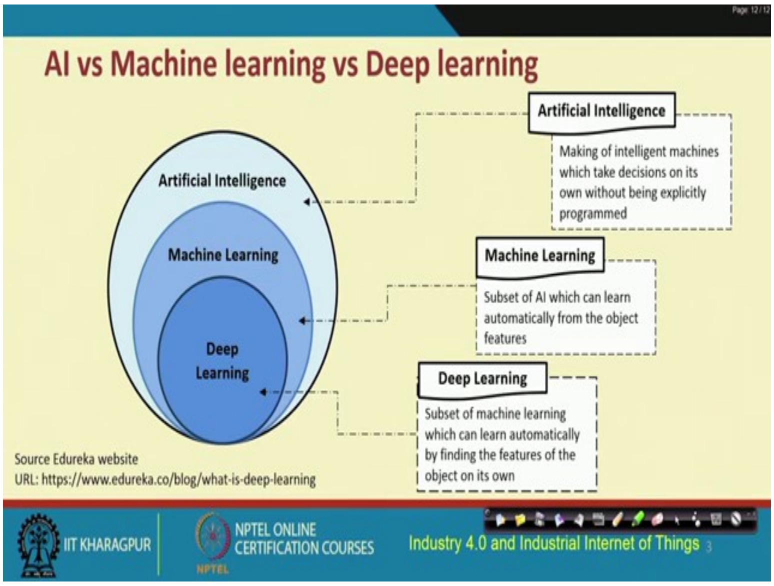

So, this is this overall comparison. So, this is AI versus machine learning versus deep learning. So, holistically it is like this that, deep learning you can think of is a subset of machine learning. And machine learning itself is a subset of artificial intelligence. So, finally, what we have is something like this, you can think of deep learning to be part of machine learning and machine learning again part of artificial intelligence.

So, artificial intelligence, we have gone through it in a previous lecture. So, artificial intelligence talks about making intelligent decisions. Intelligent machines, which will take their own decisions without being explicitly programmed to do so. On the other hand, machine learning focuses on learning automatically from certain object features. So, features may be present, may not be present. In deep learning, for exam example this is where you do not take help of any manually identified features and automatically the features are going to be found out on their own?

So, this is how this deep learning, machine learning, and artificial intelligence is compared to one another. And again, like I said in the previous lecture, if you are interested to know more about deep learning, there are courses you should basically do semester long courses on deep learning, semester long courses on machine learning, and semester long courses on artificial intelligence.

This particular course is scoped only to give you an overview of what is what, not beyond that. So, that you feel yourself empowered and knowledgeable in order to implement if required the different AI, ML or DL techniques for improving your IIoT implementations in your respective industries.

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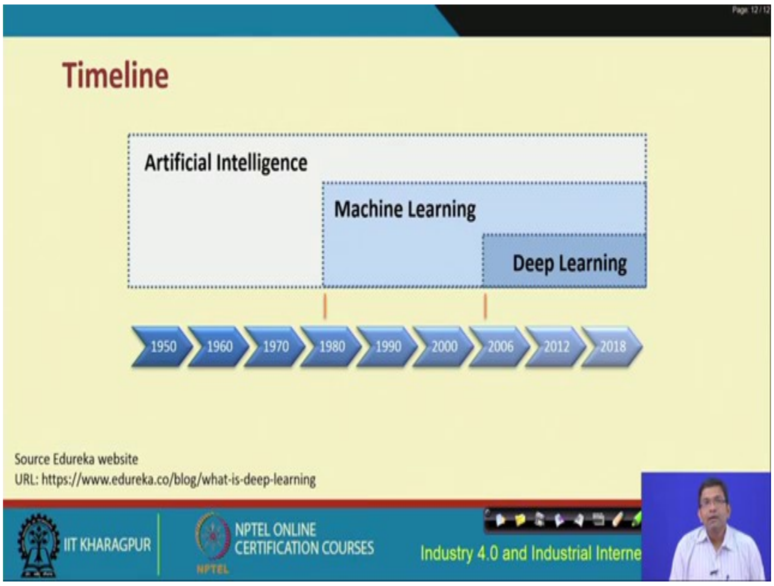


So, this is just the history. AI has been popular since 1950's, it is still popular. ML has been popular since the 1980's, it continues to be and deep learning, since last few years may be 2006, 2007 onwards and so on. But ML, so all these things have been there. You know, AI has been there. ML has been there, but in the only in the recent times these have become more and more popular due to a variety of reasons.

Due to the advent, the popularity of IoT for instance, due to the popularity of autonomous systems for example, autonomous cars, self-driving cars which basically use a combination of all of these technologies AI, ML, DL plus different IIoT technologies are used. And that is where this AI, ML, or DL are becoming even more popular

So, these are 2 examples that I told you. You know there are many more examples in the current day world, where you have to fall back on your previously known technologies such as AI, ML and so on. So, these are not new. ML has been there, AI has been there for even more for a longer time. But only in the recent times, because of the newer applications that are coming up, these technologies have got renewed attractiveness and are being used popularly in the industries.

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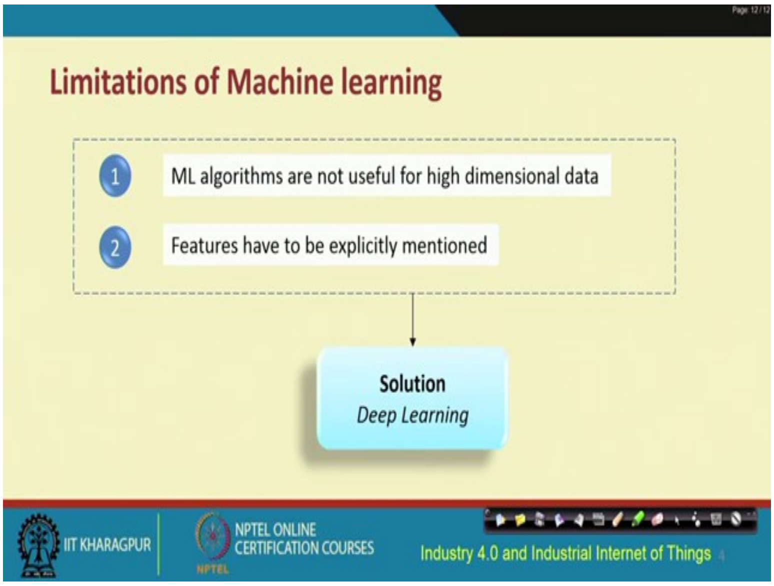


So, we have understood the benefits of machine learning. But machine learning has its own limitations. Machine learning algorithms are not useful for high dimensional data. So, clustering I have shown you x and y that is fine, but if you want to increase the number of dimensions then machine learning will gradually become less useful. Features will have to be explicitly mentioned in machine learning, a type of machine learning.

But if you are talking about deep learning, this is a newer technique where you do not have to do these two. This is basically a new learning technique, the deep learning technique which is again based on machine learning, but it tries to overcome some of the drawbacks of the, limitations of machine learning.

Particularly DL is able to deal with high dimensional data and that is where also the utility of DL becomes much more eminent. And also feature extraction, manual and explicit provisioning of these features and so on those do not have to be done in the case of DL.

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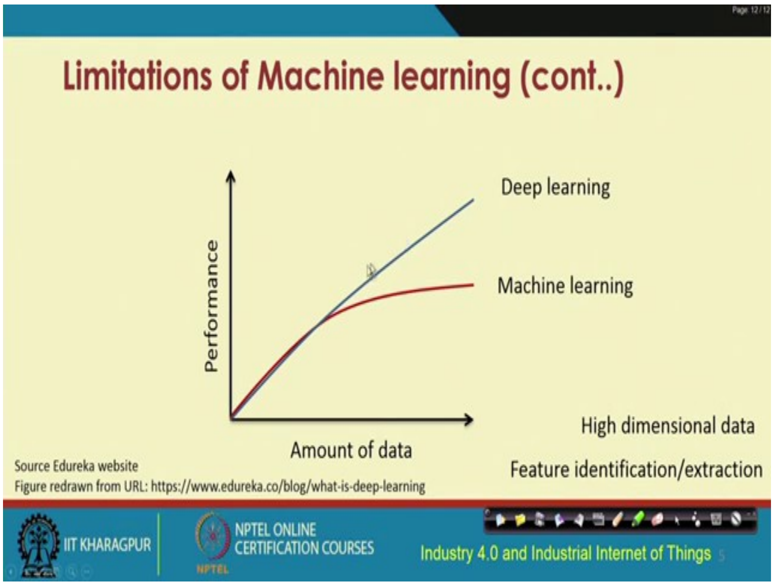


So, this is basically how these ML and DL; they compared with one another with respect to the volume of data. So, if you see that ML and DL with the increase in the number of amount of data, volume of data, and the dimensionality of the data rather. DL gradually becomes more and more popular and useful the performance improves whereas, ML the performance of ML will gradually come to a stagnation. So, also the other limitation was that feature identification and extraction is required in ML whereas, it is not required explicitly in DL.

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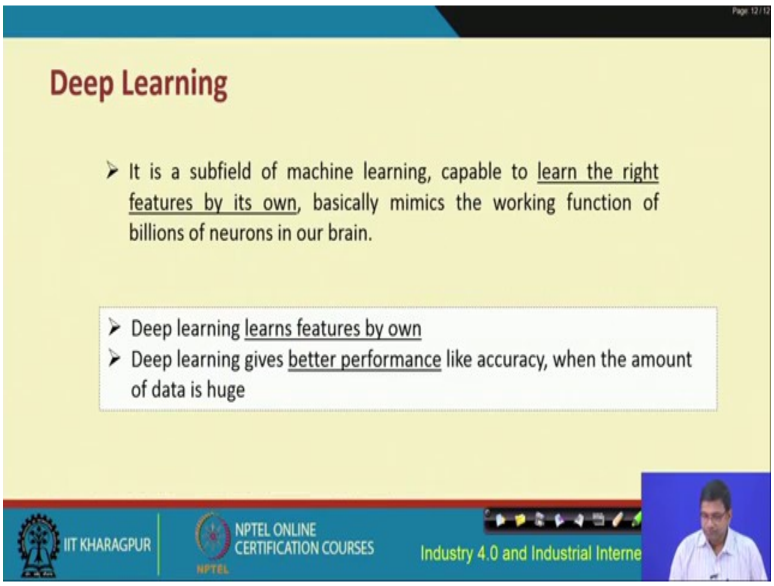

So, deep learning, it is a subfield of machine learning which is capable of learning the right features on its own. On its own, it is able to learn the features. Basically, it mimics the working function of billions of neurons in our brain deep. So, if you look at the neuron, neural structure of the brain it is a very complicated neural structure. So, inspired from that neural structure, the deep neural structure that is underneath different layers etc. Deep learning has been inspired by that and it builds upon that; it is little different understanding brain is not very easy.

So, it is inspired, but not exactly brain-based neural structure that is followed. It is inspired, but its bit different, but what DL does? It learns the features on its own. And this DL, gives improved performance with respect to accuracy when the data volume increases and the dimensionality of the data also increases.

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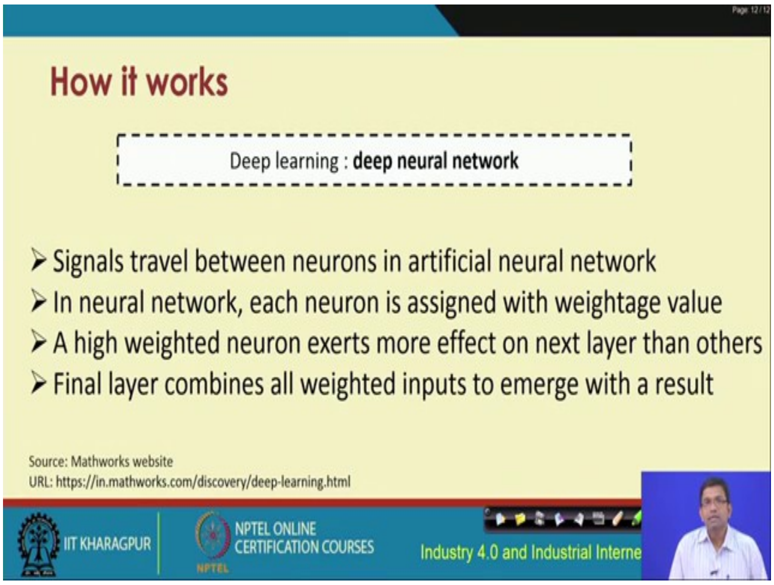


So, one of the very popular techniques in deep learning is to use deep neural network. You know, so it deep in your network is again based on neural network ANN's, but its again with deep. I will show you how a deep neural network looks like schematically, shortly. But before that, so in a deep neural network, the signals basically travel between different neurons and layers of neurons in artificial neural network. In neural network, each neuron is assigned with some weighted value, a weighted, a high weighted neuron exerts more effect on the next layer than the others and the final layer combines all the weight inputs to emerge with a result. This is how it works.

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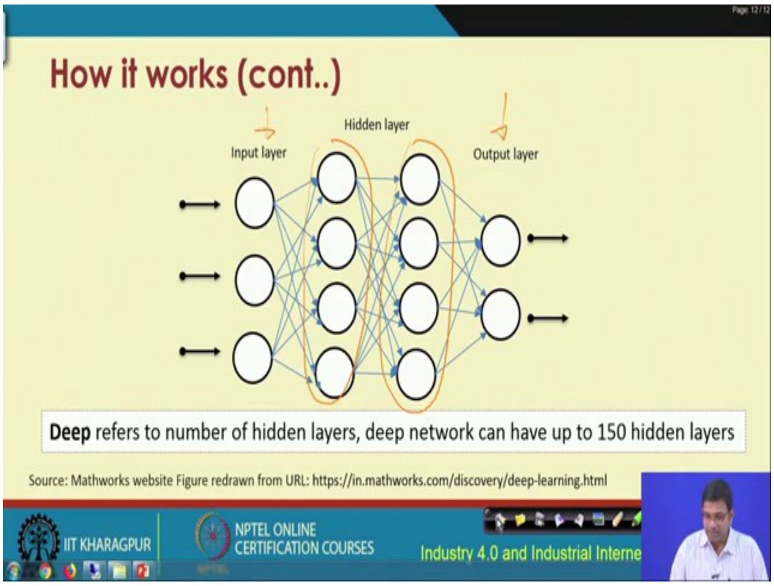


So, diagrammatically I show you over here that this DNN which is the deep neural network. As you can see here, you have an input layer and you have an output layer. So, input layer basically takes the inputs, the output through this optimization process is basically passed from the output layer. You can get the output from the output layer.

Now, in between are all these hidden layers, these are the hidden layers where lot of you know integrate relationships are there which does these computations. And you can increase the number of these hidden layers and the more and more you increase, the more and more computations will be there. The, but it is going to give you more accuracy in general, but not in all cases, but in most cases it is going to give you more and more accuracy.

So, deep basically refers to the number of hidden layers. So, the more number of layers you have, the deeper structure you are going to have of the neurons. So, it is said that the deep neural network can have up to 150 hidden layers. So, here we show only 2 hidden layers, but in a DNN up to 150 hidden layers can be implemented.

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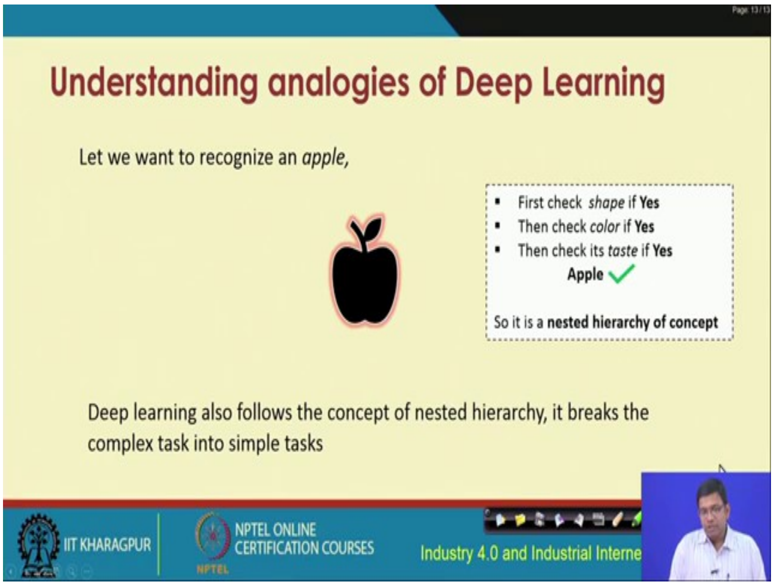


So, let us take an analogy from real life about how deep learning works. Let us say that, we have to recognize whether this is an apple or not. So, first you check the shape. If you see that the shape is what is desirable, if yes, if you after checking that the shape is ok, then you check the color, if the color is ok, then you check its taste, you bite on the apple and then you check how it tastes. If you see that the taste is ok, then you confirm that it is an apple. Right?

So, you make this confirmation or recognition of an apple based on its shape, color, and the taste. And that is basically the nested hierarchy concept. So, deep learning also follows the concept of nested hierarchy. And it makes the complex tasks into simpler tasks. So, this is just an analogy to make you understand deep learning better.

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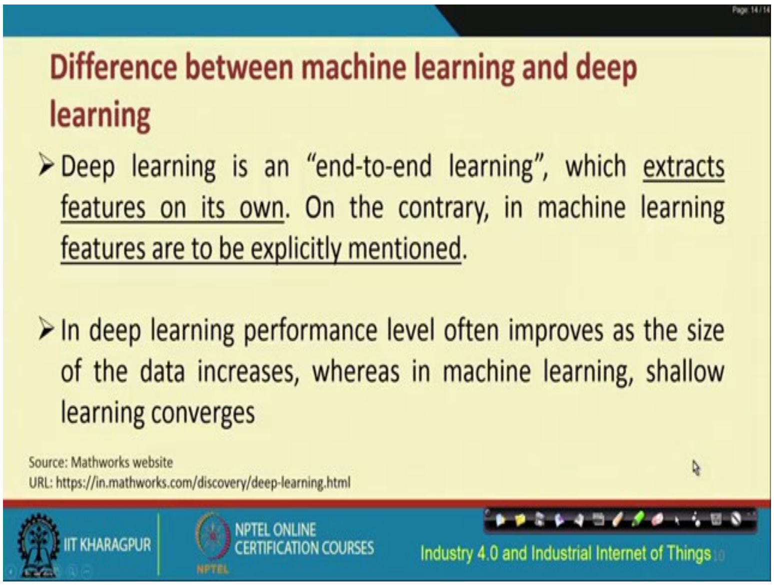


So, difference between machine learning and deep learning. Deep learning is an end-to-end learning which extracts features on its own. This is the key thing, extraction of features on its own. On the other hand, in machine learning features are to be explicitly manually mentioned. In deep learning, the performance level often improves as the size of the data increases. Whereas, in machine learning, the shallow learning basically converges.

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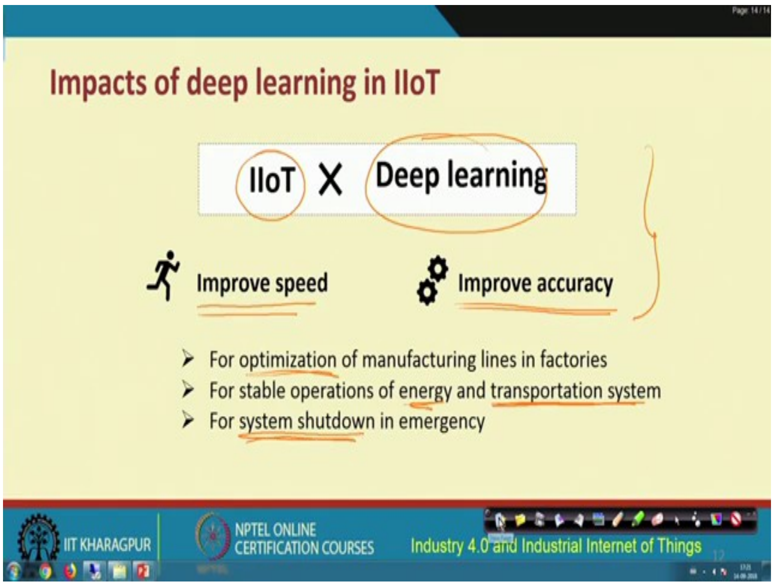

So, we have 2 things. We have IIoT, and we have deep learning. Both are very powerful technologies. IIoT is helpful for improving the speed; whereas, deep learning is useful for improving the accuracy. Now, if you put them together, what you get is a multiplicative effect.

So, this multiplicative effect becomes a very powerful thing which can help these manufacturing industries in the factories to optimize their product lines. It can help in optimizing the energy consumption, and to improve the transportation operations. It can also help for systems shut down in the case of any kind of emergency or eventualities.

So, IIoT, deep learning together makes things multiplicative in terms of the benefits that can be obtained and together you get a very powerful technology.

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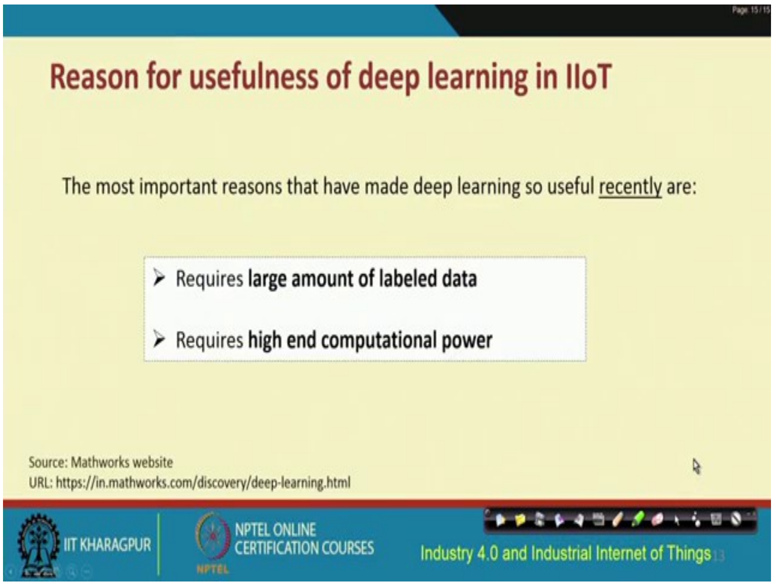


So, the reason for the usefulness of deep learning in IIoT is like this. So, the most important reasons that have made deep learning so useful in the recent times is, that only in the recent times, the amount of labeled data that is required has increased manifolds. So, it has increased and is also available. And at the same time, in the recent times, the high end computational power have also become quite high and at the same time cheap.

So, high end computational power cheaper, but available at low cost and coupled with that the amount of large amounts of data have the availability of that data has also increased and the requirements for both of these has also increased. And consequently what we have is that together people have realized nowadays that deep learning has lot of benefits because of these necessities.

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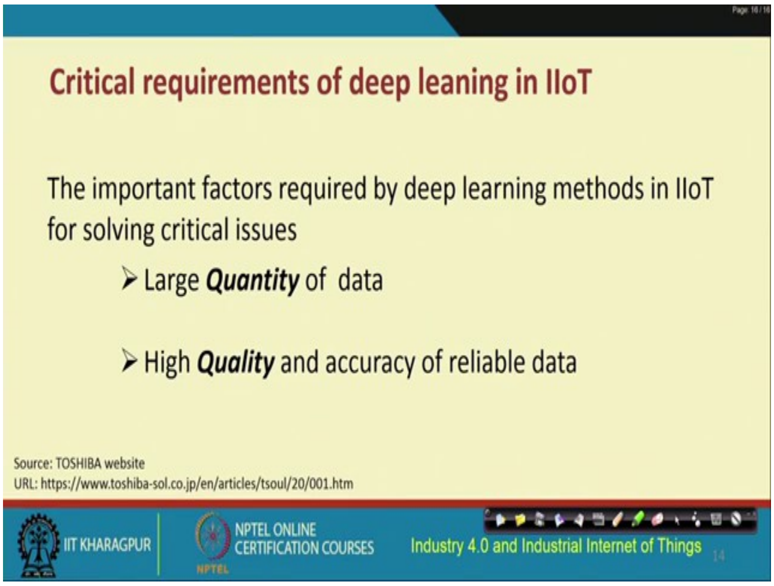


So, the critical requirements of deep learning in IIoT are that nowadays we are talking about solving critical issues such as, dealing with large quantity of data and also dealing with higher accuracy requirements higher quality and so on.

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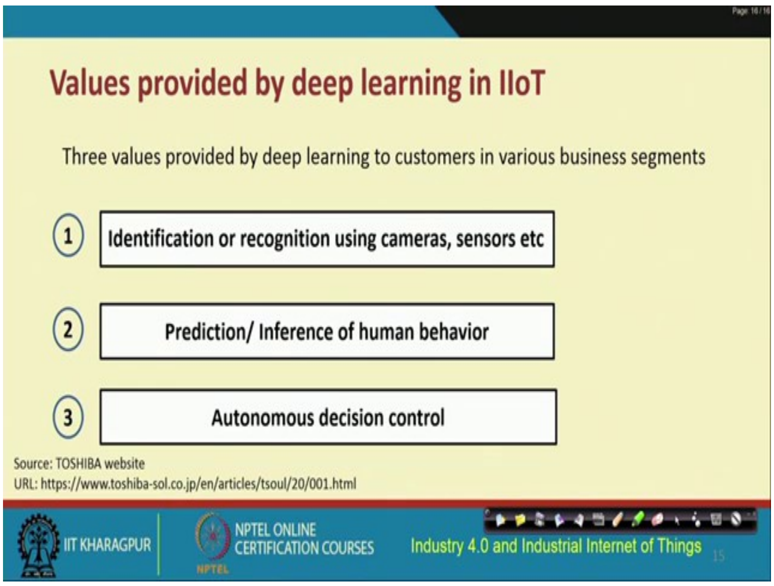


So, deep learning basically provides the values in terms of enabling the customers for identification or recognition using technologies such as cameras, sensors, etc., prediction or inference of human behavior and autonomous decision control. So, these are the different benefits that deep learning gives to the customers in different business segments.

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So, deep learning, there are uses of deep learning a lot in the industries. The company Toshiba of which we are very much familiar, Toshiba uses something known as the collaborative distributed deep learning technology. So, that is a technology that is used between the edge and the cloud. Edge means, some gateway device which can perform certain processing.

So, between the edge and the cloud, this Toshiba came up with a collaborative distributed deep learning framework. So, we are using this framework. The learning process is performed in the cloud for high end processing whereas; the inferencing process is conducted in the edge for real time processing. Basic analytics will be done at the edge whereas the deeper ones which require a lot of computation and so on. The higher in processing, higher in computation will be done will be done at the cloud.

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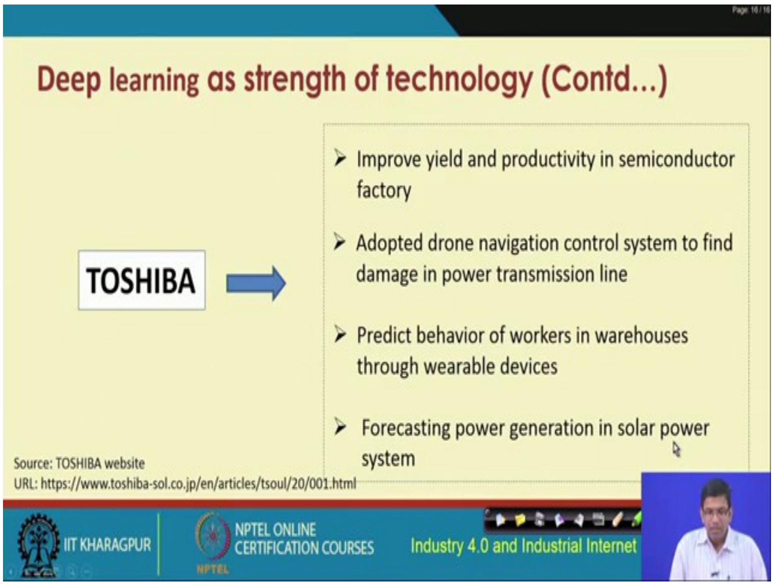


So, the Toshiba technology leads to improved yield and productivity in the semiconductor factory. They adopted the drone navigation control system to find damage in power transmission lines, predicting behaviors of workers in the warehouses through different wearable devices, and forecasting power generation in a solar power system.

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So, another example is H2O platform that also uses the deep learning framework. Intel's Nervana is a deep learning processor. Zebra medical vision system, they are using deep learning techniques for different problems in the medical domain.

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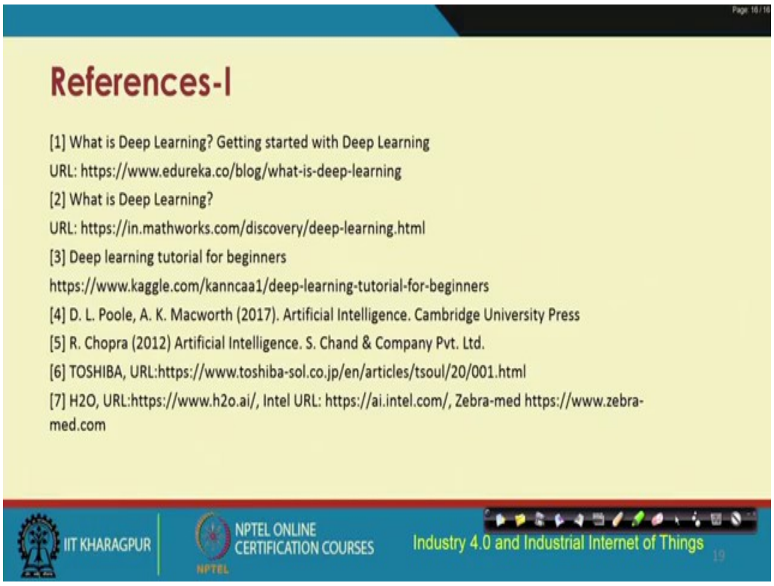


So, these are some of these examples of deep learning and where it is finding popularity. Deep learning has become very popular in autonomous driving vehicles. Nowadays, deep learning along with IoT has become very popular together. They make these the self-driving cars a reality.

So, like this, there are many different utility of machine learning, deep learning, and artificial intelligence and they are handshaking with IoT and IIoT, which make them powerful together in addition to having their individual strengths.

So, with this, we come to an end. Here are these different references like before you are encouraged to go through these different references and with this we come to an end of the getting an overview of machine learning and data science for IIoT.

Thank you.

**Introduction To Industry 4.0 And Industrial Internet Of Things**
**Prof. Sudip Misra**
**Department of Computer Science and Engineering**
**Indian Institute of Technology, Kharagpur**

**Lecture – 39**
**IIoT Analytics and Data Management: Cloud Computing In IIoT – Part 1**

In the previous lecture we spoke about understanding analytics, the basics of analytics, the basics of machine learning, how machine learning positions itself with deep learning, artificial intelligence, data science and so on. So, that is basically the analytics; that means, you have the data and you have to make sense out of the data; you have to get intelligence out of the data, the intelligence that is latent inside the data you have to get that intelligence out for that you need to use all these machine learning, deep learning AI techniques and so on.

But the question is where do you store the data? One thing is storing the data, how and where you are going to get the infrastructure that is necessary for the processing of the data, how you are going to get it, how you are going to get access to it, how much of this data will be made available, how much you have to pay for it, when do you buy whether you at all you buy or not? So, buying the computing infrastructure I am talking about so that is a challenge.

So, that is where this cloud computing technology has been proposed, so this is a technology that has become very popular now. So nowadays people are have reduced, most of these organizations, the businesses; they have reduced buying the computing infrastructure, but are taking help of many of these online computational resources that are available through subscription models.

So, you could subscribe you could basically register yourself to any of these computational platforms you could subscribe to these platforms pay for whatever you are using and could use their platforms.

So, essentially what you have? Is you have a scenario at present today if you have some computational needs you really do not need to go and buy a server, a computer or a high-end machine or whatever it is sufficient nowadays in most of the cases to basically subscribe yourself to some of these online computational resources and try to use them.

So, that this will make it clearer in the next few moments, but let us try to get an overall understanding of the things.

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So, before we do. So, I just wanted to give you a recap of what we have in terms of IIoT and industry 4.0, we talked about sensing, communication, networking and computing. It is this computing that that basically attracts the cloud technologies, so where cloud can make the business processes much more simplified and much more efficient and powerful and also cheaper. So, this is where this cloud technology becomes helpful.

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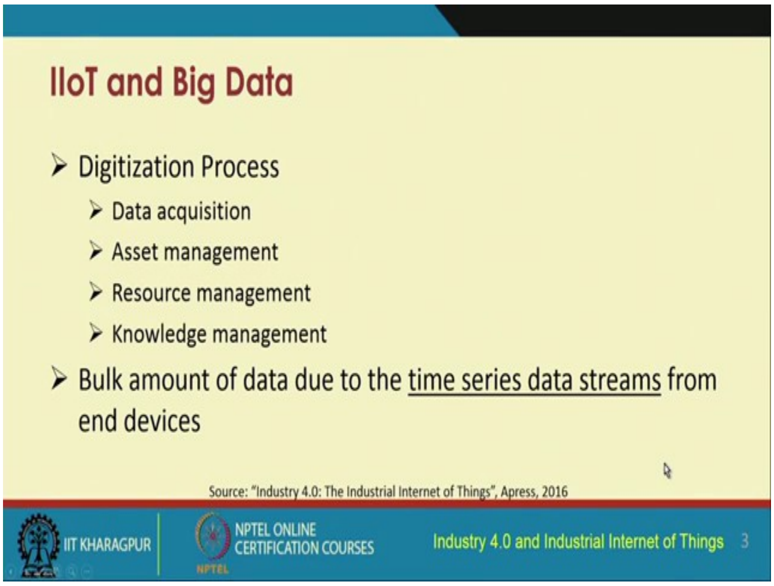

So, when we talk about digitization, so the digitization process involves acquisition of the data in the context of IIoT, acquisition of data management of assets, management of resources, knowledge management and so on. So, in the context of IIoT we are essentially talking about a scenario, where we are talking about volumes of data that come in large velocities and they have different other characteristics as well. And these are like time series data coming from different field devices, different machines, different IoT devices and so on which will have to be stored processed and so on.

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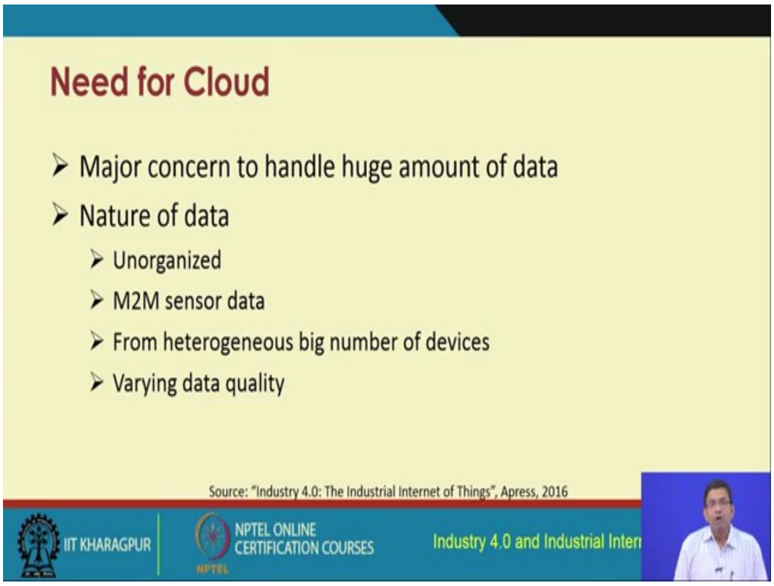


So, how do you handle that kind of data; that is where this cloud becomes necessary. So, cloud technology will help you to handle huge volumes of data; not cloud alone, cloud with different other data management techniques like the ones that we have already spoken in our analytics lectures. So, cloud will help you for storage and for processing; that means, running different computational jobs.

And for that we do not really have to go and buy a very expensive computer a expensive server and so on, we could simply get ourselves logged into some online cloud service providers and we can hook our system that we develop which basically are a combination of different IoT devices throwing lot of data to that cloud and this cloud is going to do the rest.

So, the nature of data that we are talking about in IIoT are unstructured unorganized data which cannot be stored in the form of relational tables, data which are coming from different machines, sensor data, actuator data and so, on, data which are coming from different-different other heterogeneous machines, data where the quality of the data varies with time.

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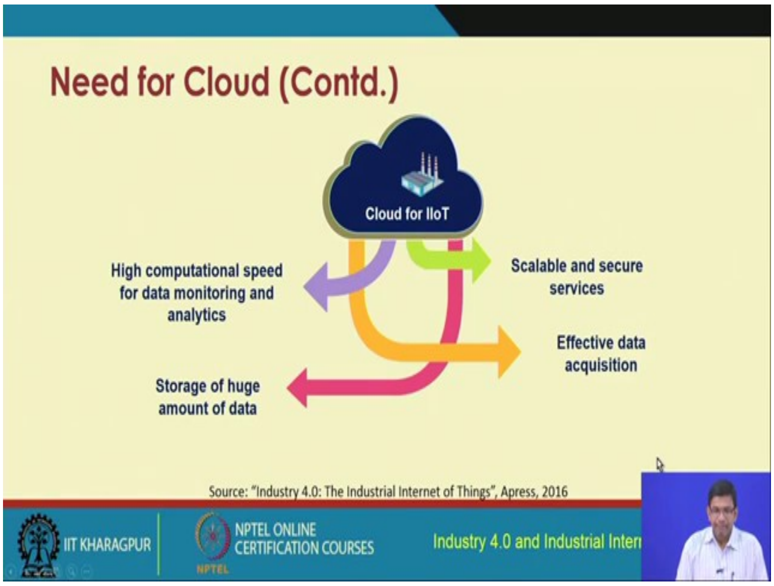


So, there is a need for cloud. And these are the reasons why cloud will be needed. The first thing is that cloud basically gives you a platform for high computational speed, for data monitoring and analytics; second benefit is storage of large volumes of data is possible with cloud in a very simplest manner.

Third is scalability and security of services, so basically because there is a separate, cloud service station a cloud service provider who has their own different processes. So, even if one CPU fails there are other CPUs which will be here to take over. So, it is a scalable and reliable and also secure service cloud based service. So security part let me tell you security and privacy there are lot of issues with it.

So, some people believe that cloud basically is not a good platform for securing your data or offering privacy of the data. Because people think that you do not know where your data is going to be stored is going to be processed and so on, anywhere in the world it could be done and because you do not know some people have lot of concerns about the security of the data, the privacy of data and so on.

But in general the people believe that cloud based platforms will give you, a reliable platform, a scalable platform and a secure platform for storage and handling of data and also the acquisition of the data with cloud can be made much more efficient.

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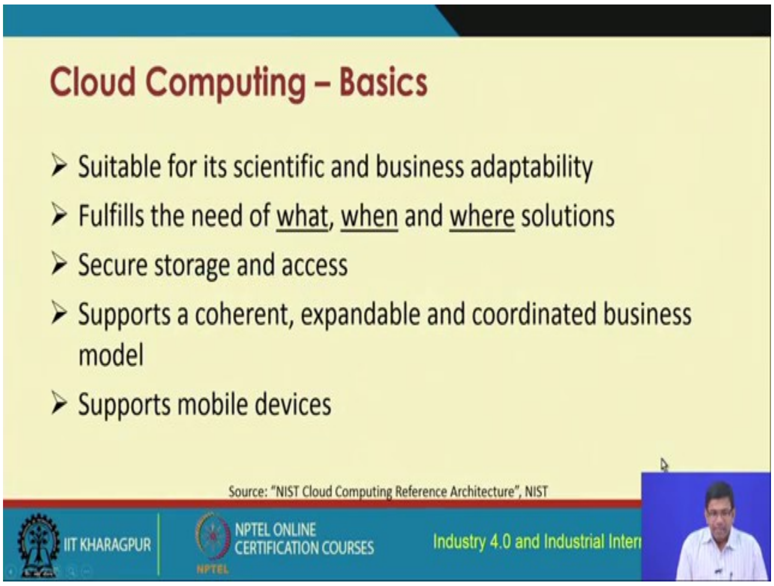


So, before we go in further, let us talk about cloud computing in little bit more detail. So, cloud is suitable for number of things, for running your high-end computational jobs, scientific jobs and so on. For business operations cloud will be helpful. So, basically cloud fulfills the need of what, when and where solutions, offerings, and different types of storage access to computational power software platform and so on different types of accesses and so on.

Supports a coherent, expandable; that means, scalable and coordinated business model. So, basically expandable means what? That some part of your job if it requires that you need more storage that also can be expanded very easily. You could just subscribe to whatever additionally you need and automatically nesting this manner you would be able to get those services.

Cloud platforms are supported by the present day mobile devices that also makes cloud very attractive. So, before I go any further I would like to make sure that you understand the utility of cloud, why cloud is so popular, why cloud is necessary? So, cloud computing; what is it? I would say that cloud computing is computing offered as a utility service. So, computing offered as a utility service means what?

We know of different utility services utility services such as electricity, utility services such as water and so many different other utility services such as LPG connections, so we know of all these different utility services. So, for all these different utility services electricity, water or LPG connections at home what happens is that we have the necessity to light our bulbs at home, to run our air conditioners, to run our fans and so on.

So, we have this necessity for that we have the necessity for electricity, but that electricity we do not really have to generate ourselves. So, what we are doing is that there is an electricity service provider and that electricity service provider, we have to subscribe our electricity services to the electricity service provider.

The service provider will then remotely give that connection of course, there is a requirement of having a physical electric connection to our prospective homes or offices, but given that is in place in what happens the remotely the electricity service provider is going to send the electricity and we can enjoy this electricity. So, we can run as many bulbs that we want, we can light as many bulbs that we want, we can run as many air conditioners that we want and so on.

We are least bothered about whether the electricity is going to get over, if we have more requirements of electricity we keep on running more we do not bothered that I have very little amount of electricity and I do not want to run more. So, that is utility as a service and the beauty about it is that we keep on enjoying as many units of electricity as we need and we will be billed for the number of units of electricity that we have used. So, pay per use concept is applied in all these utility services.

So, I took the case of electricity the same applies for water as well, so water, electricity and many different other services basically follow the pay per use model because we have meter, we are getting meter service and we will be billed based on the number of units of the meters of conjunction that we will have for each of these utility. The same concept was extended further, people thought that if electricity can be offered as utility, if water can be offered as utility and people can subscribe to this services without worrying how to generate electricity and so on.

And they will get billed based on the number of units of electricity that they are going to use or other utilities that they are going to use, why cannot we adopt the same model in computing. So, traditionally what used to happen? That if you have a huge computational job or something where you have different computational requirements you would have to go to the market, you will have to procure the different equipments the big servers you will have to procure you have to buy them you have to pay money upfront and then install them and then you will be able to use those equipments.

So, that basically delays the business requirements, business processes will be delayed. Second thing that will happen is you have to have lot of upfront investment for this computing infrastructure, as a third thing that is going to happen is that if you have further requirements you cannot expand further. So, instead imagine a scenario that there is a service provider for computing, you have a computing service provider which we call as the cloud service provider now.

So, this computing service provider will give you all these resources through online subscription. And through online basically you would be able to login to different portals and be able to run your computational jobs based on your certain requirements, this is basically the concept of cloud computing; computing as utility is what cloud talks about and you basically can enjoy in this kind of model as much of computational resources that you need, if you have less resources to start with, if you have requirements for less resources to start with you use less if you have more requirements you use more.

So, you can basically it’s an elastic kind of model based on your requirements you can expand or decrease the amount of resources that would be required and accordingly you will have to pay for units of usage of the computational resources. So, this is basically the whole idea or the story of cloud computing and how it evolved and what are the benefits of cloud computing.

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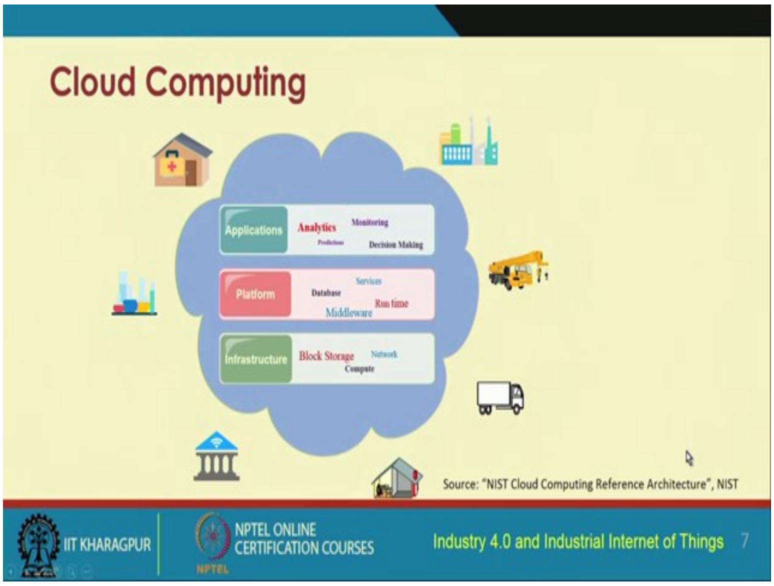


So, cloud computing; there are different models of cloud, there are different-different models, it started with three different models. So, whether it is home, hospitals factories or whatever there are different computational resources available in the form of cloud and you will have infrastructure; that means computing infrastructure in the form of computational resources CPU, storage, network and so on.

So, that is the infrastructure computing resource, then you have the platform resource which is basically in the form of the development, platform, the middleware services, database runtime and so on the platform resources. And on the other resource is basically the application resources or the software where we are talking about different software performing, monitoring, decision making, analytics, predictions, and so on. So, all of these computational resources software, platform and infrastructure can be made available on a pay per use kind of basis.

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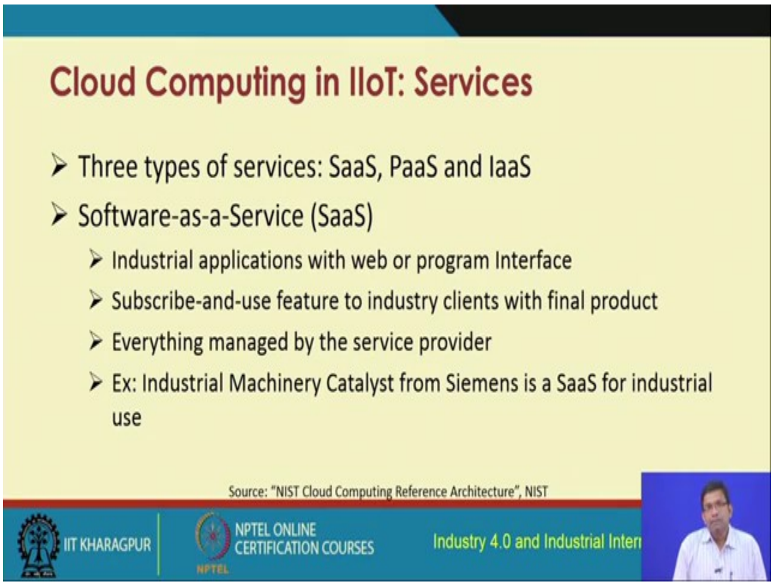


So, now I was talking about all these different cloud models and the services, so to start with there were three fundamental services one is the SaaS Software-as-a-Service, the next one is PaaS which is Platform-as-a-Service, and the third one is IaaS which is the Infrastructure-as-a-Service.

Software-as-a-service basically over here we are talking about industrial applications with web or programming interface and based on the requirements of the industry clients, there are different software that could be used can subscribe to and these will serve for coming up with the final product. So, these software will be made available for these different development or different use.

And so everything this software as a service basically, is managed through this software service provider. So, there has to be service provider who is offering all these services and he is basically billing us for whatever we are using. Examples from the industrial domain are, Industrial Machinery Catalyst that was developed by Siemens, that is a SaaS cloud for industrial use; industrial machinery catalyst is the name of the SaaS cloud from Siemens.

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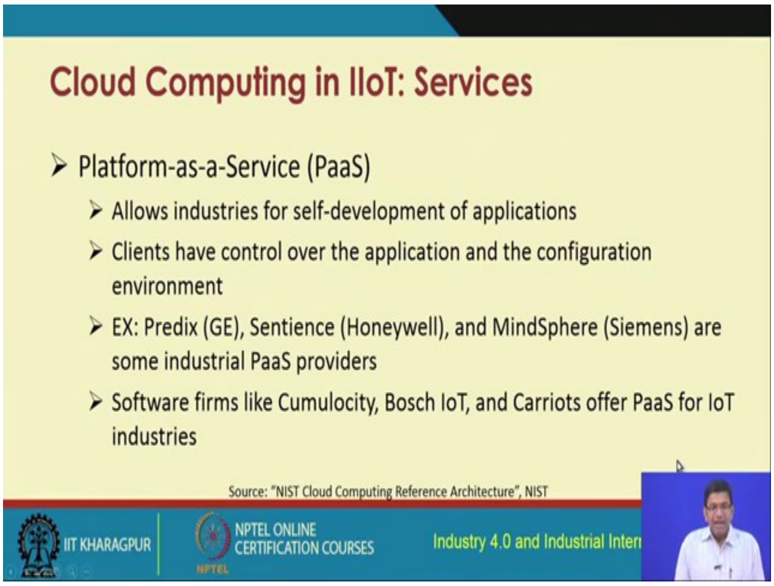


Platform-as-a-service; as this name suggests this service gives development platforms to the industries, development platforms to whoever, but in the industrial context basically the industries. So, the clients over here have control over the applications and the configuration environment that they have. So, there are different platform services are available and so the developers, particularly developers they could be interested in using any of those available platforms and they do not really have to deploy that platform everything is available online through online access and they could start using them.

Some of the examples from the industrial settings are Predix from GE, Sentience from Honeywell, MindSphere from Siemens and some industrial these are some of the industrial PaaS cloud providers. Software from like a Cumulocity, Bosch IoT, Carriots they offer platform as a service for different IoT industries.

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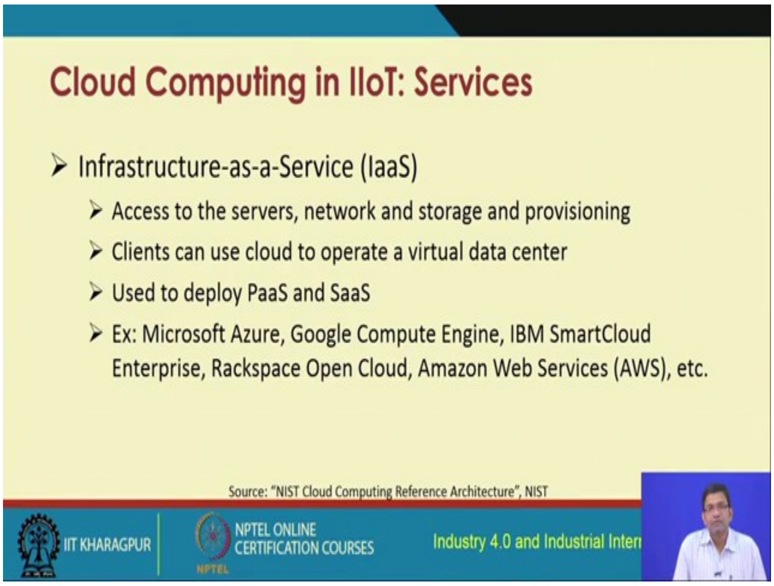


Infrastructure-as-a-service, here we are talking about the actual computational infrastructure, the network infrastructure and so on. So, here we are talking about making these computational infrastructure storage, computers and networks etc., offering those as services to the clients based on their requirements. So basically some examples are Microsoft Azure, Google Compute Engine, IBM SmartCloud, Rackspace Open Cloud, Amazon Web Services which is basically in way combined platform it has the IaaS and few different other service models are also implemented in Amazon web services and so on.

So, these are some of these examples of different types of cloud computing models and the services that they offer.

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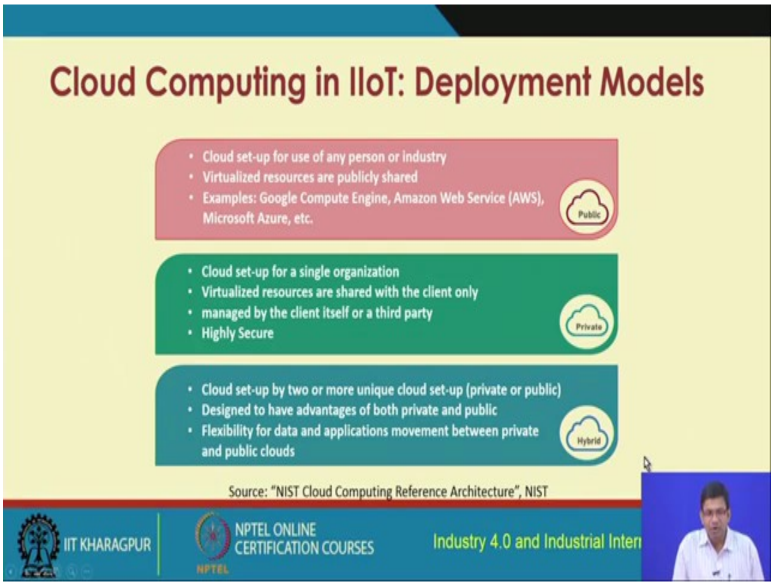


So, these are the different models another classification of these, but before that I wanted to show you something very interesting. So, let me show you an example of the Amazon cloud.

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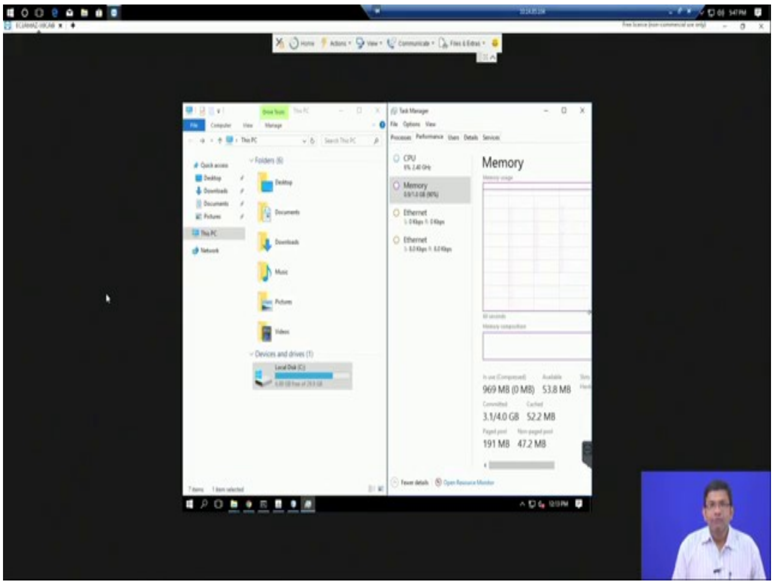


So, here as you can see this is just an instance of this cloud that we are subscribe to and I just wanted to give you and a instance of how it looks like. So, these are the units of CPU, memory, Ethernet, and so on to which we are subscribed. And also this basically shows the hard disk storage space, so you could get in go back and so on. So, it looks very similar to the way it looks for your own PC, but remember that this is not our own PC this is basically how it looks to the cloud access that we have for the remote computational infrastructure.

So, this is one thing and so I would also like to show you another one which is basically the infrastructure that you are able to see; infrastructure IaaS. So, if you look over here this is this overall platform that we have also subscribe to, this is basically the Platform-as-a-Service; windows platform as you can see and this is this thing.

I can show you something else, I can show you the software cloud. Another example of the software cloud is basically this Office 365, this is an example of basically office product online Office 365. This is an example of your Software-as-a-Service; like that actually there are many different other software's service models that are made available for different users.

So, now let me go back one second to whatever I was discussing earlier and so we have to looked at these different types of cloud Amazon cloud and Microsoft cloud example have I have also told before like that you have this software cloud like this Office 365 and so on. There are there is another classification of clouds right so cloud one is based on this models whether it is Software-as-a-Service, Platform-as-a-Service or Infrastructure-as-a-Service.

There is another classification based on the deployment model right. So, based on the deployment model the cloud can be classified into three types one is the public cloud, private cloud and the hybrid cloud. So, public cloud are set up for use of any person or industry whereas, the private cloud is set up by some single organization for example, IIT Kharagpur also has its own private cloud and hybrid cloud basically is a combination of both public and private so it is a cloud that is set up by two or more unique cloud setup providers.

So, both public and private and it has that advantages the hybrid basically has advantages of both the public and the private cloud.

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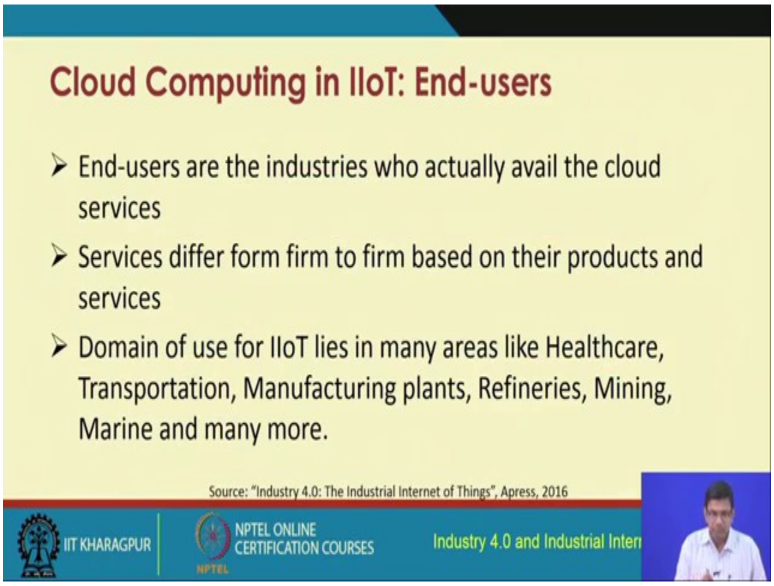


So, end users are very important in cloud computing in IIoT. So, end users in the industries would like to get access to the cloud services whether it is Software-as-a-Service, Platform-as-a-Service, Infrastructure-as-a-Service, the industrial end users need access to the cloud services and these services will differ from firm to firm and are based on their products and services.

So, the domains of used for IIoT lies in many different areas such as healthcare, transportation, manufacturing, plants refineries, mining, marine and many more.

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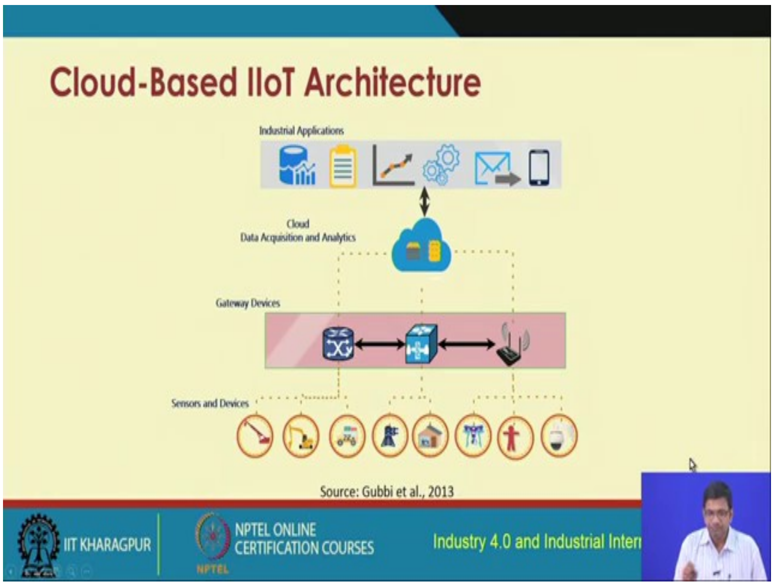

So, this is a cloud-based IIoT architecture so as you can see over here. So, at the very bottom we have these different sensors and different devices then there is a gateway layer which has different edge devices and so on. And then you have the data acquisition layer which is at the cloud and different industrial applications are running on the cloud.

So, this is a combination of IIoT with cloud and so we have a cloud IIoT architecture and essentially for industrial settings of use of cloud this is what is grossly it is going to happen.

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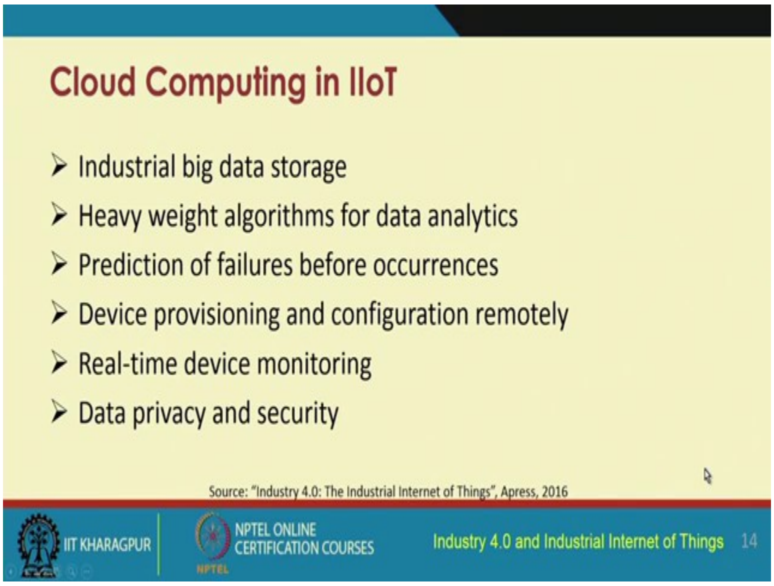


So, cloud computing in IIoT industrial big data storage it is going to offer, heavyweight algorithms for data analytics can be executed. Prediction of failures before occurrences can be done in a much more efficient manner, device provisioning and configuration can be done remotely with the help of cloud, real-time device monitoring can be done, data privacy and security access can be provided with the help of cloud.

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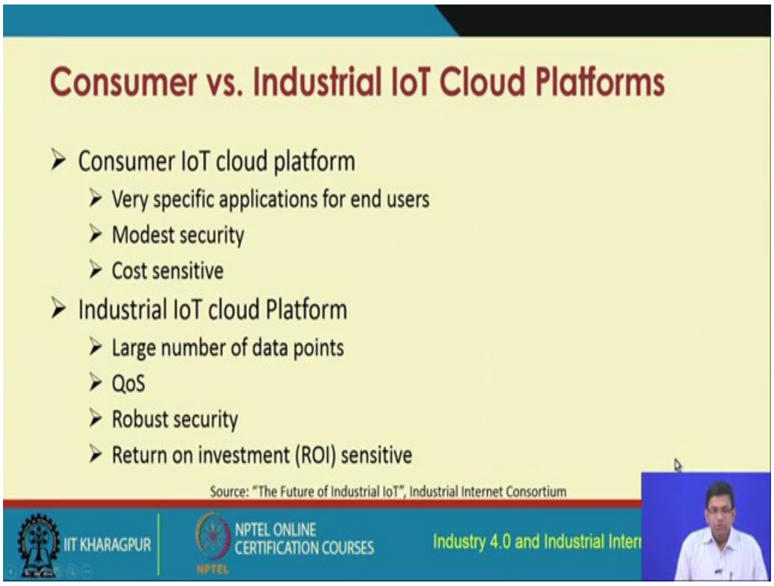


So, consumer versus industrial IoT cloud platforms, consumer IoT cloud platforms have very specific applications for from end users, they have modest levels of security implemented and they are very cost sensitive. Industrial IoT cloud platforms enable large number of data points for plugging in, supports quality of service that is very important for industry scale applications and also offers much more robust security compared to the consumer IoT cloud and also over here in the industrial IoT cloud ROI is very important consideration compared to the consumer IoT cloud.

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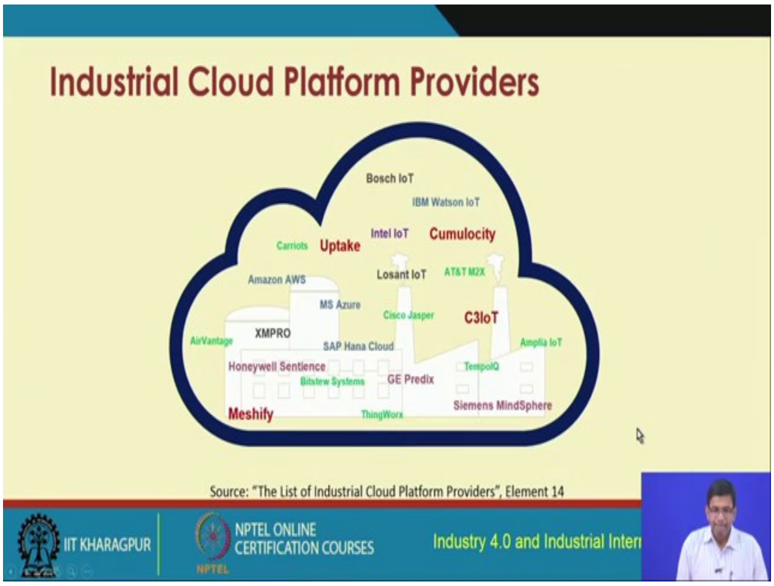

So, these are the different industrial cloud platform providers, so I am not going to through any of them, but so these are some of these examples, ThingWorx is one; there are others like Cumulocity, Uptake, C3IoT, Meshify and many different other providers industrial level cloud platform providers and their names are given. So, many of them as you can see are applicable for IoT; that means they have IoT-enablement. So, this basically are IoT cloud providers.

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So, industrial cloud platform providers so by different industrial companies things like Predix from the GE. Mindsphere from Siemens, Honeywell cloud is also there; different software development firms such as C3IoT, Uptake, Meshify are different other examples.

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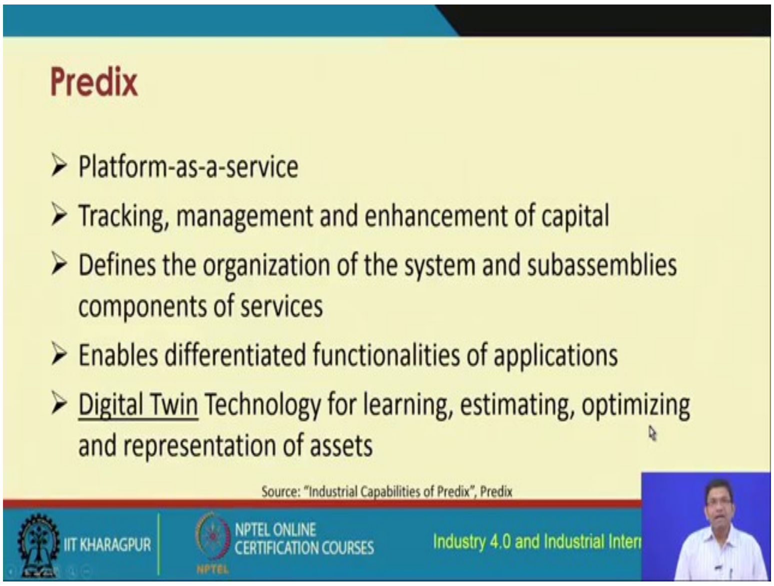


Predix is a Platform-as-a-Service (PaaS) cloud, which can be used for tracking, management and enhancement of capital. Predix basically defines the organization of the system and subassemblies and their components and also Predix basically has the support for Digital Twin which is very essential for most of the industrial manufacturing settings.

So, Digital Twin technology for learning, estimation, optimization and representation of different assets, so Predix basically has many of these support for many of these requirements that are there for industrial manufacturing sectors.

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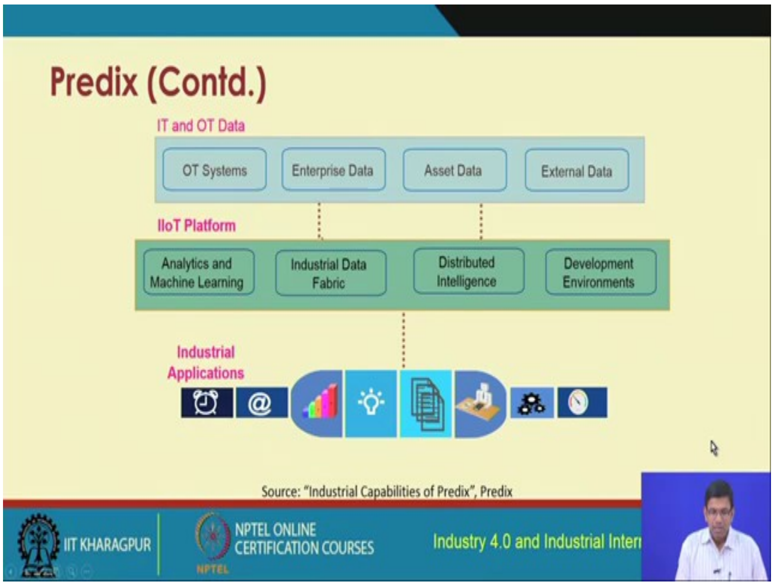


So, this is how this Predix platform looks like at the very bottom as you can see we have this industrial applications; in the middle we have the IIoT platform comprising of different components such as the analytics and machine learning, industrial data fabric distributed intelligence and development environments and the topmost layer shown in this particular figure has the IT and OT; OT is the operational intelligence and IT is the information technology. So, information technology and operational technology so, you have different components such as the OT systems, the enterprise data, asset data and external data. So, this is how this predicts platform structural looks like.

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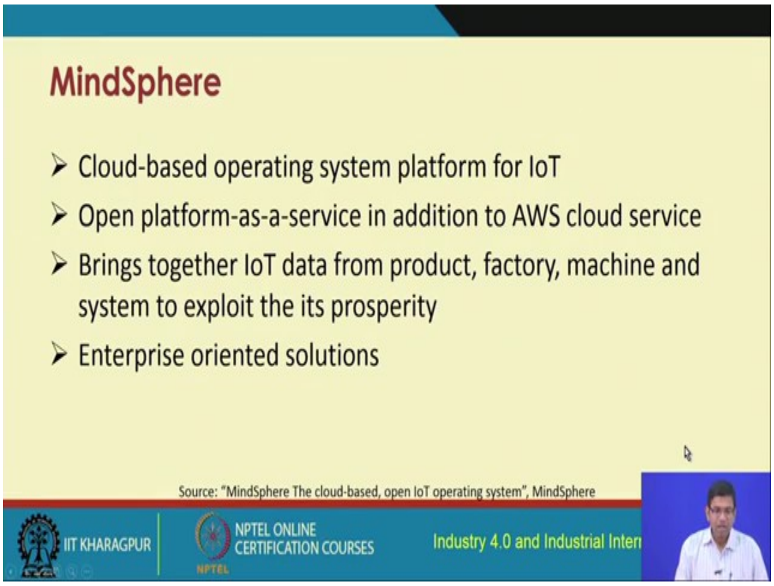

MindSphere is another cloud-based operating system platform for IoT and this is an open Platform-as-a-Service in addition to the AWS cloud service. It brings together IoT data from factory, product, machines, systems and different other industrial machinery and it provides an an enterprise oriented solution.

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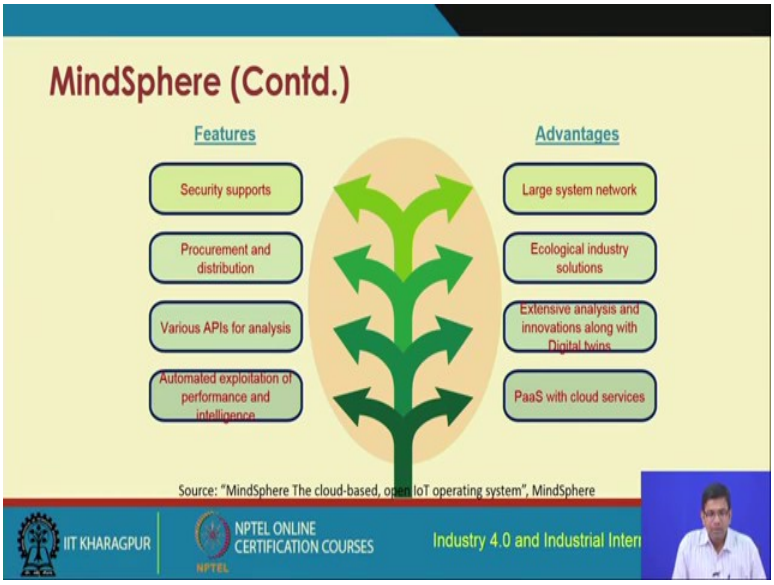


This basically shows the overall features and the advantages of MindSphere; advantages are that MindSphere basically provides large system network, supports ecological industrial solutions has PaaS cloud services for offering and there are many others also. In terms of the features it has security support; support for secured services, procurement and distribution provides various APIs for analysis and automated exploration of performance and intelligence.

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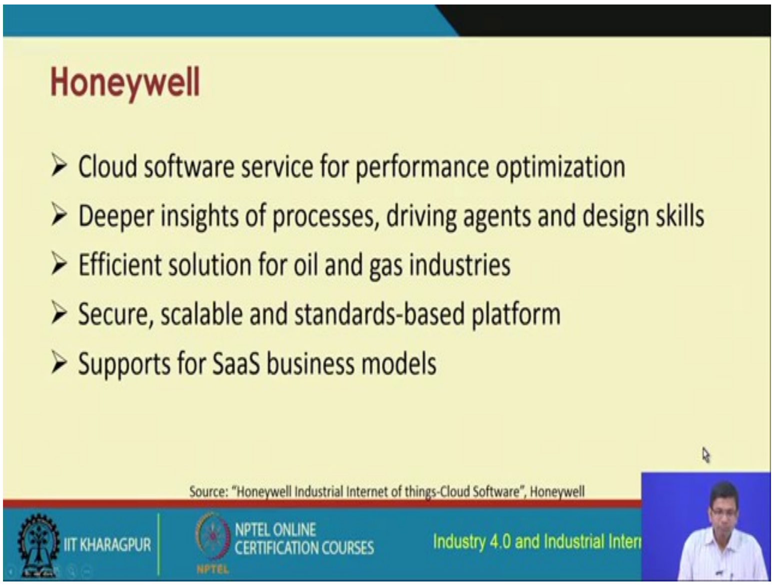


Honeywell also has its own cloud service provisioning for performance optimization, deeper insights into the processes, driving agents and design skills these are different use of the Honeywell cloud service and this is particularly targeted for different oil and gas industries. Honeywell cloud service is a secured, scalable and standard based platform, it supports SaaS business models as well.

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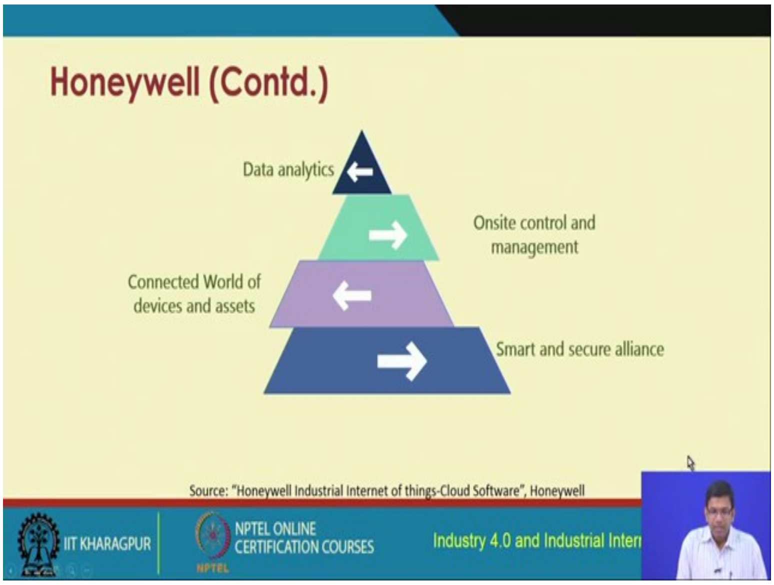


So, this is this Honeywell cloud service and you can do number of different things data analytics can be done, onsite control and management could be done connected world of devices and assets; that means, IoT basically enablement and smart and secure alliance these are the different features of the Honeywell cloud.

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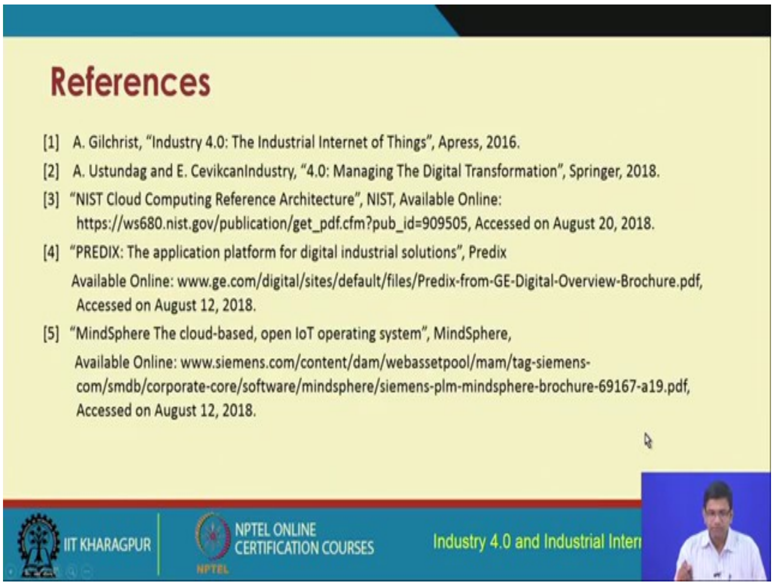


So, with this we come to an end and we have this list of different references of certain things that we have covered. We are talked about some of these different industry level solutions for IIoT cloud and we have also seen that industry specific requirements are different. So, IIoT cloud rather than IoT cloud is more interesting and there are different solutions already in the market that could be used by different industries to who have requirements for support of IIoT; IoT and their deployment.

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So, thank you these are all these different references.

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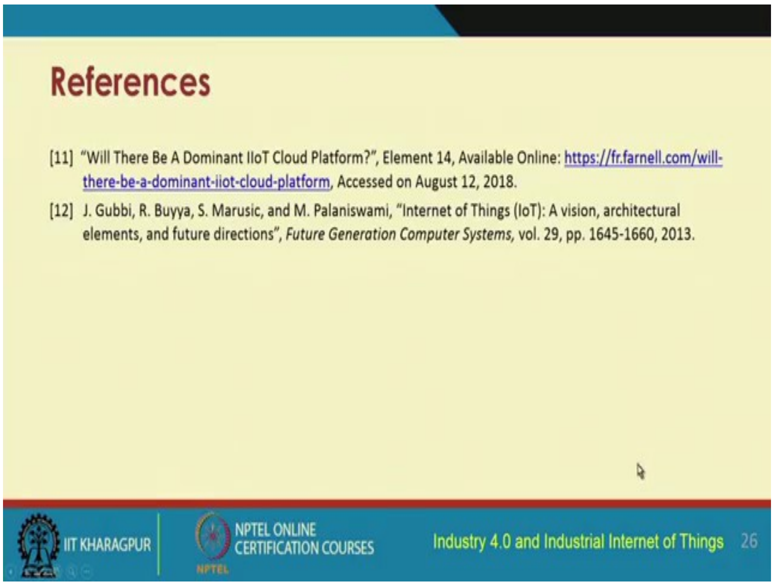


With this we come to an end.

Thank you very much.

**Introduction to Industry 4.0 and Industrial Internet of Things**
**Prof. Sudip Misra**
**Department of Computer Science and Engineering**
**Indian Institute of Technology, Kharagpur**

**Lecture – 40**
**IIoT Analytics and Data Management: Cloud Computing In IIoT-Part 2**

So, in this particular lecture we are going to continue from what we discussed in the previous part on Cloud Computing for IIoT. So, if you recall that in the previous lecture we talked about the different examples of cloud computing platforms for use in IIoT scenarios and also the usefulness of the use of cloud; cloud computing what it is and what is its usefulness in the context of industrial automation IIoT and so on.

So, we are going to continue further in this particular lecture and we are going to look at few other examples of use of cloud and cloud-based analytics in fact, for IIoT. So, in the previous lecture we talked about the companies like General Electric, Siemens and Honeywell.

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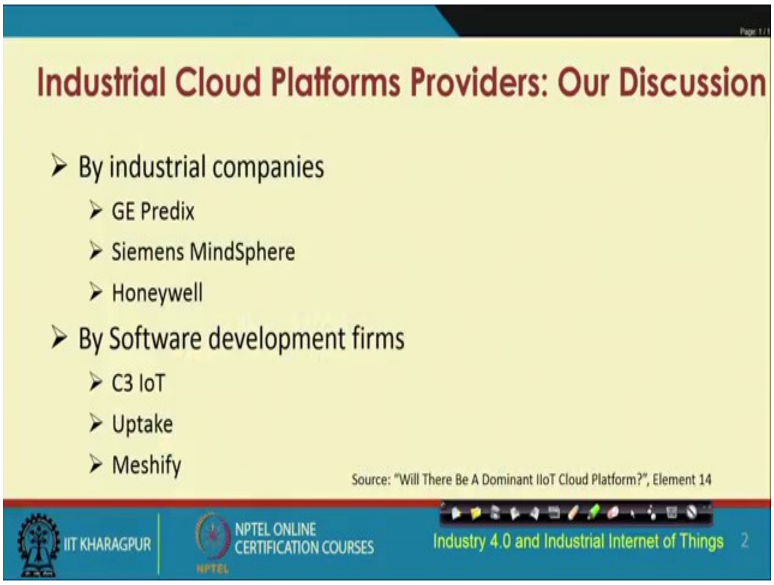


These are the different industrial service providers and their different solutions like Predix, MindSphere and the Honeywell solution we discussed in the last lecture and so there are many other company companies which have come up with their cloud-based platforms for industrial IoT solutions, but there are different other software development firms who have also come up with their IoT solutions and particularly cloud-based IoT solutions and their integration with analytics.

So, examples of this would be the C3 IoT, Uptake and the Meshify. So, these are few of the other examples of the use of cloud-based analytics for IoT and these have been developed by independent software development firms. So, we will take up each of these and we will just quickly we will glance through some of their highlights or the features that they have.

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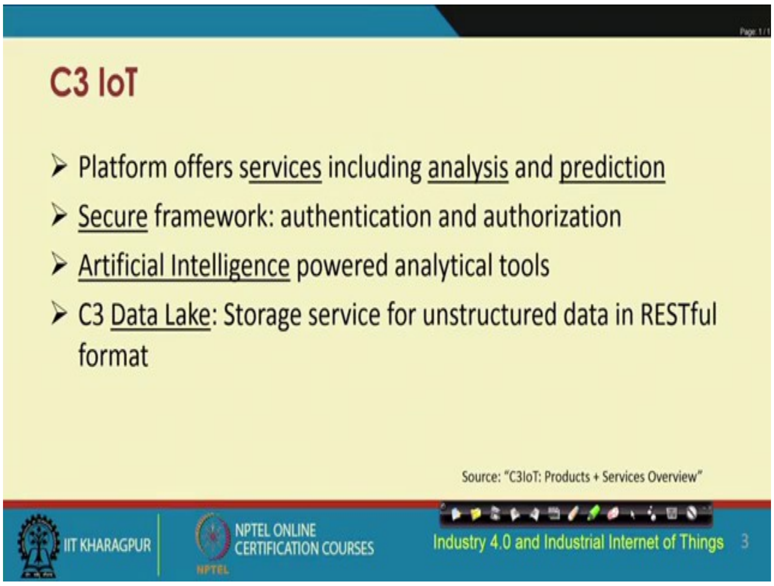


So, C3 IoT basically offers some kind of a platform that can help in different analytics and prediction and it is cloud-based. So, it is cloud-based services and including analytics prediction and so on and this particular platform is secured and there are appropriate authentication mechanisms, authorisation mechanisms etc., which have been implemented and these analytics that I was talking about in C3 these are basically AI-based, Machine learning-based analytics.

Different tools have been provided catering to the different requirements in the industrial setting and these data based on which the analytics have done are stored in something called the C3 Data Lake, which basically stores all this unstructured data that a typical of IIoT in using some kind of a format which is known as the RESTful architecture format.

So, this is how this all this data are stored, so the data stored in the data lake all these are unstructured data these are stored in the data lake plus there are different powerful AI-based analytics prediction and so on and everything together is a secured platform. And the security is offered in the form of appropriate levels of authentication authorisation and so on.

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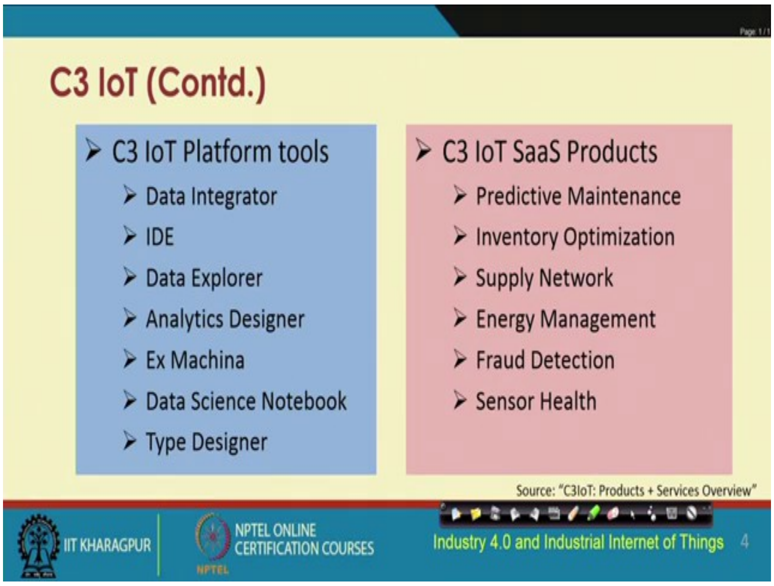


So, C3 IoT platform tools have different-different components such as the Data Integrator, IDE, Data Explorer, Analytics Designer, EX Machina, Data Science Notebook, Type Designer and so on. I am just naming these unless you are interested to know each of these tools.

I think this is sufficient just to get an overall idea of what each of these tools do and what are their different component. So, that is why I do not get into the details of each of these components of these vendor specific tools. So, the other things are the different other tools like the SaaS tools for IIoT specifically performing things such as predictive maintenance, inventory optimisation, supply network, energy management, fraud detection, sensor health monitoring and so on. So, these are the two classes of tools that have been provided in C3.

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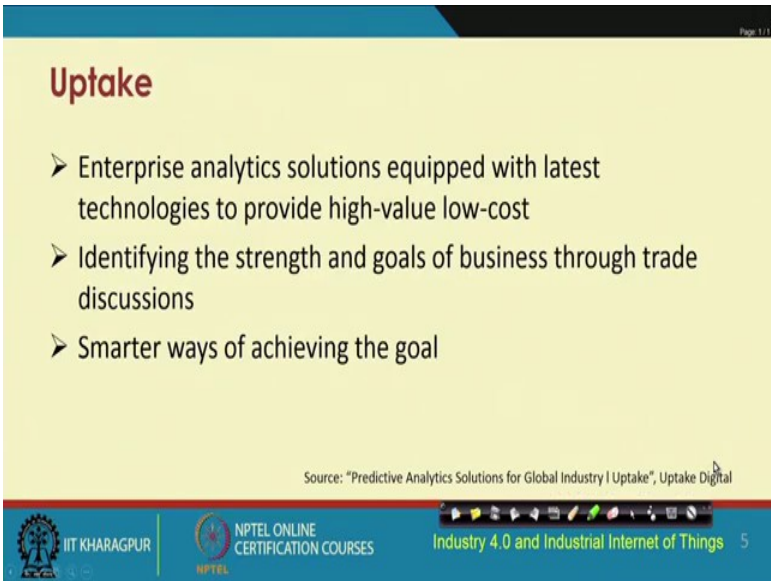


Uptake is another solution which is an analytics solution for enter catering to enterprise requirements and uptake basically gives high valued services at a low cost that is their motive their objective which is basically to offer high valued solutions at low cost and identifying the strength and goals of business through trade discussions; this is what uptake does.

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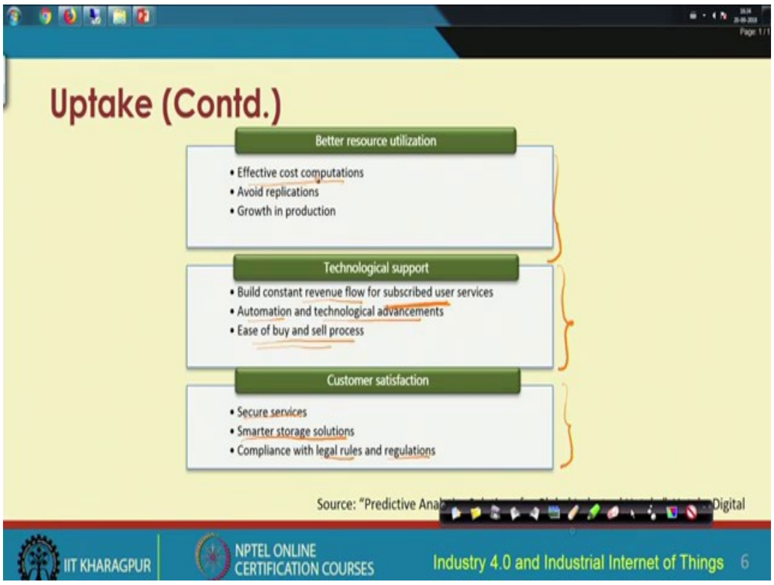


So, as we can see that uptake overall is talking about offering advanced analytics, catering to the requirements of the business or the enterprise and it is cloud-based and targeting in the specific industry-based requirements that are there. So, these are this is the overall architectural view of Uptake. So, there are different layers one layer basically talks about the customer satisfaction, the bottom layer basically talks about the customer satisfaction which caters to requirements of securing the services, offering smarter storage, complying with legal issues, regulations and so on.

The second tier offers technological support talking about taking care of revenue flow for the subscribed user services, automation, technological advancement, ease of buying and selling and so on. And the third tier basically talks about improved resource utilisation, avoiding replications, growth in production, effective cost computation these are the different properties of this particular layer, so that was Uptake.

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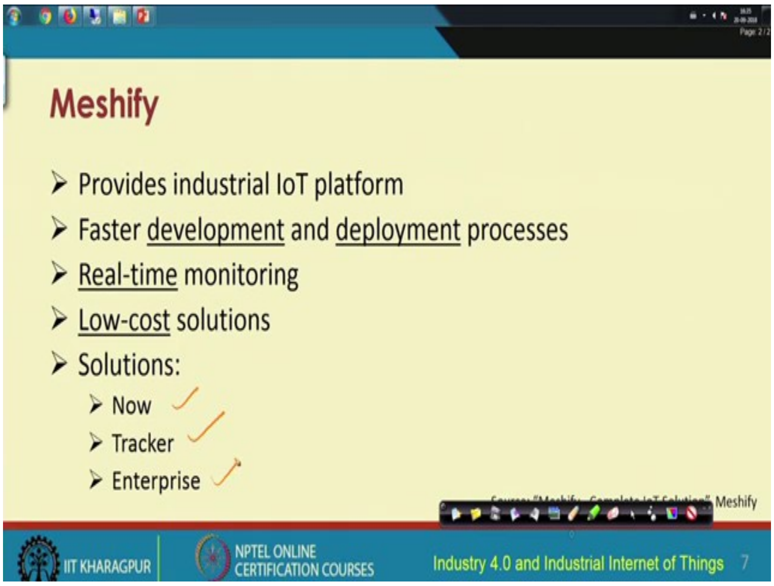


The third one is Meshify; Meshify is an IIoT platform that helps in faster development faster deployment of the processes, helps in real time monitoring of all kinds of machinery, processes, different instruments etc. The solutions that they talk about are of low cost and there are different components over here of Meshify, one component is this Now.

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The second component is the Tracker and the third one is the Enterprise. So, let us look at a very high level what each of these components do and how they position themselves with respect to each other?

So, let us assume that this is our Meshify, this Meshify has these different components Now; Now is 1, which takes care of issues such as asset tracking, asset tracking in real-time because that is what is important for IIoT asset tracking in real time, then this Enterprise talks about full stack IoT solutions, fixable configuration support custom notification facilities and so on.

And the third one is this Tracker which takes care of faster deployment, real-time monitoring and visualization. These are the three main components of this platform Meshify which has been developed for higher IIoT requirements.

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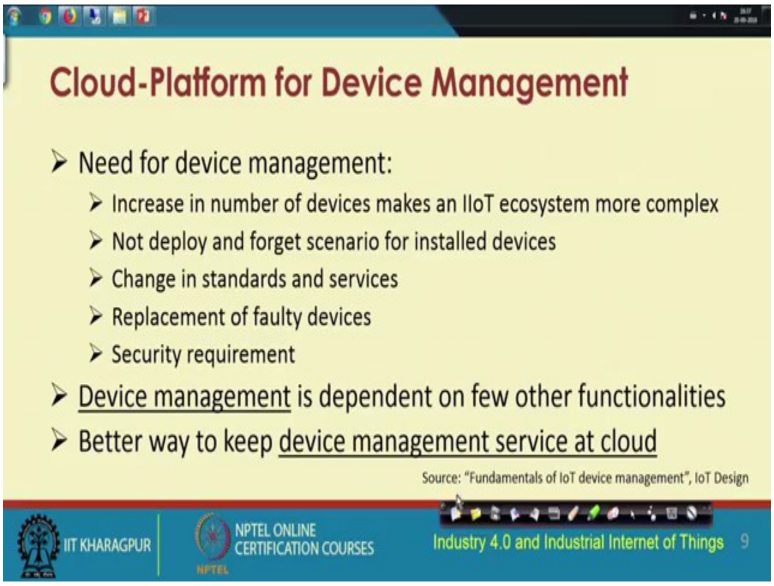


Now, let us come to this cloud which is the focus over here of this particular lecture, cloud is very important, cloud helps in doing number of different things.

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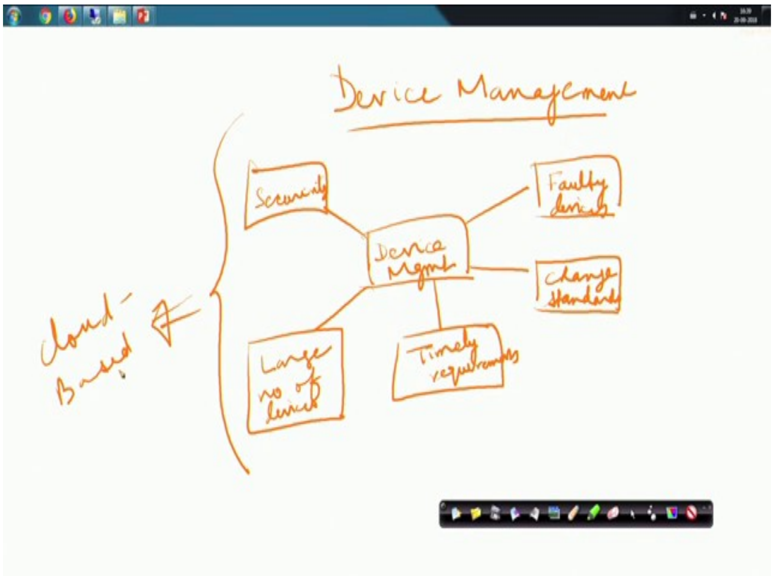


So, cloud basically will help in doing number one; device management, now what is this device management? Device management basically talks about managing the devices. So, let us now look at why this device management is important? So, we have this device management and why this device management is required? There are number of reasons why it is required.

There may be faulty devices; there may be change in standards that might happen from time to time, there may be a need for catering to some requirements in a timely manner. Device management is also required for several other reasons for example, taking care of large or other huge number of devices together which is typical of Industrial IoT solutions and also last, but not the least over here that I can think of is this security.

So, security offering so whatever the device management that we do securing the overall devices and the platform is the most important thing. So, catering to all of these is what is required and that is where device management is helpful. So, for this device management, cloud-based solutions are going to be useful. So, why do we need cloud-based solutions? Cloud-based solutions will help us in doing a number of different things.

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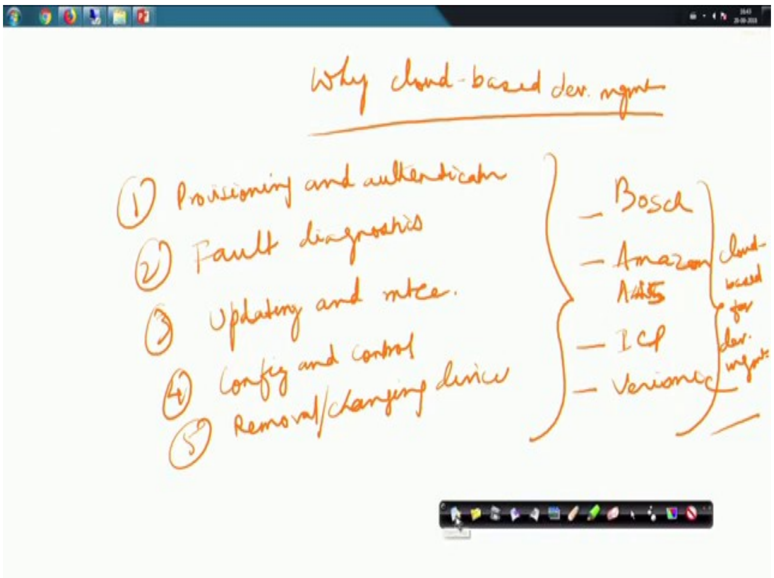


So, why cloud-based device management? Cloud-based device management has different features; number 1 is, it is going to help in efficient provisioning and authentication, efficient way of doing it authentication. Cloud-based device management will help in efficient fault diagnostics because if it is cloud-based then we are going to run the analytics in a much more efficient manner. And that can be done in the cloud so cloud will give us ample processing whatever is required processing power plus storage etc.

So, running this real time analytics etc. for fault diagnostics etc., are going to be much more do able if it is cloud-based. So, cloud-based device management for fault diagnostic. Number 3 is efficient way of carrying out updations and maintenance, number 4 would be the issue of efficient way of configuration and control, number 5 would be if it is required sometimes to remove a particular device, to add a device, to change a device, to remove a device and so on.

So, that will be also facilitated, so removal or rather changing a device much more efficiently can be done with the help of this cloud-based device management IIoT device management. So, there are different companies which have come up with their solutions companies such as, Robert Bosch they have their solutions, companies such as Amazon they have their AWS and also the specific solutions creating to IIoT requirements, then we have ICP, then Verismic and so on. So, these are the company, this is some of the companies like this. There are many other companies which do cloud-based which offer cloud-based solutions for device management.

Now, let us go back to what we were discussing earlier. So, we have understood that device management is very important because we are talking about in IIoT scenarios large number of devices taking care of large number of devices in a typical IIoT deployment scenario and you have to take care of different requirements starting from their configuration provisioning faults security and so on and so forth.

So, the ecosystem overall is highly complex and you need some kind of a solution, the solution if it is cloud-based we have seen that what are the advantages of doing it and overall cloud-based device management solutions are going to be helpful to offer different attractive services to the clients.

So, these are the needs for device management we have already seen and their different functionalities and why it is required to have this cloud-based device management solution?

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So, these are some of the features that clouds platform service providers should offer for device management; provisioning and authentication which we have seen already, fault diagnostics and monitoring, updates, security patches, maintenance, device decommissioning, configuration, control these are different things that cloud-based device management solutions will offer.

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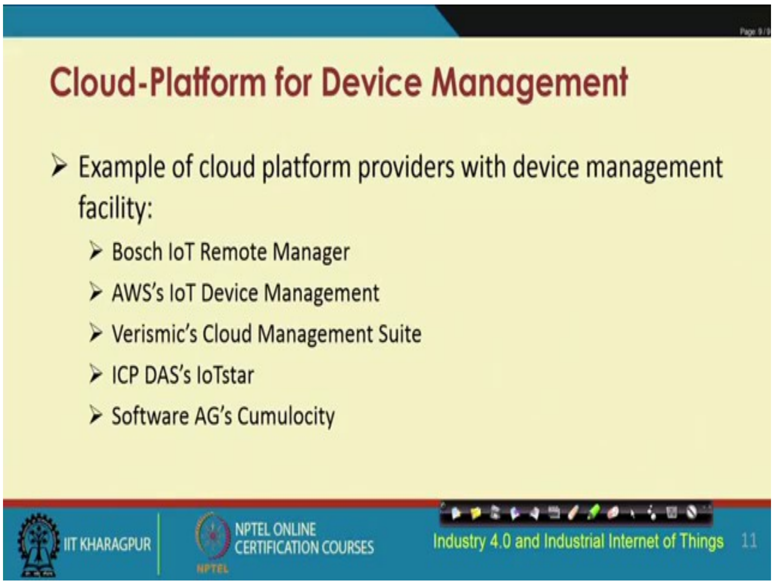


These are some of these companies that I mentioned Bosch's IoT Remote Manager, Amazon's IoT Device Management for AWS, Verismic's Cloud Management Suite, ICP's IoTstar, Software AG's Cumulocity and so on like this there are many different other cloud-based device management solutions out there.

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The next thing is that Service Level Agreement. So, Service Level Agreements or SLAs are very important particularly when you are talking about cloud. So, SLA is Service Level Agreement between whom, between the provider about what services are going to be provided and the consumers of the service. So, cloud service provider and the cloud service consumer who are basically this companies which are using these different services the IIoT solutions which are cloud-based and so on.

So, there are many IIoT applications that are real time where safety is very important. So, you need to have some kind of SLAs which will catering to the specific requirements that are there and the services should be offered as per the agreement with the cloud provider. So, it is some kind of a promise; promise of delivering something through some formal agreement which is often legal in nature. So, SLAs basically help the industrial clients to check what and how the cloud provider gives as services.

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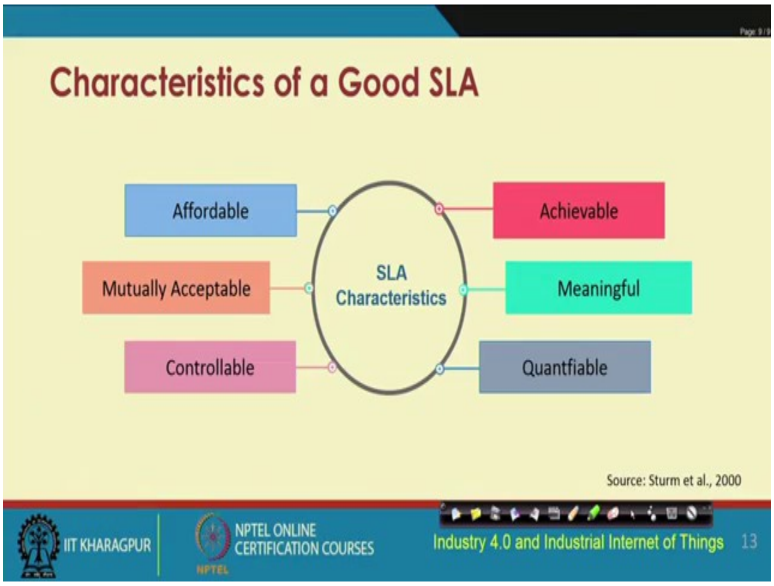


So, how good these services are this is what this SLA and the measurement of these which is important. So, SLAs have different features SLAs can be very simple, naive, and so on, but meaningful SLAs will have certain good characteristics certain characteristics which are desirable. So, these are some of the different characteristics that you see in front of you, a good SLA should be achievable something that can be achieved not something that is a dream and so on which cannot be done in within the required span of time and so on.

Second is that the good SLAs should be meaningful, it should not be vague it should be precise meaningful quantifiable because only if it is quantifiable then it can be measured and you can enforce certain requirements and legalities etc. based on these different measurable quantities. Fourth is that a good SLA should be controllable, fifth is that it should be mutually acceptable which is also quite will easily understood and should be affordable.

So, these are the six different characteristics of a good SLA when we are talking about cloud particularly in an industrial setting IIoT-based setting. So, let us now again take a look and take a recap of what we have discussed.

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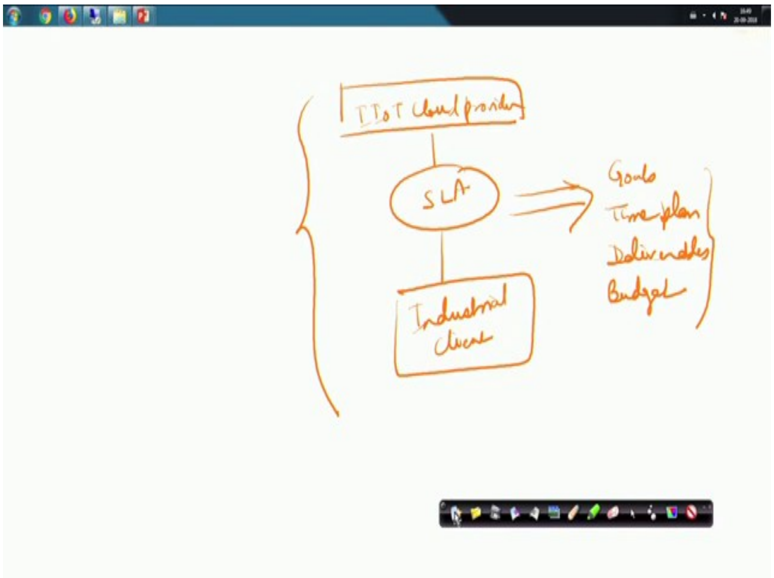


So, let us say that we have this IIoT solution, so we have this IIoT cloud service provider. So, this cloud provider is going to sign up an SLA with the industrial client. So, this SLA basically as we have seen will have different goals, time plan, list of deliverables and the specificity about the budget. So, this is what should be done in a cloud-based IIoT solution that is offered to the industrial clients. So, SLA should be there catering to these different requirements and the features.

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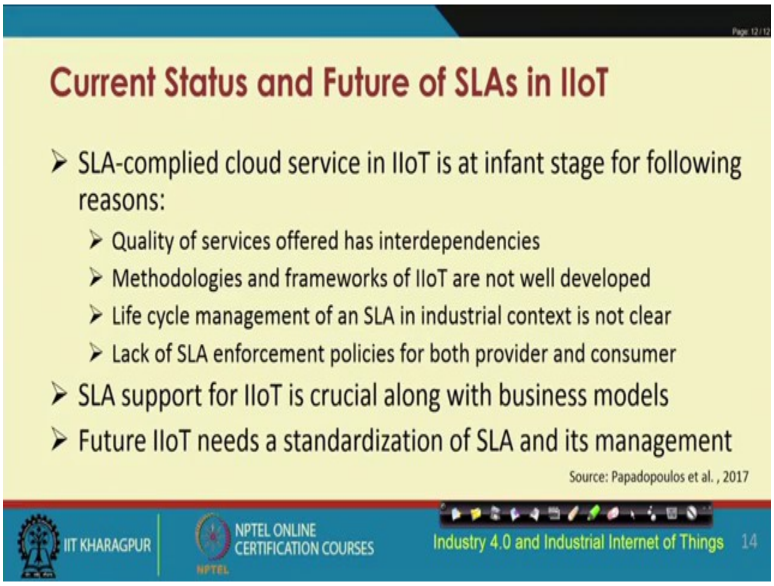

So, let us go ahead and look further, so the current status and future of SLAs in IIoT. So, SLA complied cloud service in IIoT is still in an infant stage because IIoT itself is in its infancy although there are bits and pieces that are already implemented particularly from an automation point of view, but cloud-based this kind of solution particularly SLA complied, you will find that it is not much matured at in most of the cases.

So, quality of services offered at this point has lot of interdependencies that is why it is still in its infant stages. The methodologies and frameworks of IIoT are not well developed, lifecycle management of an SLA in the industrial context is not clear, and the lack of SLA enforcement policies for both the consumers and the providers is also quite evident at present. So, there is lack of SLA enforcement policies.

So, SLA support for IIoT is crucial particularly from a business model point of view. So, whenever we are talking in the future of IIoT standardization of a SLA etc., we have to take all these different lacuna into account and try to address them in the future so that it becomes a very important necessity in the business negotiation process.

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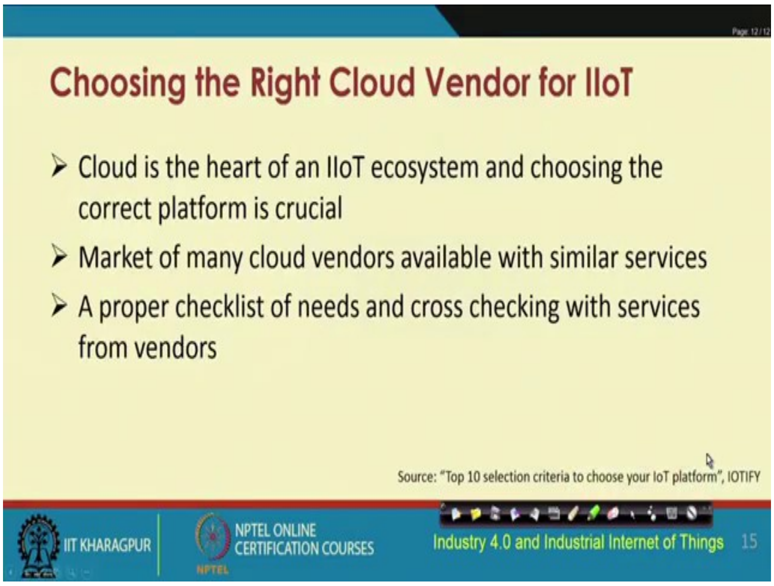


So, it is required to choose the right cloud vendor for IIoT, there are different cloud-based IIoT, cloud-based solution providers that are already there. So, it is very important to look for the correct vendor that will cater to the specific requirements that a particular industry has. So, a checklist will help in basically trying to identify the right cloud vendor for IIoT.

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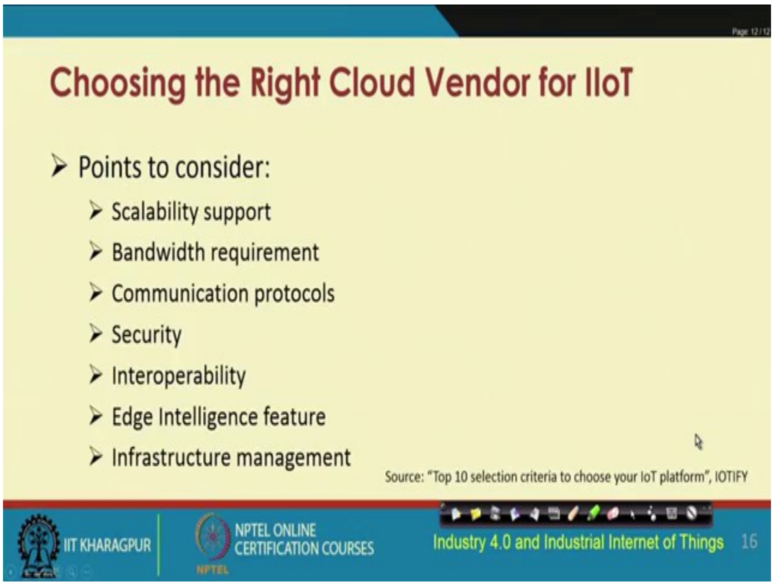


So, this checklist is given over here taking into consideration points such as scalability support whether the particular cloud vendor that you want to choose has support for scalability; that means, if you have dynamically if your requirements increase and so, on in terms of these different computational resources etc., whether the cloud vendor would be able to support that number one.

Number two is the bandwidth requirement which is well understood the communication protocols that are supported whether it is MQTT, AMQP, HTPP or the other protocols that are there. So, which ones are supported MQTT is more common, but then AMQP is also coming and so on. So, which ones are there that are supported by the cloud vendor and what will which of these protocols are going to help you cater to your specific requirements that you have for the IIoT solution that you want to deploy or is already deployed.

Security, I do not need to elaborate further, interoperability also the same, edge intelligence feature is very important. So, edge intelligence so whether this particular cloud-based solution has offers certain edge intelligence; that means, that wherever close to the point of collection of data; that means, the machines which have these IoT devices installed to them, whether all these data are sent to a remote cloud which will take lot of time etc., to send the data and also to process and give back the real sense own or some of the analytics can be done at the edge; that means, at the local gateway or hub or whatever.

So, that will make the life faster, but at the same time not everything can be processed at the edge. So, ultimately some of it will have to be done remotely at the cloud. So, edge intelligence features infrastructure management these are some these different parameters that can be taken into consideration for choosing the right cloud vendor for IIoT.

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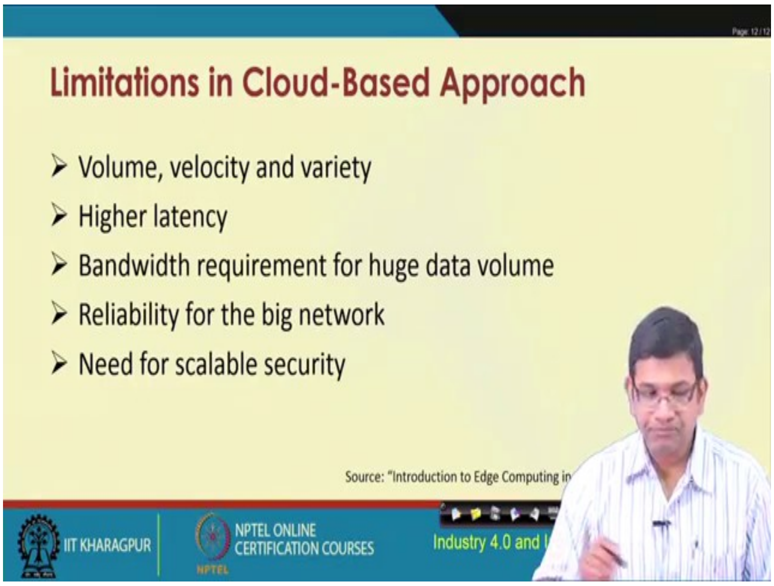


So, limitations in the cloud-based approach is that we are talking about a scenario in the case of IIoT we are talking about scenarios of machines large number of machines equipped with large number of IIoT devices, IoT devices and so, on sensors, actuators and so on and so forth. And supplying large volumes of data coming at huge velocity is having high variety; big data basically essentially big data characteristics are there and whether your cloud-based solutions will be able to cater to their requirements or not these kind of requirements.

So, if you are sending everything to the cloud; obviously, taking care of issues of volume is fine, but velocity particularly real-time processing faster processing etc., that may be difficult because there is going to be higher latency, you want to send everything to the cloud backend, which is maybe the server where it will get processed is located continent survey.

So, this is going to in turn impact the overall latency, propagation delay is going to increase of the packet that is sent from the device in the machine to that cloud and also processing it over there and then getting it back again the results to the user end that again will add to the time. So, higher latency is going to be there if it if everything is cloud-based. Bandwidth requirements for huge data volume will be there because you are talking about huge volume, high velocity, variety, and so on all this big data characteristics. So, you need the channel also to be of a high capacity high bandwidth.

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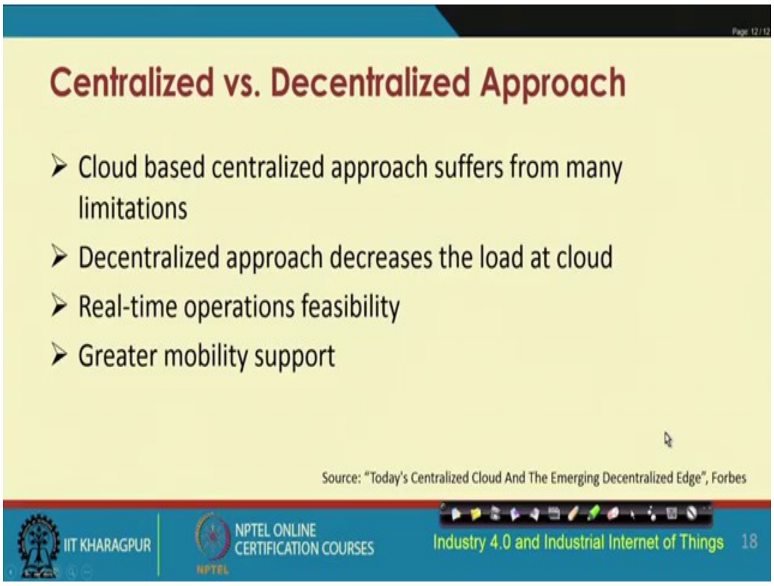


There is a requirement for the big network and need for scalable security, these are some of these limitations in cloud-based IIoT solutions, that is why there are these different other solutions people are thinking of. So, entirely centralized cloud-based solutions are the ones that we talked about and they suffer from many limitations which we have already seen. Now people are talking about decentralized approach that will decrease some of the load on the cloud and will also makes our lives faster by processing certain things at the edge.

So, it is sort of like partial cloud at the edge; that means, closer to closer to the devices from where this data are generated and real time operations feasibility greater mobility support, these are some of these cloud-based centralized approaches and how they suffer from these different elements and the different other characteristics, the desirable characteristics mobility support operations real time operations feasibility those are required and so on.

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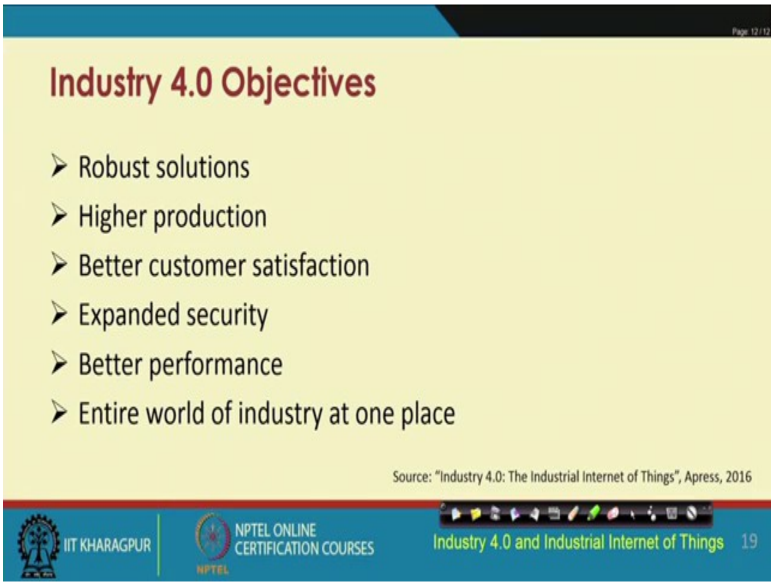


So, if we are talking about Industry 4.0, take a look at what we discussed earlier several lectures back we talked about Industry 4.0 having objectives of robust offering, robust solutions, higher production, improved customer satisfaction, expanded security, improved performance and so on and so forth, these are some of these different Industry 4.0 objectives.

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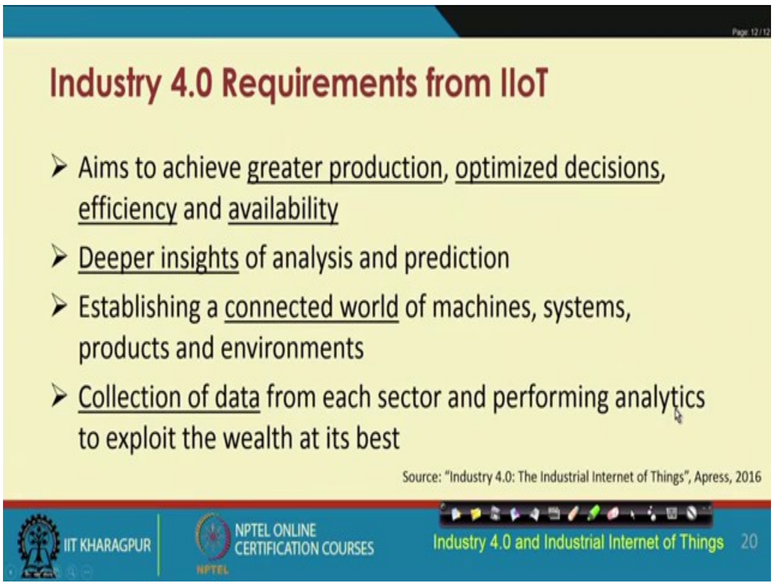

So, so from IIoT view point these requirements will aim to achieve greater production optimized decisions will be possible with higher efficiency and availability. It is also possible to have deeper insights of analysis and prediction, establishing a connected world of machines, systems, products, environments with the help of IIoT. Connected IoT, connected machinery, connected IoT devices on these machineries and so and the collection of data from each sector and performing analytics to exploit the wealth of its benefits, these are some of the requirements from IIoT perspective.

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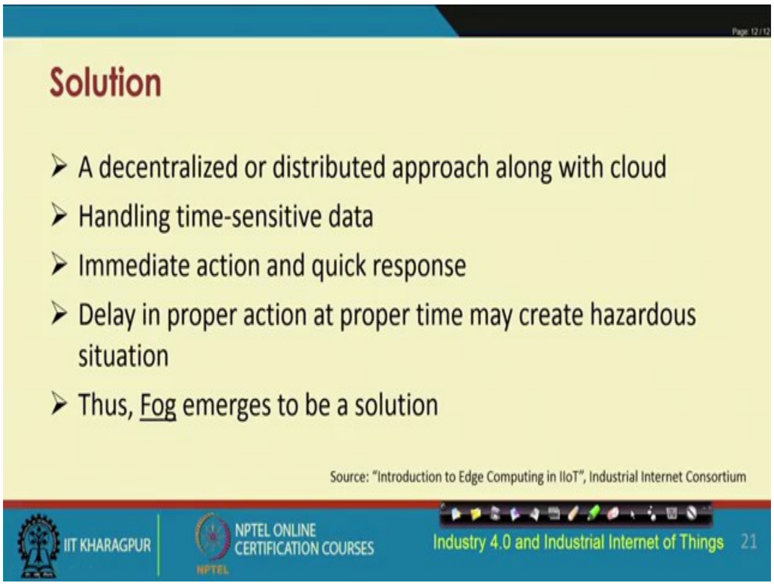


So, the solution is to have some kind of a decentralized or distributed approach along with the centralized cloud, which will help in handling some time sensitive data, where immediate actions will have to be taken some quicker responses will have to be taken and some processing will have to be done faster instead of sending everything at the cloud which will overall increase the latency.

So, that promptness in the processing at least to some level that can be done with something in your solution that is coming up which is the fog. So, fog is an emerging technology which will help to perform some of this processing closer to the point of origination of the data and the rest of the processing can be done at the cloud.

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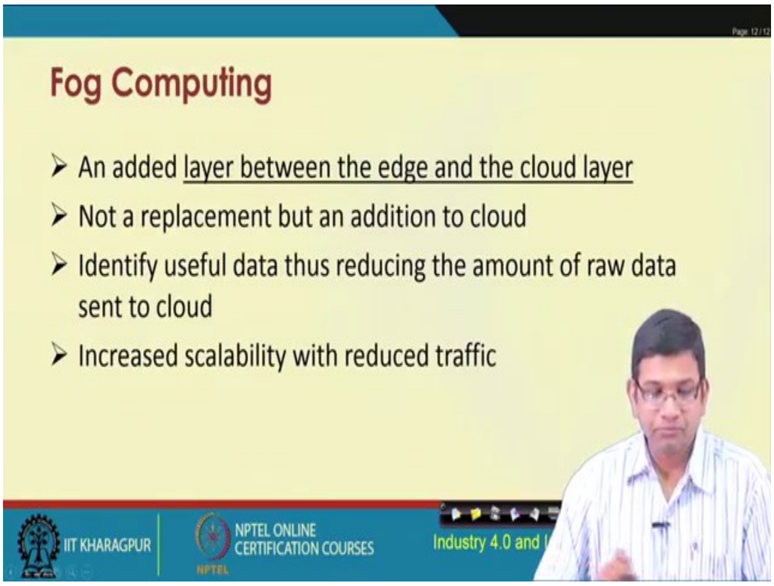


So, fog computing basically offers an added layer between the edge layer and the cloud layer. However, keep in mind that fog cannot do everything; it cannot solve all your problems it is not that fog layer can do all the processing, that would be otherwise done at the cloud. So, only some meaningful processing of some raw data, before it is actually sent to the cloud and also some processing, that has to be done quite fast will be done at the fog.

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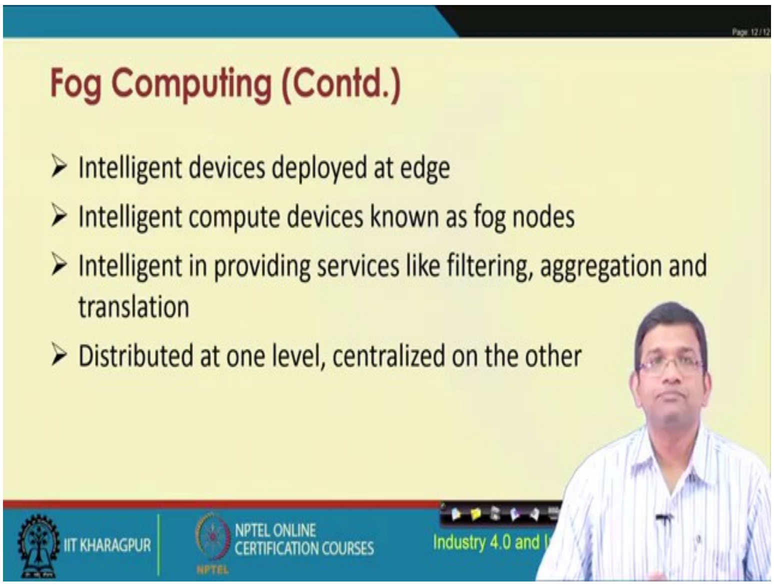

So, intelligent devices are deployed at the edge, intelligent computing or devices such as the fog nodes, which are known as the fog nodes would be would be deployed which can offer different services such as filtering of the data, aggregation of the data, translation of the data and so on.

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So, with this we come to an end of the lecture on cloud computing for IIoT, holistically previous lecture and this lecture included, we have seen the different features of cloud we have looked at the requirements of cloud why cloud-based solutions are required, why cloud-based analytic solutions are required and how they are useful and how this cloud-based solution is going to help in catering to certain real life industry 4.0 IIoT requirements that are there in the industries.

We have looked at certain specific solutions that are there some industry specific solutions, some independent software company based solutions and so and how they can help in addressing some of our requirements. So, with this we come to an end and these are some of these different references that are there and if you are interested you could go through these different references, I would suggest that you go through this particular paper that was authored by me.

So, Assessment of the Suitability of Fog Computing in the Context of Internet of Things which was published in the IEEE Transactions on Cloud Computing in 2018 and so the other papers and this one together will help you to get an understanding of 2 technologies; one is cloud; cloud for IIoT and also the newer upcoming technology fog which I am going to again discussing further depth in the next lecture.

So, fog and cloud together in all these references will help you to get a deeper insight and what is required to have is some kind of suitable cloud, fog-based solutions for catering to the IIoT requirements, with this we come to an end of this particular lecture.

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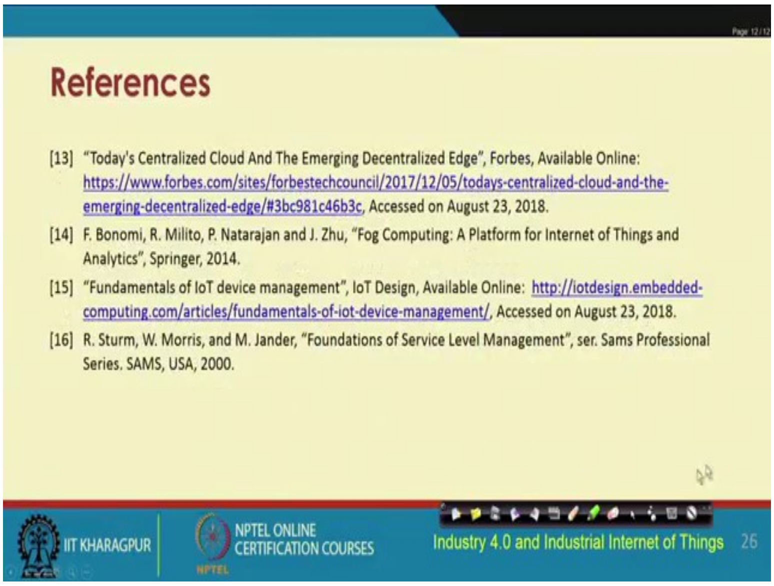


These are these are the references that are there.

Thank you.

**Introduction to Industry 4.0 and Industrial Internet of Things**
**Prof. Sudip Misra**
**Department of Computer Science and Engineering**
**Indian Institute of Technology, Kharagpur**

**Lecture – 41**
**Analytics and Data Management Fog Computing in IIoT**

In the previous lecture we looked at cloud, cloud based solutions, but cloud based solutions are typically centralized. So, you have all these different industrial machinery that are basically connected to the cloud, these industrial machinery they themselves are attached to different sensors, actuators, IoT devices overall and so on.

So, the all this data are basically over a specific communication channel which has a fixed bandwidth, all these data continuously typically for most of these industrial scenarios and the machinery. These data are sent through this particular fixed channel to this centralized entity called the cloud where lot of storage is existing and lot of processing can be done.

So, this data that are sent to the cloud are analyzed, lot of different types of analytics are performed, analytics to gather different meaning, analytics which will give you some idea about what is going on at present real time maybe non real time as well and analytics which will predict certain things that are going to happen in the future maybe the downtime maybe the time after which if certain machine or a certain part of a machine is going to go down.

So, all of these things are going to be predictive or current operational analytics can be done at the cloud. We have also seen that centralized models are not always good particularly in IIoT scenarios where real timing-ness is very important, where quicker response is very important, because you are talking about machinery operating at very high speed where safety of the humans operating these machines is very crucial.

So, IIoT solutions which are purely cloud based may not be ideal. So, we are now talking about a different approach which is called the fog based approach where we are talking about a layer of computation, a thin layer of computation performing some lightweight computation processing and so on, which will be done closer to the origination of the data. That means closer to this edge devices and this particular layer is going to sit between this particular edge layer and the cloud layer and that is called the fog layer.

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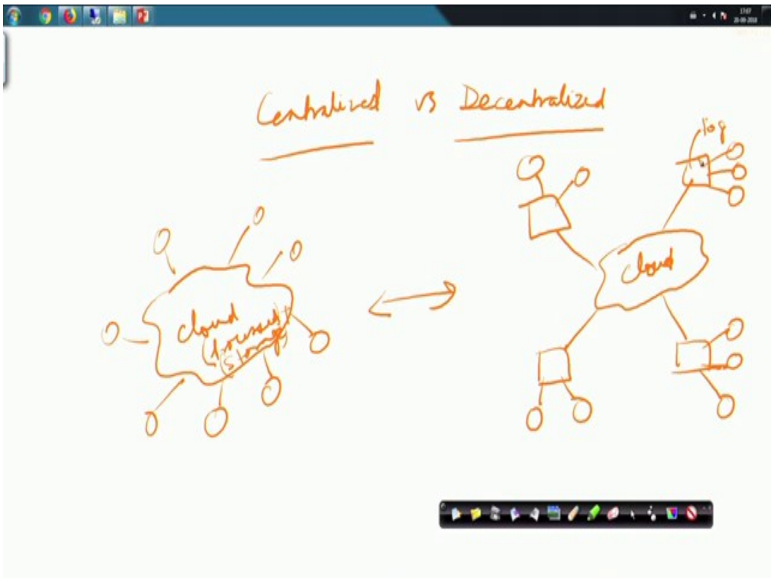


So, let us look at what we have just discussed so, we talked about this different centralized and decentralized models. So, centralized essentially is purely cloud based where you have all these different IIoT devices which will throw in lot of data and this data will all be processed and stored at the cloud. So, this is your centralized.

On the other hand you could have a solution which is a combination of your whatever you already had the cloud and some kind of you know these devices like these boxes over here which are representationally shown, which will be like your fog which will have reduced computational capacities than the cloud, but have certain capacities for doing some preliminary level filtering, processing, faster, decision making and so on. So, these are your edge devices and this is this fog layer that is sitting in between. So, now, let us look further at these different advantages of fog computing for IIoT.

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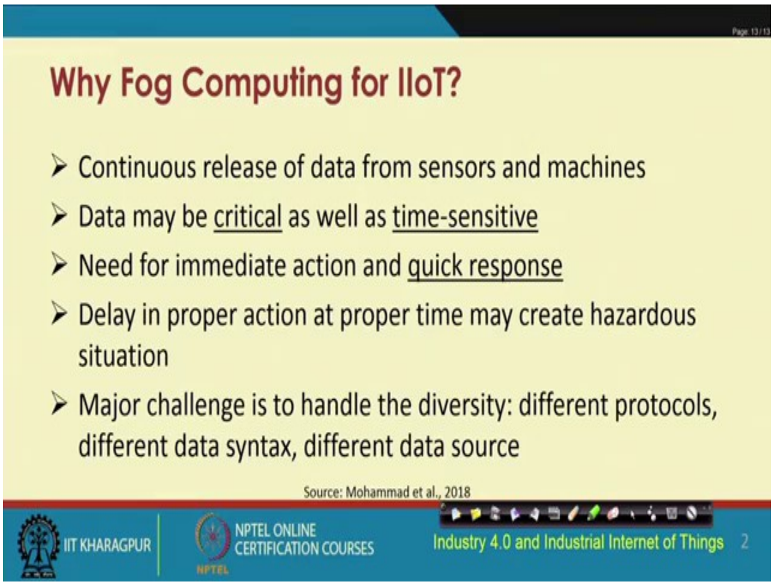


So, we already saw that in IIoT we are talking about scenarios where there are large numbers of different sensors, actuators, different devices, other machinery attached to these different other machinery and so on. So, all these machinery to machinery you know one machine connected to another machine and so on. So, all of these are connected and these machines are operating at huge speeds, not only that, but they are also sending data through their different sensors at very high speeds and many of this data are very time sensitive and could be critical.

So, there is a need for immediate action or quicker response. So, it is not quite desirable to have any delay in sending the data from the point of origination to the cloud processing it over there and sending it back because the whole thing will add to the delay and that might lead to certain hazardous situations because we are talking about machines being operated by different people, different hazards will happen even if your data reaches the intended destination after maybe even a millisecond or a microsecond by that time maybe the hazard will happen, because everything is moving very fast, lot of data are getting generated and so on. So, we have a different very highly dynamic kind of scenario.

So, the major challenge is to handle the diversity of the data in real time and as close as possible and as fast as possible to the point from which the data are originating.

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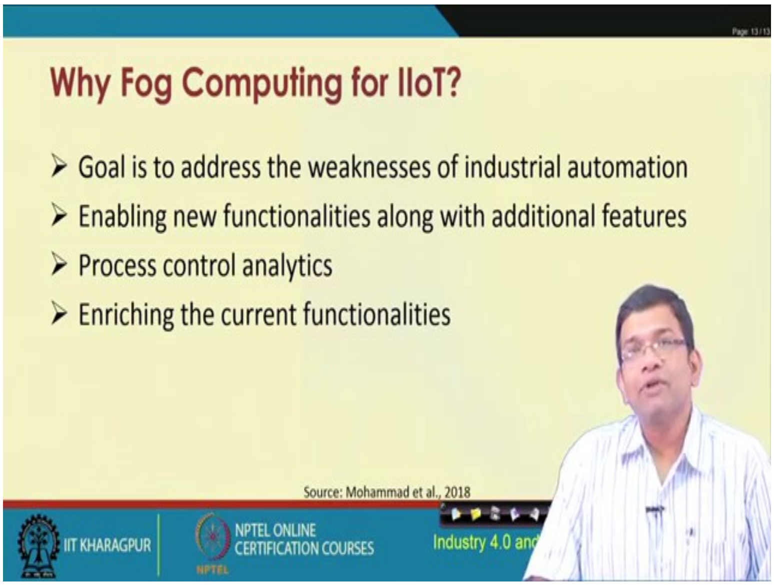


So, the goal is to address the weaknesses of industrial automation, that have been there and that is why this new technology which is called the fog computing technology will help in this particular regard. So, why fog computing? -- Taking care of existing weaknesses of industrial automation the cloud based solutions and so on. Enabling newer functionalities to be implemented along with the additional features and also enabling real time efficient process control mechanisms with the help of improved and faster analytics, and enriching the existing functionalities overall. This is how fog computing is going to help.

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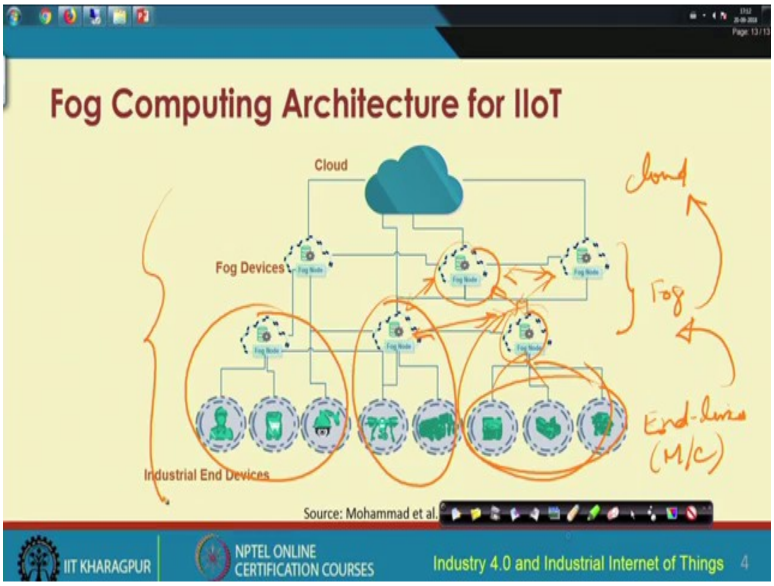

So, this is how this fog architecture looks like, as I told you earlier we have these different layers. We have these layers of this end devices that are the ones which are basically fitted to your different machines. Then you have this fog layer and this is your cloud right so, we have these 3 tiers.

So, as I told you earlier that the idea is to have certain executions done at the fog layer at the fog node and the rest being sent to the cloud for further processing. So, as you can see over here these different fog nodes they basically are fitted to different end devices. So, every fog node essentially takes care of a few end devices. In fact, as you can see from this also these fog nodes may also be interconnected they might be interconnected with one another.

So, these are the different clusters of these fog and end devices in this manner and these fog nodes they themselves could be interconnected like this. So, this is this overall architecture of fog computing for IIoT.

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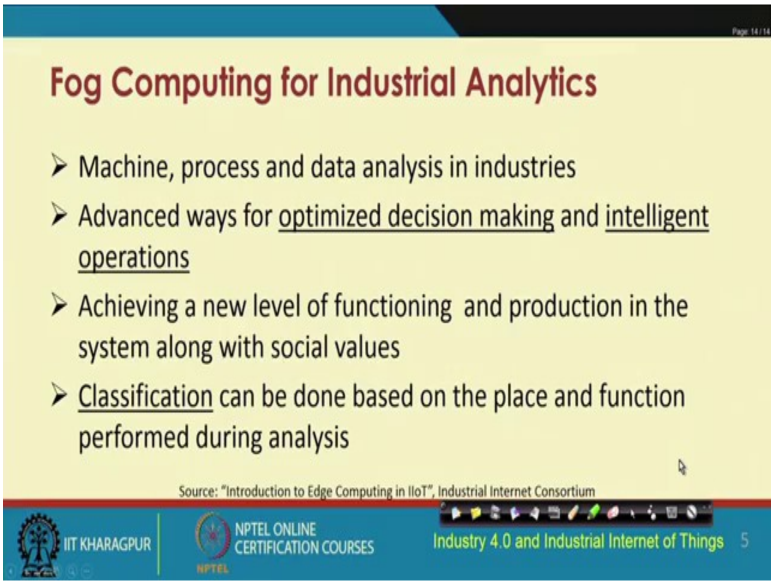


So, fog computing helps in improving the performance of machines, processes the data analytics and so on, helps in optimizing decision making. Intelligent operations can be performed with the help of fog computing and different features such as data classification, i.e., classification of the data coming through from the same source maybe and trying to segregate that kind of data can also be done with the help of fog computing.

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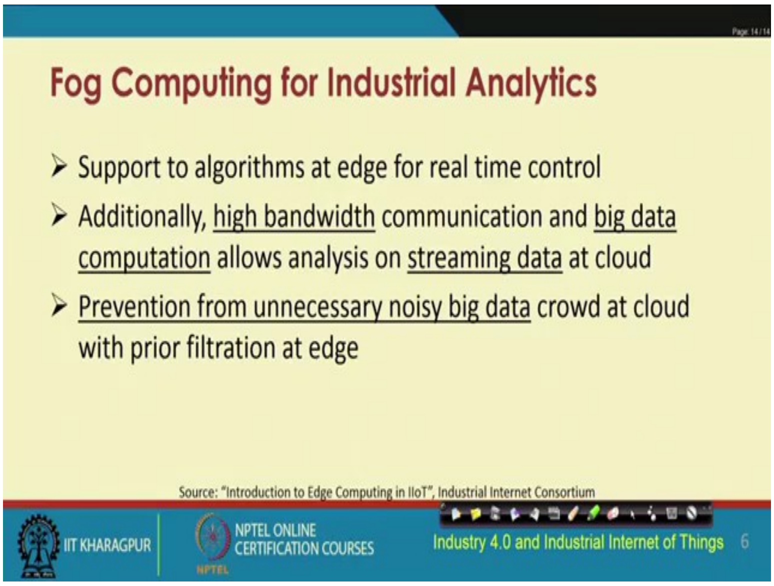


Fog computing has support for different algorithms that can be executed at the edge for real time control, for industrial scenarios there is a requirement of all these devices connected to each other and sending the data and this data are sent continuously in real time in large volumes and so on they are streamed.

So, high bandwidth requirements are also there in the industrial settings and also it is required to prevent as much as possible the unnecessary noisy data from the crowd through some kind of filtration process so this filtration can also be done at the fog. So, taking care of all of these requirements and the density of doing certain computation filtration, basic analytics and so on could be done at the fog layer.

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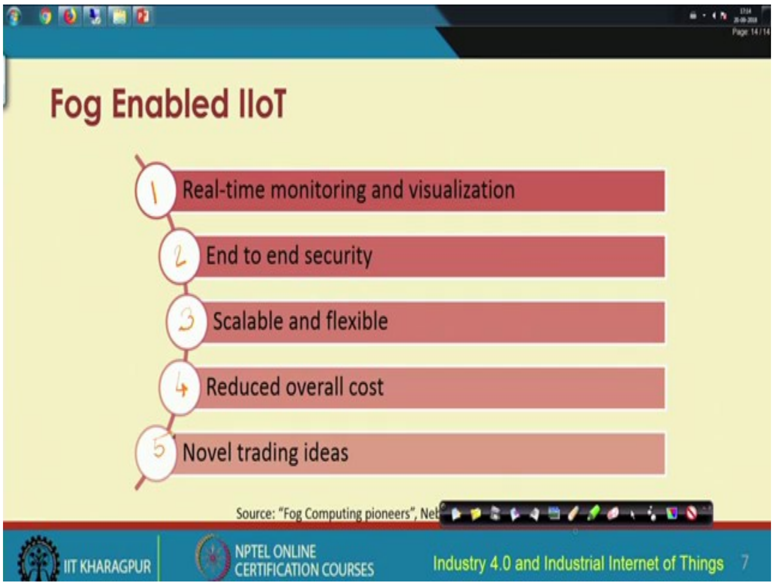


So, a fog enabled IIoT solution can help in, real time monitoring and visualization, offering end to end security, taking care of scalability issues and making the architecture flexible overall, reducing the overall cost and novel trading ideas. So, these are some of the different features of fog enabled IIoT.

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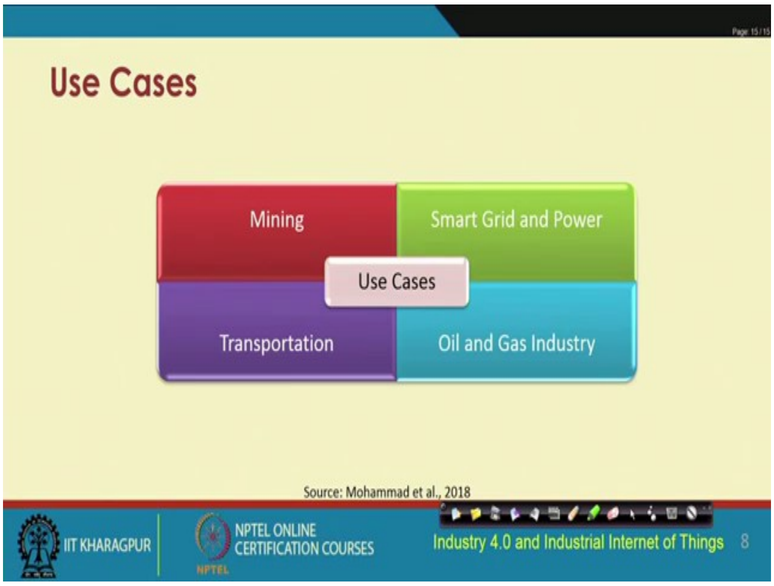


There are different use cases fog computing: could be used in mining industry, in the power sector, smart grid, in transportation sector, in oil and gas industry and so on.

We ourselves have been using fog based solutions for certain mining projects that we have in the underground coal mines we are deploying fog nodes, fog architecture overall for doing some basic analytics in the mine itself right close to the point of origination of the data. So, like that for smart grid also fog is very important transportation, oil and gas industry and so on. So, this is not the only list there are many other different applications of fog.

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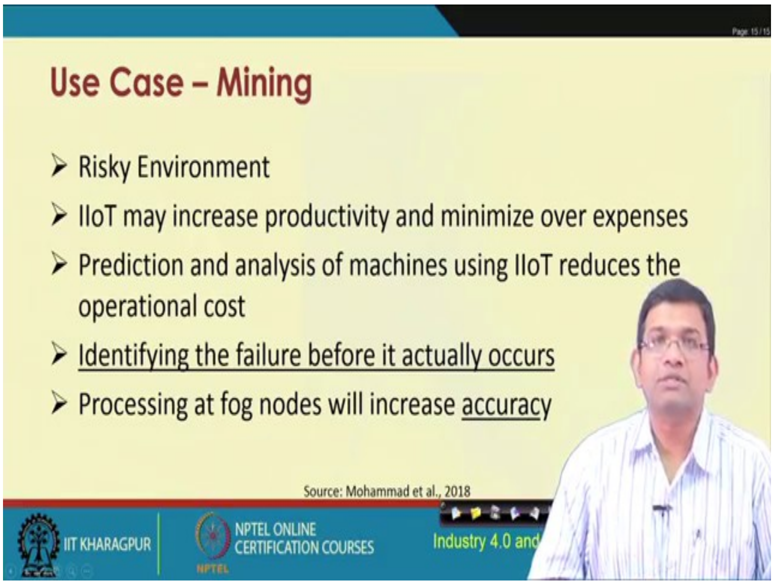


So, take the case of mining, as you know that mines typically are risky environments where productivity is indeed important, but overall safety is also very important. There are different mining machinery that are basically operating in huge speeds and working continuously. So, hazards are quite common due to mining machinery, monitoring of these different underground mine gases that are harmful. So, all of these different issues are there.

So, mining industry finds lot of these scenarios where fog can help, because fog can help in reducing the overall response time. Accuracy can be improved with the help of fog, response time reduction, & improvement of accuracy all of these things can be done with the help of fog based deployment of IIoT solutions in the mining industry.

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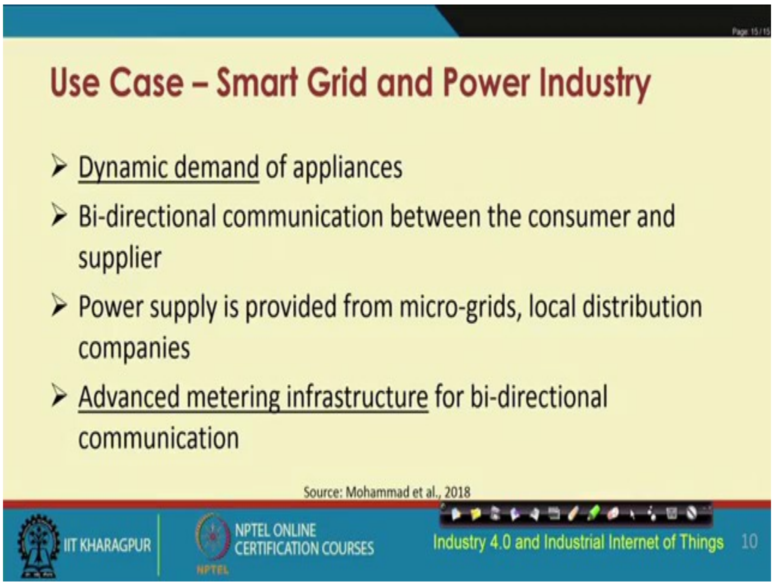


So, this is just in a nutshell that I have told you like this for other industrial sectors as well for smart grid power industry etc. fog is very important. In the context of smart grid now a days we are talking about dynamic demand scheduling of appliances (appliances dynamically will be scheduled). They will be programmed by the consumers depending on the specific criteria such as the time of the day and the pricing etc. different appliances could be scheduled.

So, in certain cases what might be required is to basically implement these different solutions for dynamic demand scheduling and the others to be done as soon as possible. So that the responses can be sent to these end equipment and machinery quickly so, the response time could be improved. So, that is why in the case of smart grid and power sector as well the implementation of fog is very interesting and efficient.

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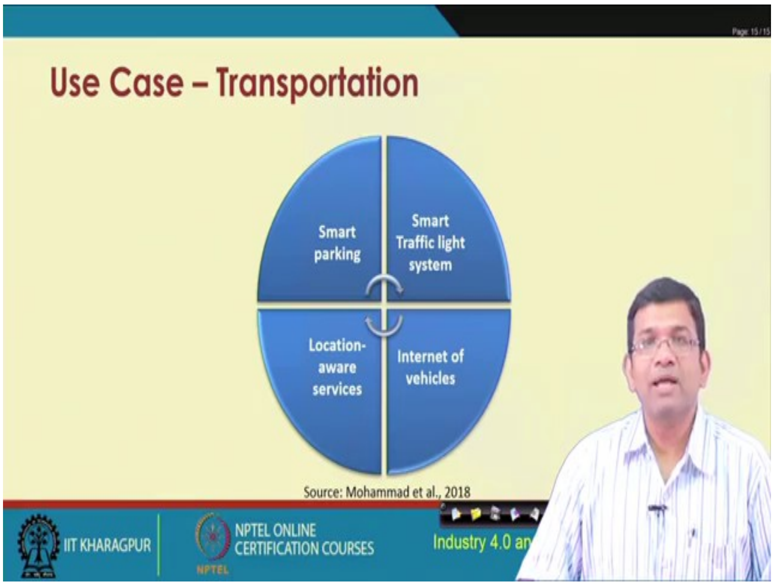


In the case of transportation, smart parking, traffic lights, internet of vehicles, location aware services to the vehicles and so on. All of these basically fog computing for the reasons that I mentioned earlier in the context of mine and smart grid, these are also applicable here. So, you can basically extrapolate those different benefits of fog computing that makes fog based mining, fog based smart grid attractive you could extrapolate those and try to think of a fog based solution for transportation which will be attractive as well.

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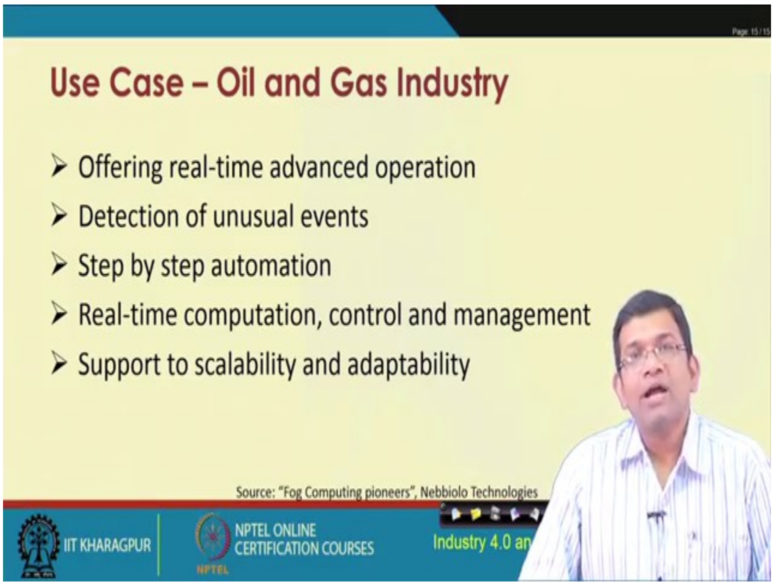

Oil and gas industry also finds lot of use of fog computing, offering real time advanced operations is very important in the oil and gas industry, detection of unusual events detection of leakages through different transmission lines (where this gas is being transported through pipes). Those gas pipe transmission lines, step by step automation, real time computation, control, management, support to scalability, adaptability etc. all of these are different things that can be done using a fog based solution.

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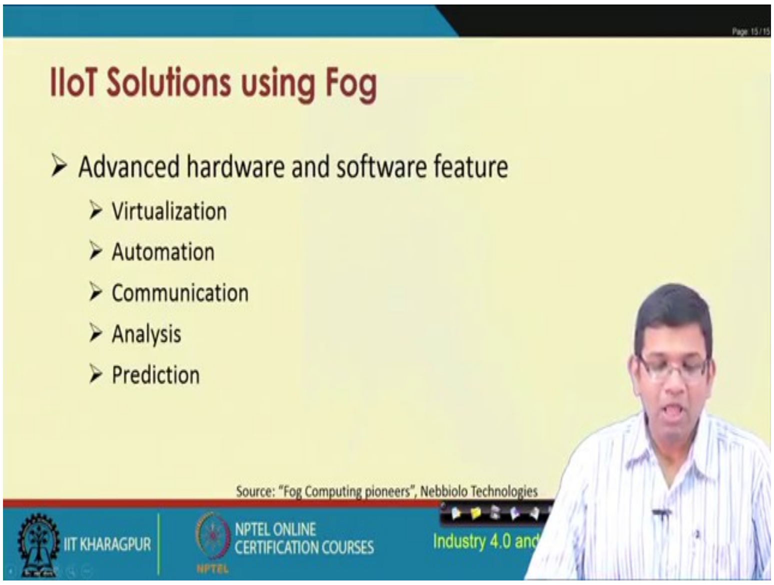


So, using fog advanced hardware and software features such as virtualization, automation, communication, analysis, prediction, all of these can be done.

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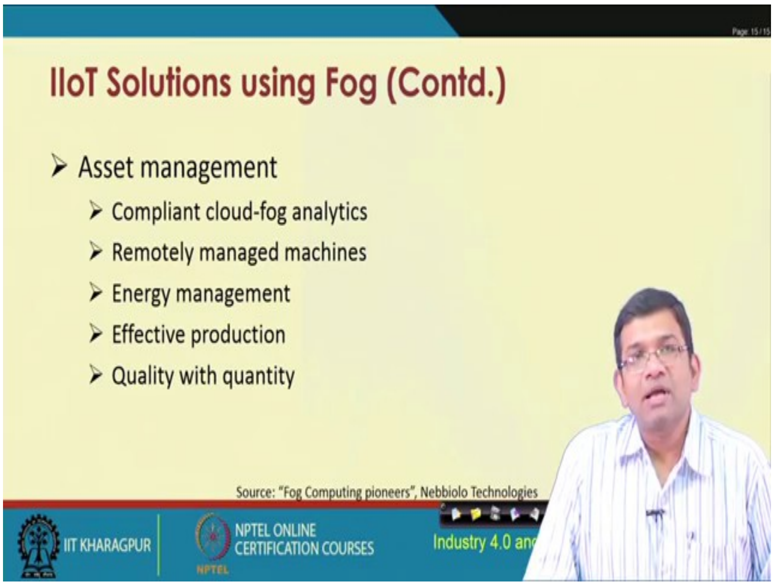


Asset management can be done with the help of fog based IIoT, where compliant cloud fog analytics can be executed, remote management of machines can be done, energy management can be done, effective production, quality with quantity all of these can be done for asset management using fog based IIoT problems.

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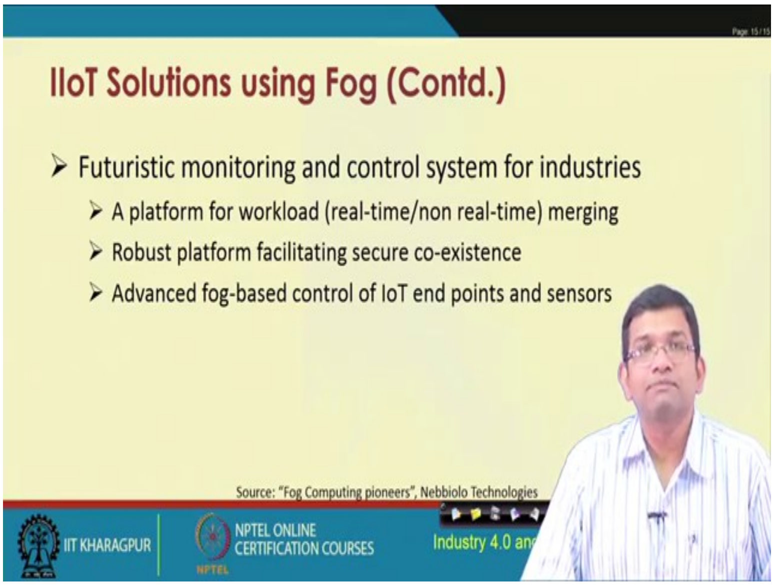


Futuristic monitoring and control systems for industries, they are also you know IIoT based solutions using fog are useful.

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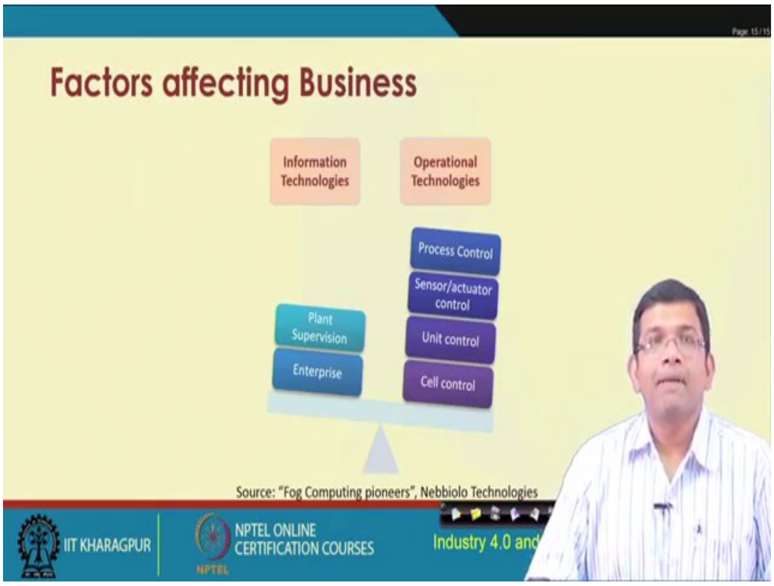


Now, the factors that affect business, if we talk about that, so these are the different factors that will typically affect the business.

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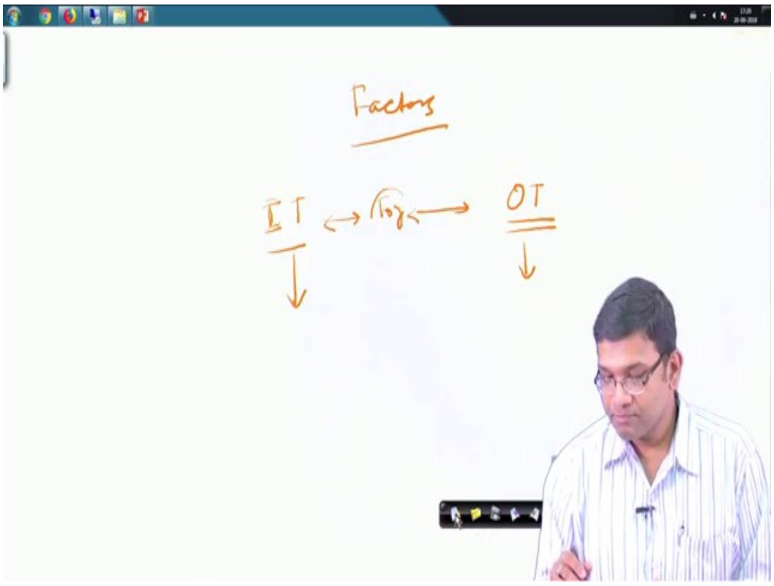


So, these factors if we look at can be classified in this particular manner, you have these IT based factors and the OT based factors, IT means information technology and OT means operational technology, these different factors with the help of fog can be implemented right.

So, different operation technologies factors and IT factors is what we are going to look at and how fog can help in addressing these requirements. So, IT factors include plant supervision, enterprise and so on whereas, the OT factors include process control, sensor actuator control, unit control, cell control and so on. So, these are the different OT factors and these OT operational technology factors typically in most of these industrial automation settings these outweigh the IT factors of plant supervision, enterprise control and so on and this is where this integration and handshaking of these IT and OT parameters for improving the business outcomes this is where this fog can help.

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So, let us go ahead further. There are different fog platform service providers that are already there like the cloud service providers that I told you previously, for industrial contexts. So, one is the Fog Horn, say next is Nebbiolo, third is Crosser and fourth is Sonm. So, these are some of these fog platform service providers.

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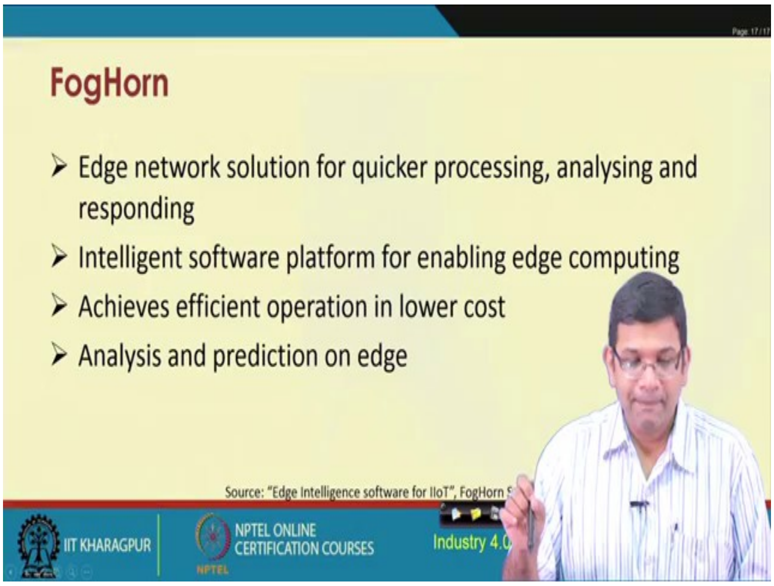


So, FogHorn just in nutshell offers edge network solution for faster processing, analysis and response. So, it is basically an intelligent software platform that is provided for enabling edge computing.

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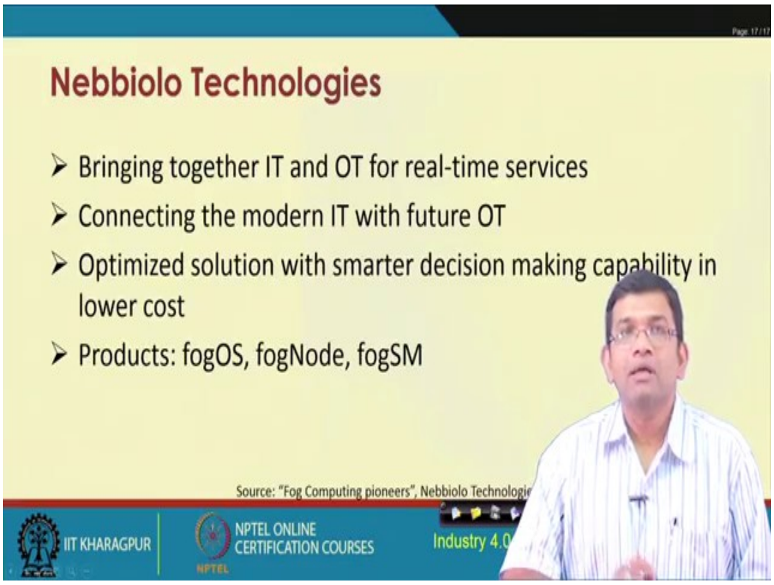


Nebbiolo, basically helps in this integration of IT and OT. Offering this integration of all these different components is done with the help of Nebbiolo, they have different products fogOS, fogNode, fogSM and so on.

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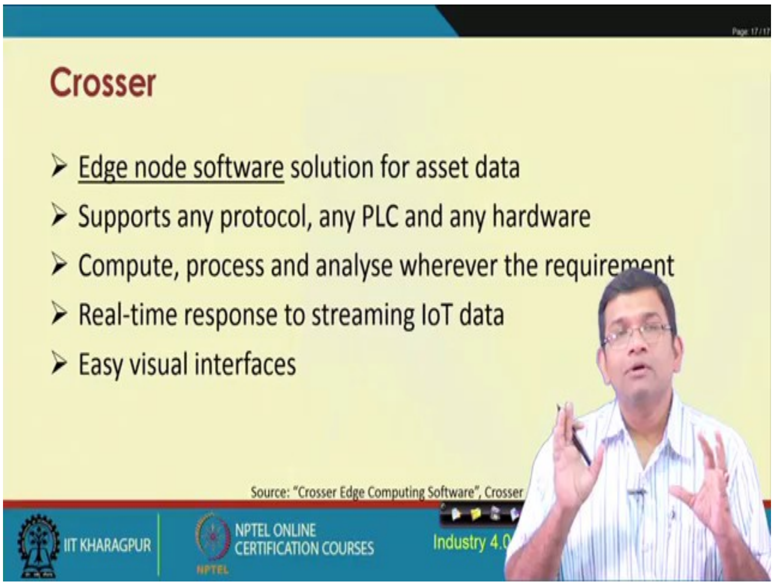


So, this connection between this IT and OT with the help of this technology is possible. Crosser is an edge node software solution for asset data. So, it basically runs on different machines PLCs, end devices, computer hardware and supports different varied types of protocols.

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Sonm, is basically a distributed cloud service for customer hardware, this is basically essentially a fog solution and they have different components supporting block chain infrastructure, video streaming, machine learning, video rendering. Block chain probably may most of you are already familiar with. Block chain is good for security, offering decentralized security particularly, but also the centralized ones. So, overall security of the infrastructure block chain based services, basically are useful and are quite popular at present.

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So, with this we come to an end and these are some of these different references we have gone through in the last few slides, these different fog based services that are available and how they could be integrated with cloud and so on and these are fog based solutions for IIoT scenarios which we have discussed.

So, these are different references and we come to an end of this fog based solution. Fog remember is not the solution, fog is a complementary solution that can be offered along with cloud. In most of the cases fog does not stand on it is own. So, fog and cloud together a converse solution is what is typically found useful in most of these IIoT implementation or deployment scenarios.

Thank you.

**Introduction to Industry 4.0 and Industrial Internet of Things**
**Prof. Sudip Misra**
**Department of Computer Science and Engineering**
**Indian Institute of Technology, Kharagpur**

**Lecture - 42**
**IIoT Analytics and Data Management: Tutorial for R & Julia Programming**

In this particular lecture, I am going to show you two tools, platforms in fact, which could be used for IIoT analytics. One of these is popularly known as the R, the R tool which offers it's a comprehensive tool offering different platforms has its own language for implementation and so on. So, R is basically a tool that is widely used for analytics. So R and another language which is known as Julia, Julia is also a very popular high level language which could be used for implementing these analytics solutions. So, both R and Julia are quite popular in the IIoT analytics scenarios and their implementation.

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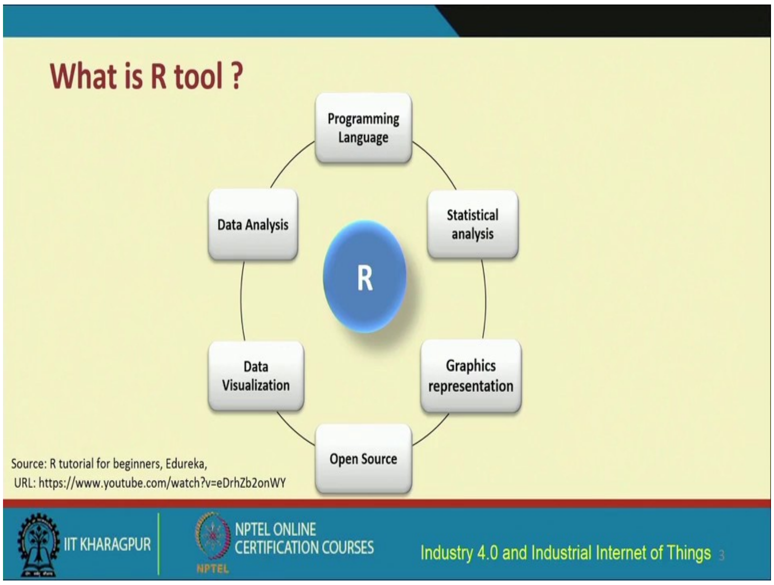


So, let us first look at R, what is R and the R programming. So, R it is a tool; R is a tool which offers different features of programming so it offers a programming language, it offers statistical analysis platform, it has graphical representation platform, data visualization, open source and has different data analytics features. So, these are the different features of R.

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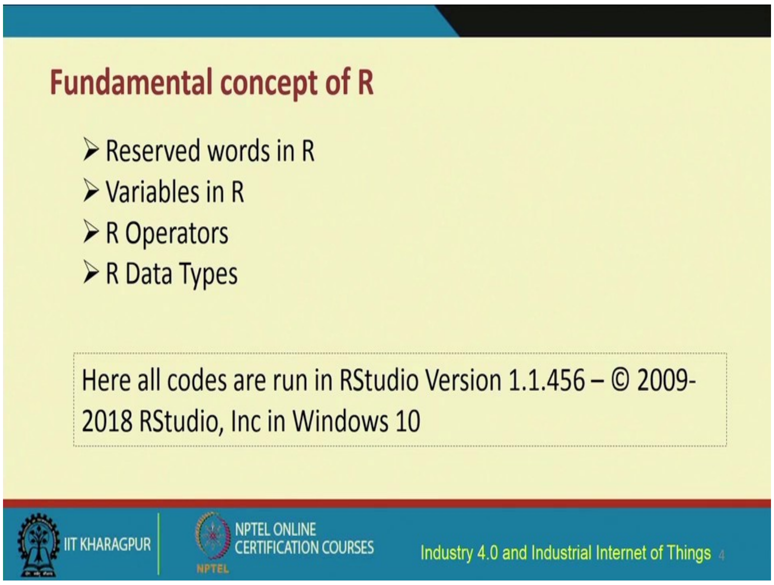


And the programming environment in R supports different features. So, the fundamental concepts are like this that there are certain reserved words in R, their certain variables that can be defined in R, there are R operators, R data types and these I am going to show you shortly and what are these and is just a simple instance of all of these is what I am going to show you.

So, here basically everything will be shown in the RStudio. RStudio basically has support for this R programming platform. So, I am going to show you this thing in the RStudio, but let us first proceed further and see that what are these reserved the words in R.

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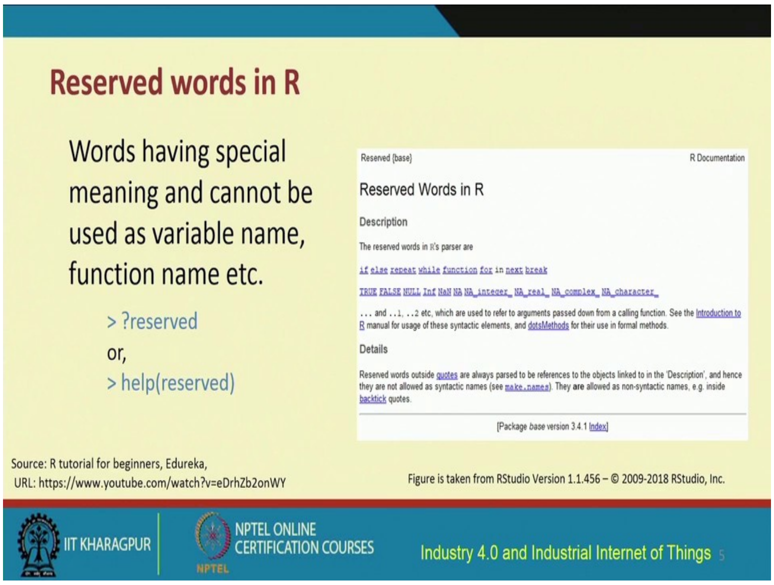


So, there is this reserved words which have some special meaning and which cannot be used as a variable name. For example, this reserved itself. So, if you basically type in the RStudio if you type in question mark reserved or help within parenthesis reserved, this is what you are going to get you are going to get these reserved words that are supported in R.

So, these reserved wards are like if else, repeat, while, function, for, then next, break, true, false etc. So, these are some of these different reserved words and their corresponding details are also available. So, if you just type in this in the RStudio this reserve then you would be able to see this.

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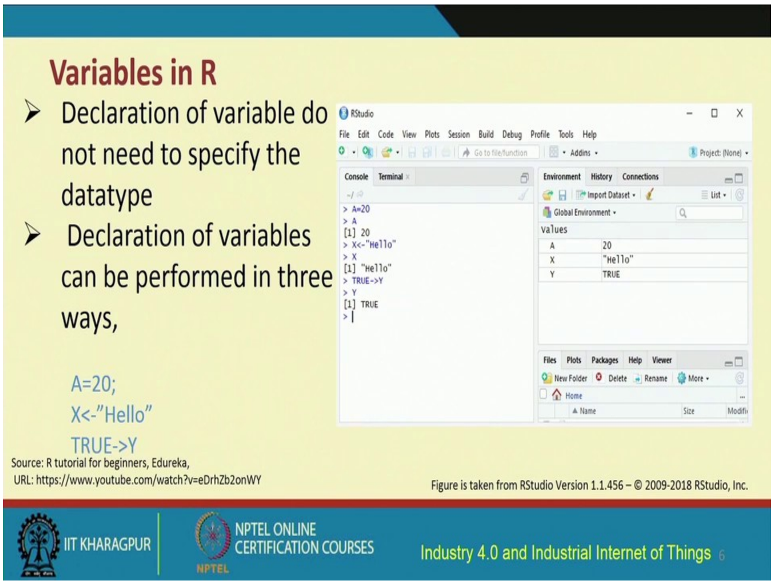


Then what is a variable? Variables are basically like the variables in any programming languages, these are basically declarations that I that will have to be done and these will be assigned certain values. So, these variables will have to be declared for example, these are some of these variables A is a variable, X is a variable, Y is a variable. So, these variables they could be assigned different values.

So, for example, A equal to 20, 20 is the value that is assigned to this variable A, then hello is a string which is assigned is a value that is assigned to this variable X and true is a value that is assigned to this variable Y so these are the different types of variables and how they can be used in the or they can be declared how these variables can be declared in the RStudio platform. So, these are basically the essential features of this R programming language.

So, as you can see over here this is just as snap shot that is taken screenshot that is taken from the RStudio and as you can see over here this is how you will make certain declarations A equal to 20 and now then if you want to print A you get this value 20. Similarly you declare this variable X to be hello and if you print X then you are going to get this value the result is going to be hello, then true Y basically if you print Y then you are going to get this value true because that is what this variable Y is going to have this value and also in this RStudio platform which I am going to show you shortly you will be able to see these different there is a separate panel over which you can see all these global environment values of these different variables A, X and Y and their corresponding values shown.

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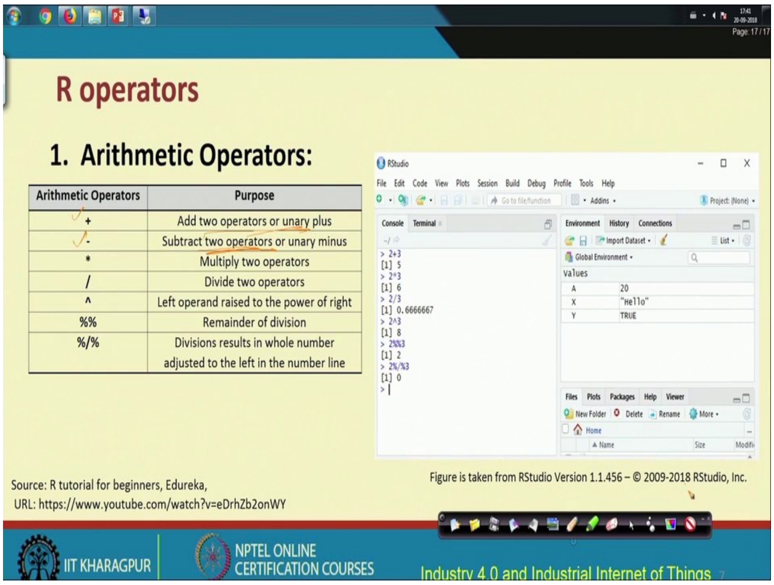


Next I am going to show you how different other things are done. For example, the use of different parameters sorry operators in R different operators such as arithmetic operators are possible operators such as different arithmetic operators such as the plus operator which will do the unary plus; this minus will do the subtraction and then star is for multiplication, slash is for division then this cap is basically for power basically two to the power x. So, you have to use this power with the cap then you have double percentage which is basically the remainder of a division and this percentage slash percentage basically this is the division resulting in a whole number adjusted to the left in the number line.

So, these are some of these different arithmetic operators that are supported in R and this is a screen shot that is taken from RStudio as you can see over here it will show you the different arithmetic operators 2 plus 3 and then if you hit enter you will get this result 5 right so this is just a this is just a unary plus or rather not the unary plus, but the binary. So, here actually what you are doing is you are just adding these two different operands with the help of this plus operator and you are getting this result 5, similarly the star is for multiplications 2 into 3 so you get the result then this will be divided by 2 divided by

3 in floating point and this is 2 to the power 3. So, 2 cube will be 8 and so on. So, these are these different operators that are supported in R.

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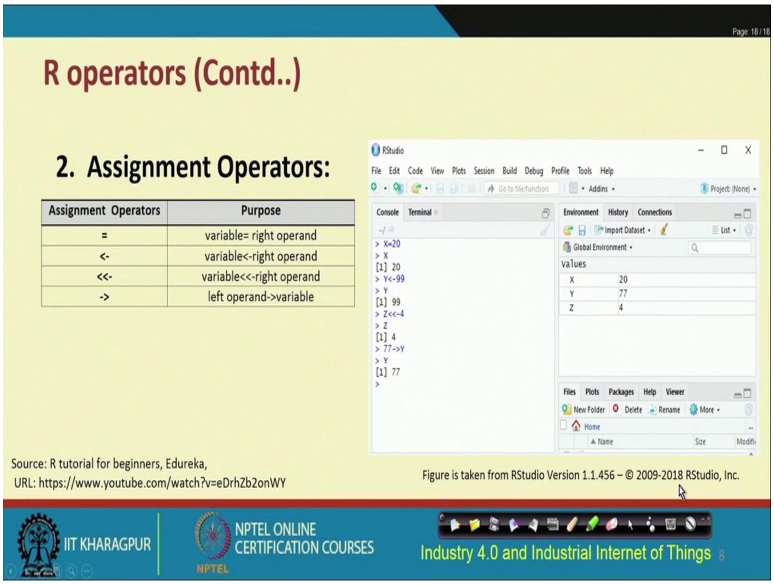


There are other operators, assignment operators. Operators like equal to, then you have this less than signed hyphen, then you have this double less than hyphen and hyphen greater than and their corresponding purposes are also mentioned over here. So, this is just an example likewise like the previous slides I have even given you an example of all of these different other assignment operators like the equal to etc. So, X equal to I will just give you an example one of these X equal to 20 basically assigns this value 20 to X and then if you print the value of X you see that you get the result as 20 and the use of these different other operators are also given over here and there examples given over here so you may go through and try to understand how they work.

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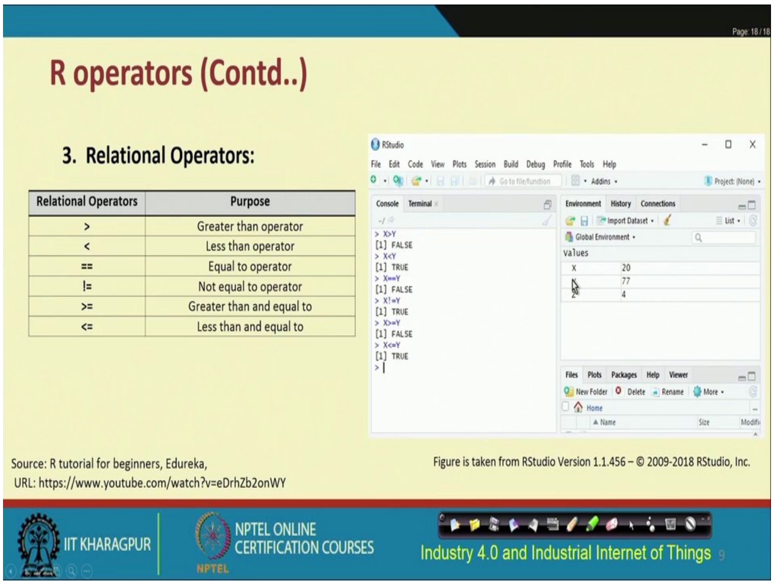


A relational operators are also possible. Relational operators like less than, greater than, double equal to, this is not equal to and then you have greater than equal to, less than equal to and so on and their corresponding use and examples are also given over here. So, X greater than Y, if X, Y and Z are configured to have these different values corresponding values as shown over here in this variable window so then if you write X greater than Y, obviously, X is not greater than Y, so you will get the value false. Similarly X less than Y true, X double equal to Y false and so on.

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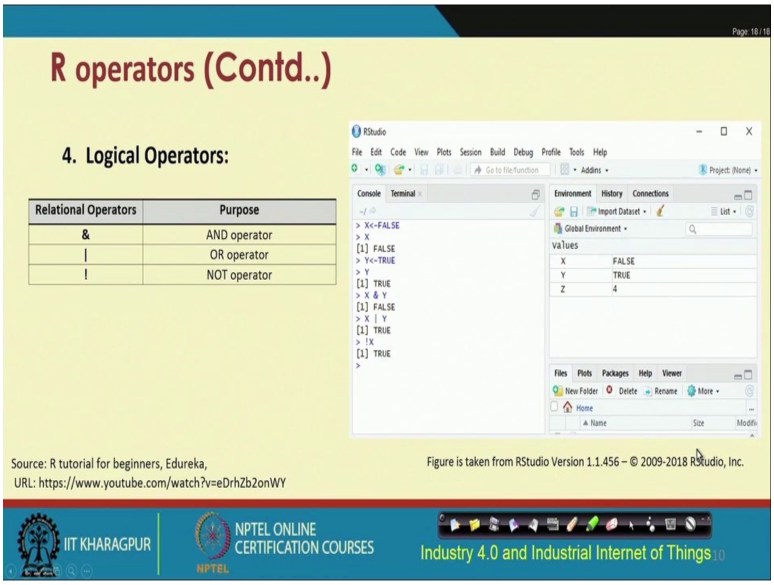

So, then you have this logical operators like ampersand, then you have this vertical bar and this exclamation sign and there corresponding meanings are also given over ampersand is AND, then this is OR and this is NOT.

So, if these values are preconfigured to have these variables are preconfigured to have these values like this X false, Y true and Z 4 then, all of these different operators if you use them in this manner you are going to get these results that are shown over here like in the previous slides with the other operators.

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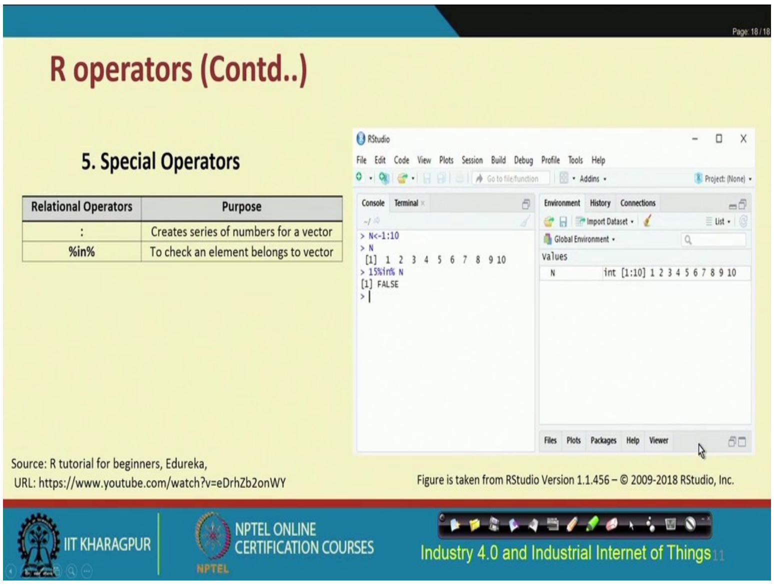


There are certain special operators, this colon basically creates a series of numbers for a vector, then percentage-in-percent will help to check an element belonging to a vector or not so for instance if you have this N which is a set of 10 different integers like this defined like this, then if you print N then what you get is basically this particular list 1 through 10 and this other operator also and its corresponding example is shown over here.

So, there are different data types that are supported, but before we understand these data types, we need to understand that there are different something called objects, R objects that are supported by R.

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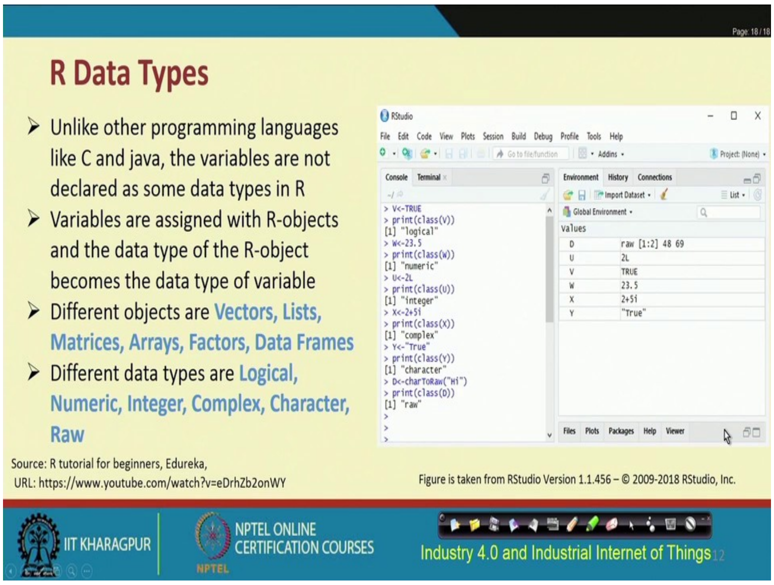


So, these are these different R objects that are supported vectors, lists, matrices, arrays, factors, data frames and so on and so forth. So, these different objects and the corresponding data types that are supported are the logical, numeric, integer, complex, character, raw etc. So, these together are used in order to build different complex programs that could be executed in this RStudio platform. So, so this is just a screenshot once again these are these different parameters and the different data types that are used. So, you have V which is true then if you print class V then you get logical and similarly for these different other ones also it is given over here.

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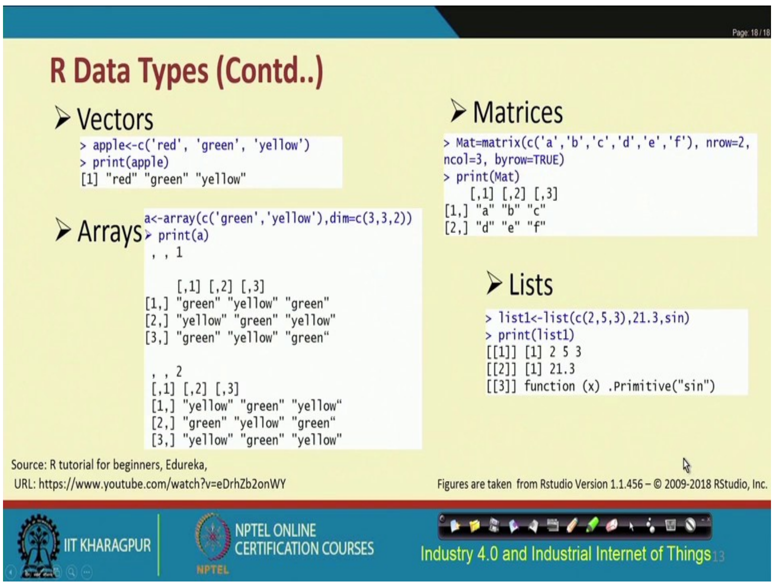

So, what are these different R objects? So, one is this vector. So, vector is basically like a one dimensional array. So, you can have something like this you can define a vector like this apple less than hyphen c within parenthesis you can give these values red, green, yellow and then if you print apple, then what you get are these different values of this particular vector red, green and yellow. So, this is just a one dimensional array and then you have matrices matrix can be defined in this manner. So, mat equal to matrix then you define this particular matrix so here you are saying that this is going to be the matrix where nrow; that means, the number of rows is going to be 2, number of columns equal to 3 and byrow = TRUE; that means, that you are going to build this matrix by row.

So, this is just a this matrix that we are going to build this matrix will have 2 rows, these are; these are the 2 different rows and it is going to have 3 columns like this and if you print this matrix then you get a, b, c, d, e, f like this. Then you have this arrays, arrays basically help you to get the multi dimensional kind of array so it is like a 3D, 4D kind of array it can be built with the help of this arrays. So, this is how to do it a less than hyphen array c green, yellow dimension equal to c 3, 3, 2 print a.

So, if you print that then you get this is this one dimension, this is the second dimension, so this is this first dimension and then this is the second dimension as shown over here and this corresponding values green, yellow, green, yellow, green, yellow, green, yellow, green and so on. So, like this, this is one layer and this is the second layer you could have the third one also, fourth one also so you can build multiple layers of these matrices and you are going to get a multi dimensional array which is over here known as the array in R and then you have this list.

List basically can be built in this manner it is so; basically the previous arrays, matrices we considered are of homogeneous type and in the case of list you are going to have heterogeneous values. So, you can have a floating point along with integer and so on. So, you are going to have all of these built in one unit. So, this is known as the list in R.

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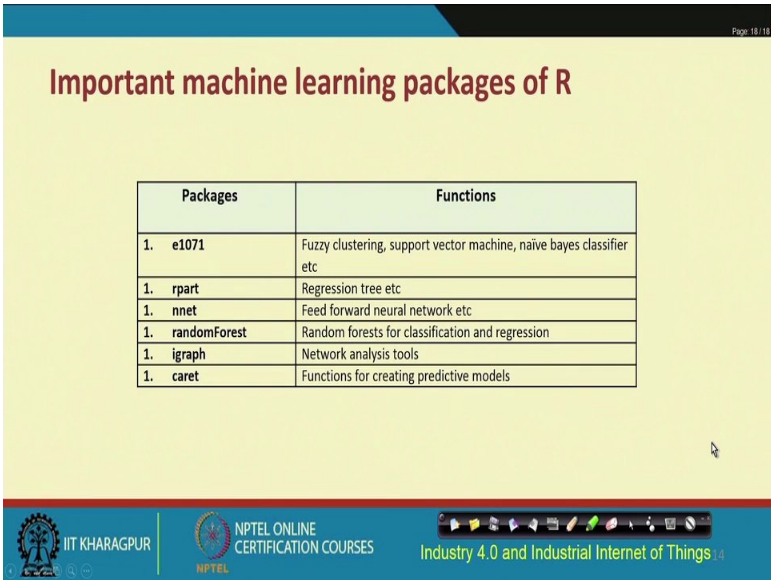


So, there are different machine learning packages that are also supported by R the different packages for let us say random forest, there is a package which; which basically implements this is a library which basically implements this random forest of machine learning, then you have different other things like igraph which is for network analysis, caret for having different functions for creating predictive models, e1071 is a package or a library which supports fuzzy clustering svm, then nice Naive Bayes classifier etc., rpart is for building regression trees, nnet is for feed forward neural network like this there are many other different packages that are supported for R.

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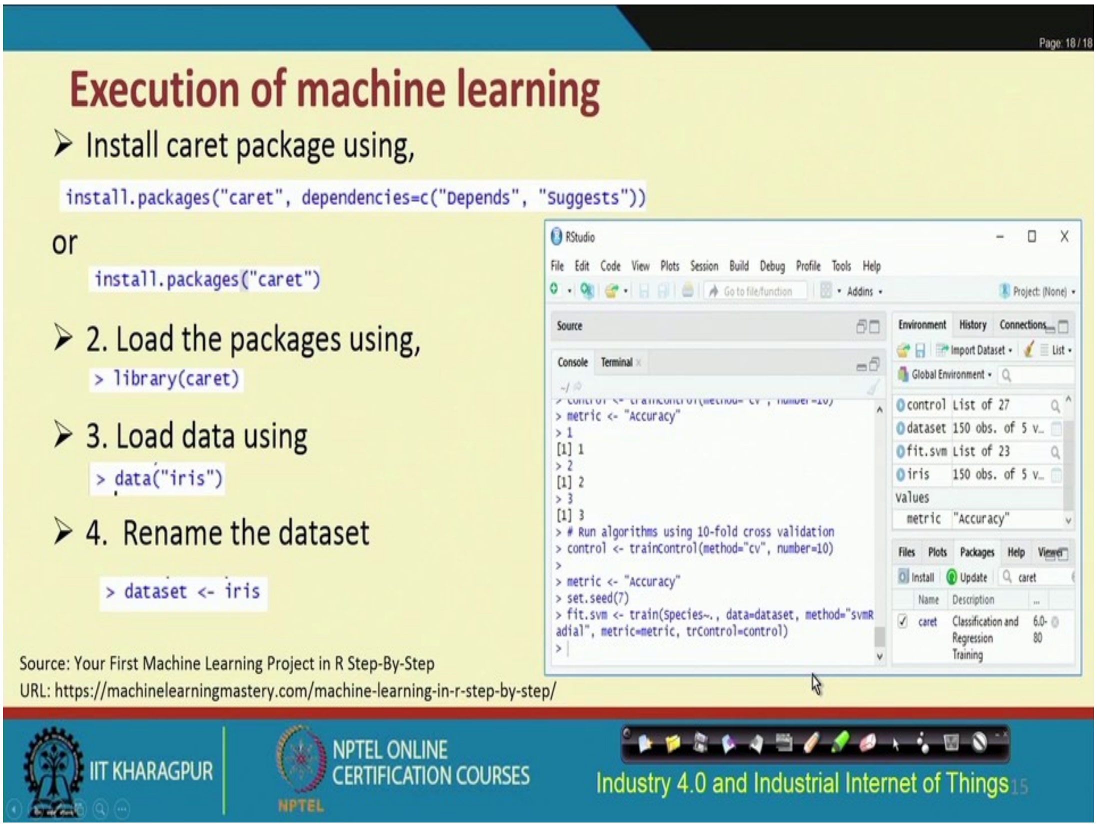


So, how do you execute these in for machine learning implementations? So, again this is a snapshot of this RStudio. So, first of all I will I am just going to give you an example. So, here we have this installation of the caret package we will be using this caret package so we are we have to install it first. So, this installation is done using this particular command, install.packages “caret” and then you have certain other things or you can use install.packages (“caret”) this will also install this caret package or this library which has which has different functions already which are already implemented.

Then to load that particular package this is this command that you are going to use library(caret) loading the data using this package for that loading the data basically you can do with the help of this particular command, data(“iris”). Iris is the data set and for example, over here as you can see this iris data set and the corresponding values that are over here, the features are given over here these are these different other data sets like the data set, iris, the control etc. So, the corresponding values that are given over here are shown in this particular window.

So, data iris will basically load the data from this iris dataset and rename the data set can be done. So, data set less than hyphen iris will basically rename this particular data set to data set and as you can see over here so this data set and iris will both have the same contents.

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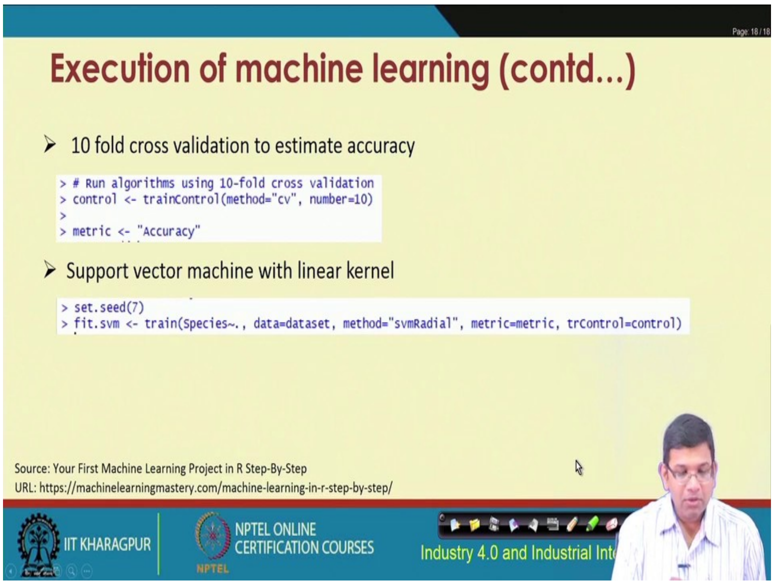


So, then you have different other commands for cross validation 10-fold cross validation for estimation of accuracy these are actually different things that you can do with the help of machine learning algorithms such as support fixed vector machines and so on. So, for cross validation this is the command that you use control train control method equal to cv, number equal to 10 and the metric is accuracy. For use of support vector machine you first set the seed, so this is the random number seed, the seed you set first and then basically to invoke svm on a particular data set, data equal data set and the methods that will be used are also specified you use this particular command. So, fit.svm, this svm command will be executing svm on this particular data set; data set the name of which is data set.

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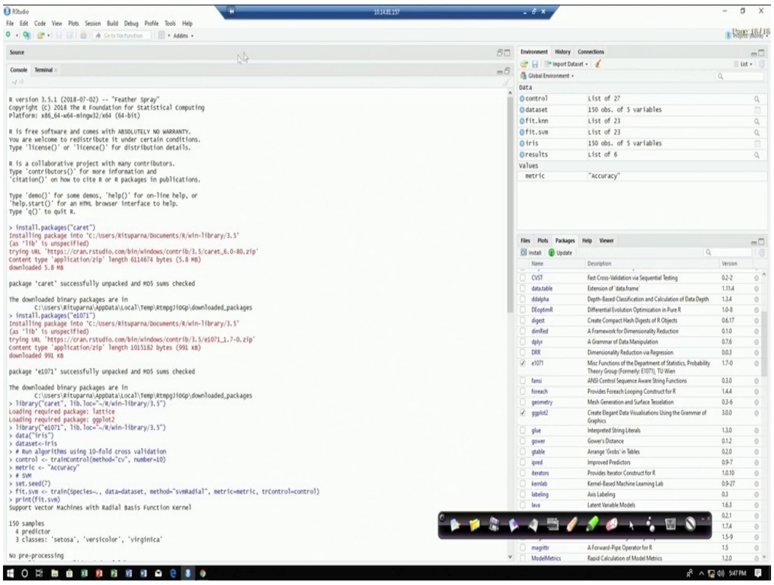

So, this is basically this RStudio environment platform that you can see over here all these different data sets and their corresponding features are given over here in this particular panel and for installation of these different libraries you have to basically from this particular check list you will have to check the libraries that you want to include.

So, as I was telling you for installation, this command will install the caret package. So, install.packages caret will install this caret package over here through this particular command. So, then install dot packages e1071 will install this package e1071. So, this is this other package and as you can see over here e1071 which has miscellaneous functions of the department of statistics probability theory etc. from TU Wien that basically will be installed and also then if you have to want to include these libraries then these are the commands to be used.

So, library caret this will basically help you in loading these libraries, then library ten e1071 will also load this library then data iris this data iris will basically import this particular data set and this is going to be renamed to this data set data set and then using svm you execute the data that you have in that data set in this particular manner. So, this will be executed as svm will be executed on this data set which has the name dataset. So, what we have got is a glimpse of the R platform which is widely used for analytics.

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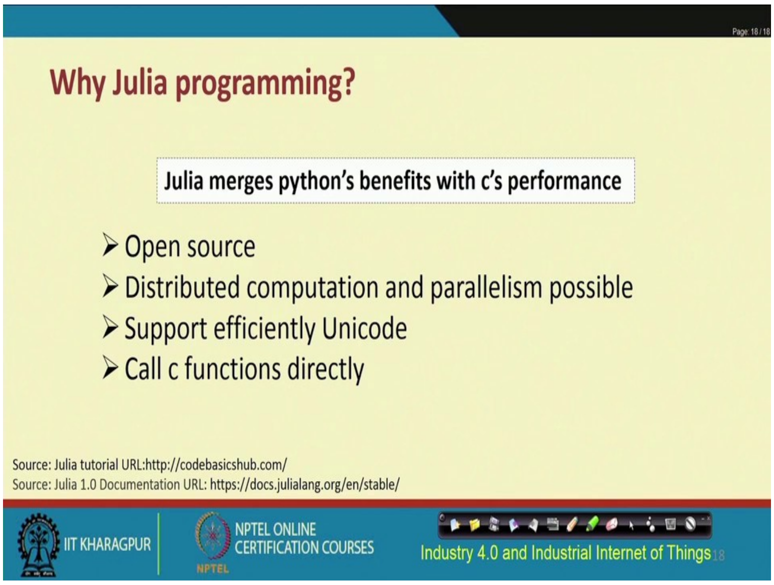


Let us now have a glimpse at the Julia programming language which is quite popular programming language used for analytics programming high level programming of analytics and Julia is a popular programming language that builds on the benefits that are obtained from python and the performance that is achieved with c language. So, it is a combination of you can think of conceptually as a combination of benefits from python and c.

So, Julia is an open source programming language and it supports distributed computation and parallelism and there are different c like called function calls that are supported by Julia.

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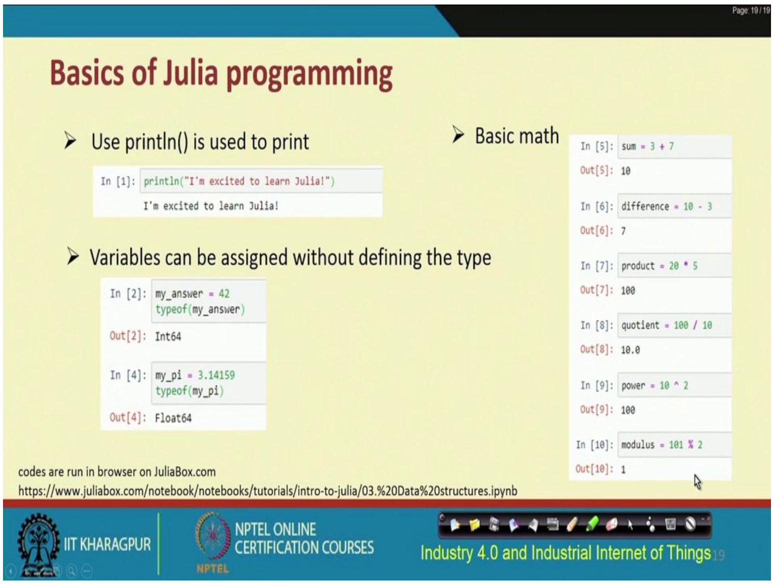


So, these are some of these different common programming features that are there; one is this println. So, this println is for printing, so it is used for printing and for example, if you type in println I am excited to learn Julia then after that if you hit enter you will get I am excited to learn Julia so this is the use of println and then for different other variables you can define these different variables in this manner for example, this particular variable my_answer equal to 42; typeof my_answer and then if you execute this the output will be in 64. So, typeof; type of this variable is integer. So, you get integer 64 which is the type of this my_answer. Then my_pi equal to 3.14159 and then if you type in typeof my_pi you get this 14.64. So, these are the different outputs of this command typeof. Type of is a basically command for getting that type of a particular variable and this assignment of values to variables can be done in this manner as shown in Julia.

So, the basic math functions are supported sum equal to 3 +7 will basically do the sum of two different integers which are given over here so 3+7; 10. Difference equal to 10-3 will give you 7, product equal 20 x 5 will give you 100, quotient equal to 100 / 10 will give you 10.0. So, this basically will be in the floating point and then you have power equal to 10^2 so this cap is basically for the power. So, 10 ^ 2 will give you 100 and then modulus 101 %2 will give you this mod value of 1.

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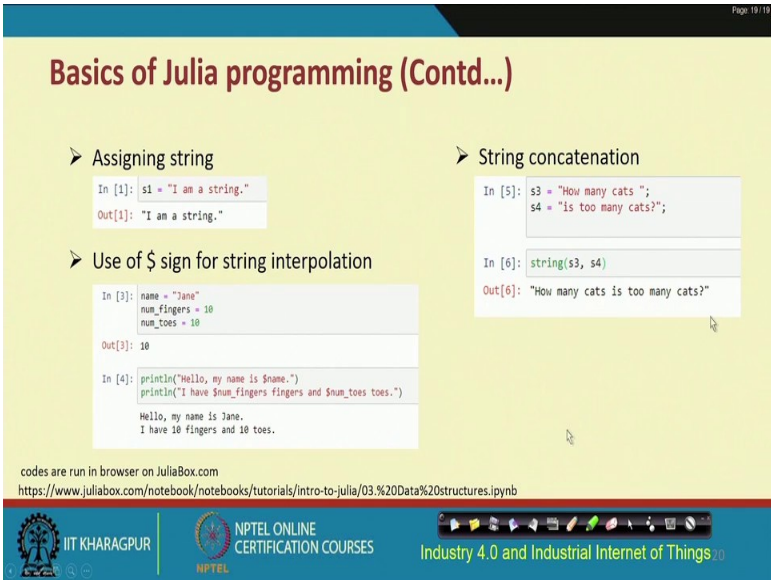


So, these are the different other operations that are supported; assignment of strings. So, for example, you can have a string defined in this manner s1 equal to within quotation mark I am a string, this will basically create this string s1 and then if you execute then you get this output I am a string.

So, dollar sign is used for string interpolation. So, name equal to Jane, number of fingers equal to 10, number of toes is equal to 10 then the output will be 10. Now if you type in println hello my name is dollar name then the value of name which is Jane is going to be printed in this manner. So, similarly printing I have dollar number of figures fingers and dollar number of toes, then you will get the corresponding values the dollar basically dollar number figures will give you the corresponding value that is stored in this particular variable. So, dollar number toes will give you this particular value that is stored for this particular variable which is 10. So, I have 10 fingers and 10 toes is what is going to be printed if you execute this particular statement. Then you have for string concatenation you can use something like this s3 equal to how many cats is a string s4 is another string is too many cats, then string s3 comma s4 will concatenate the strings, s3 and s4 concatenate means like these two strings are going to be joined together. So, you are going to get this joint string which is how many cats is too many cats.

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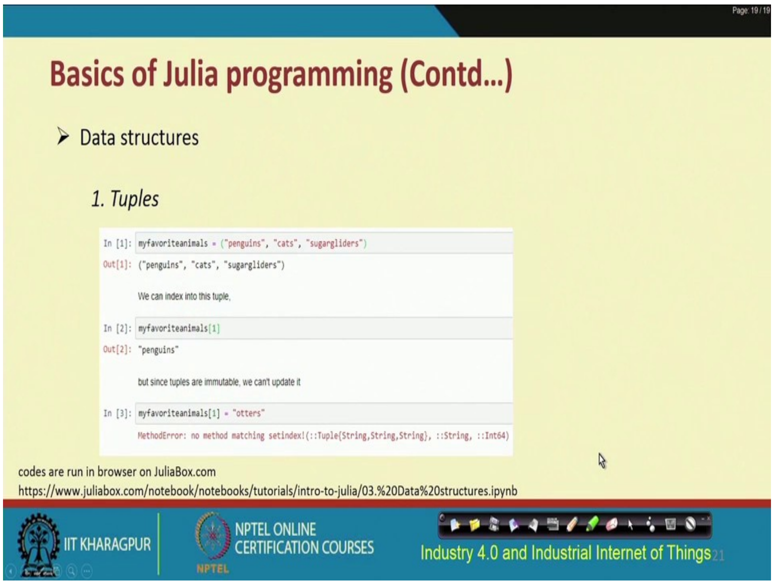


There are different data structures that are supported in Julia. So, these are the ones that are shown over here. So, tuples basically. So, this is how you can create these tuples. So, my favourite animals equal to penguins, cats, sugargliders this will create this particular tuple and so the output will be is so if you execute this thing so output is going to be penguins, cats, sugargliders. So, like this you can built different other types of tuples as well.

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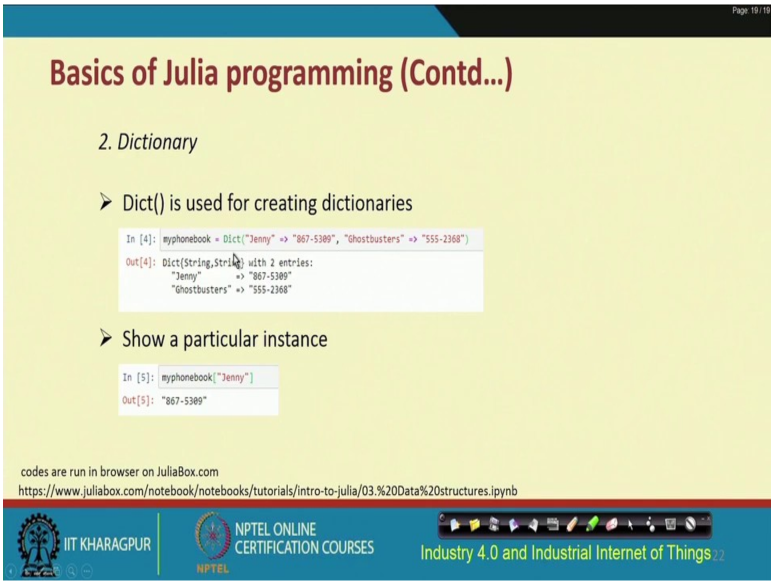

To create a dictionary this is the command to be used. So, my phonebook equal to dict is this particular command will create this dictionary. So, dict then you have all these different values that are going to be stored against these different variables. So, this will create this particular dictionary named myphonebook. So, then if you print this particular myphonebook dictionary, then this is how it is going to look like. If you want to show a particular instance this is the way to do it.

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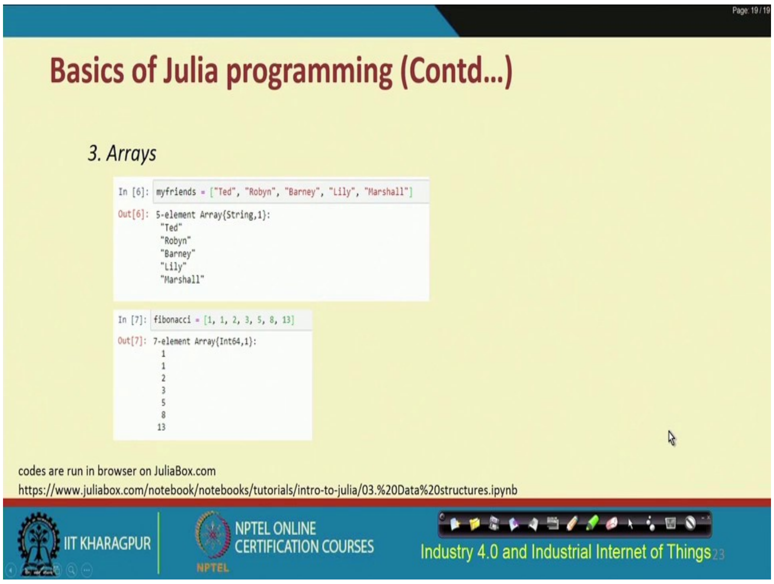


Arrays to build arrays in Julia you can do it very easily with the help of putting all these array items within square brackets. So, this will create this 5 element array myfriends having these elements Ted, Robyn, Barney, Lily and Marshall. So, this one will create a seven element Fibonacci array having these different elements over here.

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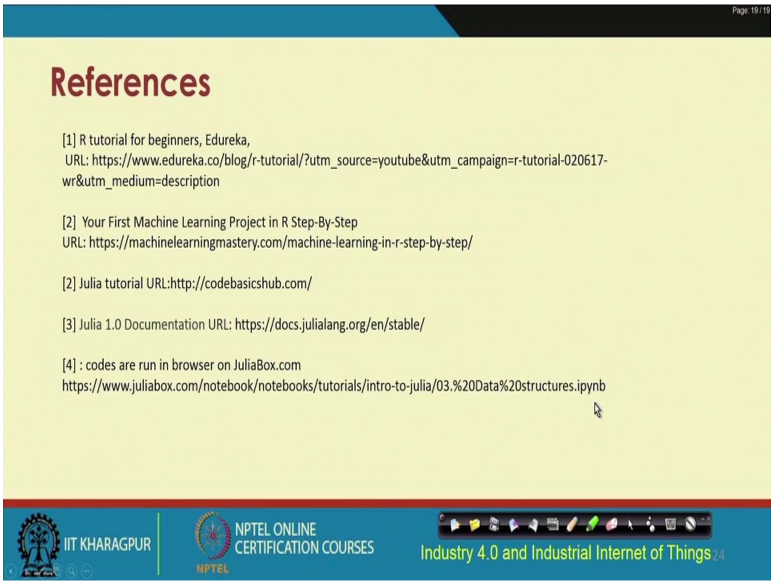


So, with this we come to an end of Julia. These are these different references that what I have done is basically, I have given you a very high level expository view of what is R, what is Julia, how is this RStudio platform like, what are these basic operators that are there, what are the different functions that are supported in Julia and so on. So, these are the only very basic half an hour kind of glimpse of what is there. With this particular lecture you are not expected to become an expert of R or Julia; however, if your job requires you or if you are indeed interested to have a deeper understanding of R and Julia you have to build your knowledge further and you have to take different tutorials that are there for R and Julia and you have to become master of these languages if you are required to, but from a course perspective for IIoT an Industry 4.0, I think this particular knowledge that you have been provided through this particular lecture this will be sufficient for you at least to start with. So, these are some of these different references if you are interested you can go through these different references for in the future.

Thank you.

**Introduction to Industry 4.0 and Industrial Internet of Things**
**Prof. Sudip Misra**
**Department of Computer Science and Engineering**
**Indian Institute of Technology, Kharagpur**

**Lecture - 43**
**IIOT Analytics and Data Management: Data Management with Hadoop**

In this particular lecture we will focus on data management. So, what is data management overall not just in the context of IIoT and industry 4.0. So, what is data management overall is first what we are going to understand and thereafter data management with Hadoop is what we are going to understand. So, basically this particular module as you have noticed focuses on analytics with the help of different technologies and so on.

So, we are focusing on cloud computing different analytic techniques including machine learning etc. and also we have understood machine learning, AI etc. we have understood. So, how do you manage this data before even you can do all this analytics, how we manage this data. So, data management overall is what we are going to understand and data management in the context of IIoT is what are going to understand next and thereafter we are going to switch our gears and we will understand what is data management in the context of use of Hadoop, that is what we are going to focus on thereafter.

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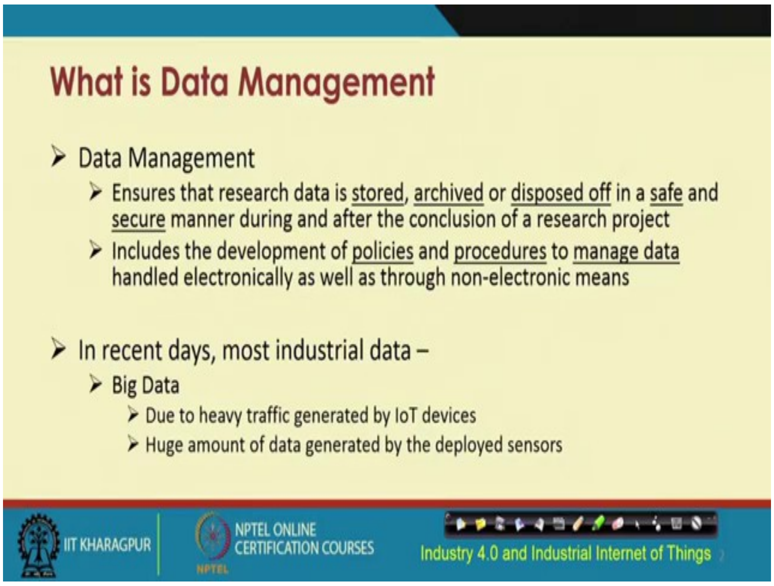

So, data management basically when we are talking about as the name suggest as the term suggest focuses on different attributes such as storing the data, archiving the data, then once the date has been used and is no longer required disposing of the data, securing the data, keeping the data in a safe manner secured manner at the end of the project completion requirements etc., these are some of the different requirements of data management.

This basically also includes development of policies procedures to do all these above things that I mentioned just now either you are storing the data in electronic or non electronic manner and so on. So, these are these different aspects of data management and as I told you at the outset that, this is something that what is data management in general and not necessarily in the context of IIoT or data management with Hadoop. Those are the things that we are going to discuss next, but this is the overall per view of data management so the different attributes of data management and so on.

So, in recent years as we have seen before we had a lecture which was completely dedicated to big data so we have understood what big data is, but what we have understood is also that big data at present is an important technology because big data is what most of the data, that we are dealing with at present particularly in the industrial context, particularly in the IIoT and IoT contexts, the nature of the data that we deal with are typically unstructured and having the characteristics of the big data.

So, if you recall that in the context of big data in the lecture on big data we earlier discussed about the different characteristics of big data, we talked about the definitions of big data starting from 3 V's, through 5 V's, through 7 V's and so on. Data having high volume, coming in high velocity, having high variety, variability, velocity and so on and so forth, so many different attributes all these different V's where used to characterize the big data and big data is unstructured typically unstructured data. So, how do you deal with all these unstructured data is what big data concerns.

So, managing this kind of data; managing this kind of data in this particular lecture we are going to focus on to get an overview of use of Hadoop to manage this kind of data. Of course, you need to have this cloud enablement and cloud enablement is, what we have already discussed earlier and we have we are also going to talk about data centre, data centre networks and so on in another lecture.

So, putting everything together is how you are going to manage the data and thereafter use the data for analysis, processing, analysis and deriving intelligence or meaning out of this data. So, typically industrial machinery having fitted with large number of different sensors, actuators and so on, all these different IoT devices. In most of these IIoTs settings you are going to have this industrial machinery with these different sensors, actuators and so on basically generating large volumes of data having all this big data characteristics. So, this kind of data will have to be dealt with adequately.

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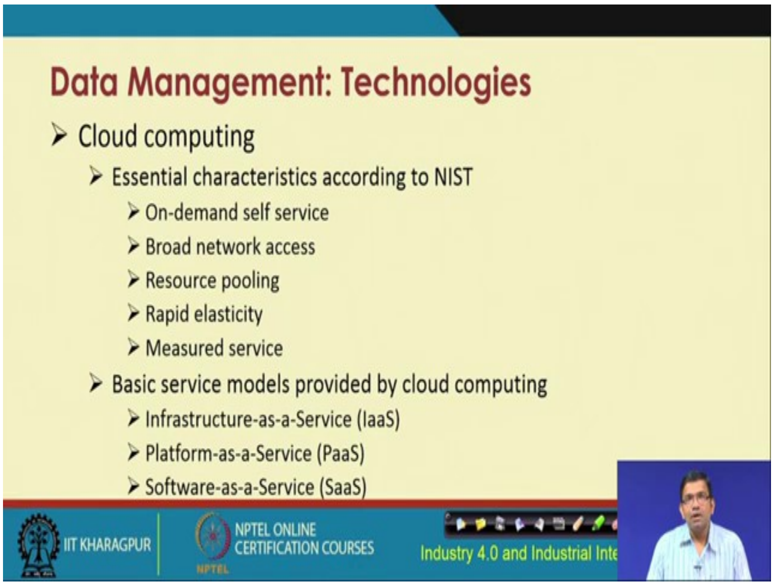


So, cloud will help you with the help of it is different models such as the Infrastructure-as-a-Service, Platform-as-a-Service and Software-as-a-Service that we have understood in the cloud computing lecture earlier.

Cloud with the help of all of these different cloud models and architectures will help you to offer on-demand self-service, on-demand service of computation, computation services on-demand will be made available to the end users. Broad network access, resource pooling, rapid elasticity, measured service, cloud is a measured service so depending on the units of usage of this computation resources one will first of all one will be able to measure the units of use and then accordingly one is going to be built. So, billing is going to happen depending on the units of measured service that are going to be used.

So, these are some of these different characteristics of cloud computing which makes it is makes it popular in the context of data management. So, cloud models all these cloud models IaaS, PaaS, SaaS along with it is different characteristics that we just spoke about and to be discussed at in-depth or the cloud computing lectures so, together we are going to use it for the data management.

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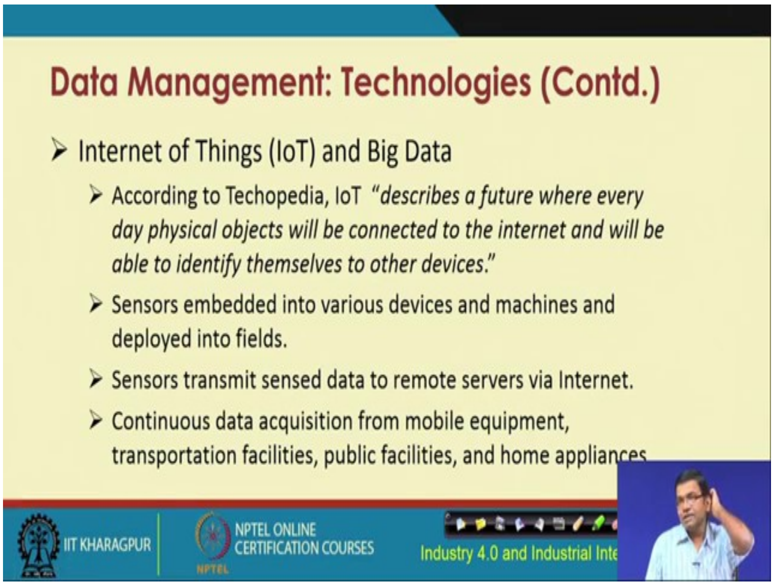


So, just as a recap in the context of IoT big data basically describes use of or management of this kind of data that are coming from the day to day physical objects being used for serving day to day activities and so on, which are interconnected together typically through the internet and this devices the IoT devices, the sensors etc. which are have their own different identity and which generate lot of these different types of data.

These sensors fitted to this different machinery, industrial machinery devices etc. which are working in the field and so on. And each of all of these basically connected to the through the internet work or the internet, generating lot of data, how do you handle this data, IoT data, IIoT data, how do you handle it is, what we are talking about in the context of IIoT data management.

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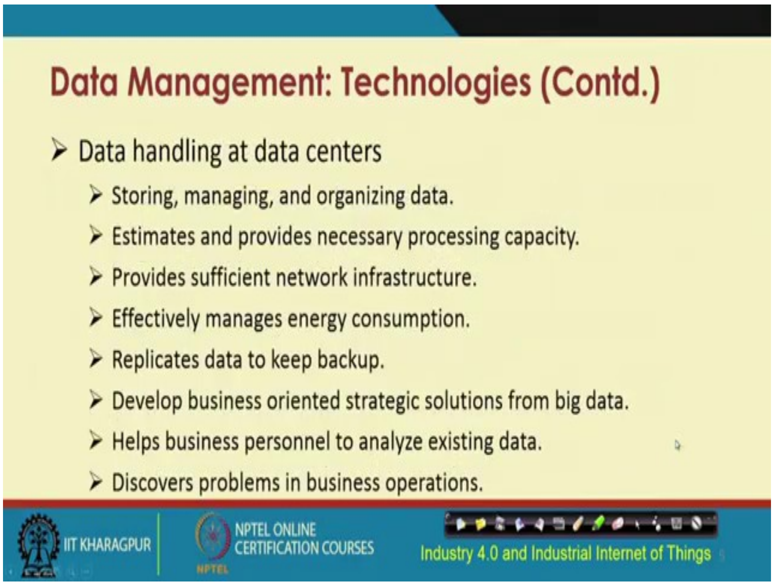


So, data centre we are going to talk about in depth in another lecture, but handling this kind of big data at the data centres is very important, IIoT data IoT data having different characteristics that we spoke about just now will have to be handled properly handling with respect to the storage of the data, management of the data, organisation of the data, estimating and providing necessary processing capacity this will also have to be done.

So, data centres are useful in all of these things that you see listed in front of you, storage management organisation of the data estimating and providing necessary processing capacity, providing sufficient network infrastructure, effectively managing energy consumption, repeating the data to keep the backup, developing business oriented strategic solutions from this kind of data the big data, helping the business personal to analyse the existing data and discovering problems in the business operations.

These are some of the data handling aspects that are very important in the context of IIoT and data centres which we are going to talk about in another lecture is going to help a lot in catering to these data handling and data management requirements that are there in the context of IIoT.

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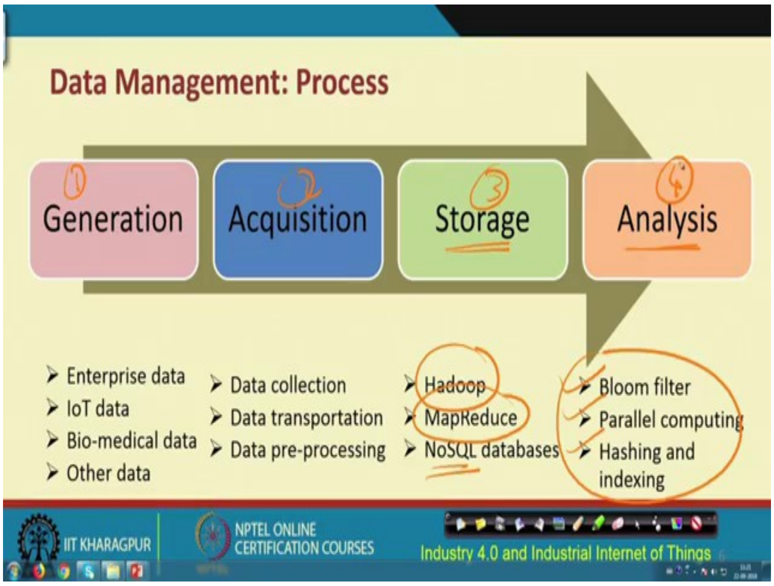


So, this is the overall process of data management it starts with the generation of the data, then acquisition of the data; that means, getting the data, storing the data and thereafter analysing the data. So, for each of these 4 steps in the data management process the corresponding attributes the corresponding characteristics are mentioned.

The only thing that I would like to highlight are 2 things, number 1 is storage, storage is very crucial over here; for storage you are going to use the cloud, but not just the cloud itself, but we are going to use this Hadoop and enabled with MapReduce etc. which are also going to help in performing NoSQL queries and so on. So, NoSQL is basically querying the databases this is a query language which can help you in querying databases which store unstructured data.

So, if you have structured data stored in relational table traditionally so, there you can use your SQL, SQL language for querying those tables, but if you do not have the data in the form that can be stored in the form of tables then this NoSQL will help. So, NoSQL is useful for big data is useful for unstructured big data and so on and NoSQL works very well with Hadoop, MapReduce etc.

So, this is basically your storage and queries and so on and the other thing that you like to highlight in this particular slide is basically the analysis, for analysis you have large number of all these computational techniques that are there, including use of bloom filters, parallel computing techniques, hashing, indexing, machine learning, clustering, then classification use of neural networks SVM all of these can help in different ways for this analysis. So, it starts with generation of the data, acquisition of the data, thereafter storage of the data and finally, the analysis of the data.

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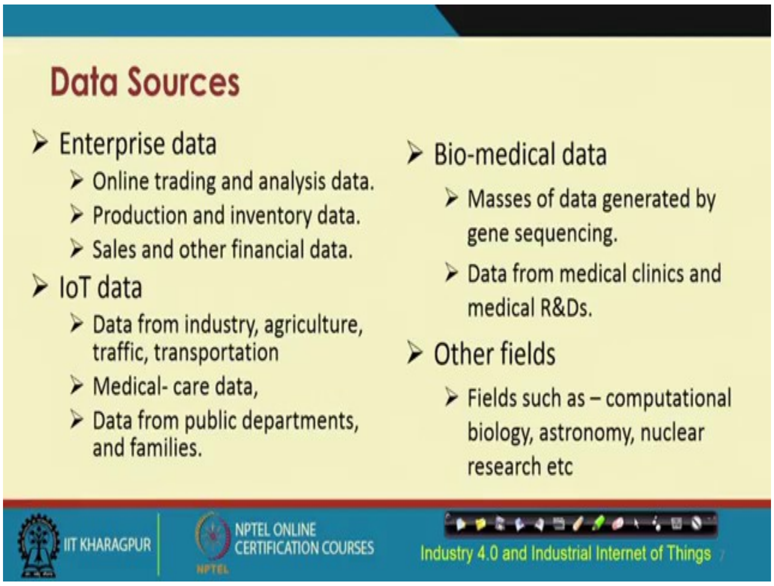


So, data can be generated from different sources can be enterprise data, which talks about trades; trading data, data coming from different machinery from different systems different parts of the systems, sales data, financial data, productivity data, inventory data, all kinds of enterprise data. IoT data that means, all these machinery in these different industry, manufacturing industry, transportation, agriculture, etc. the sensors and IoT device that are fitted they continuously basically generate lot of data so that in that IoT data that we are talking about in the context of industries.

So, then bio-medical data generated from the medical clinics, medical R&Ds through different biotechnological different biotechnological methods such as gene sequencing etc. so all of these are data sources for this big data. Other fields also generate lot of data nuclear power plants, astronomical devices such as big telescopes, which look into the sky continuously 24x7. So, those computational biological fields also generate lot of these kind of data which are unstructured and having this big data characteristics and so on these are the data that we have to be managed.

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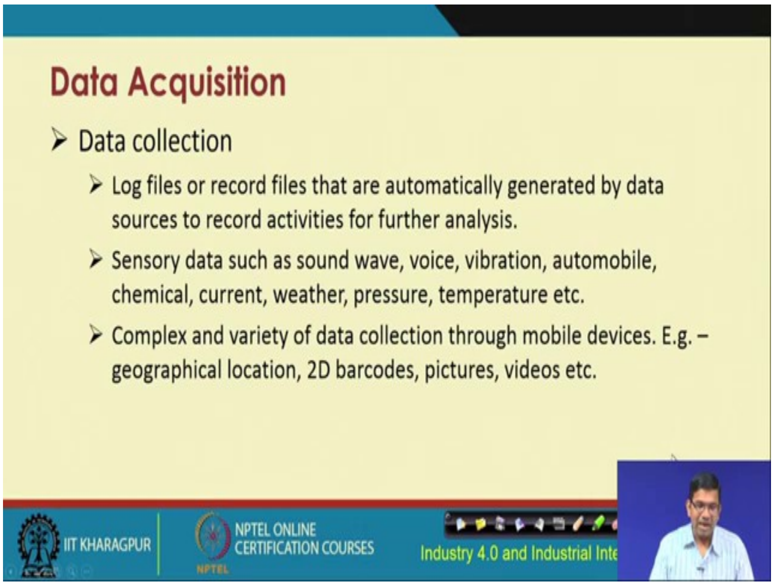


Acquisition of the data in terms of collection to logging the data and recording the data automatically generated from this data sources and how do you basically collect and log this data that is important. Sensory data such as sound wave, voice, vibration, automobile, chemical, current, weather, pressure, temperature, etc., these are all these different types of sensory data which will have to be acquired. And complex and variety of data collection is possible through the use of different mobile devices such as geographical locations, 2D barcoding, pictures, videos etc.

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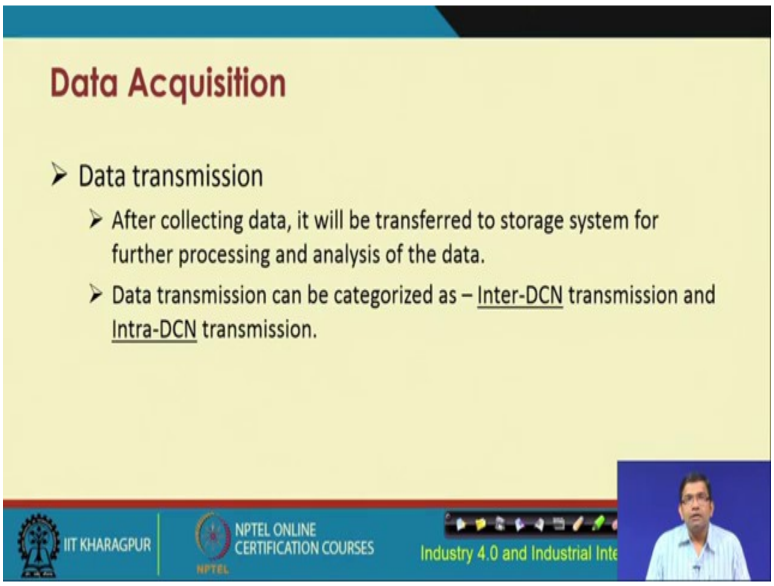

Data transmission through the network through the system and we will see in another lecture, how the data can be sent through the network through different interconnected data centres which will have inter-datacentre data traffic and also intra-datacentre data traffic. So, transmission of the data within and outside the data centre networks is what is very important.

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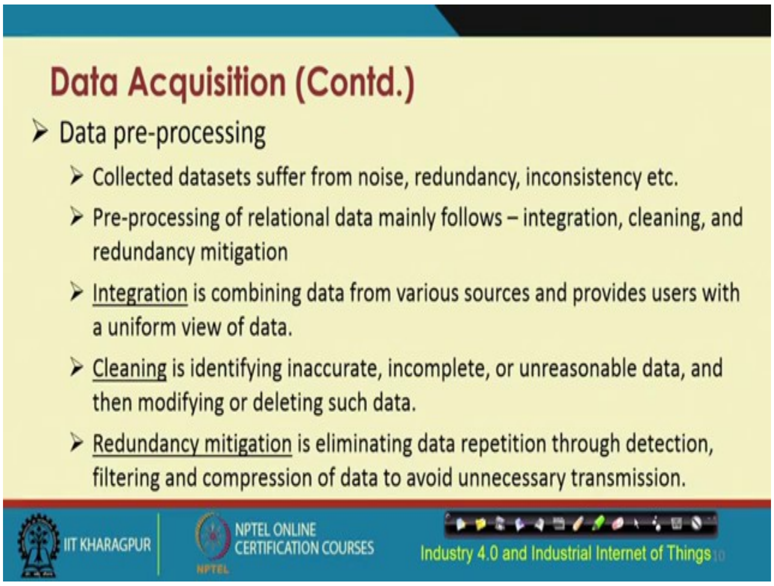


Pre-processing of the data, collecting the data removing noise redundancy that might be existing inconsistencies that might be found out. So, these are some of these pre processing tasks that are relevant. It is also very important to pre-process the data for serving this different needs, integration, cleaning and redundancy mitigation.

Integration talks about combination of data from arriving from different sources and providing users with unified integrated view of the data, even though the data is originated and is coming from different channels. Cleaning of the data to remove all these incompleteness, inaccuracies, incorrectness that might be there, if there is any unreasonable data that might be there modifying that particular data or deleting that data.

And also mitigating the redundancies such as eliminating data, repetition through detection, filtering, completion of data to avoid unnecessary transmission of data through this limited resource limited or resource constant networks is what is done as part of data pre-processing.

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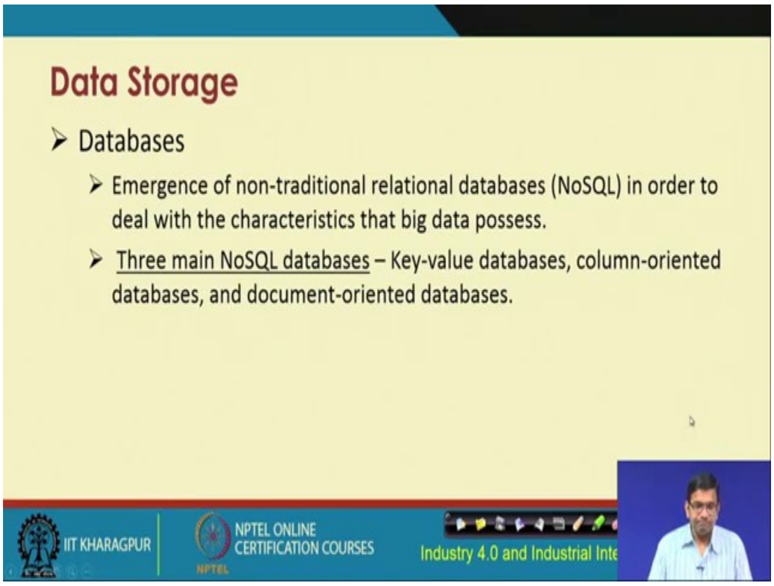


Storing the data in different databases traditional or non-traditional data bases such as the NoSQL databases that I mentioned earlier is very important. NoSQL databases, we will support different thing such as key-value database, column-oriented database and document-oriented database and their corresponding techniques of how to handle the data in each of these different databases is what is of concern in the context of data management.

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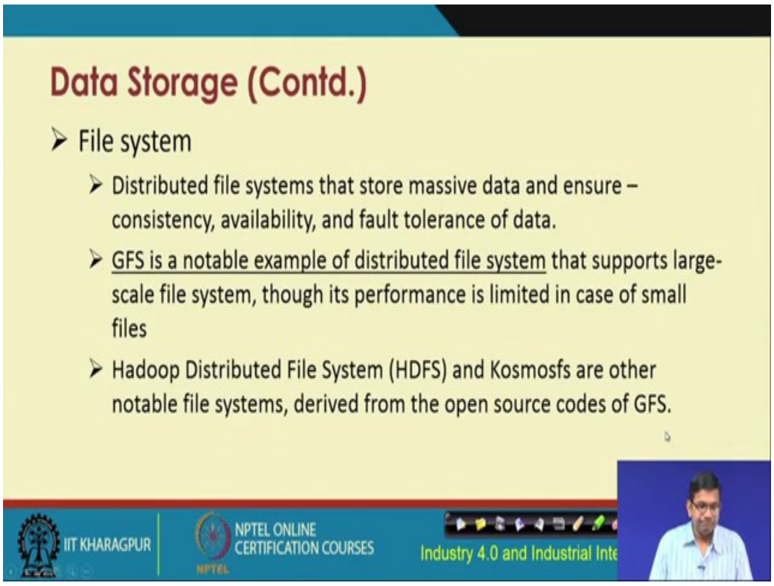

Data storage in the files GFS, Google file system is a notable example of distributed file system storing large scale file system data store, data store in different file systems HDFS in this is an another example, Hadoop Distributed File System, then Kosmosfs is another example these are different examples of the file systems used for data storage.

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So, industrial data is what concerns IIoT industrial data managing such kind of data using all these different techniques that I just mentioned will have to be done. Incorporating industrial data management basically will incorporate data that is generated from different processing plant manufacturing plants and so on and the management is done in the entire value chain. So, basically what it means is that the industrial data will have to be handled properly in order to deliver value to the end users properly and this value chain consideration is very important.

Availability of the data has to be ensured in industrial data scenarios. So, availability of the data in order to derive intelligence later on because if the data that is continuously coming etc. is not handled adequately, then it is meaningless basically it is meaningless to derive any intelligence if the data is not available properly then you cannot do any further intelligence on it. So, this is basically will also help the higher availability of the data will also help in enable proper decision making whenever it is required.

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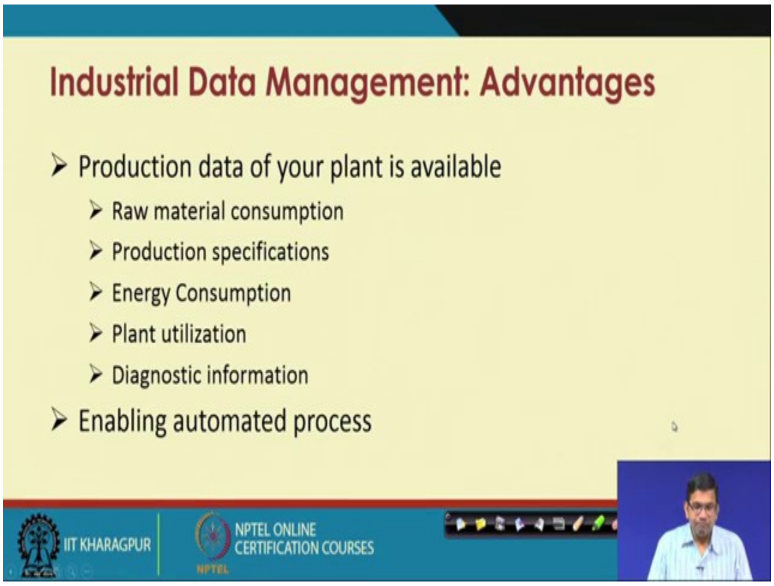


The advantages of industrial data management are that production data of a particular manufacturing plant is made available through such kind of activities such as raw material consumption and production specifications, energy consumption, plant utilisation, diagnostic information and so on and so forth and then for industrial management we need to have an automated process implemented which will do all these data management activities autonomously.

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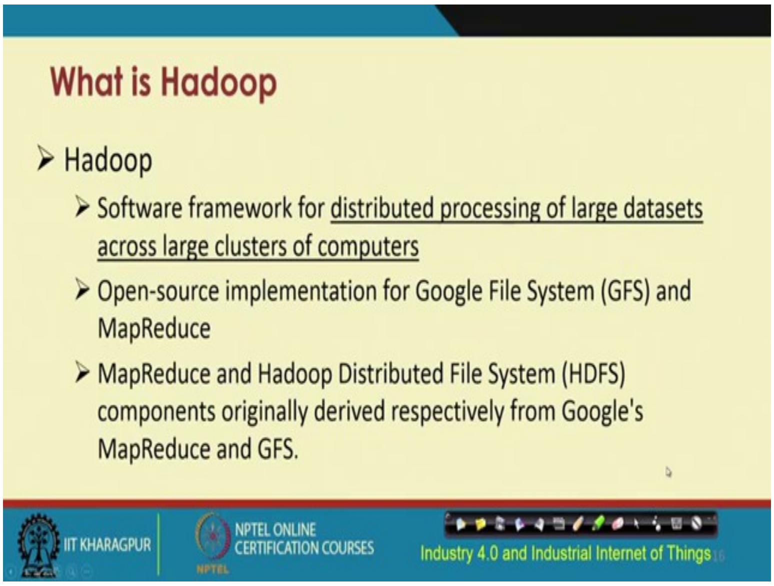

So, let us now take a specific example of how Hadoop a popular technology could be used for data management in IIoT scenarios. So, what is Hadoop? Hadoop is basically a very popular technology from apache, which gives a software framework for distributed processing of large datasets you have large datasets distributed processing of those data sets in a cluster of computers is what Hadoop basically specifically gives you the framework for. So, open source implementation for GFS and MapReduce and MapReduce and HDFS components, these are all the different aspects of Hadoop.

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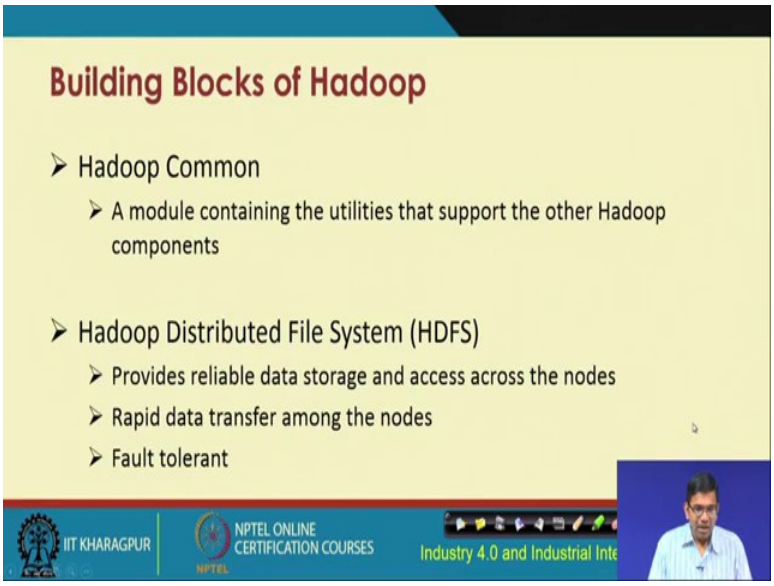


So, there are different building blocks of Hadoop. So, number one is Hadoop Common which is basically a common component which is basically a module that contains the utilities that would support the other Hadoop components like the once that I am going to mention next. So, it is basically a common module that will help other modules to work together in a connected fashion.

The HDFS is the central thing in Hadoop; HDFS Hadoop Distributed File System is the core of Hadoop. It provides reliable data storage and access across different nodes in the system, the rapid data transfer among the nodes is going to be possible with the help of Hadoop Distributed File System, HDFS and fault tolerant session attribute that is inherent to HDFS architecture.

This HDFS architecture as I will show you later on, HDFS architecture basically has different layers and in one of these layers basically what you have are something known as the blocks which actually contains the data. So, what happens in HDFS is this blocks are replicated. So, basically the different data nodes which I will tell you later on, this data nodes basically have different blocks and each of these blocks is replicated across multiple data nodes. So, this basically ensures fault tolerant; if something goes wrong with one of these different blocks the other blocks the replicas of these different blocks are there in the other data nodes.

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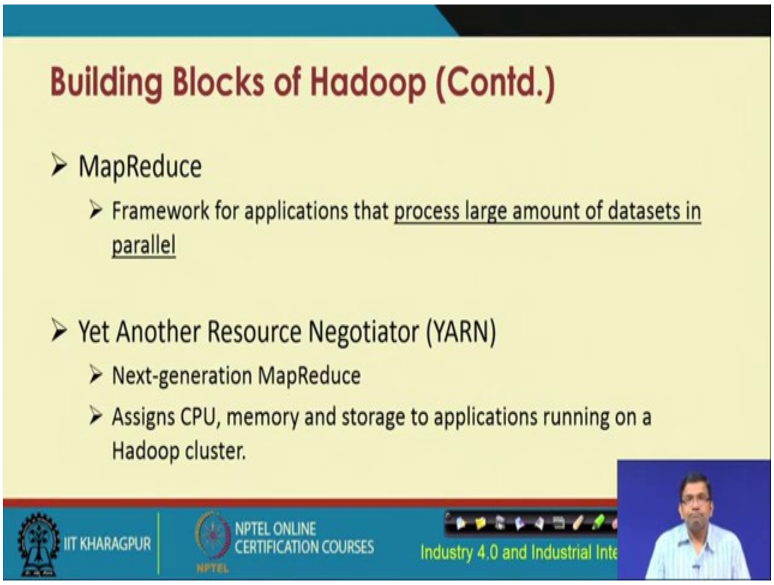


So, the other building blocks of Hadoop input the MapReduce which is like a framework for processing large number of large amount of databases in parallel. This is a MapReduce, MapReduce is also core to Hadoop, but MapReduce the algorithms that are there large number of different types of algorithms and it is just a philosophy, it is a framework that Hadoop basically also uses. So, YARN is basically the next generation MapReduce which assigns CPU, memory, storage to different applications running on the Hadoop cluster of different computers.

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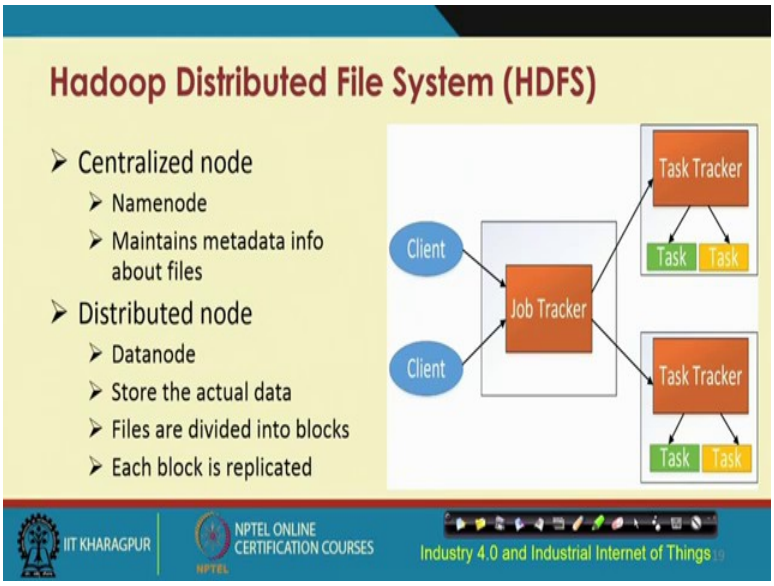


So, this how this HDFS which is central to Hadoop looks like. So, in HDFS you have 2 types of nodes, one is the Namenode, the other one is the Datanode. The name node is centralized node so, this particular job tracker for example, is a Namenode so, it is being done in the Namenode. So, this is a centralised node and then you have this different other task trackers for example, which are basically being executed in the data nodes.

So, this Namenode is basically the centralised node maintains all this meta data about the different files different meta data are basically maintained about the different files in the Namenode the centralised node, whereas the distributed node these task tracker the Datanodes etc. store the actual data and these files are divided in these into different blocks and each of these different blocks is replicated and this is what I was telling you earlier, this different blocks have their own the data, the data are replicated across this different Datanodes and so on in this HDFS architecture.

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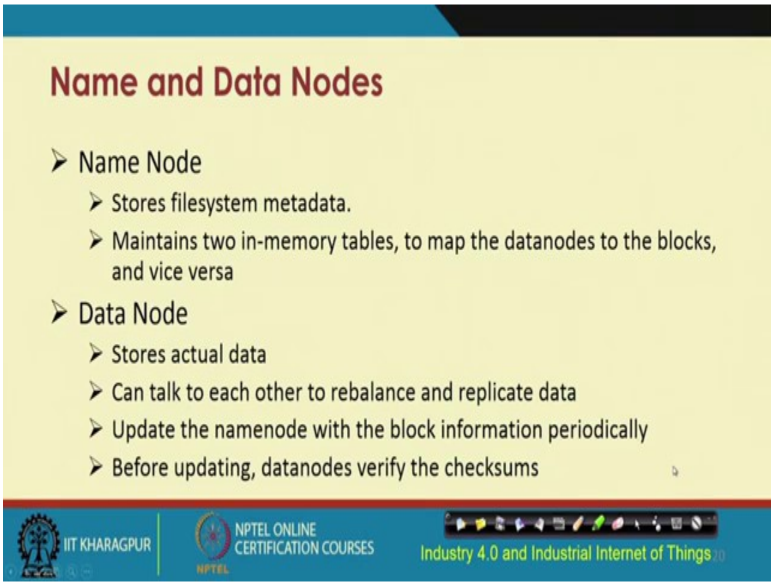


So, the Namenode basically is something which is the centralised entity which stores the metadata about the file system, it maintains two in memory tables to map the data nodes to the blocks and the vice versa. So, Namenode are connected to the data nodes which are actually the once where the storage of the actual data is done.

So, this data nodes also are interconnected with each other, they can imbalance, they can replicate the data across each other in this Datanode layer and they update the Namenode with the block information periodically. So, that the Namenode has a proper metadata and the updated metadata in place. So, before updating the data nodes would verify that check sums for ensuring the integrity of these data.

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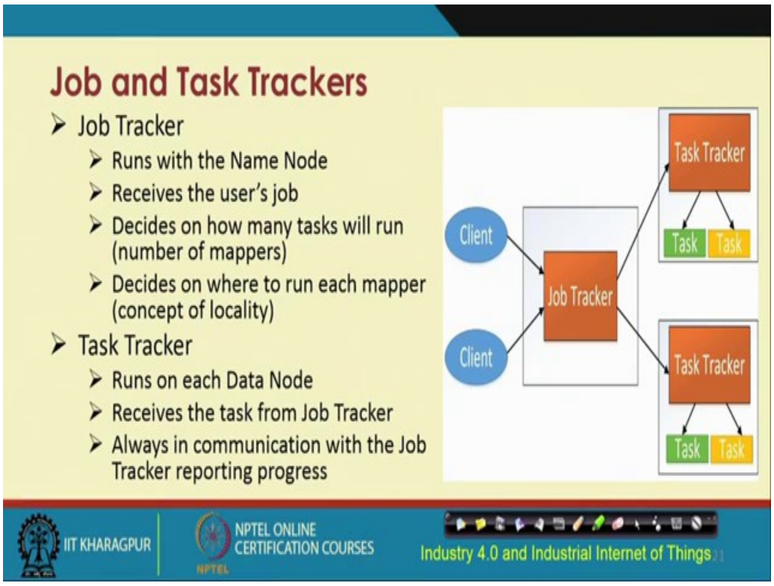


So, are these concepts of the job tracker and task tracker, the job tracker are basically running at the name nodes and the task trackers are running in the task in the data node. So, these name nodes these job tracker will receive the users job will decide on how many tasks will run using the concept of mapping and how many jobs and which jobs are going to run that mapping is going to be done and it is going to also decide on where to run in each of these different jobs.

In the task tracker on the other hand will run at each of these data nodes so, this is one data node, this is another data node. So, this task trackers are running on them, receiving the data receiving the tasks basically from the job tracker. So, this tasks that are going to be executed over here in this data nodes are going to be retrieved are going to be received from the job tracker and these are going to always be in communication with the job tracker, the task tracker is going to be in communication with the job tracker and these are always going to also report the progress to the job tracker.

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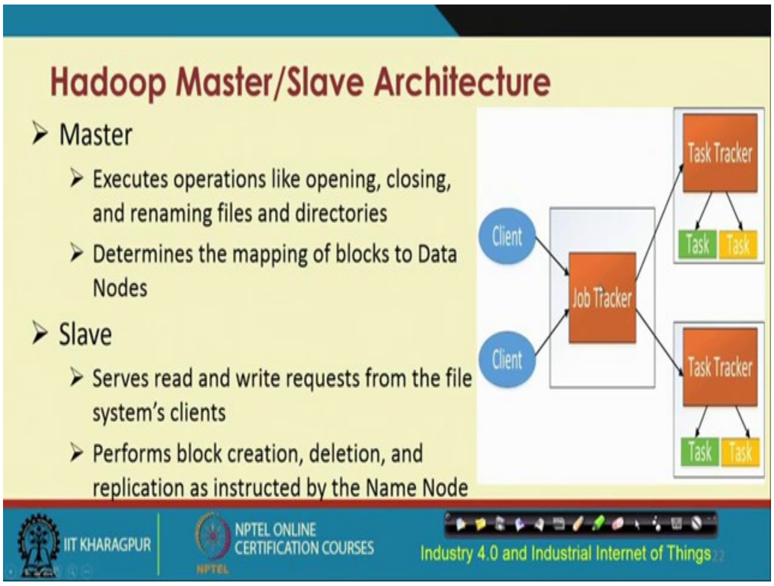


So, basically it is a master slave architecture, where basically the master executes the operations like opening, closing, the renaming the files and dictionaries and determines the mapping of the blocks to the data nodes. Slaves are the once which read, write request from the file systems clients and perform block creation, deletion, replication and so on.

So, this is basically this becomes your master node, the name node becomes a master node, these are like the slave nodes and slave nodes are basically continuously get the different tasks from the job tracker which will have to be executed at each of these different data nodes and basically these task tracker after completion of the task or in between also they would be updating the status to the job tracker. So, this is basically the master and this becomes your different slaves.

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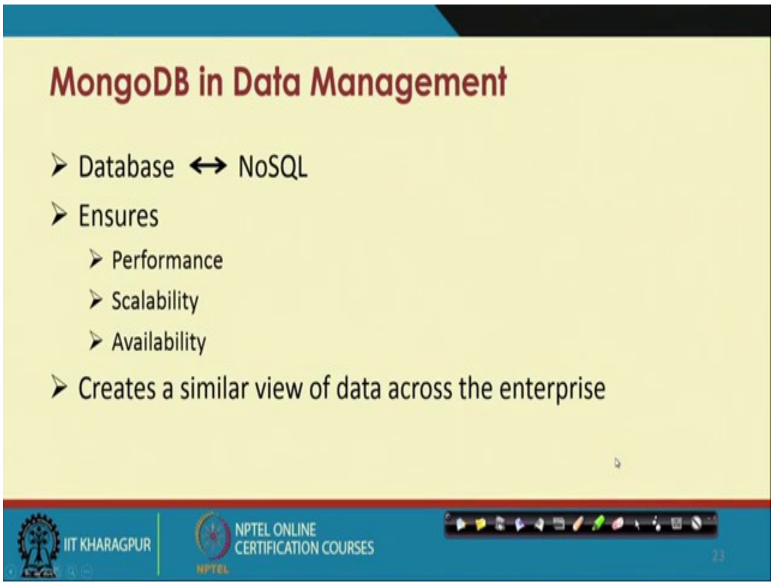


So, another thing that I would like to highlight over here is something known as the MongoDB. So, MongoDB is a data management tool which basically supports databases, different databases and particularly in this context of IIoT we are talking about NoSQL database is because of the unstructured data that we are typically experiencing.

So, NoSQL database is supported by MongoDB, it ensures MongoDB is database basically it is a database it is a NoSQL database and it works in conjunction with Hadoop. So, this particular database will ensure performance improvement, performance ensuring, overall good performance is ensured, scalability, availability and so on and creating a similar view of data across the enterprise.

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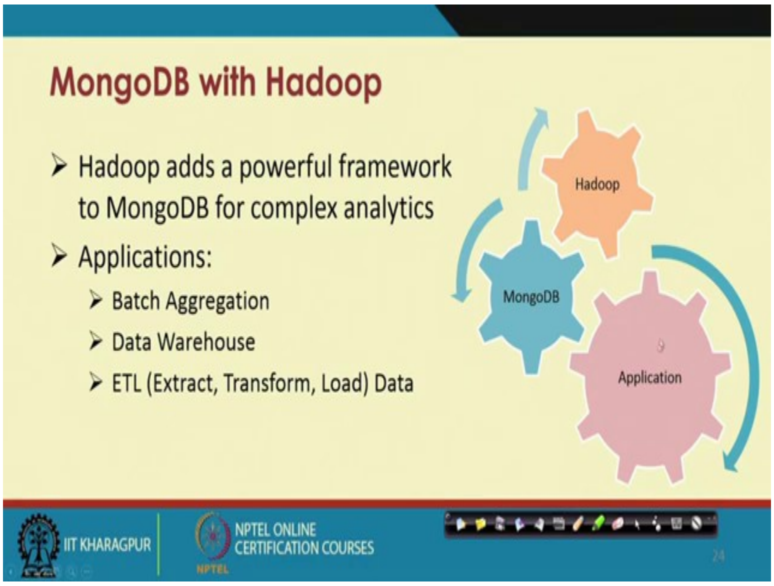


So, MongoDB basically works hand in hand with MongoDB works with Hadoop. So, Hadoop basically adds as a powerful framework to MongoDB for complex analytics and different applications are supported by MongoDB such as batch aggregation, data warehousing and ETL data; that means, extract transform and loading of data, this is basically common term ETL in the context of databases so, ETL data handling. So, batch aggregation data warehousing and ETL data handling these are the different characteristics of or the different functionalities of the MongoDB along with Hadoop.

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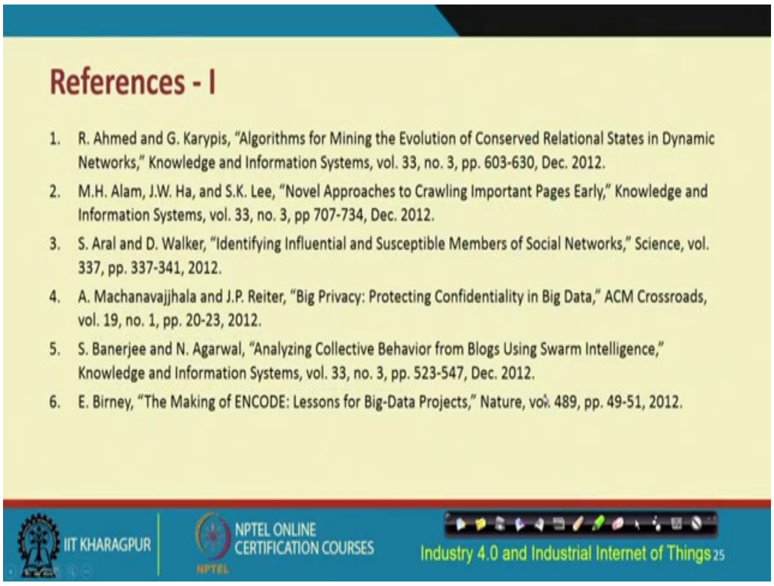

So, with this we come to an end of this particular lecture we have this different references given to you, for you to benefit from and if you are interested there is a lot to do with data management and if you are interested particularly Hadoop is very popular, MongoDB is very popular, MapReduce is also very popular, these are once which work hand in hand and this can help you in proper data management of big data that is being experienced typically in the context of IIoT.

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So, with this we come to an end and this is the assortment of different references that is listed for here.

Thank you.

**Introduction to Industry 4.0 and Industrial Internet of Things**
**Prof. Sudip Misra**
**Department of Computer Science and Engineering**
**Indian Institute of Technology, Kharagpur**

**Lecture - 44**
**IIoT Analytics and Data Management: Data Centre Networks**

So, this particular lecture will focus on Data Centre Networks which is a very important concept a very important technology that is required for building large scale industrial internet of things. In the previous lectures I already highlighted the need for analytics, the data will have to be managed properly will have to be analysed thereafter. We have also seen that the data that we talked about in industry scale for IIoT scenarios. This kind of data has the properties of big data which have different challenges of it is own. These are typically unstructured data having different characteristics of 3 V's, through 5 V's, through 7 V's and this is what we have gone through in detail in the previous lectures.

So, without getting into the characteristics of big data further; the question is that how do you handle the data? So, from an analytics point of view we have already seen that what are the different methodologies, what are the different tools and techniques that could be adopted in order to handle this kind of data, but where do you store the data, where do you process the data, that is very important. And if we are talking about large scale implementations we have to talk beyond single servers, low capacity servers, we have to talk about large scale not singular servers, but servers, server firms, connection of different servers and so on. And this is known as the Data Centre Network.

So, in a typical data centre what is a data centre? Data centre is basically a facility which has lot of high capacity computational facilities of all kinds, high capacity, high performing computational systems having, high end processor, high end storage, high end memory and also high end computational or network facilities. So, everything has to be high end, but that gives you a data centre only, a single data centre is often not enough to cater to the requirements of most of the real life industrial IoT scenarios, in which case a network of data centres would be required. So, this is what we are going to talk about in this particular lecture.

So, we are going to try to connect to try to understand the requirement of data centre, Data Centre Networks and how they bridge the gap between the origination of the data and the analysis of the data. So, analysis comes next, but then how do you handle the data that is coming so you have to store the data, you have to process the data in these data centres and the Data Centre Networks and that is what we are going to talk about here.

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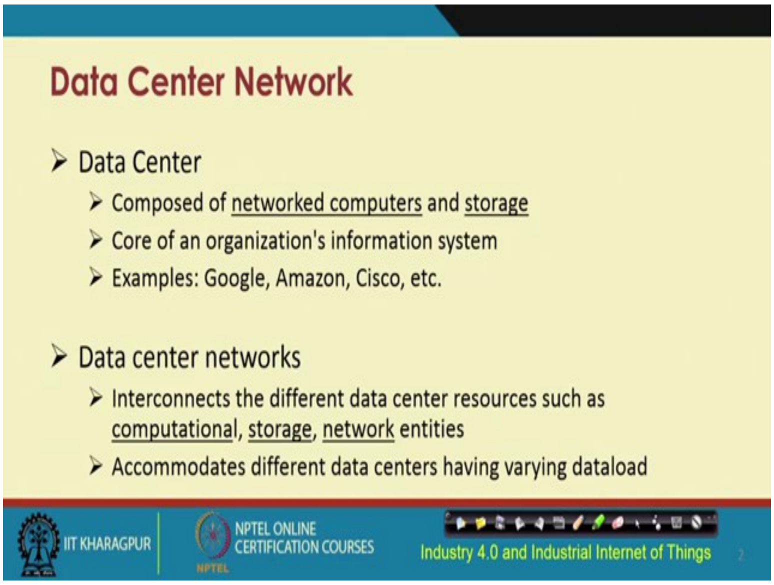


So, what is a data centre, as I was telling you earlier here we are talking about high end computational facility which are networked, networked computers, networked servers, high end servers which are networked together and also networked storage. Most of these large scale enterprises their information systems are highly dependent on these data centres, it is these data centres as this name suggests which stores all this data.

Here there are different examples of data centres, data centres are quite widely available. Large scale companies such as Google, Amazon, Cisco they have their own data centres others rent the data centre facilities and so on. There are many other companies which also have their own data centres and maintaining the data centres is a different topic by itself. So, we will not get into that, but let us try to understand beyond what is a data centre. So, here in this particular lecture we are not talking about a single data centre, we are talking about a network of data centre because that is what is more relevant and that is more used in the IIoT contexts.

So, in a Data Centre Network basically we have all these different data centre resources involving computational, storage and network entities, which interconnect with one another. So, different data centres will be connected to one another and that will help in different ways including handling the varying data loads that are going to come over time. So, handling that kind of thing data loads and computational loads that are going to come over time that can be handled load balanced in a proper manner, if you have these network interconnected data centres. So, before we go any further let me just show you pictorially how a data centre looks like.

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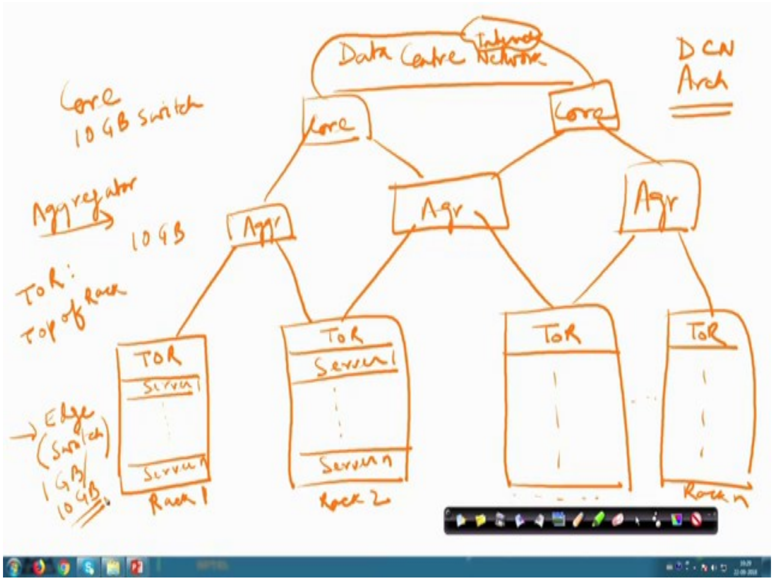


So, in a typical data centre so I am going to show you the architecture of a data centre; so, in a typical data centre we are talking about what in a typical data centre we are talking about a single platform of different computational resources and servers etc., a network of servers not a network of servers, but an interconnected platform of servers and so on. And, in the Data Centre Network what we are talking about we are talking about these kind of data centres which are internet worked together. So, let us talk about this Data Centre Networks and how they look like schematically let us talk about that.

So, in a typical data centre we will have let us say that different servers: server 1, server 2 to let us say server n. So, this is one edge device which could be like connected through some kind of a switch. So, we are talking about these kind of different servers which are placed together. So, this forms something known as a rack. So, let us say that this is rack 1 every rack has something known as a TOR, TOR switch it is basically a switch which will help these different individual servers in a rack to be interconnected together and also it has different other management and maintenance capabilities.

So, this is like a switch and this is known as TOR means Top of Rack. So, we have every rack having a switch and is controlled it controls basically number of different servers. So, we have one TOR, we have another rack with another TOR, server, server 1, server 2 to server n so, whatever be the n. So, n may be equal to 5, 6, 10 or whatever depending on the type of rack, like this we will have other such edge devices in a data centre. So, we will have these different TORs and with different servers and this will be rack, rack n, rack 2, rack 3, rack 4 and rack n. So, we will have all of these.

So, then what we are going to have is the next layer over here in a Data Centre Network will be some kind of an aggregator, this aggregator is another switch which is going to aggregate these different rack devices this is another aggregator. So, this was the edge layer here you have the aggregator layer and so, like this you have all of these different aggregators.

Then you have the core layer where you have core level switches this is core 1, core 2 and so on, these are all core level switches which basically again aggregates at a higher level. So, these core level switches are even more powerful switches and then you have these core switches connect to the internet.

So, this is basically typical Data Centre Network, architecture how it is, how it looks like. So, core basically will be something like 10 gigabit switches will support this core, here also you are going to have at the aggregator level also you can have something like 10 GB switches. Whereas, in the edge you may have lesser like 1 GB or it can be even 10 GB depending on the resources that are available and the particular requirements of the client. So, this is a typical Data Centre Network how it looks like.

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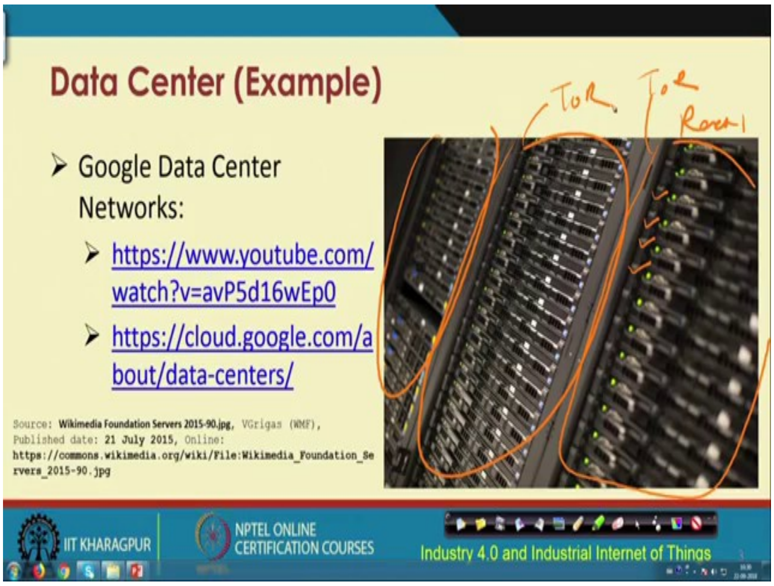


So, let us now go ahead and go further and look at the different characteristics of these data centres. So, on the right hand side what you see over here in this particular picture is a picture of a Data Centre Network. So, it is a network it is a Data Centre Network picture and here as you will notice these are like different servers, showing this different green lights these are different servers that you have like this there are different servers. Each of these this is one rack like that you have different other racks like this each rack has it is own TOR so, they have their own different TOR and so on.

So, if you want to get little bit more idea about what is a data centre and how it looks like in real life etc., there are plenty of videos that are available if you search in the internet there are two different references that I have given you over here of a Google data centre how it looks like. So, this particular reference will help you to understand the Google data centre what is inside. So, they have their own videos I am not going to play it, but Google data centre and it is link is given in this particular slide.

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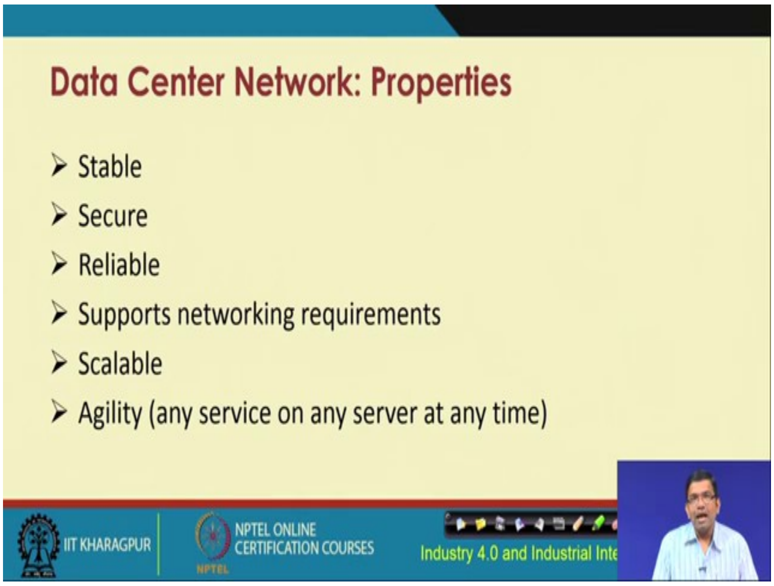


So, let us go further and try to have a look at the different properties of these Data Centre Networks. I am not going to elaborate all of this because this is something that you will understand on your own. So, basically these are some of these desirable properties of the Data Centre Networks a Data Centre Network has to be stable, secure, reliable, should support different network requirements, should be scalable and should be agile.

So, out of all of these which are pretty much easily understood agility is something that I would like to briefly mention agility property means that a Data Centre Networks should be able to provide any kind of service on any server at any time. This is known as the agility property of a DCN and the other properties as I said are easily understood and I do not need to elaborate further.

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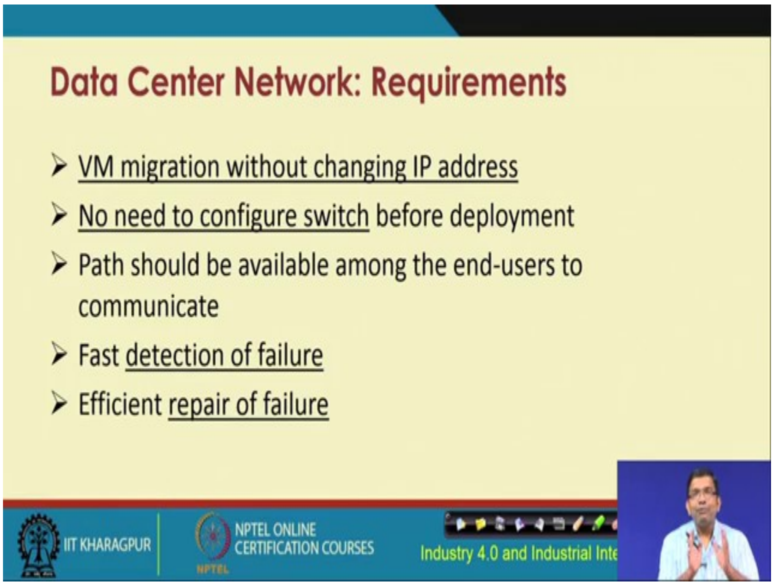


So, Data Centre Networks have their own individual requirements VM migration without changing IP address should be supported this is very very important without changing the IP address, VM migration, VM is the virtual machine. So, basically to the end user end user gets a virtual machine and is mapped to a particular physical machine having its own separate IP. So, the end user has its own virtual machine which has its own IP.

So, even if the physical machine to which it connects to changes its IP; that means it changes it is machine still to the end user this particular virtual machine and the corresponding IP address that it has got is not going to change. So, basically this IP address does not change in the case of the VM migration in the case of Data Centre Networks. Second requirement is that there should not be any need to configure switch before deployment. So, you deploy the servers first then you deploy the switches and thereafter you expand this particular thing further so you scale it up further. So, servers, switch and you scale up further.

Say third requirement is that path should be available among the end users to communicate, end users should have different paths in the Data Centre Network which will help them to communicate between different instances between different users and so on. So, basically it has to be fully networked in other words it is it has to be fully network this is very important fully network means then only you will be able to have different paths as per the dynamic requirements that are the that come up.

The fourth and the fifth properties are quite understood. So, Data Centre Networks should be able to detect any kind of failure and should be if should offer efficient repair of failure. So, self healing behaviour; that means, that the Data Centre Network if anything goes wrong should be able to heal on it is own should be able to repair the particular component that is there I mean whatever has failed or is going to fail should be repaired on it is own that is basically the self healing property of a Data Centre Network.

A Data Centre Network should be as much autonomous as possible and that is why all these different expectations and requirements are coming up. So, Data Centre Network are huge you can abstract a Data Centre Network like a huge computational resource which has huge processing, huge storage, huge computational resources, which can be offered to end users as per requirements and so on. And so they have to be yes fully autonomous they have to repair on their own and whenever there is some kind of failure the detection of the failure should also be done by this particular autonomous Data Centre Network system.

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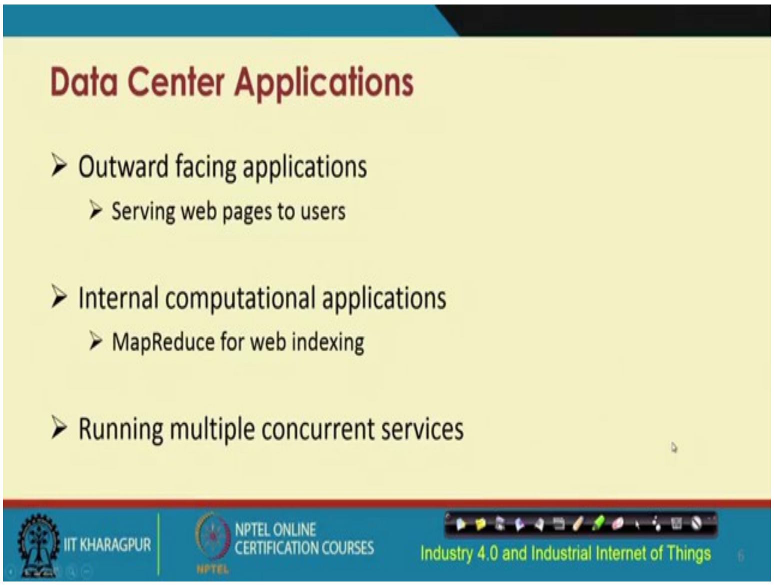


There are different applications of data centres, serving outward facing applications such as serving web pages to users, through internal computational applications such as use of MapReduce for web indexing, through running multiple concurrent services and many many more these are some of these different applications of data centre and Data Centre Networks.

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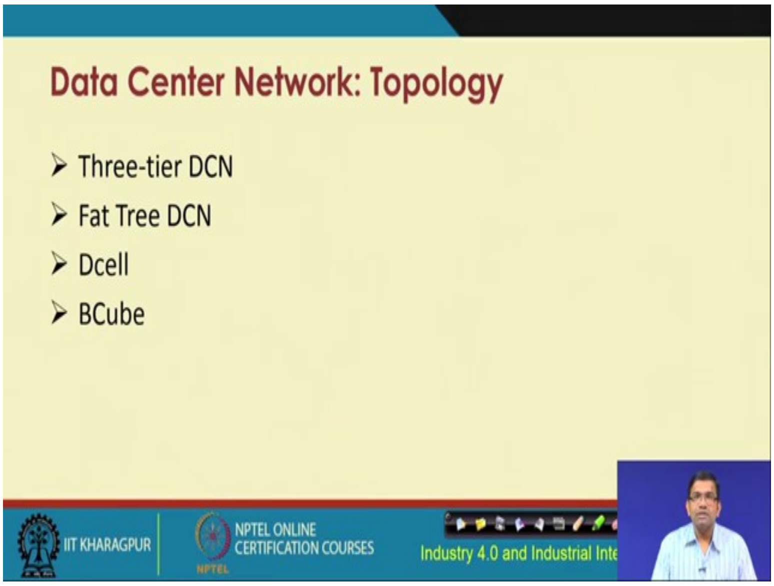


There are different topologies that are supported of a Data Centre Network the common ones are the three-tier DCN that means, the three-tier Data Centre Network, the fat tree Data Centre Network, the Dcell and the BCube these are the four different Data Centre Network topologies that are available.

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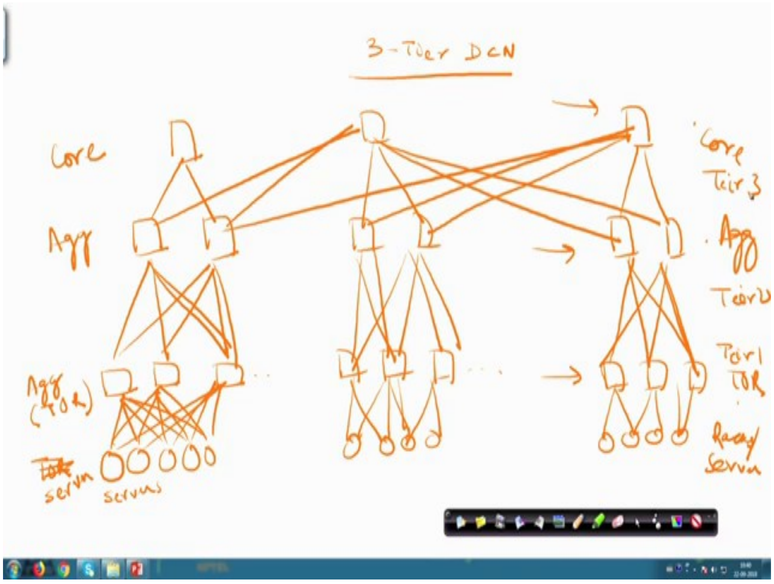


So, let me talk about some of these. So, we will start with the 3-tier DCN architecture. So, essentially at the outset when I discussed or when I explained the concept of a DCN the architecture that I had showed you consisting of different servers in a rack having

TOR etc. that is basically 3-tier architecture. So, you have the edge, you have the aggregator layer and then you have the core, but let us look at it look at it from another viewpoint.

So, what we are going to have at the very bottom; at the very bottom what we are going to have are let us say different servers, these servers will be interconnected with each other to these devices known as the aggregator device. So, this becomes your aggregation layer, this becomes your TOR so, servers in a rack each rack having a TOR.

So, let us say that this is the TOR layer, this is the aggregation layer and then on the top you will have let us say this can be even like this and so on and then you have over here something like this becomes another level of aggregation or in other words let us do it like this that let us say that we have all these are like the different different individual racks with servers, this is we can call this aggregation layer had like a TOR layer kind of thing.

And this one we can think of another layer up which is the aggregation layer which has it is own aggregated switches and then for this one again we will have this core, this is the core. So, exactly I mean this is something that I had shown you in the at the outset when I talked about the Data Centre Network when I explained to you the architecture typical architecture of a Data Centre Network.

Now you can basically what you can do you can have something like this repeated once again. So, this becomes one data centre, this becomes another data centre and so on so, you can have another like this. So, this is your to TOR and these are your different servers. So, then you have like this your aggregator and then you have your core, this is your core. So, this can be like this, this can be like this, and similarly over here as well.

The beauty of a 3-tier DCN would be to have connections of this sort you could also have something like this and so on. So, this would be possible. So, you are going to have a huge Data Centre Network with racks and servers at the very bottom layer, then you have this tor layer, then you have this aggregation layer and then you have this core layer. So, TOR, aggregation and core these are the 3 different tiers so this becomes your tier 1, tier 2 and tier 3 so, this is how a 3-tier DCN looks like. So, let us go back once again and have a look at the properties of a 3-tier DCN.

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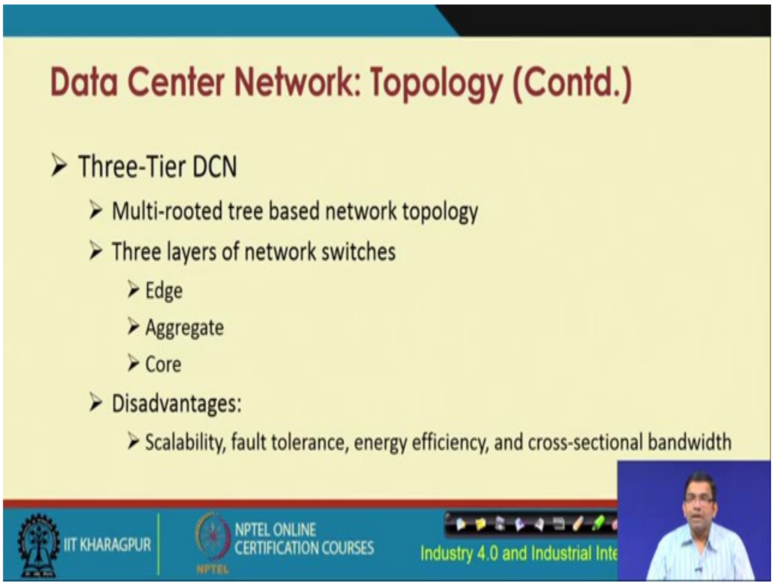


So, a 3-tier DCN as we have seen has a tree based network topology and there are multiple roots in the tree topology. So, multiple trees with multiple roots networked together this is your 3-tier DCN. There are these different layers of network switches core, aggregate and edge and then there are different disadvantages that are also listed over here, disadvantages of scalability, fault tolerance, energy efficiency, and cross sectional bandwidth, these are some of these different limitations or the disadvantages of the 3-tier DCN.

So, we are not going to elaborate on this different disadvantages rather let us use our time to understand the different other network topologies that are supported in the DCN.

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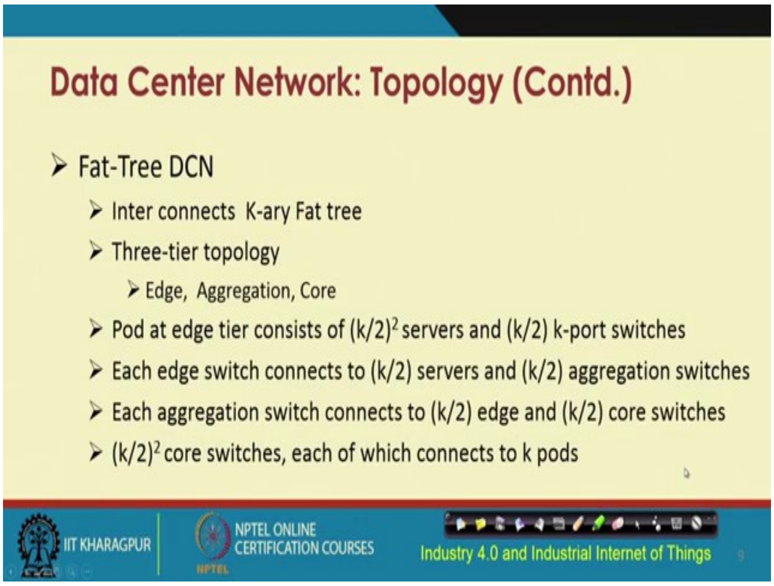


So, the next one that we are going to go through is the fat-tree DCN. So, let us try to understand this particular fat-tree DCN architecture.

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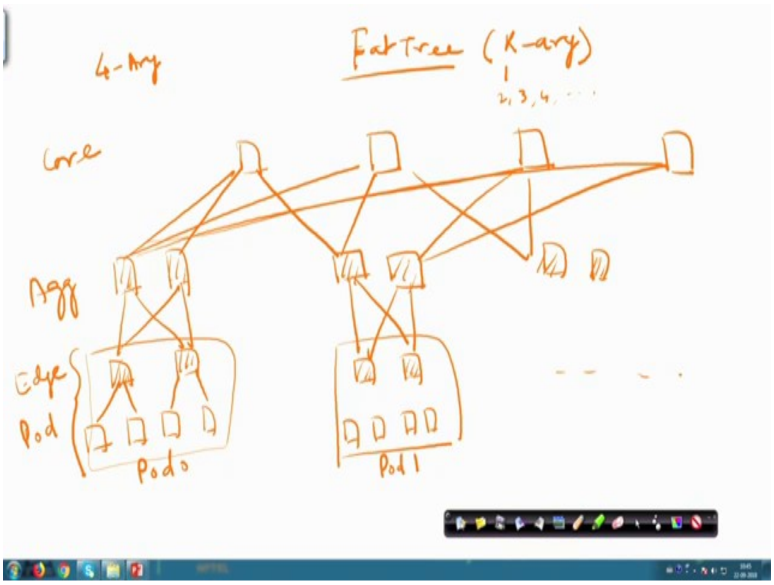


So, we have in a Fat-Tree DCN architecture very quickly I am going to show you what it has. So, it has you can have a K-ary tree architecture in fat tree architecture. So, K can be any integer it could be 2, 3, 4, whatever. So, K-ary so it could be 2-ary, 3-ary, 4-ary and so on. So, I am going to show you an example of a 4-ary fat tree architecture of DCN.

So, in a 4-ary fat tree architecture it will be something like this. So, there are concepts of something known as pods so, there are different pods. So, let us say that you have these different servers or computers or whatever. So, these are going to be connected to some switches let us say that these are your switches, these switches together with your end devices these computers etc. this one is known as a pod. So, this entire thing over here this is your pod.

So, this pod will again be connected to some other switches in this manner and again this becomes your aggregation layer, this becomes your edge layer and finally, you will have also the core layer like before where these are going to connect. So, you are going to have another one another pod like this. So, you will have another pod and these are your server so these are the, these are, these are the switches and these are your different servers or computers etc.

So, you will have another pod, pod 1. So, pod 1 also like before is going to be connected to other switches in this manner and again it also will be connected to these core so, this is your core so, like this is going to continue. Now what is going to happen is, you will have each of these pods and the corresponding switches to which it connects, this will be let us take up this one, this one will be connected to this core switch, this will be connected to this core switch. Again this one is going to be connected to this one it will be connected to this one and so on and so forth this is going to happen

And so, what this pod tree or the K- ary or the 4-ary tree does is that it ensures that every switch in this aggregation layer is connected to at least one core in all of these so, from here to here, again here to here, again here to here and so on. So, it is very similar to your 3-tier architecture, but here there are certain properties. So, what are these different properties is what we are going to look at.

So, in the fat tree DCN we have a K- ary fat tree, there are 3 tiers like before which are basically the edge tier, the aggregation tier and the core tier. So, the pod which I explained to you earlier at the edge tier consists of k by 2 square servers. So, k equal to 4 so, 4 by 2 is 2, 2 square servers; that means, the 4 servers that I had shown you at each of these different pods and correspondingly there are going to be 4 divided by 2; that means, 2 to 4 port switches are going to be there. So, each of these edge switches are going to connect to k by 2 servers which are basically the 2 servers that I had shown you and k by 2; that means, 4 by 2 equal to 2 aggregation switches. So, 2 servers, 1 below and 2 aggregation switches above.

Each aggregation switch in turn will be connecting to 2 edge switches and 2 core switches and that is what we have seen in the previous diagram that I had shown you and k by 2 that means, 2 square core switches; that means, 4 core switches each of which will connect to each of these different key pods. So, this is basically how the concept of the fat tree DCN looks like it is centred on the concept of this pods and these properties that I just enumerated just now these are the properties that will have to be held for a fat tree architecture which is again a tree based architecture having these three different tiers etc. But, there are certain specific constraints that I just mentioned this enumeration of constants makes this particular fat tree architecture a specific 3 type 3-tier architecture.

So, there are different advantages and disadvantages of each of these different architectures.

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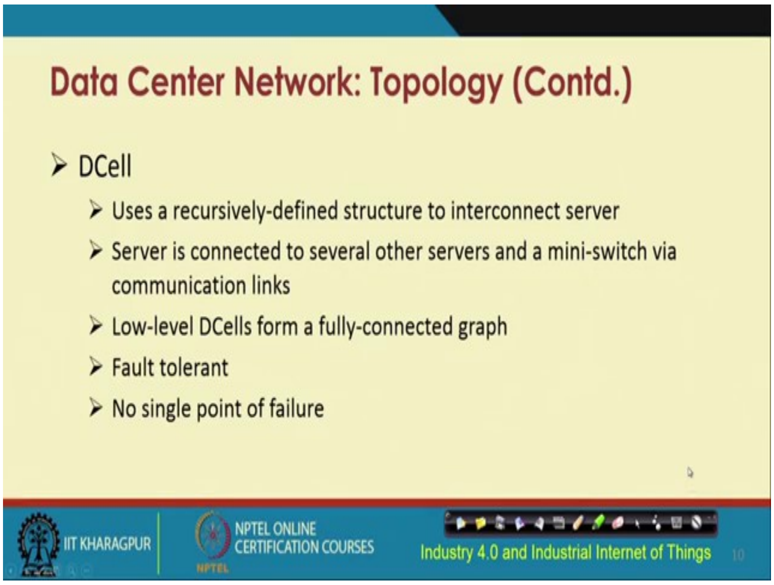


So, let us look further there are there is this another architecture which is known as the DCell architecture which uses a recursively defined structure to interconnect the server. The server is interconnected to several other servers and a mini switch via communication links and a low level DCell will form a fully connected graph and there would not be any single point of failure in this kind of architecture this is the advantage and also this kind of architecture is fault tolerant. So, let us now look at this DCell architecture how it looks like.

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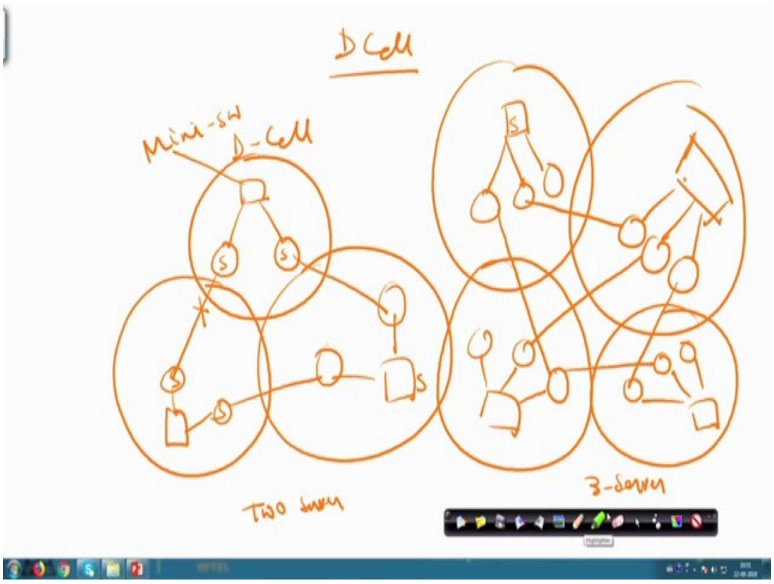

This DCell architecture as we will see in this DCell architecture we will have the concept of something known as the DCell we will have the concept of the DCell. So, in a DCell you have something called the mini switch and every mini switch has every mini switch has a server, this is a server, this is another server.

Every server in a DCell will connect to another DCell server, this is another server, this will be another server which again will be connected by a mini switch, this is another mini switch and this mini switch this mini switch basically connects to two different servers, again you are going to have something very similar you are going to have a mini switch with two different servers like this and these again will be like this and this is how basically this DCell architecture will look like if we are talking about 2 servers only 2 servers.

You can extend this particular concept is as you can see over here that this is more fault tolerant architecture let us say that if this link breaks and so, you will find another path between these servers through which the data can be routed so, this is a fault tolerant architecture. So, let us say that you take the case of a 3 server, 3 server architecture so, here basically what you are going to have is one mini switch with 3 different servers this is your mini switch and 3 different servers to which it connects.

Then you are going to have similarly another mini switch with three different servers like this. So, this is one DCell this is another DCell, you can have another DCell with another mini switch and three different servers in the likewise manner. So, this will be your another DCell and you will have a mini switch with 3 different servers like this forming another DCell. So, essentially what is going to happen is one server from here is going to connect to another server over here, this server over here may connect to this one over here, this one may connect to this one over here, this one may connect to this one and this one may connect to this one and like this, this will continue. So, as you can see over here this is again a pretty elegant fault tolerant architecture of a DCN which is known as the DCell architecture.

So, this D cell architecture has different properties. So, these are some of these different properties that I am going to highlight now. So, a DCell basically uses a recursively defined structure to interconnect the server, where the server is interconnected to several other servers and a mini switch via different communication links and the low level DCells form a fully connected graph and there are these fault tolerant architecture that we have seen. So, these are once again these different properties of a DCell DCN architecture.

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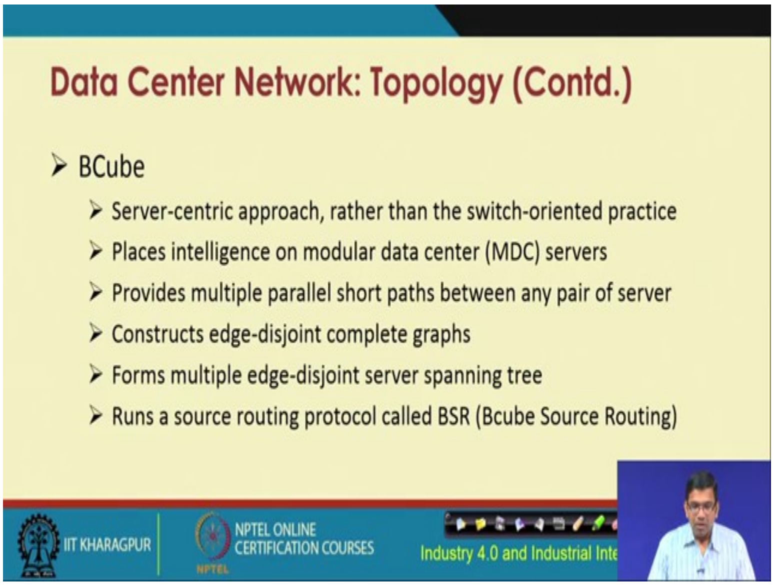


Let us look at the last one which is known as the BCube architecture.

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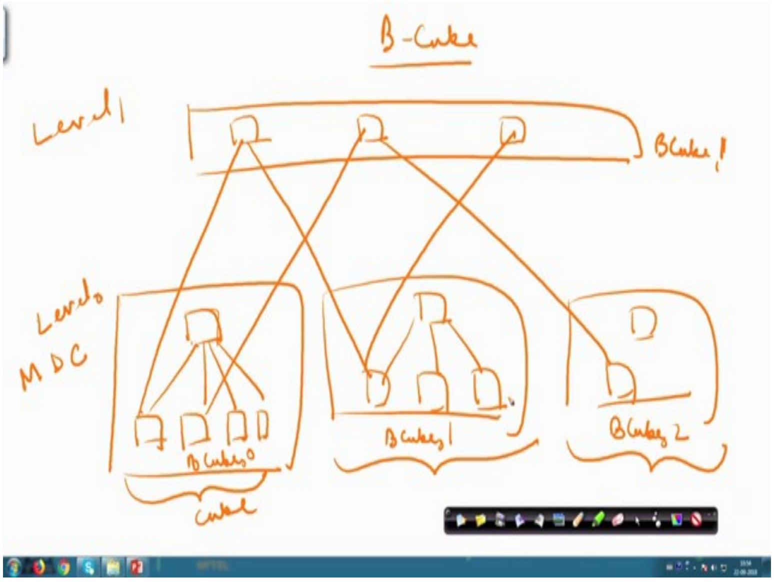


Here in the BCube architecture I will show you that we have BCube architecture, in a BCube architecture you have the concepts of something known as the modular data centre MDC modular data centre. So, this modular data centre has different BCubes each of let us say that these are the different BCubes and this is one cube, like that you can have other cubes and so on. So, in the BCube architecture you have all this different switches and these will be connected to another level of BCube the let us say that this is your BCube 0.

This will be let us say your BCube 0 1, this we let us say that this is 0 0, this is 0 1 BCube 0 2 and so on. So, you will have another BCube, another BCube and so on and this one will become your BCube 1 and you can even have 1 1. So, these are your different switches at this particular level this becomes your level 1, this becomes your level 0.

So, these essentially from this mini switches they are not going to connect to the level 1, but from here these are going to connect. So, this is how it is going to happen over here not to this one not to this one. So, only it is going to connect to these this is how your BCube architecture grossly looks like.

So, we proceed further and we try to have a look at the different properties of the BCube architecture it is a server centric approach rather than a switch centric practice and it places the intelligence on the modular data centre that I just showed you and it is corresponding servers provides multiple parallel short paths between any pair of servers. Constructs edge-disjoint complete graphs and forms multiple edge disjoint server spanning tree.

So, there is a specific type of routing protocol that is that supports these BCubes which is known as the BSR the BCube source routing protocol which basically helps in routing in this particular BCube architecture. These are some of these highlights of these properties of the BCube architecture that I had drawn and showed you how they look like.

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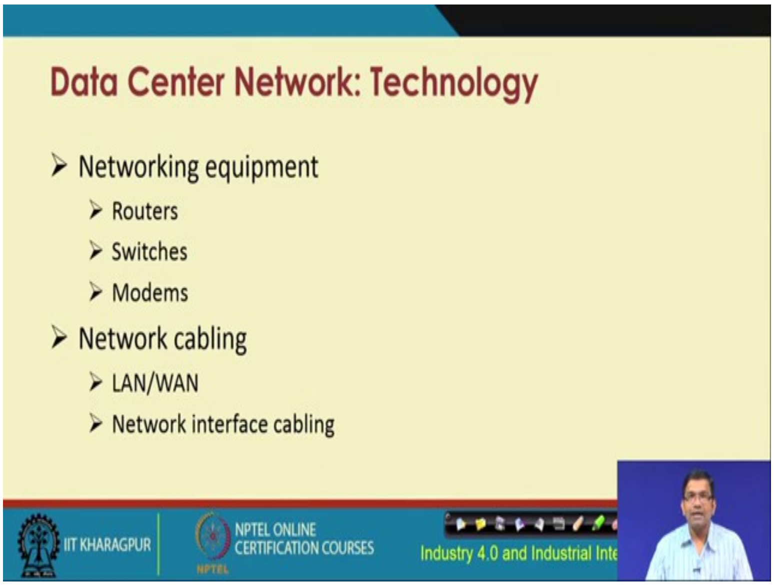


So, let us now quickly very quickly let us go through the different other requirements. So, a Data Centre Network requires different networking equipment such as routers, switches, modems, supports cabling of LANs, WANs, network interface cabling and so on.

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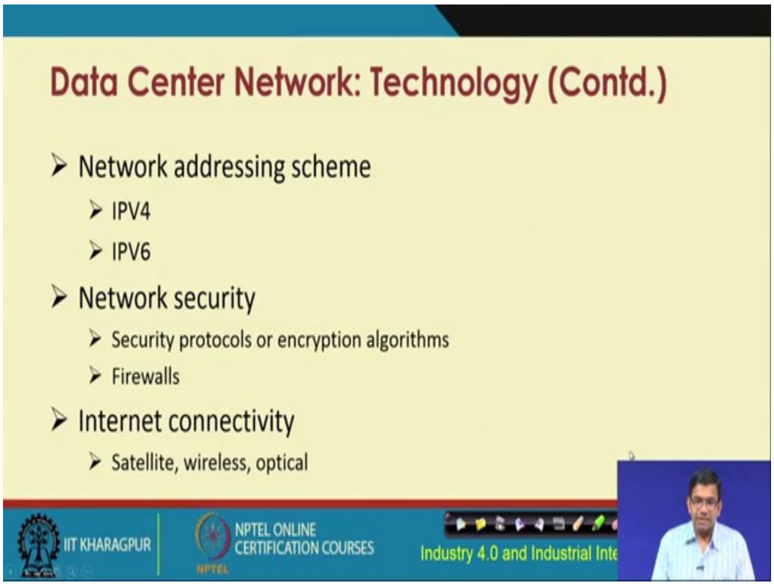


Has addressing schemes supported IP addressing scheme supported by IPV4, IPV6 or whatever is required these are the only 2 options at present if you are talking about the internet. So, IPV4 or IPV6-based network addressing scheme or supported network security protocols, algorithms, firewalls etc. are already in place you in these Data Centre Networks, internet connectivity is offered through optical wireless or satellite can communication.

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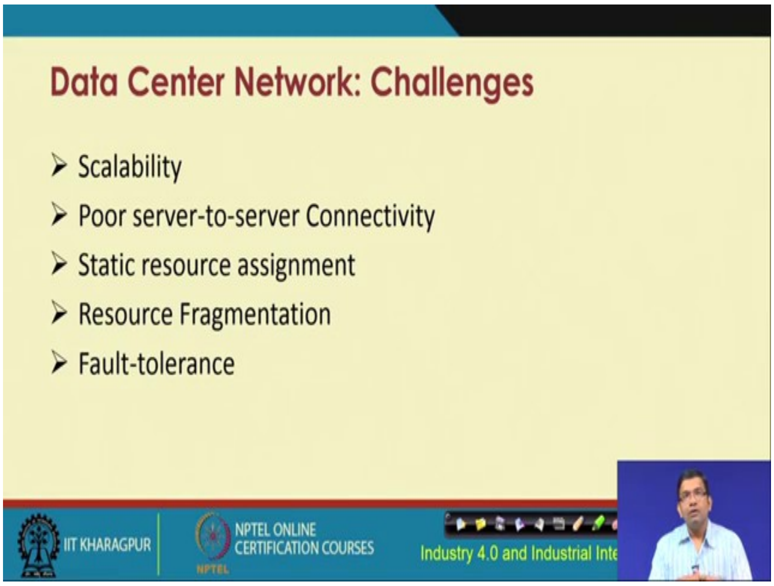

Different challenges of Data Centre Networks include scalability challenges. So, if you want to scale up the issues are not very trivial you have to deal with large number of different things and poor server-to-server connectivity can be a challenge because it heavily bases on fast connectivity between these different distributed servers and distributed Dcells, Bcubes and racks and so on um.

Static resource assignment is a challenge so dynamically you have to assign these different resources as per the availability and the requirements that are coming from these clients. Resource fragmentation some part of the resource lies in one location another part of the resource lies in another location so the distributed resources will have to be handled properly. Fault tolerance is a challenge so, if some part of the network goes down the system as a whole will have to be able to detect that and will have to recover from it.

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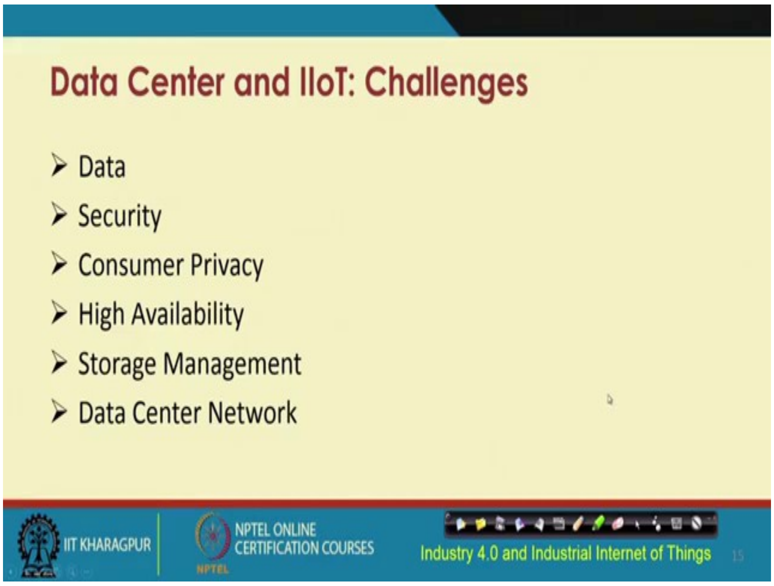


Other challenges are with respect to the data centre connecting to the IIoT, IIoT is data centric, security issues are there, privacy issues are there, availability is very important if we are talking about industrial machinery fitted with different sensors, actuators, and so on. High availability of this machinery means that high availability of these different sensors which produce data. So, availability of this data at any time based on the different requirements is very important. Storage of the data is important and building of the Data Centre Network for catering to the requirements of IIoT is very important and is challenging.

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In the context of data IIoT generates lot of data substantial amount of data which will have to be continue continuously learnt from the end user is obtained from the end user and will have to be made sense out of using different algorithms, intelligent algorithms, machine learning algorithms and so on and different challenges with respect to the storage of this particular data. The storage could be consumer driven or based on the requirements of the enterprise so different data and storage requirements and the challenges are there when we are talking about data centre with IIoT.

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Security issues I do not need to elaborate further security issues are there in any network if you are talking about a Data Centre Network and that too with resource constrain IIoT connections here security is a huge issue and will have to be dealt with adequately.

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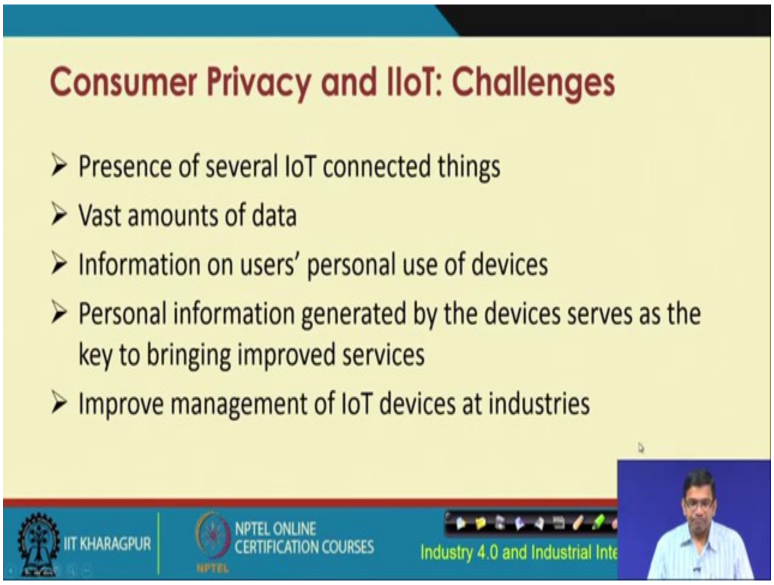


Privacy issues are paramount in IIoT data where this data going through and where this data is going and through which different parts of the network it is going through depending on that because, this data sometimes will have sensitive data the privacy of this data are very important. So, privacy of the data privacy protection in the context of IIoT and it is interconnectivity with DCN is an important challenge.

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Availability of the data high availability of the data with IIoT will make the connectivity of IIoT with DCN very important, taking care of different requirements such as connectivity of in innumerable number of devices which are interconnected. Then increase in the complexity of security management, impacts due to security challenges, real time business processes, personal data safety, etc. are different challenges with respect to high availability and IIoT in the context of DCN.

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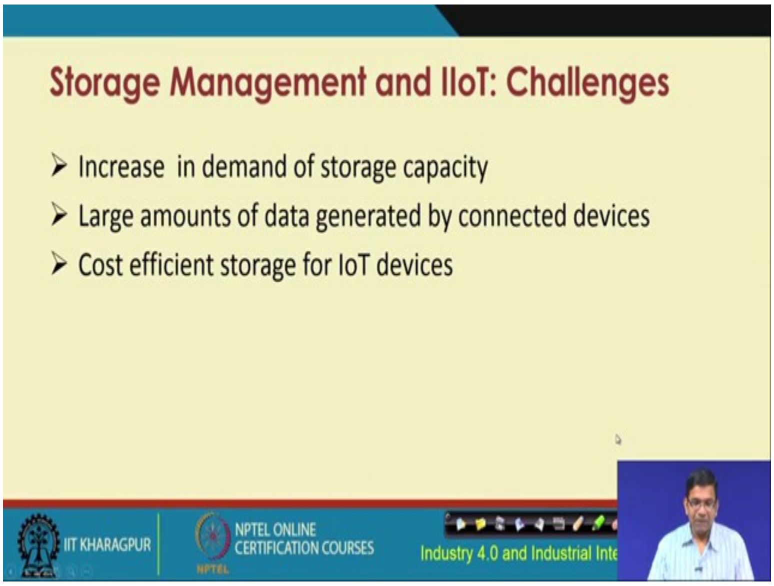


Storage management is important here we are talking about large volumes of data coming from IIoT, how do you store the data in a cost efficient manner is very important.

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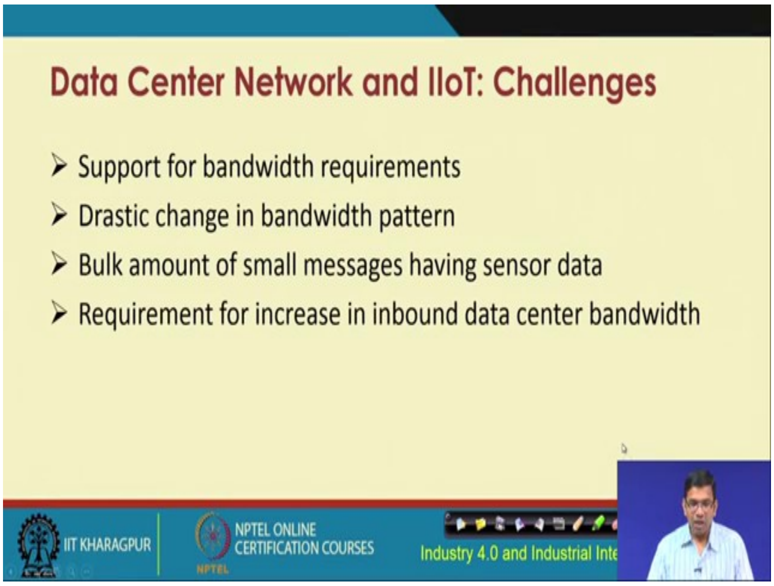


So, Data Centre Networks support different bandwidth requirements are there, because it is a network there could be dynamic changes in the bandwidth pattern availability of their bandwidth and so on. So, correspondingly the performance of the Data Centre Network will also change and if we are talking about IIoT, IIoT is a fully distributed system and these different bandwidth requirements coming from the different parts of the system might also change over time so, catering to this particular requirements are very important.

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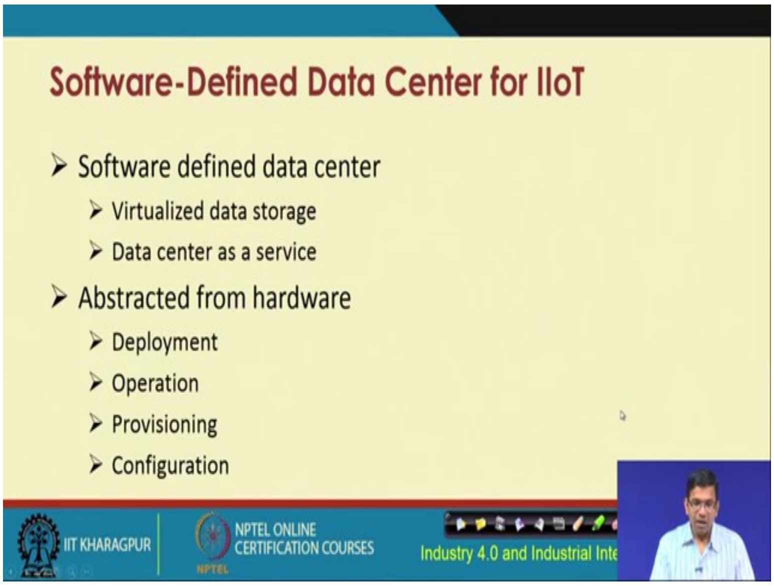


So, lastly I am going to talk about the software defined Data Centre Network, in a software defined Data Centre Network we are talking about virtualized data centres which are basically the physical instances beyond the sorry the virtualized instances the logical instances beyond the physical ones. And, how do you interconnect this virtualized instances and cater to the specific requirements is what software defined data centre talks about.

So, in a software defined network essentially we are talking about separating out the control plane from the data plane. So, data plane and the control plane traditionally were put together in a software defined architecture, a software defined Data Centre Network we are talking about separating out the control plane from the data plane. So, that you can effect effectively efficiently in a centralized manner depending on the dynamic requirements changes in the requirements and so on, you can change the execution of different jobs in the different parts of the data centre.

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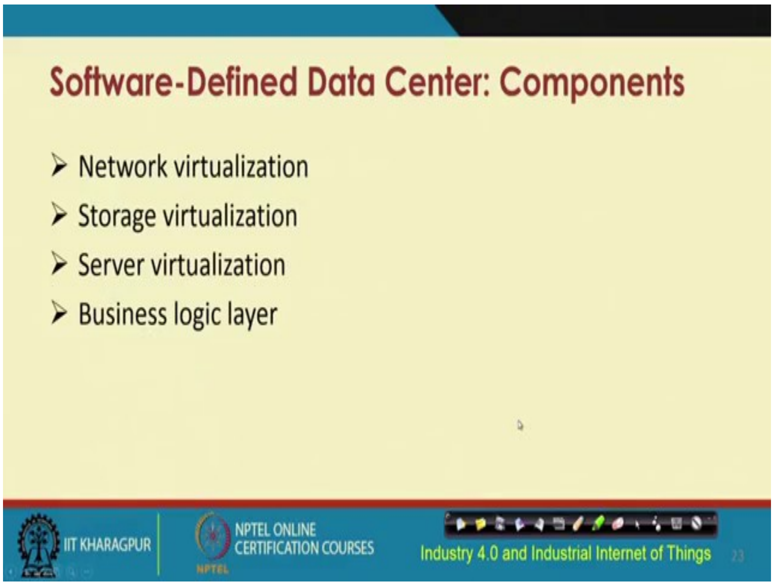


So, network what network virtualization, storage virtualization, server virtualization and so on these are core to building software defined data centres and taking care of the business requirements business logic these also will have to be taken care of adequately. So, there has to be a separate business logic layer, in addition to the network virtualization layer, the storage virtualization layer and the server virtualization layer in a software defined data centre.

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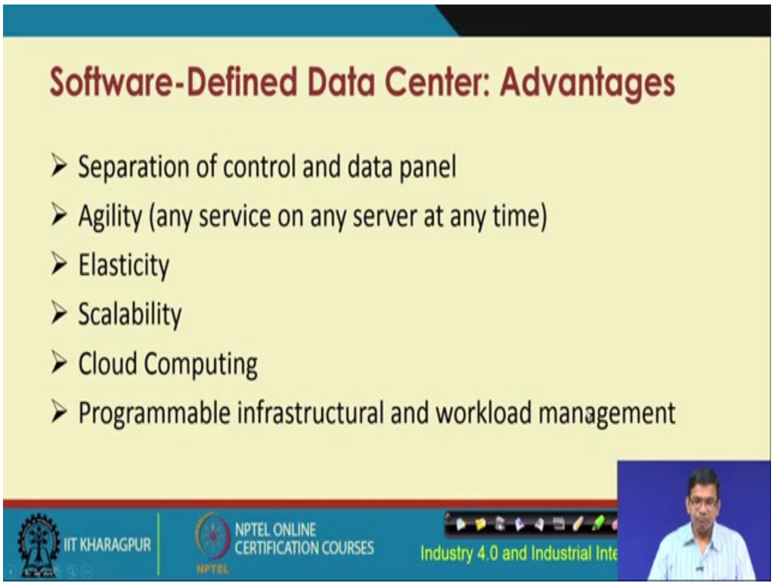

So, it is very important to separate the control and data planes and to cater to the requirements of elasticity; that means, dynamically depending on the increase in the requirements, scalability of the requirements and so on, the resources will also be elastically proficient and made available to the end users. So, agility is a very important property and this is something that I talked about in the context of get the property of a data centre.

In general Data Centre Network in general and for software data centre as well agility is very important and should be supported. So, catering to agility requirements with respect to supporting any kind of service on any server at any time is a very important requirement of any Data Centre Network and definitely for software defined data centre.

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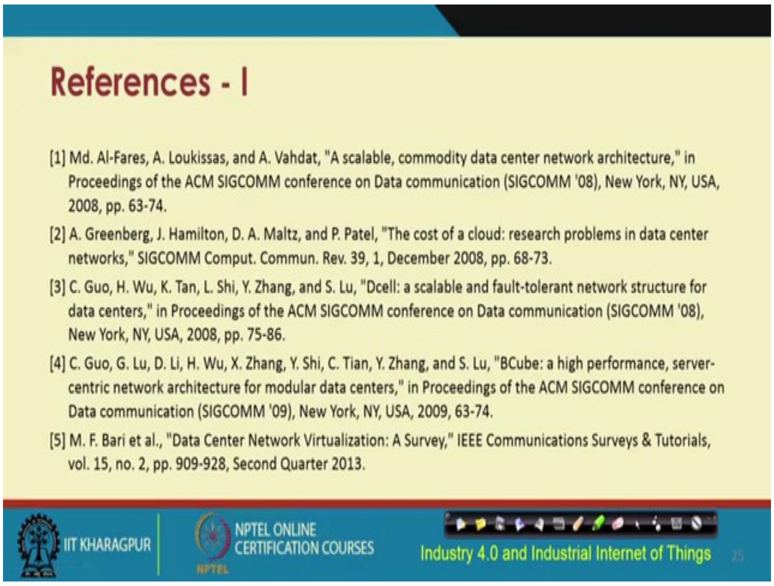


So, these are some of these different differences of Data Centre Networks I would encourage you if you are interested to go through at least some of these different references to this basically this particular lecture has given you an overview of Data Centre Networks and how it positions itself with respect to IIoT, what are the different challenges of Data Centre Networks particularly when you are talking about in the context of IIoT and so on is what we have discussed.

We have also discussed in detail the different architectures that are available for Data Centre Network and how you are going to use them. So, this particular lecture focused on getting some overview of Data Centre Networks and their corresponding architectures and challenges and so on. And, this we have to keep in mind that this particular high level understanding of Data Centre Networks will help us to also build IIoT systems holistically for scattering to the specific requirements of the industry segment that, this particular IIoT that you are building the system that you are building where is going to support.

Thank you.

**Introduction to Industry 4.0 and Industrial Internet of Things**
**Prof. Sudip Misra**
**Department of Computer Science and Engineering**
**Indian Institute of Technology, Kharagpur**

**Lecture – 45**
**Advanced Technologies: Software-Defined Networking (SDN) in IIoT – Part 1**

In this particular module I am going to highlight 2 important advanced concepts which are advanced in the sense that you may or may not use them for building your IIoT for a specific industrial problem, but these will help you to do efficient network setup for efficient network management and so on and also for securing the system. These are important, these are not mandatory, but are definitely important and I would recommend that one should consider these technologies for implementation in a real IIoT setup that is being made.

So, these 2 technologies are number 1 the Software-Defined Networks and number 2 the security; security is more common which is more applicable usefulness of securities quite imminent, but SDN is something whose benefits will be clearer to you in this particular lecture once we go through all the different concepts that we are going to.

So, what is this SDN, what is Software-Defined Networks and where does it position itself in the IIoT context? Software-Defined Networks basically targets to have efficient and more effective representative network management in the IIoT setting. It is not necessary that SDN has to work only with IIoT, but because this particular course focuses on IIoT we are going to talk about SDN in the context of IIoT, but SDN applies for any kind of networks and also for networks such as your traditional internet, other different types of wireless networks and definitely for industrial IoT and IoT in general.

So, efficient and effective network management how it is going to be done, if we are talking about IIoT specifically the nature of traffic the requirements from the organizations these basically are non static, these basically change with time the traffic, the nature of traffic, the requirements of the traffic, the requirements from the clients, the specific installations the machinery everything is dynamic they change with time.

So, if we are talking about network management static traditional network management techniques are not very suitable to cater to the requirements of dynamism. They could indeed be used, but if we are talking about autonomous deployments, autonomous setups and so on. It is important to cater to the dynamic requirements as much autonomously as possible, take for instance the routing tables, routing in traditional network. Routing in a traditional network basically you have routing tables which are stored which are pre-configured in different routers, switches and so on.

These routing tables will basically help the data packets that are coming to these devices to know where they are going to go to. So, and these rules basically are fixed rules which are embedded in each of these different devices the routers, switches and so on. But if the traffic requirements change, if the overall requirements of the system changes, if the system architecture changes over time, then static rule-based routing mechanisms are not very suitable this is just an example that I just gave you.

And you can extrapolate it to cater to the other different types of requirements scenarios and so on so, for which you need to have dynamic mechanisms in place. So, SDN is one such technology which can help you to address the requirements of dynamism that are there in most of this industrial communication settings.

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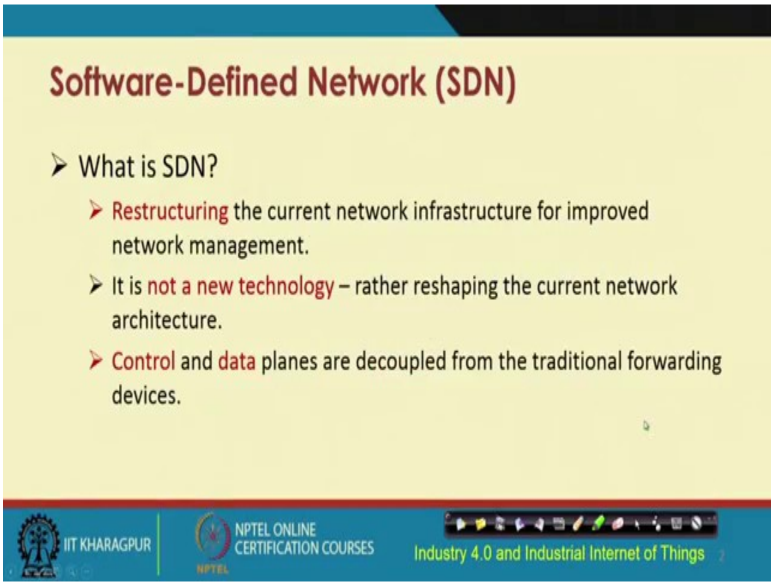


So, what is this SDN? In SDN we are typically talking about decoupling of the data plane from or the decoupling of the control plane from the data plane.

So, earlier traditionally in most of these switches, routers that are used in the internet conventionally used to have everything together. The control mechanism the data everything is basically stored, pre-configured static in each of these individual network equipment like your router, switches and so on. In SDN what we are talking about is how you can separate out the control from this individual data that are stored in each of these different network equipments and have a separate layer which is the control layer having an entity a network entity which is termed as the controller.

So, that controller is the one which is going to control each of these different network entities which are there like switches, routers etc. and this controller entity the network entity controller basically is going to help in controlling each of these different devices which are part of the data plane. So, what is this SDN, it is the restructuring of the current network infrastructure for improved network management.

So, when we talk about restructuring as this particular term the qualifier suggests that it is not a new technology, but a technology that will help you to reengineer to reshape to relook at the current network the conventional network architecture and provide an efficient mechanism of doing things.

So, how it is done as I told you earlier it can be done by separating out the control plane from the data plane a process of decoupling that will have to happen and by which the traditional forwarding devices will only take care of what they are instructed to do by the controller the control plane equipment.

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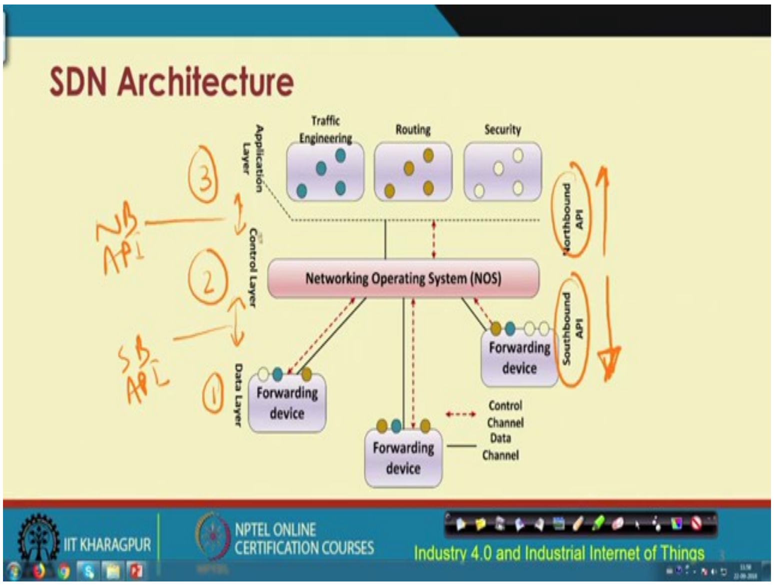


So, holistically this is how this SDN architecture is going to look like. So, this SDN architecture irrespective of whether it caters to the IIoT or IoT traffic or not, is going to have 3 different layers broadly; 1 is your data layer, 2nd is the control layer and 3rd is the application layer.

So, we have 3 different layers, layer 1 devices are like forwarding devices like your routers etc. these different forwarding devices, layer 2 device is the controller which basically also takes care of the network operating system which runs the network operating system. And then you have the applications which are running on the very top in the layer 3 this is this application layer where your business logic your different applications are running.

So, basically you have 3 different layers. So, the one switcher below these layers which are below the control the controller or the control layer this basically is known as the Southbound API, once which are above are known as the Northbound API. So, there are 2 APIs application programming interface one interface between this control layer and the application layer.

So, this is one interface over here and this is another interface. So, this interface is known as the Northbound API and this particular interface is known as the Southbound API. So, this Southbound API in other words basically concerns the interface between the control layer and the data layer whereas, the Northbound API concerns the interface between the control layer and the application layer.

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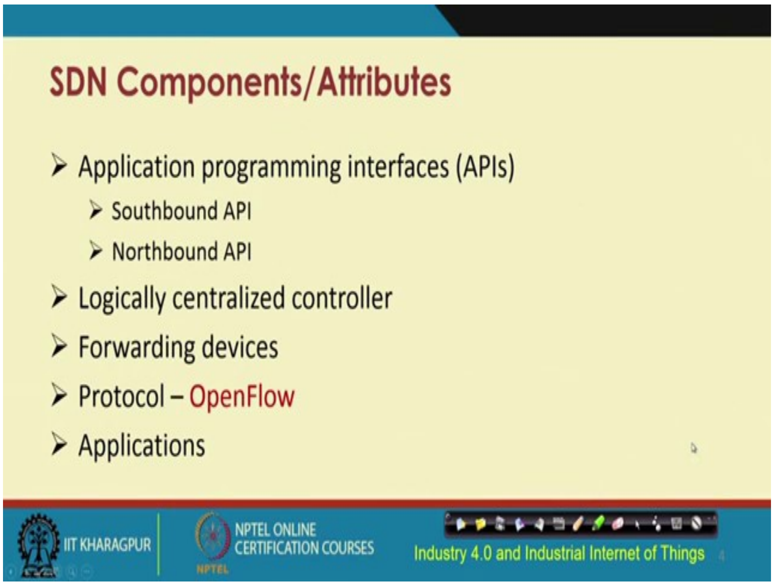


So, there are different components of the SDN Northbound and Southbound APIs are the ones that I just mentioned likewise there is this controller which is a logical centralized entity which is basically controlling this different data layer devices. There are forwarding devices in the data layer which basically takes care of mere forwarding based on the rules that are basically implemented in them that are configured in them. You also have to support this entire stuff you have to have some protocol which is going to help you to do whatever I just explained earlier.

So, there is a very popular protocol which is known as the OpenFlow protocol which is specifically designed to cater to the requirements and the necessities of supporting SDN in a network Software-Defined Networks basically will be supported by this open protocol. The protocol started from the 1.1 version and currently it is at 1.5.

So, OpenFlow 1.5 is the protocol that is OpenFlow protocol that is the latest one which could be used and each of these different protocols and its different versions 1.1, 1.2 till 1.5 has its own individual features. But holistically OpenFlow as a whole will cater to the configuration of SDN in a particular network and on the top you have these different applications so, these are these different components of SDN. So, these apply as I said earlier to any kind of network wired, internet, wireless or IoT or IIoT, but IoT or IIoT has it is own specific requirements and the configuration of the deployment of SDN for IoT, IIoT is something that is nontrivial.

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So, before we discuss about those non trivialities let us talk about some of these different aspects. So, in SDN we need to understand few different concepts which will make us to understand further how SDN can cater to the requirements of IIoT. Number 1 is rule placement, second is controller placement and third is security, rule placement, controller placement and security are the 3 most important concepts that one should know in SDN.

So, let us try to go through each of these there are different research papers that talk about different ways of rule placement, different ways of controller placement, different security mechanisms and so on, but we will go through some of these very naive high level views of each of these different concepts to make us understand what these are.

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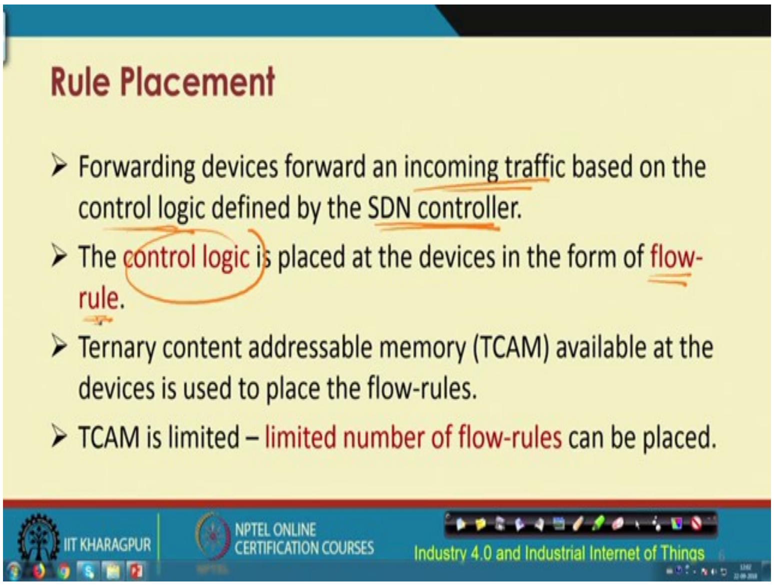


So, in the rule placement basically what we are talking about is that we have different forwarding devices that forward the incoming traffic based on certain control logic that is again defined by the SDN controller. And this control logic is basically placed at the devices; that means, in the data layer in the form of something known as the flow rule and it is this flow rule that we are talking about in this particular context.

Before we talk any further I should also tell you something else, these flow rules are basically stored in a memory in each of these devices which is known as the TCAM memory the full form of which is Ternary Content Addressable Memory. That are there the TCAM memory are there in each of these devices; that means, the data plane devices; that means, your router or the forwarding devices you have all these TCAM memory that are there which will store the different flow rules.

Now, this TCAM memory is very small and consequently this TCAM memory in each of these forwarding devices will store only a limited number of flow rules. So, this only a limited number of flow rules can be stored and that makes the life challenging about how you are going to design your flow rules and so on, because you have very limited space in the TCAM which can store your flow rules. If that was not there you could have if that constraint was not there you could have a bunch of different flow rules all being stored in the TCAM memory for further use, but because that constraint is there you need to now know how you are going to design your flow rules, where you are going to place, how you are going to place and so on of these different rules.

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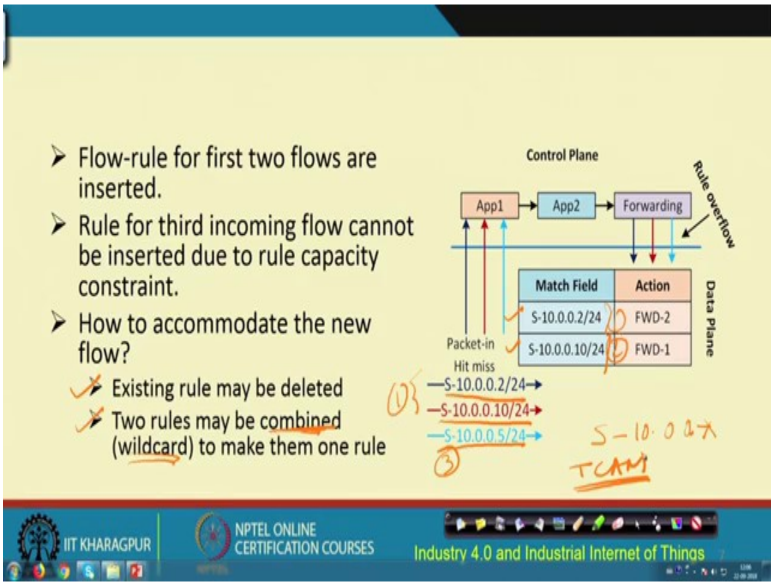


So, let us now try to understand further how this TCAM and this 4 rule placement is going to work together what is this constraint all about and we have to try to appreciate how this constraint is going to bring in these different issues which will have to be addressed.

So, let us say that you have all these different flows that are coming. So, let us say that first you have 2 different flows like the ones that are shown over here, you have 2 different flows; like the ones let us say that these 2 flows have already come in. So, the flow rule for the first two flows are already inserted because that was not already there so, it is already inserted in your TCAM.

So, then corresponding actions for these different flow rules are also mentioned in that data plane. So, basically you have for each of these flow rules you have the corresponding actions that are also specified. So, if certain traffic comes next so, what is going to happen is this matching is going to be done with this particular flow rule and based on this particular matching if the matching happens, then the corresponding action that is specified against these flow rules are going to be; so, these actions are going to be taken.

Now, let us say that you have a third incoming flow that comes this is this third one let us say that we have to deal with this third one so, first and second already dealt with stored over here. So, one and 2 already store now the third one comes. So, let us say that this particular TCAM memory can store only 2 flow rules, the third one comes and you will have to be either inserted to give the constraint to specify that constraint in this particular table or how do you deal with it; how do you deal with it. So, how do you accommodate this new flow?

There are 2 ways, one way is that you delete one existing rule and you insert the third one the other possibility is that you have to combine. So, you can using some wild card or other mechanisms you can have combined rules which will cater to multiple such rules together which will combine multiple rules together. For example, over here you can have is S-10.0.0.2 here also you have S-10.0. 0. 10. So, you can have a wild card and you could have something like S-10.0.0.* which will match both, but then although you can combine in the using a wild card like star etc. you could combine these two in the form of one rule, but then that will also not make it very specific.

So, those constraints are also there, but certain cases this kind of combination will make sense and one could use. So, you we what we have seen is that TCAM memory has its own different constraints, we could only store few rules in it and if you have a additional rule coming in which cannot be stored, then it has to be handled in a certain way wild card mechanism is one, but then it has its own disadvantages.

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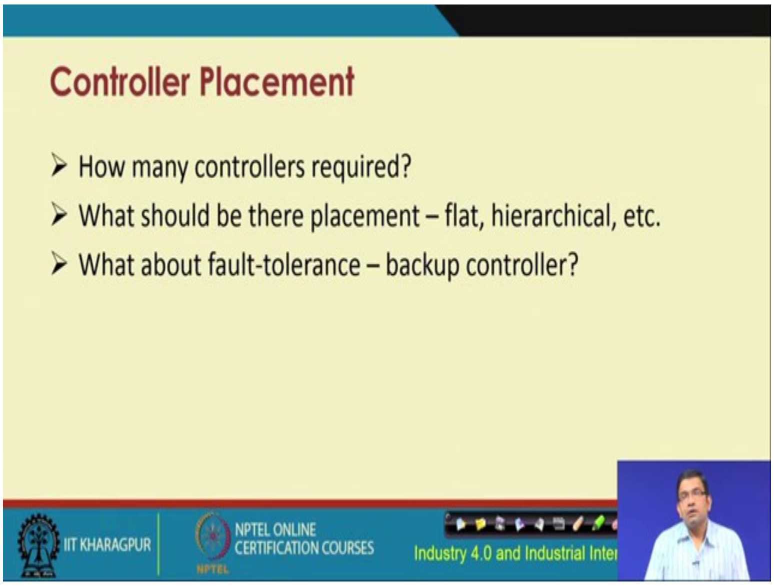


So, let us look further. So, that was the rule placement and one problem with rule placement like this there are so many different problems these different research papers that talk about rule placement in SDN deal with and they identify the problems they solve the those problems and so on, but I think it is sufficient in a short lecture like this to know only what the issue main issue is and what are the different aspects of it.

The next issue is the controller placement, in controller placement we are typically talking about issues of dealing with identifying the number of controllers that might be required in a particular setting, identifying what should be there to be placed? How you are going to place it? Which architecture will be followed?

Whether it is going to be flat architecture, hierarchical architecture or other architectures that might be used to place the controller? And whether we are going to have some kind of fault tolerance in the event that some entity may be the main controller fails? Whether we are going to have fault tolerance to adopt a backup controller to be also in place which will take over if the main controller fails? So, all of these different controller placement issues are the common ones that are researched in the literature and different solutions are provided.

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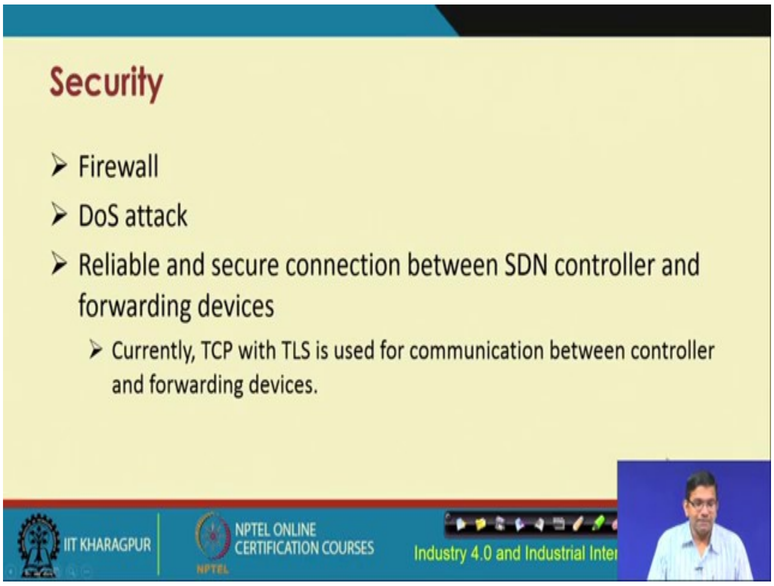


Security issues like installing firewalls, dealing with denial of service attacks, offering reliable secure connection between the controller and the forwarding devices in the data layer, these are the some of these different security issues that are also of concern in the context of SDN.

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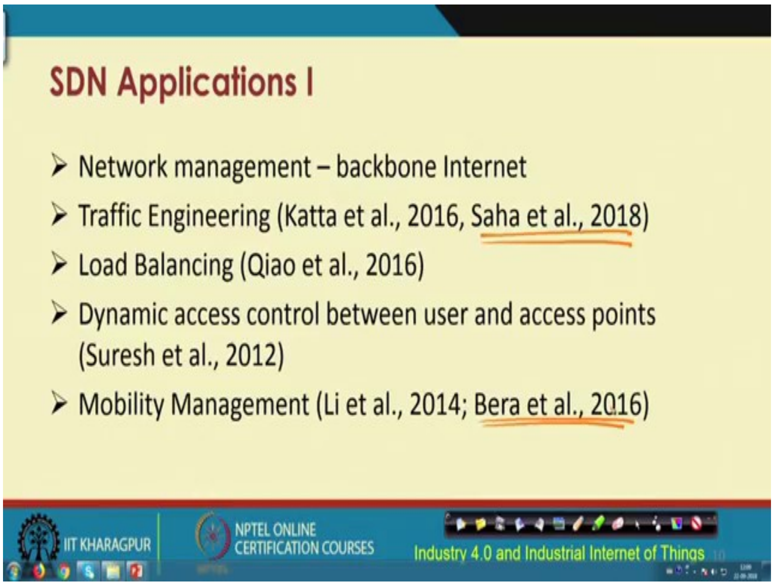


Different applications serving different requirements such as network management for backbone internet, traffic engineering, load balancing, dynamic access control between the user and the access points, mobility management, these are some of the issues that are researched and there are different solutions to them. I have cited some of these different literatures in case you are interested to know about in detail about any of these different issues their corresponding applications in SDN and so on.

Then these are some of these different research literature that one could go through these are some of these different papers that belong to us we are the ones who have authored these papers in our research group. So, you could go through these there are many other papers on SDN that we have authored in case you are interested you are encouraged to go through my Google scholar profile you will be able to go through the you will be able to find the corresponding literature the works that we have done on SDN. And if you are interested further you can go through them and if you are in doubt you could connect with me regarding any of these different papers that we have on SDN.

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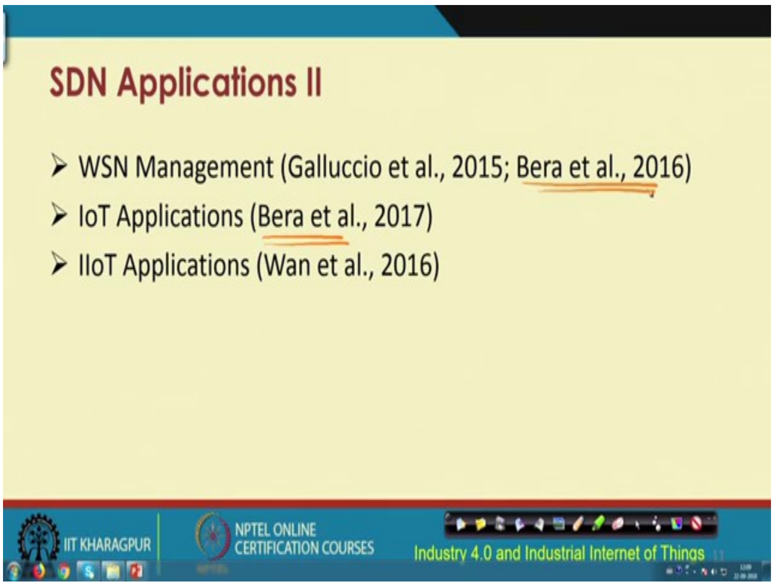


Different other issues such as the issues of management or sensor network management application level issues IIoT, IoT and so on, these are some of these papers again that belong to our research group and you are encouraged to go through them along with the other research papers that I have listed over here in these two slides.

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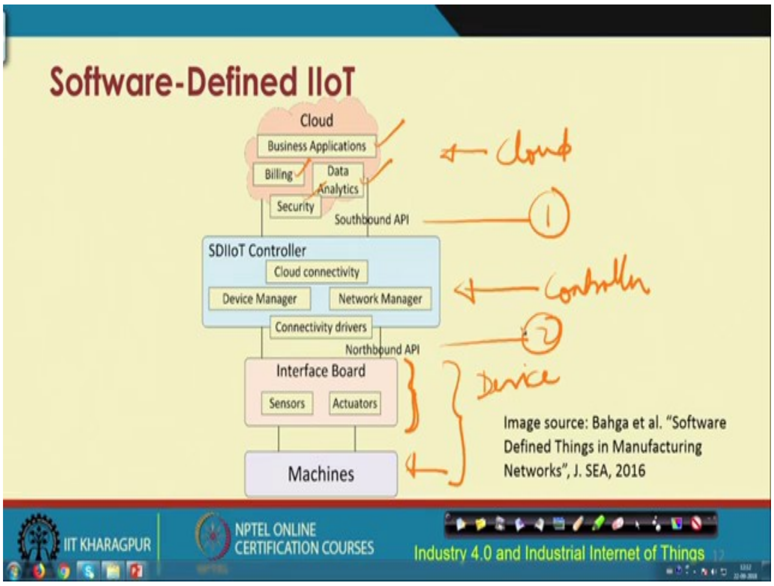


So, let us now get into the issue of SDN for IoT. So, far what I have made you understand is what SDN is and what is the overall architecture of SDN, what are these different components of SDN, what are these different API is the Northbound API and the Southbound API and so on. And the different protocols that will have to be used in order to deal with SDN because SDN has its own different characteristics features and requirements so, you need to have specific protocols to deal with it.

The OpenFlow versions 1.1 to 1.5 these different versions of the OpenFlow protocol is a popular one that is used for catering to the requirements of SDN. So, let us now look at IIoT, catering to the IIoT scenarios, industrial IoT, industrial machinery, machinery fitted with different sensors, actuators and so on and Software-Defined IIoT what is this architecture. So, this is this architecture that I have taken from this particular difference that you see in front of you.

So, basically what you have in a Software-Defined IIoT scenario at the very bottom is the layer which deals with these machines which are fitted with the different sensors, this is your machines, these machines could be any industrial machinery, manufacturing machinery, powered machinery and so on. So, any machinery basically which has these different devices such as sensors, actuators and so on, these are fitted these sensors, actuators etc. these are fitted through this interface layer, interface board having these sensors, actuators on top of these actual physical machines.

And then you have this controller these are basically your devices, device layer, this is your control layer, controller and then you have on top you have these the cloud which basically caters to these business applications, business logic, pricing, billing, analytics and so on security and so on. So, this particular API is your Southbound API over here and this is your Northbound API so, these two APIs are over here catering to these different requirements.

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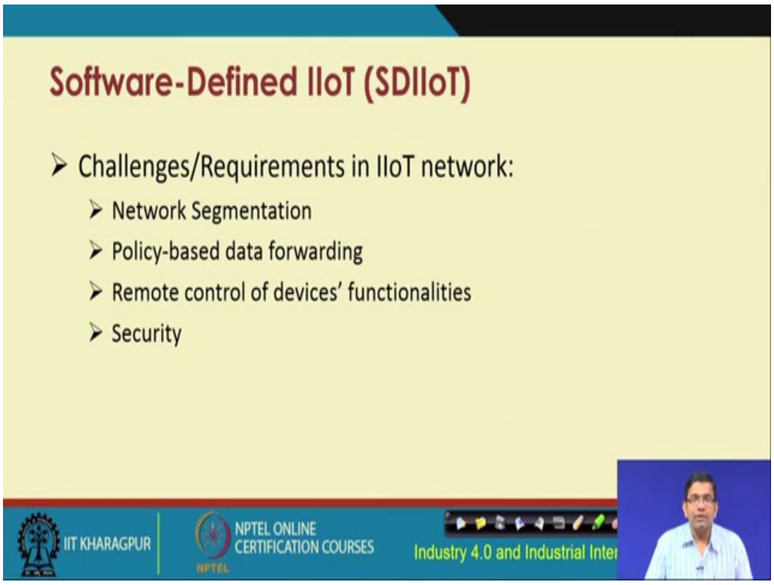


So, there are different challenges or requirements in IIoT network, challenges with respect to network segmentation, challenges with respect to having policy-based data forwarding, remote control of different devices and their functionalities and offering security, security is there all through. So, basically security issues I am not going to go through in detail, but the mind you that security is very important and it is even more important in the context of IIoT and particularly SDN, SDN implemented on IIoT.

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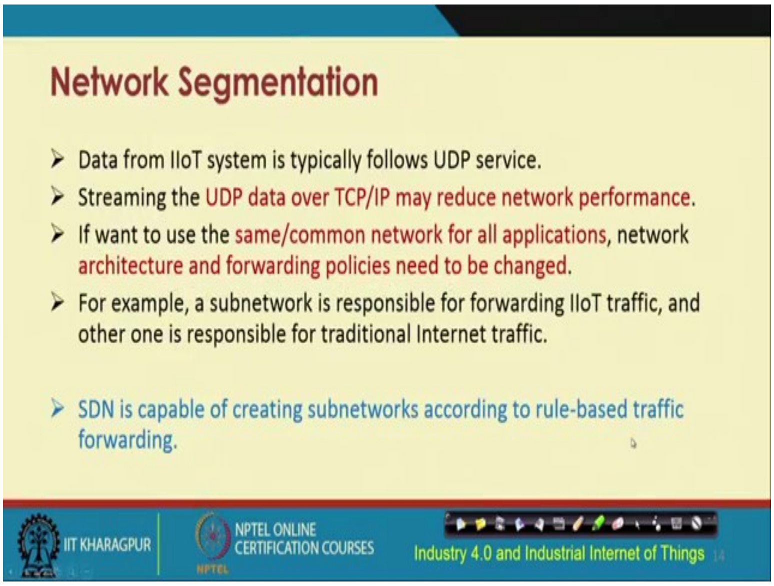


So, what is this network segmentation? So, network segmentation we are talking about segment is segmenting the network dynamically with the help of these different rules to have one part of the network follow certain requirement and the other part the segment other segments of the network follow other requirements and rules. So, let me just show you what I mean by this.

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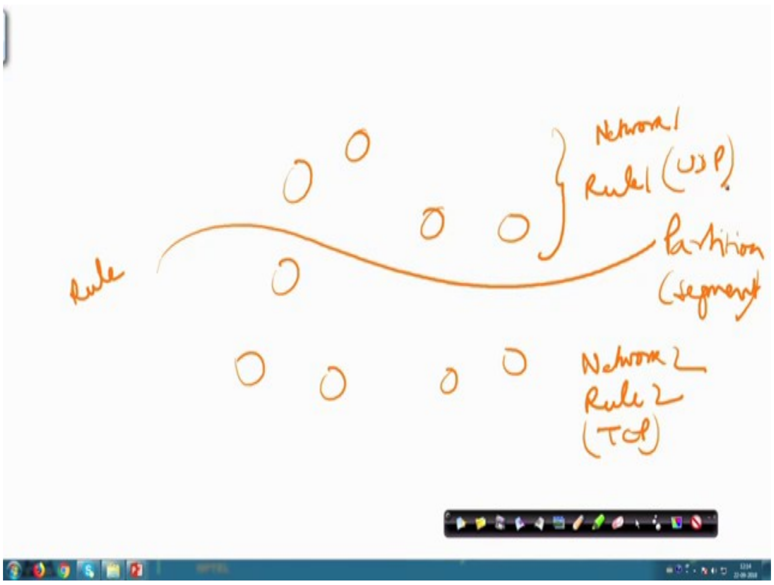


So, what we are talking about in this context is let us say that you have a certain network like this. So, we are talking about in network segmentation let us say that coming up with certain rule which will partition this network or segment this particular network into 2 dynamically-based on a certain policy or a certain rule. So, rule-based partitioning it is going to happen and it is going to happen dynamically. So, that one part of the network this network partition 1 and network partition 2 these are going to work together, but will follow different rules this will follow let us say rule 1 and this will follow rule 2.

So, rule 1 could be like at the transport layer this could be following let us say UDP where as this one this part of the network part 2 will follow maybe TCP this is just an example, but you could have different other policies implemented in the different parts of the network and this is very very important in the context of IIoT. The reason is that in IIoT you have a large industrial setting and in this large industrial setting consisting of largely different types of machinery not all of which are homogeneous all of which are catering to different requirements and so on.

Some machinery might be catering to real-time ultra-real-time requirements whereas, other parts of the other machinery and other parts of the system then other parts of the network might be catering to other non-real-time requirements and so on. So, basically implementing segmenting this network dynamically-based on certain rules, based on certain policies and having them run different protocols, different policies etc. is very important in an industrial or manufacturing power plant, manufacturing setting.

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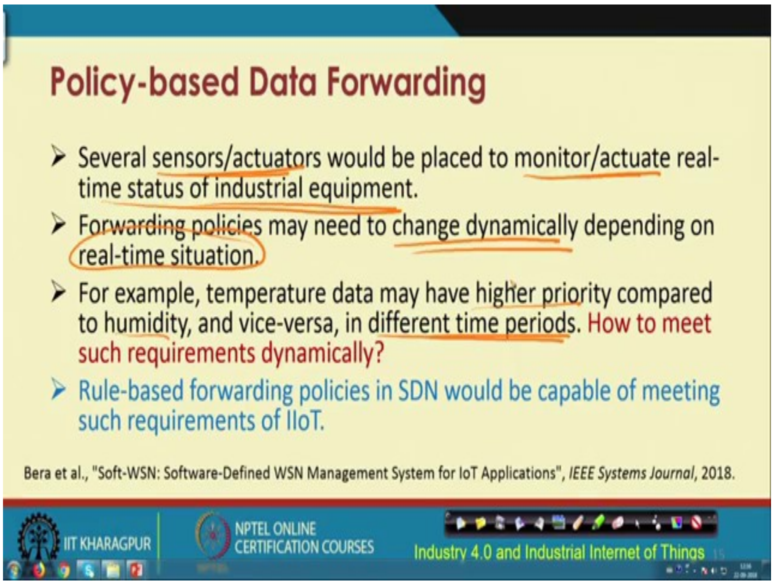

So, policy-based data forwarding is the second one. So, you here we are talking about different in a context of IIoT we are talking about the use of sensors and actuators again and they will have to be placed to monitor or actuate real-time status of certain industrial requirement and these forwarding policies will need to be implemented and they will. So, in many cases they will change dynamically depending on the requirements that the real-time situation that is there.

So, these will have to change for example, temperature data may have higher priority compared to humidity data or vice versa and in different parts or different periods of implementation different time periods basically these requirements may also change. In certain the certain parts of the network at certain points will have higher priority let us say to the temperature data.

Whereas, in the other instances of the time domain basically it might so happen that the humidity will have more priority over the temperature and so on to dynamically catered cater to this kind of requirements changing requirements and so on, SDN is useful and this is even particularly useful for IIoT requirements of this particular sort there are example of which I just give you. So, rule-based forwarding policies in SDN would be able to meet the dynamic change in the requirements of IIoT.

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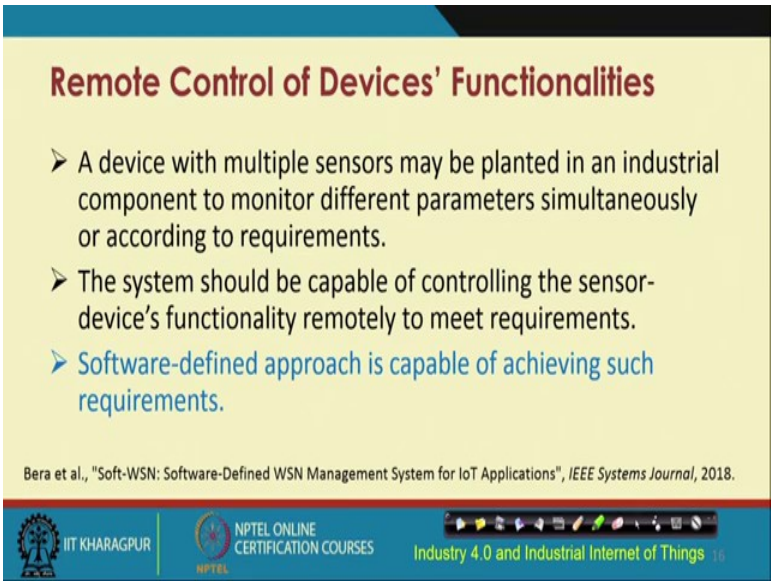


Remote control of the devices functionalities is very important remote activation remote control of these different devices is important and SDN can cater to this particular requirement in a dynamic fashion as and when and the requirement changes it can be done so, these things are very important.

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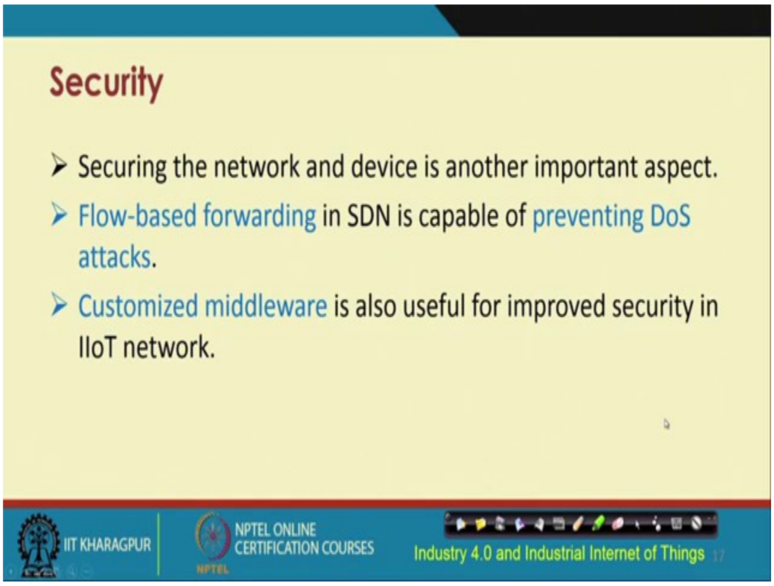


Security as I told you before we are talking about the security of an SDN-enabled with SDN-enabled on top of IIoT. So, flow-based forwarding has its own security vulnerabilities and also different DoS attacks can be form can be performed and we can think of these different vulnerabilities where the DoS attacks can be performed in the case of use of SDN and so on.

So, taking care of these issues implementing security protocols in the controller for instance is very important so, to get taking care of all these different issues is very important. So, you need to have a security layer basically implemented or it can be implemented vertically across all these different layers this is very important from the point of view of implementation of security either horizontally or vertically across the different layers of SDN for IIoT.

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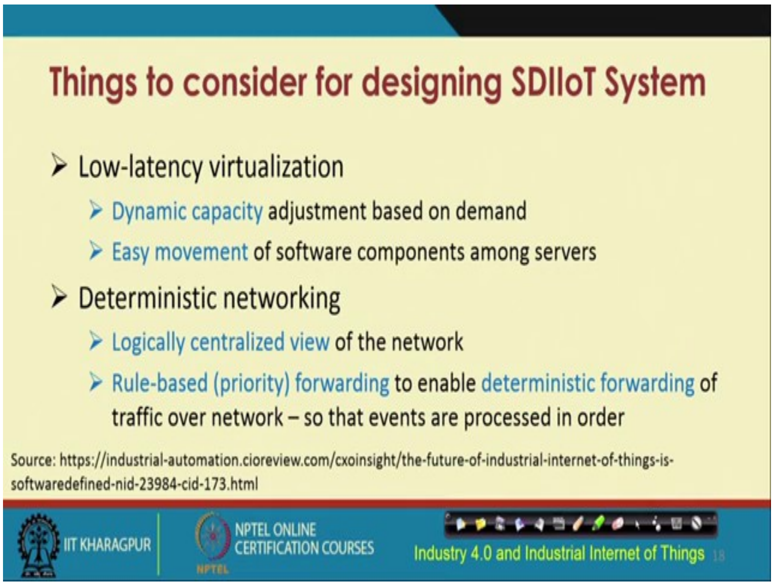


So, there are different requirements which will have to be taken into account to build SDN-enabled IIoT systems. So, for example, low-latency virtualization is a very important requirement. So, here actually Software-Defined also brings into picture the necessity of virtualization network virtualization, storage virtualization and so on. So, low-latency; that means, very little less time we will have to cater to these virtualization requirements, because you are dealing with industrial machinery operating in very high speeds throwing large amount of data actuating in very high speed and so on.

So, low-latency is very important; that means, in very less time the things are going to be done low-latency virtualization; that means, virtualization in very less time least time virtualization will have to be done in order to cater to all these high speed requirements, real time requirements and so on. Deterministic networking is very important here it is very important in SDIIoT scenarios to have the logical centralized view of the network, logical instantiation of the physical network and so on and rule-based priority forwarding has to be implemented to enable deterministic forwarding of traffic over the network so that the events are processed in order.

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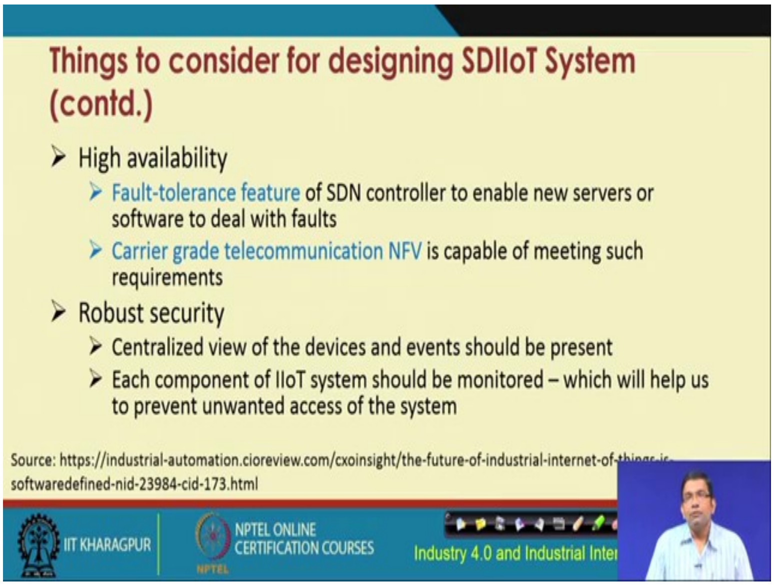


High availability is very important, fault tolerance feature is very important, we are talking about industrial machinery dealing with carrier grade telecommunication equipments, protocols and so on.

So, high availability with fault tolerance ensuring there is least downtime if at all there is any these are very important considerations of SDIIoT. Security I have time and again talked about security, security issues, robust security mechanisms taking care of all of these different issues of SDN and SDN for IIoT is very important.

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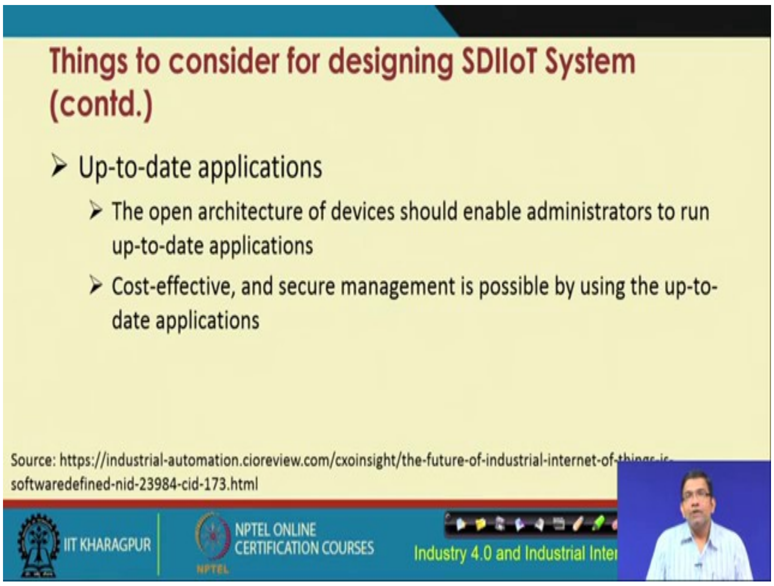

Applications up-to-date applications having open architecture of devices, running different administrators specific requirements and up and making them up-to-date, in a cost effective secure manner is also very important for SDIIoT.

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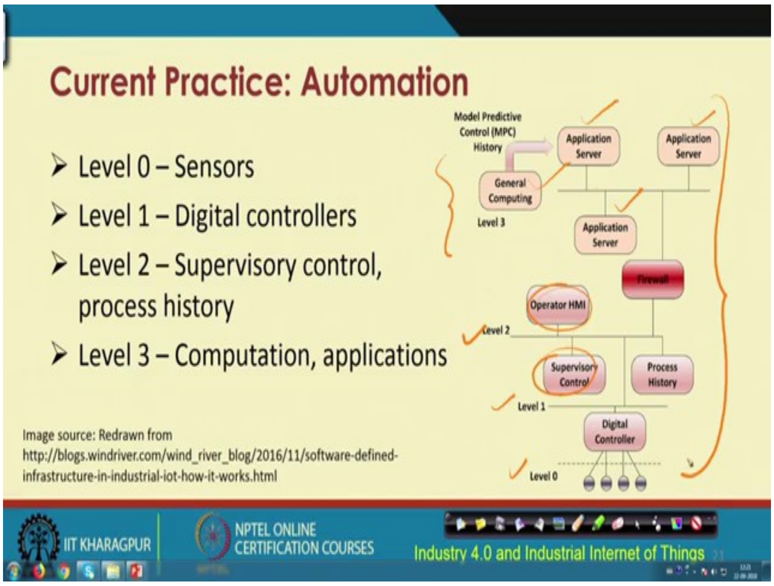


So, if we look at the current state of practice in the case of automation in industries. So, this is a global view an architectural view of automation as it currently stands now. So, basically you will have in the case of automation in these settings you are going to have different levels. So, you have level 0 you are going to have level 0 sensors basically having different sensor equipments level 0. Level 1 is going to be the digital controller and the controller devices and so on. Level 2 is going to be the supervisory control like SCADA, PLC, HMI and so on and so forth. And level 3 is going to be dealing with all these different applications, computation, applications computation business logic, implementation, analytics and so on, this is the typical layered architecture of automation as it stands now.

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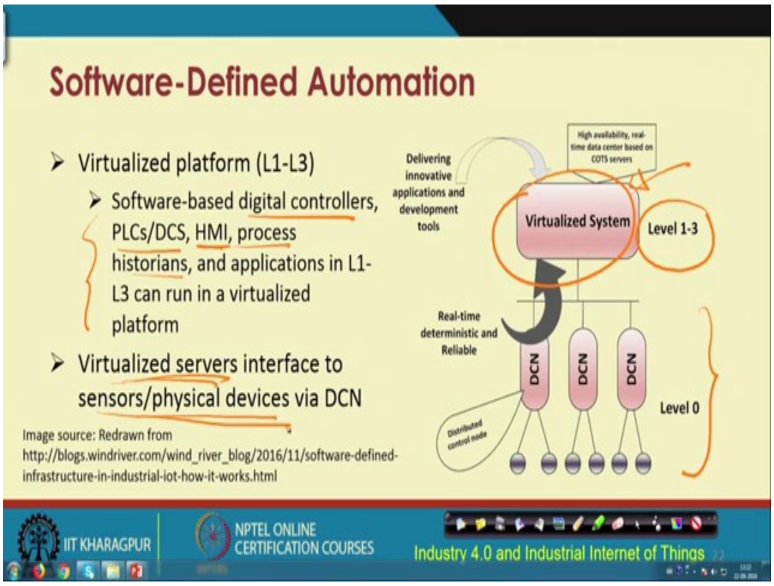


Now if you want to implement SDIIoT on these kind of settings you are going to have something like that you have this is the holistic pictorial view of Software-Defined IIoT or Software-Defined automation. So, unlike in the previous scenario what we are going to have over here is something like this you are going to have levels 1 2 3 from before in this virtualized system.

So, basically these levels 1 2 3 will deal with stuff like Software-Defined digital controllers, Software-Defined PLCs, Software-Defined data acquisition systems, Software-Defined HMI process control and so on. And so these are going to be Software-Defined virtualized systems virtualized instances and so on and in level 0 you are going to have these virtualized servers that will interface with the sensors and the physical devices via the data center networks.

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So, with this we come to an end of this particular part of the Software-Defined Networks for IIoT, we have gone through the different examples of the use of a Software-Defined Networks for IIoT the different requirements the challenges and so on. We have also gone through the overall architecture of SDN and thereafter how it applies to catering to the requirements of automation in most of these different advanced manufacturing industries where automation is required and so on.

And we have also finally, looked at the overall architecture of how you can transform the Software-Defined how you can transform automation architecture that is typically encountered in the IIoT settings in these industries or the manufacturing plants and so on to the automation Software-Defined automation architecture where you are going to have the logical view the virtual virtualized instances of all these controllers the overall SCADA controller in the controller devices and so on and also the virtualized instances of these different servers at the bottom and so on. So, you are going to have reduced number of layers in the virtualized or Software-Defined automation architecture.

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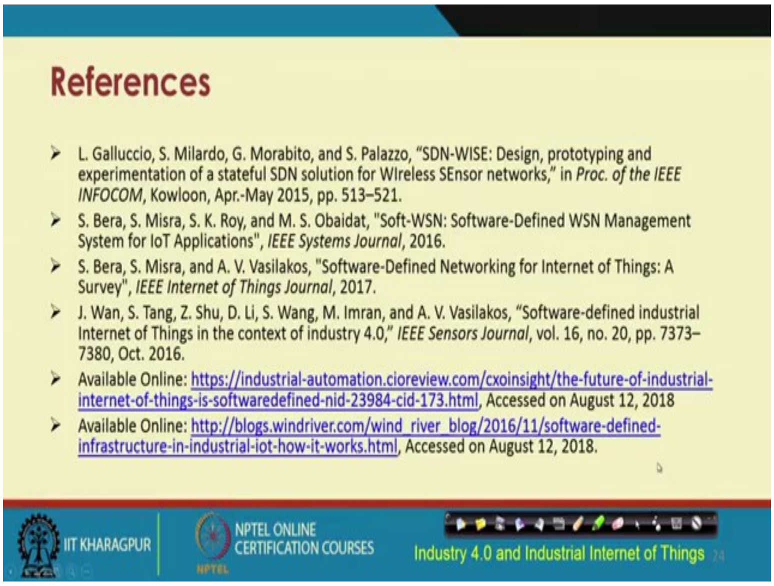


These are some of these references which have been given to you as usual for growing your curiosity further in order to understand these concepts in further depth if you are further interested to know them in detail. So, these are these different references and with this we come to an end of this part of the lecture on Software-Defined IIoT.

Thank you.

**Introduction to Industry 4.0 and Industrial Internet of Things**
**Prof. Sudip Misra**
**Department of Computer Science and Engineering**
**Indian Institute Technology, Kharagpur**

**Lecture – 46**
**Advanced Technologies: Software – Defined Networking (SDN) in IIoT –Part 2**

In the previous lecture on SDN for IIoT we looked at 2 things, first of all we understood what is the SDN architecture, what are the different components of a generic SDN architecture and thereafter we looked into this IIoT specific requirements and how SDN can integrate with a IIoT and catering to these particular requirements of IIoT in a much more efficient manner. We continue further and now we are going to look at few different solutions and applicability of SDN catering to different network scenarios in this particular lecture.

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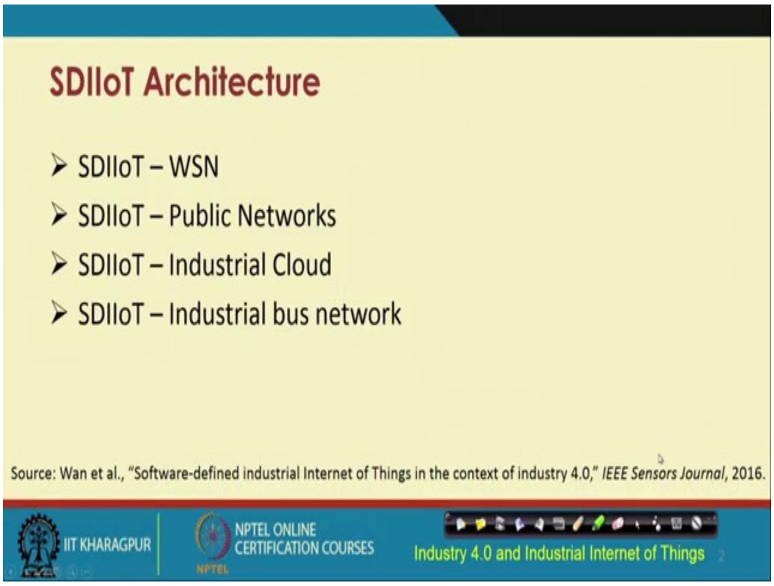


So, if we are talking about SDIIoT we have different types of networks, the traditional networks like internet public networks, sensor networks which is more specific to IIoT and you also have this cloud particularly industry grade cloud, industrial traditional bus networks connecting different sensors at the device layer and so on. So, how you are going to make them SDN enabled is what we are going to look at a very high level and particularly try to identify the main difficult areas in each of these architectures where

SDN implementation will pose challenge and how you are going to do that to cater to these specific requirements, this is what we are going to look at in this particular lecture.

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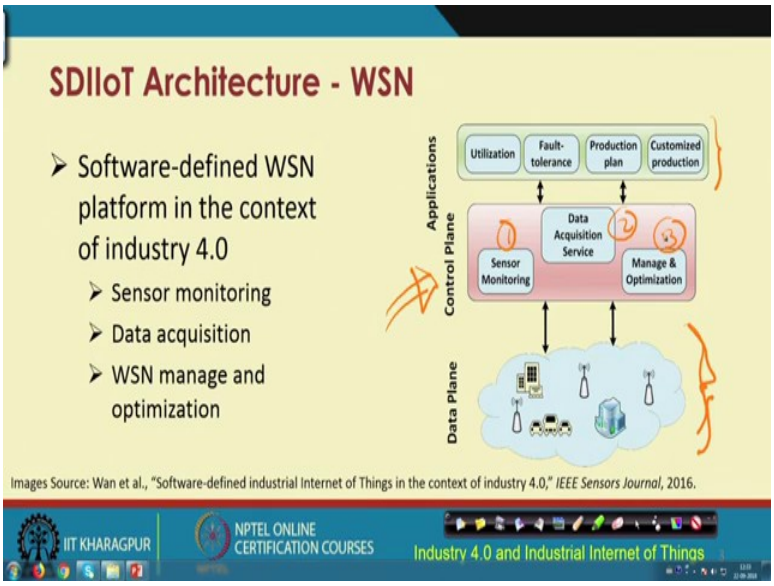


So, first let us start with the sensor network, sensors are key to IoT and IIoT. So, if we are talking about the virtualization, the software defined sensor network platforms; that means, the existing sensor networks you want to make them software defined if you want to do that what you need to take care of is basically issues of sensor monitoring, data acquisition and management and optimization of these sensors and sensor networks.

So, typically you are going to have one view of a SDN or SD enabled sensor network like this. You are going to have at the very bottom the data plane. The data plane will have all these different sensors, which may be interconnected through different access control access devices and so on. And these different devices in the data plane the sensors etc. might be there in these different transportation devices cars, buses and so on or they might be there in the different industrial, buildings or different other parts.

Then you have the control plane, this control plane basically has different components for sensor monitoring, data acquisition and management and optimization. Self optimization is very important in autonomous systems. Self optimization and self management overall has to be implemented in a software defined sensor network architecture. And on top as before we have all these different applications taking care of issues of utilization, fault tolerance, production, planning, customized production, billing, and business logic implementations, and so on so all of these different applications over here.

So, let us now focus on this particular control plane. So, we have to take care of issues of sensor monitoring, data acquisition and management and optimization particularly from an autonomous management and optimization point of view. So, these 3 components as you will notice shortly will recur in different other network settings as well, look at the internet the public networks in general.

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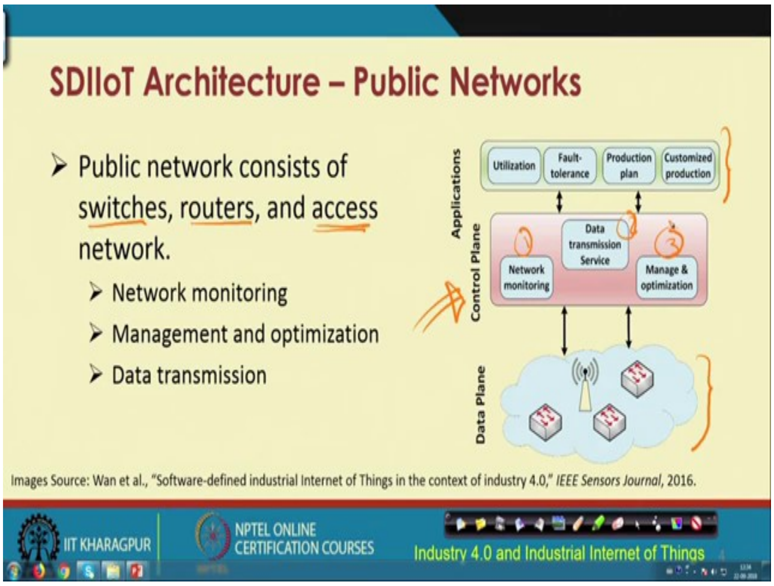


So, public networks will consist of different components such as the switches, routers and access devices. So, these are the ones that will be there in the data plane. In the application layer basically you have whatever we talked about earlier that does not change more or less, but over here in the control plane in the context of public networks you have similar kind of things like the similar kind of issues like we discussed in the context of software defined sensor networks.

So, here we are talking about network monitoring, then data transmission service and particularly autonomous management and optimization, it is very similar to the ones that you had seen in the control layer for software defined sensor networks.

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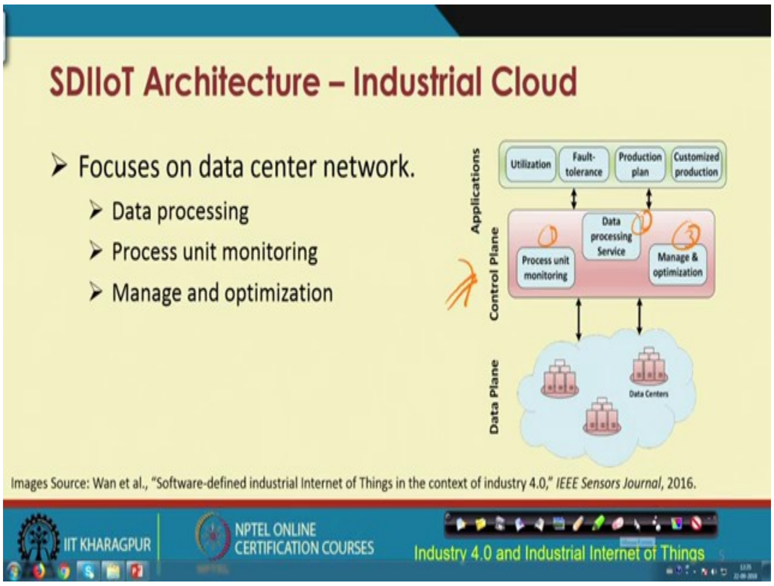


In the context of industrial cloud, cloud as we have seen is very important. Data center and cloud data center networks more specifically and cloud are very important for implementing IIoT. And software defined IIoT for industrial cloud settings you need to take care of issues like the ones over here in the control plane. So, here we have to take care of issues such as process unit monitoring, data processing service and again this management and optimization stays the same like the ones before.

So, processing and process unit monitoring these are the ones that are there in addition to management and optimization in the control plane. These are the building blocks of the control plane in the industrial cloud software defined industrial cloud in IIoT settings.

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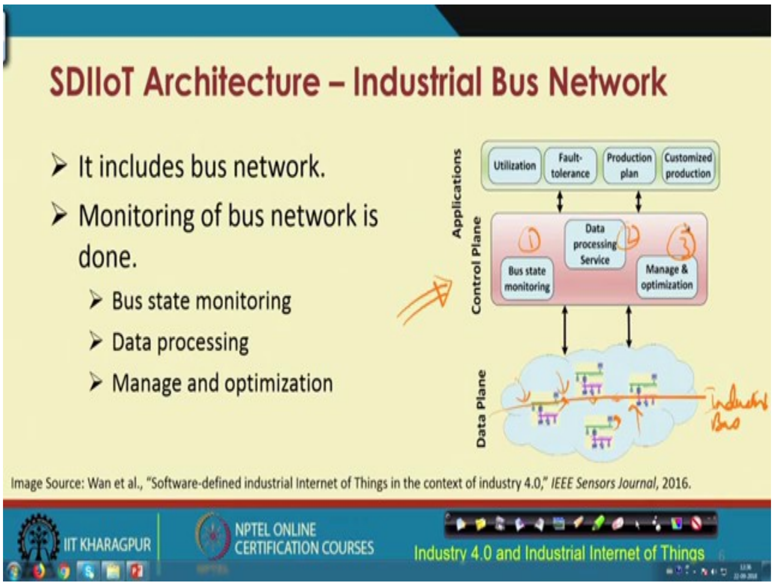


If we are talking about industrial bus network, in an industrial bus network what is going to happen? At the device layer you are going to have this industrial communication, the industrial bus, (the communication bus) to which these different sensors and other network devices are going to be fitted to the industrial bus.

So, this is your industrial bus network and to which all this different machinery with different sensors are going to be fitted and as usual on top you have these applications, but this is very important these are the different components specific to industrial bus network for the control plane in SDIIoT. So, you have over here bus state monitoring, data processing service and the management and optimization.

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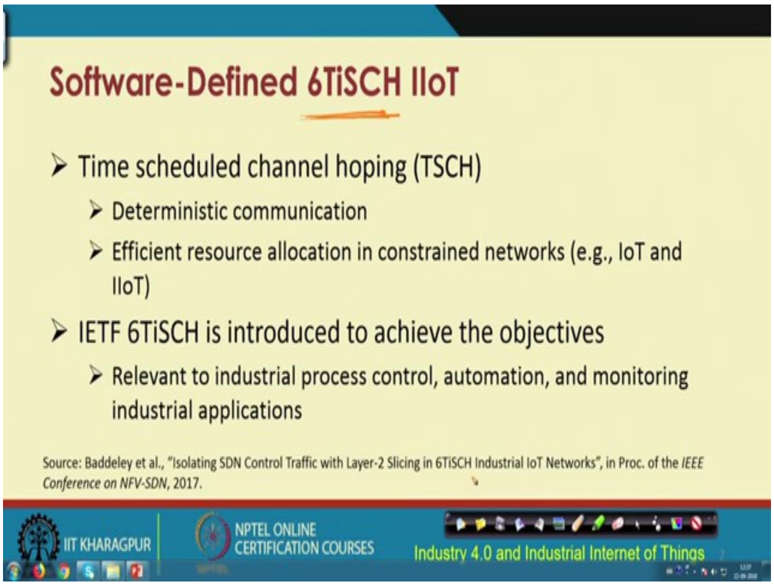


So, software defined networks for different settings and different architectures are all there a lot of research work is going on catering to software defined networks of all different sorts and more specifically for IoT and IIoT. IIoT industrial settings requirements are more specific, there are certain specific requirements over here.

So, there is a working group which is known as the 6TiSCH working group. So, this is basically TSCH, basically stands for Time Scheduled Channel Hopping. So, time schedules channel hopping here actually what they are talking about is channel hopping in a time slotted mechanism where they are going to be time slices that are going to be there and assigning these different time slices or time slots to the different devices and the controller at the same time this is what this particular software defined 6TiSCH basically talks about.

This is a huge work that is going on in a very nutshell let me just give you the highlights, but if you need to know more beyond this, this is particular literature that you can refer to, there are so many different other literature talking about 6TiSCH particularly software defined 6TiSCH there are so many different research literature that are available for you to go through.

So, in a time schedule channel hopping TiSCH scenario we are talking about deterministic communication which is very important in industrial settings. So, this deterministic communication will help in ensuring provisioning of resource allocation efficiently in constraint networks such as IoT and IIoT because these are constraint with respect to energy, computation storage network resources and so on.

So, there is this IETF 6TiSCH working group which introduced different objectives which are relevant for industrial process control, automation, and monitoring industrial applications.

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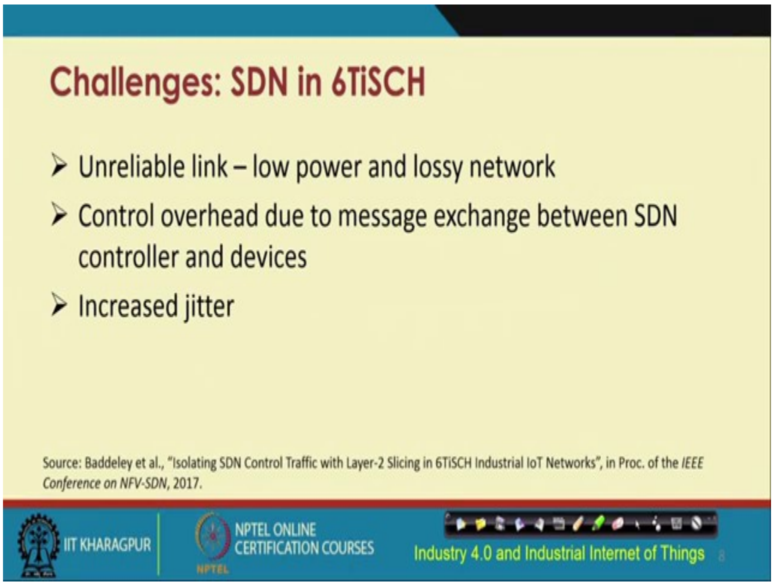


For implementation of SDN in 6TiSCH there are different challenges; challenges of dealing with unreliable links in IIoT scenarios. We have low power network scenarios, network scenarios which are lossy unreliable and so on with respect to links and components and scenarios. So, it is a highly dynamic unreliable low power highly constraint scenario where we have to implement SDN. So, this is a highly challenging job and so many research efforts are being poured in order to do so, and here is this reference that you can look at to start with in order to understand how one could think of SDN implementation in 6TiSCH.

So, control overhead is also there, because you are talking about SDN. SDN one of the important you know challenges is to deal with this overhead of control, control overhead in SDN is an important challenge. It gives lot of benefits, but it is also a challenge and how do you deal with this control overhead for this basically the slicing mechanism has been proposed.

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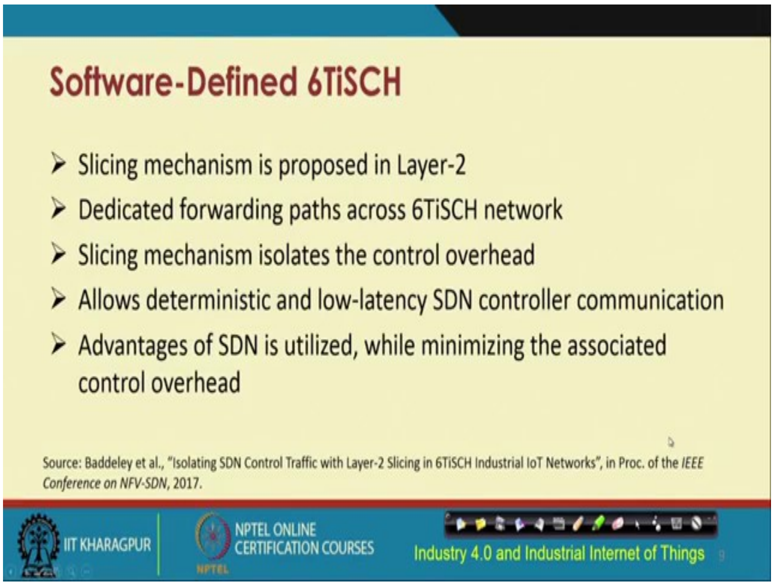


And in this particular slicing mechanism what we are talking about is to have different time slices or time slots similar kind of concepts like that and have certain devices have certain time slots the end devices, edge device you know share certain time slots the other time slots will be given to the controller. So, all of them will be using this you know the different time slices or time slots at different points of time and using them.

So, basically the slicing mechanism will give you dedicated forwarding paths across the 6TiSCH network in a much more efficient manner and will also help you in reducing the control overhead. So, basically holistically one is going to have software defined 6TiSCH providing through the slicing mechanism, providing deterministic low latency, communication for improving the performance of the network, particularly from a overall reduction of control over head and so on. So, the advantages would be that if you use SDN you are going to take care of all of these things in a much more efficient manner.

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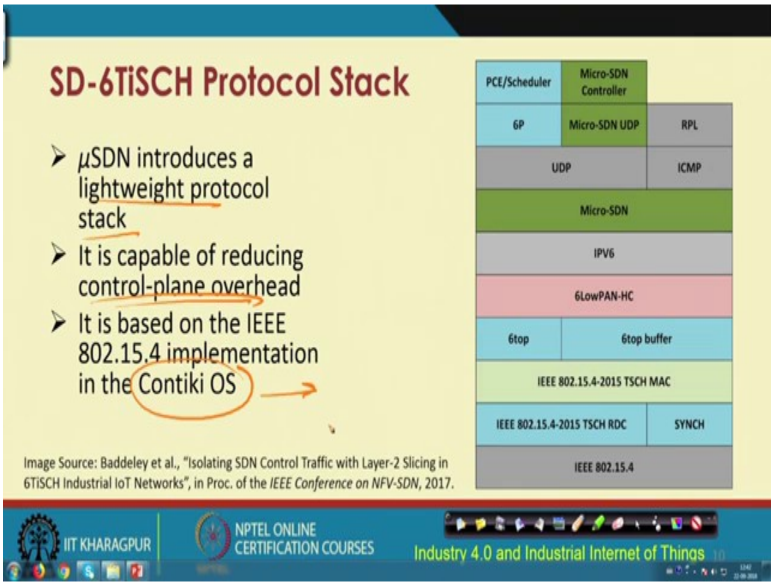


This is at very nutshell this is how this software defined 6TiSCH protocol stack looks like. So, I am not going to go through any of them in detail, but as you can see over here these are these different layers. So, layers at the very bottom 802.15.4 standard that we have talked about earlier, but these you know customized ones like the TSCH RDC, SYNCH, then you have this 802.15.4-2015 TSCH MAC and the then you have this 6 Low PAN - HC. So, 6 Low PAN basically as you know that this is a network layer protocol. 6 Low PAN we have talked about it earlier in a different lecture and this 6 basically comes from IPV6 and has been used in the 6TiSCH protocol. So, this name 6TiSCH basically the 6 comes from IPV 6 or from the 6 of the 6 Low PAN.

And then you have this concepts of the micro SDN and this micro SDN basically introduces a lightweight protocol stack that is capable of reducing the control plane overhead and it is based on the IEEE 802.15.4 implementation in this Contiki operating system which is for simulation of sensor networks Contiki is widely used. So, this basically runs on top of the Contiki operating system.

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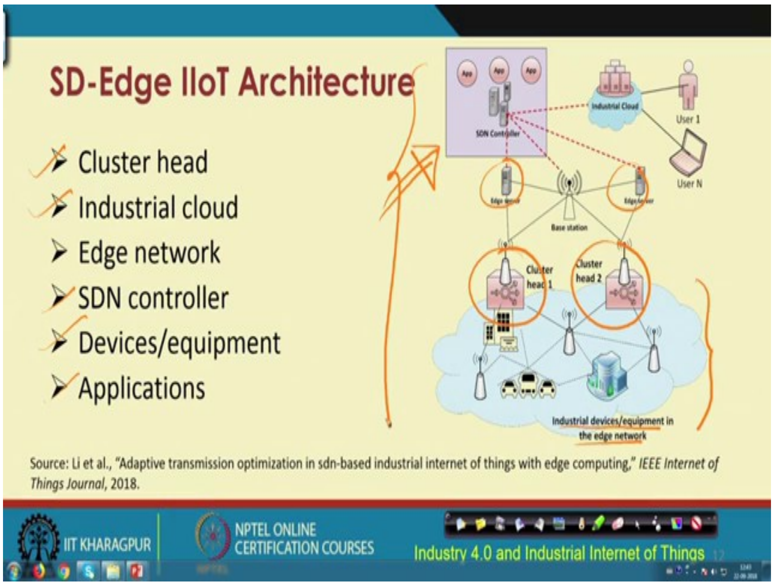


So, a software defined edge for IIoT -- this is the overall architecture you have different industrial devices and equipments in the edge network like the ones that are shown over here. And then you have these different cluster heads and you have these edge servers there after which are going to be internet work in this particular manner and then you have this SDN controller which is sitting on top in order to control the entire thing.

So, you are going to have in the software defined edge IIoT architecture different components such as the cluster head, industrial cloud, edge network, software defined network controller, devices and equipments and these applications which holistically has been shown in this particular architecture and this is quite self-explanatory. So, I do not need to go through each of these different components in further detail.

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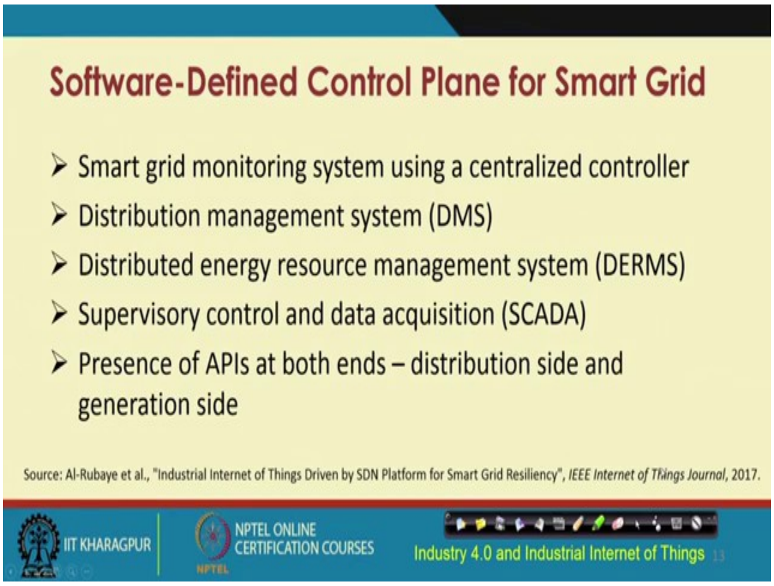


So, software defined control plane is also applicable for smart energy, smart read scenarios, in smart grid monitoring systems one could be used using the centralized controller. There are different other components in the software defined smart grid components such as the Distributed Management System the DMS, the DERMS which is basically they are Distributed Energy Resource Management System. The SCADA is there, which is important for automation as we have seen before automation and enablement of a IIoT and for SDIIoT as well SCADA is a very important component for enabling whatever we have discussed.

So, basically this particular literature in case you are interested for SDN enabled smart grid this particular literature will give you the highlights of how you are going to deal with the software defined control plane for the smart grid. So, this is the holistic view of the software defined control plane for the smart grid.

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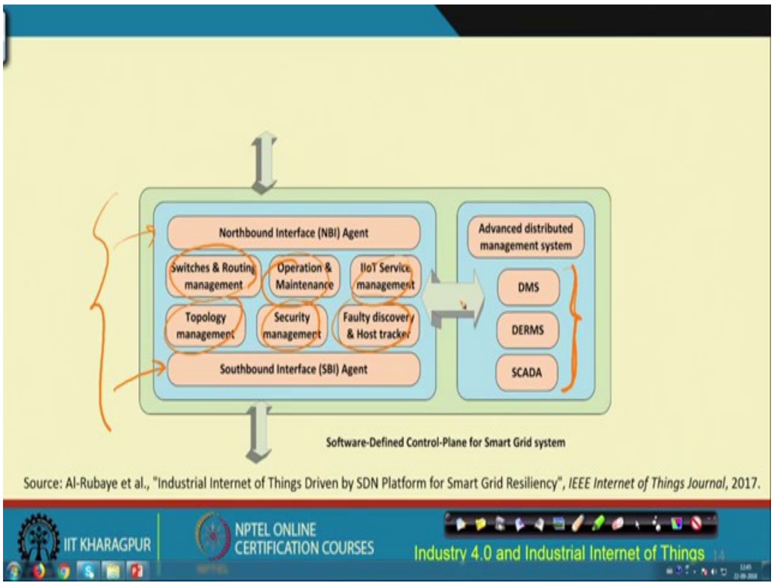


It shows only the control plane so, you are going to have all of these different components including your Southbound (SBI), North bound (NBI) and intermediate components such as switches and routers, operations and maintenance, service management, fault discovery tracking, fault tolerance in general security issues top topology management and so on. So, all of these basically are taken care of in this particular layer the control layer.

And then you have on the other side all these different components like the ones that I had shown you in the previous slide. So, SCADA, DERMS and DMS are part of this advanced distributed management system. So, together basically they work hand in hand in order to offer the software defined SDN services for smart grid.

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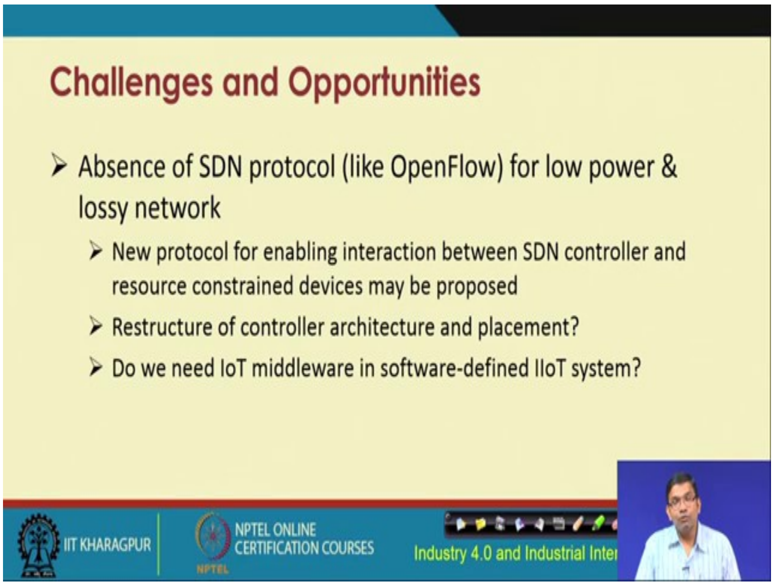


So, the challenges with respect to SDN and it is implementation in IIoT is IIoT we are talking about a highly constraint lossy network having low power and so on. SDN implementation in this kind of constant environment for example, implementation of open flow in this kind of constrained environment is required, but is a huge challenge. Open flow protocol itself is heavyweight and implementing open flow as such in IIoT constraint environments, lossy environments is a huge challenge which is quite understandable, but it has to be done as well.

So, there are consequently different works that are focusing on how you can make in open flow or other software defined solutions, light weight for implementation in these kind of constraint lossy environments of IIoT.

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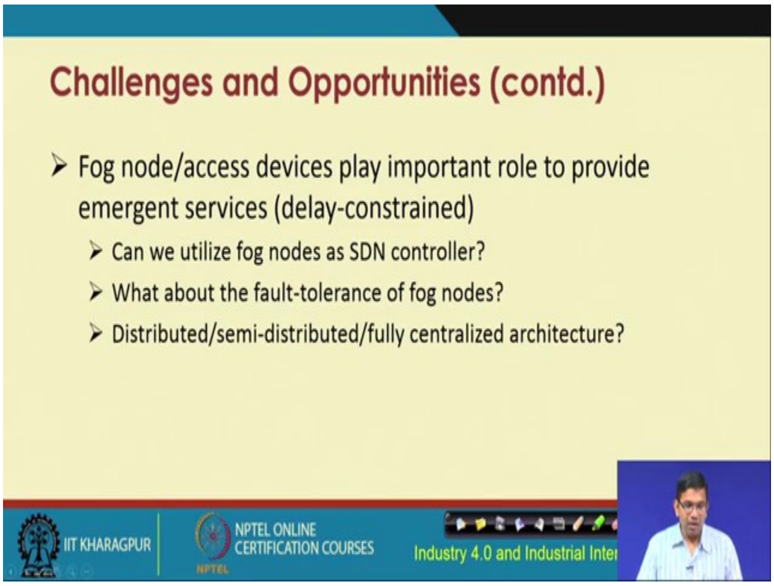


So, there are different issues different solutions for example, consideration of fog architecture where some part of the open flow or the software-defined solutions that you talked about can be implemented in the fog nodes, in the edge devices and so on and the other parts can be implemented in the centralized manner in the cloud and so on. So, there are like fog enabled solutions that are also being proposed in order to take care of these different challenges of implementing software defined networks for this constraint and lossy environments of IIoT.

We are now going to show you the implementation of open flow through Mininet which is a popular emulator that is there in the community. So, how you can use Mininet for implementing software defined networks and catering to the requirements of IIoT is what I am going to give you shortly a brief demo. So, I have with me Mr. Samaresh Bera along with me will help me in giving this particular demo. So, I am going to show you first of all how this architecture that is going to look like for implementation in Mininet. So, let me just show you this thing first that let us say that we want to implement the software defined networks in Mininet.

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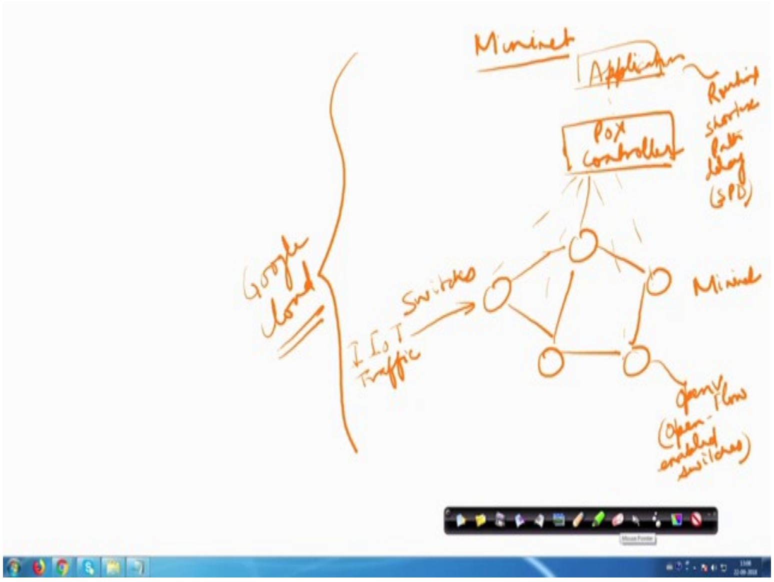

So, Mininet is the emulator with which we are going to emulate this software defined network scenario and we are going to use the IIoT traffic; IoT traffic more specifically. So, let us say that we have this Mininet which is going to take care of instantiation of these different nodes.

Let us say that these round circles are your different switches. So, these are your switches and that we will have a scenario like this that you are going to float some IIoT traffic through these switches and these switches will have something known as openV which is basically open flow enablement in those switches. So, we have this open rounded circles, let us assume that these are openV enabled switches.

So, which implements the open flow in it and we are going to have IIoT traffic coming through any of these different nodes and then we will have a controller. So, in SDN we have already seen that we need some kind of a controller and is the specific controller that we are going to use it is name is pox. So, pox controller is going to have this particular control over these different switches which are these openV switches right, and on top you have an application or different applications that might be running as well. So, let us say that some application is running.

So, in our case I want to show you the execution of let us see some routing protocol. The simplest routing protocol that I can think of is the shortest path delay; that means, that the shortest delay path is going to be chosen. So, in short this is known as SPD the shortest path -- the path which has the least delay is going to be chosen. So, shortest path delay protocol is going to be executed using this particular controller.

So, this is this scenario that we are going to show you now, how you are going to implement and how this routing is going to happen. And this is the Mininet environment which is executed over this Google cloud and I am going to show you how we are going to have this implementation done using Mininet emulator.

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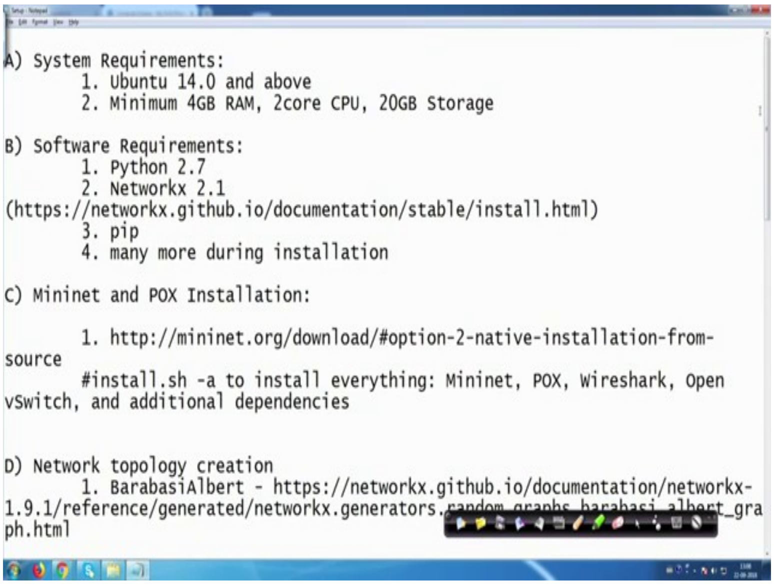


So, before I do that let me also show you something what you need to do before actually you learn this. So, for implementation first of all we need to basically have certain system settings. So, these are these different settings that will have to be done before we run our shortest path delay protocol on Mininet.

So, first of all these are the system requirements so, you need to have Ubuntu 14 and above with a minimum 4 GB RAM with 2 core CPU and 20 GB storage. The other requirements are like you know you need to install a few software python 2.7, networkx 2.1 and pip and few more installations will have to be done. Also after you have installed all of these then you have to install the Mininet and the POX. So, Mininet installation you know I have given you the source for downloading Mininet and also for installation the command that can be used is also given over here.

So, install.sh, this is going to install this mininet, pox etc. whatever the other dependencies are there so, everything is going to be installed after the downloading over here. So, thereafter we are going to have the network topology creation for that this particular package can be downloaded and it can be installed in this manner.

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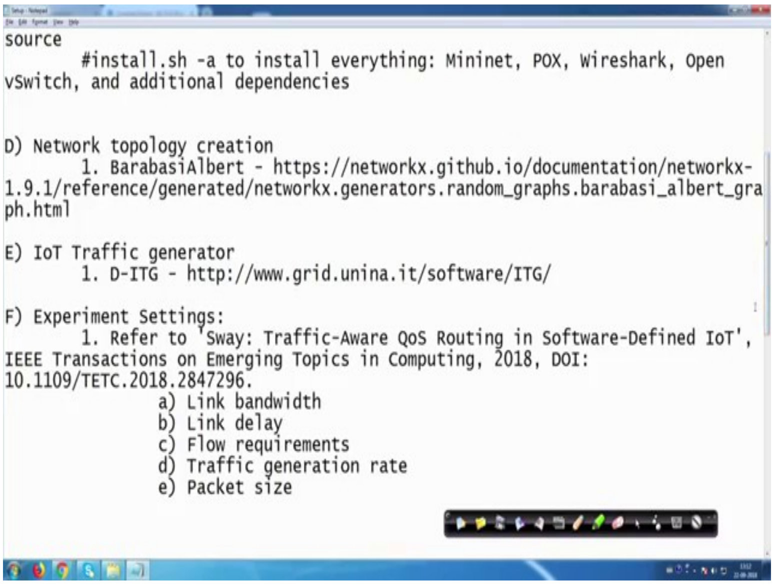


And for IoT traffic generator, this is this traffic generator that we have used; we have used the D-ITG traffic generator and it can be you know it can be procured from this particular source. And therefore, experiment settings basically you know please go through our paper which is the title of which is given over here.

It was published in the IEEE transactions on emerging topics in computing in 2018 and the corresponding DOI is also given for you. So, using this particular reference you can go through our paper the corresponding settings that are there. So, we will be using those settings for showing you this particular experiment. So, settings of the link bandwidth, link delay, flow requirements, traffic generation, rate, packet, size, etc. all of these are specified in this particular paper. So, use those settings.

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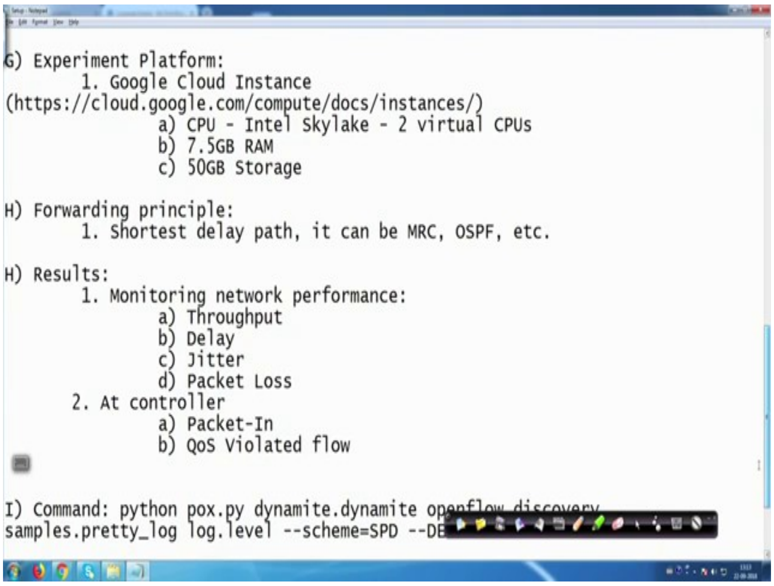


The experimental platform as I told you will be using the Google cloud and so this particular Google cloud instance we are using so, with the CPU - Intel Skylake - 2 virtual CPUs, RAM 7.5 GB and 50 GB storage and the forwarding principle will be using the shortest delay path, you could use any other routing algorithm you as well like your open shortest path first protocol or MRC or any other routing information protocol reap or whatever you want.

So, for just example sake we are going to show you the shortest delay path and you know how it is going to forward the packets from 1 point to another. So, these packets are basically routing traffic packets that we are talking about. The results that we are going to show you are basically the ones which will take care of network performance monitoring, with respect to throughput, delay, and jitter (basically the rate of change of delay with respect to time).

So, jitter, packet loss are some of the standard network performance monitoring parameters and these will be used, also for at the controller in the packet- in; that means, the number of packets that are coming to the controller and the QoS violations that are there. So, all of these will be measured and will be shown.

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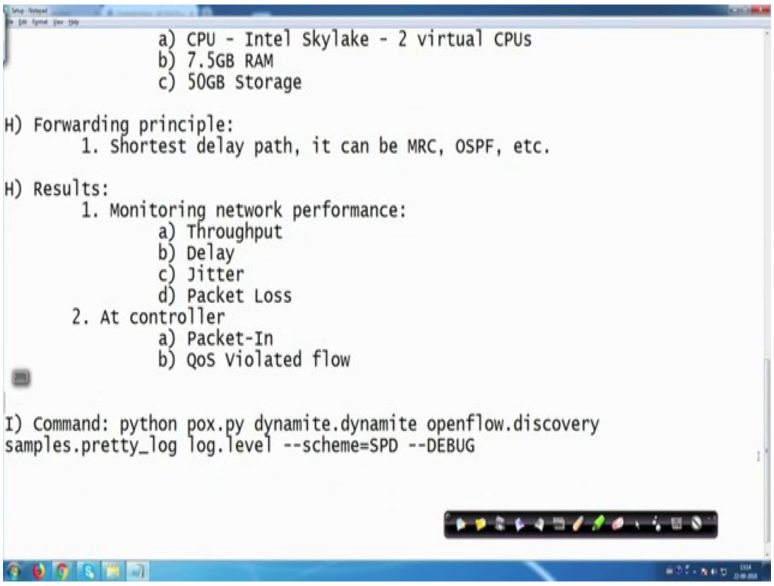


So, if you are talking about a research paper then basically you plot these network parameters, you show how these network parameters very with respect to time and. So, this is the command that you are going to use in order to execute this particular protocol that we are going to show and it is performance. So, this is this particular command that we are going to use.

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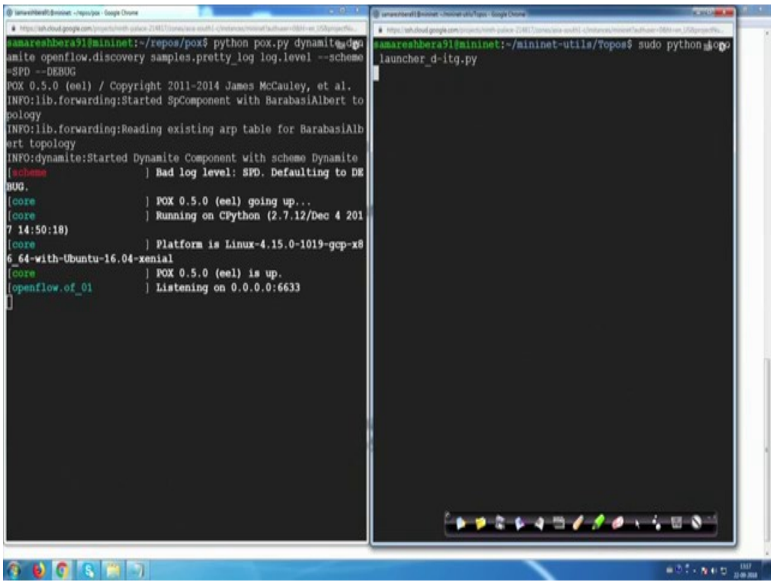


So, let us now go to this particular window and let us show you how things are going to work. So, as professor Misra mentioned that we will be using the Mininet emulator to creating the network topology using Barabasi Albert and we use the POX controller to control the switches and we are using open flow 1.1. As Mininet supports 1.1, it does not support 1.2 or 1.3. So, we will be using open flow version 1.1. So, in left side window we have the pox controller terminal and in the right side we have the Mininet topology terminal.

So, first we have to enable the POX controller so that it can listen to the switches. So, I will use some command. So, this is the command that we have written a code according to the requirements like the shortest delay path, will be running and executing the Python program, "python pox.py" which will enable all the modules of POX controller. Then we have the design scheme then open flow dot discovery so, that it can listen to all the switches whichever is been discovered. And finally, we have enabled the debugging method. So, let me run this command so, you can see the open flow is listening on port number 6633 and it is the local controller so that is why we do not have any external IP address.

Now, the POX controller is listening. So, after enabling the pox controller we will emulate the network using Mininet. So, for that we have the specific command that "sudo python ___.py" we have created a particular script to create the topology as well as to generate the traffic.

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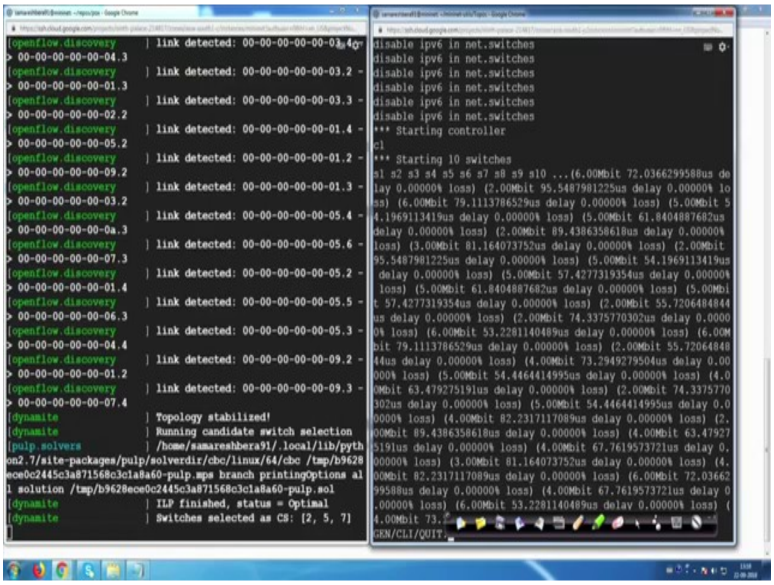

So, after emulating the network, you have created the network using Barabasi Albert topology and the pox controller listening to the switches that is why you can see that open flow dot discovery, discover different switches, the link detected, the switches detected. If I go up at the pox controller side you will see that different links are detected and these are the switches which are connected to the POX controller.

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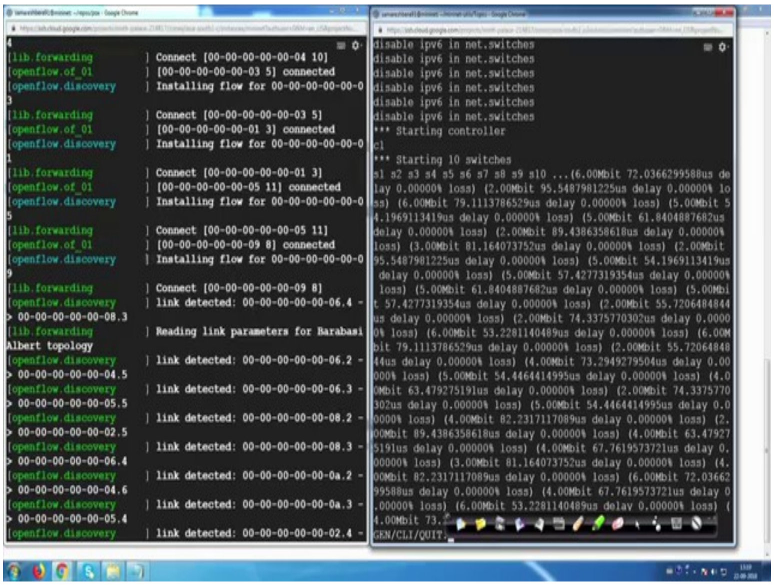


Now after creating the topology, the topology is stable and it is connected to the POX controller now using the command gen, I will generate the traffic. So, writing gen means it is enabling to generate the IoT traffic which we have defined, we have written in the script. So, if I place on gen then it is going to generate the IoT traffics.

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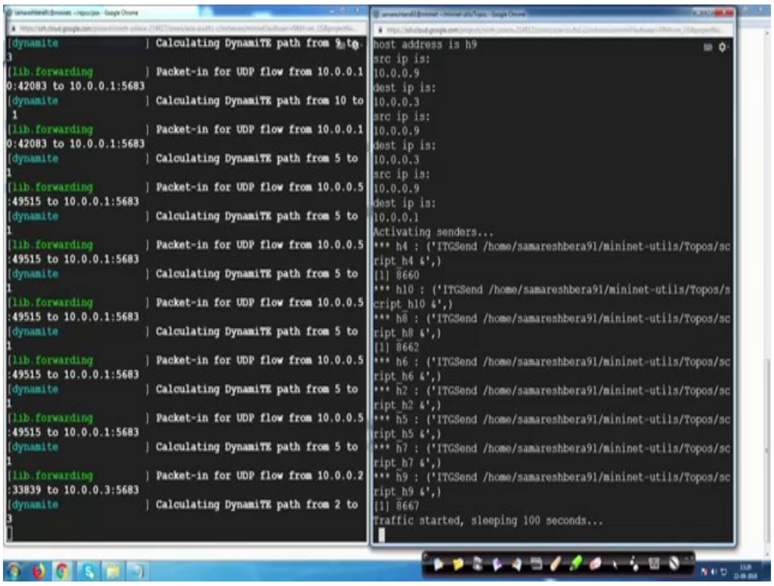


So, we have emulated the traffic for 100 seconds; that means, for 100 seconds it will generate few number of flows. So, a flow is a stream of packets; that means, we have generating few number of flows, but number of packets are in the order of 1000. So, in the left hand side at the pox controller you can see a packet in for UDP flows packet in for TCP flow. So, different packet flows are generated and the pox controller receives the packet in messages. So, just let us wait for some time to complete the experiment and then we will show you the results.

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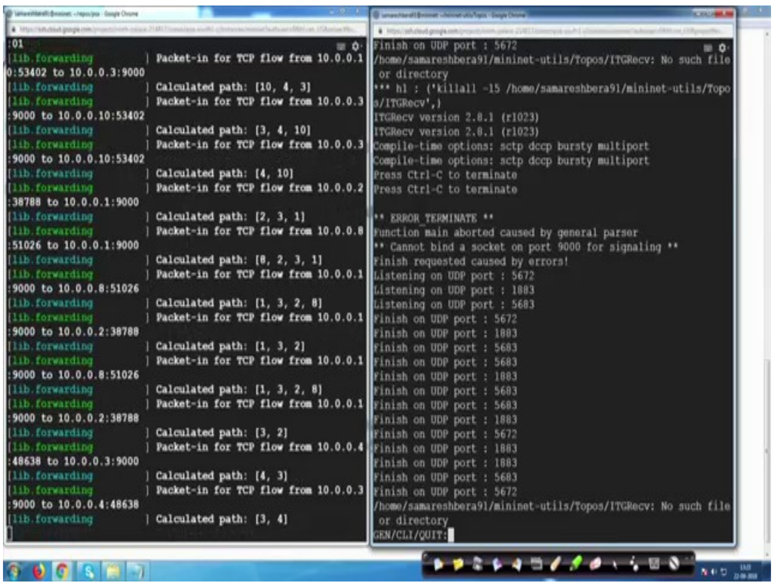

So, all the traffics are generated, the flows are generated and you can see the finish on UDP ports of different ports are generated as source. So, we have completed the traffic generation.

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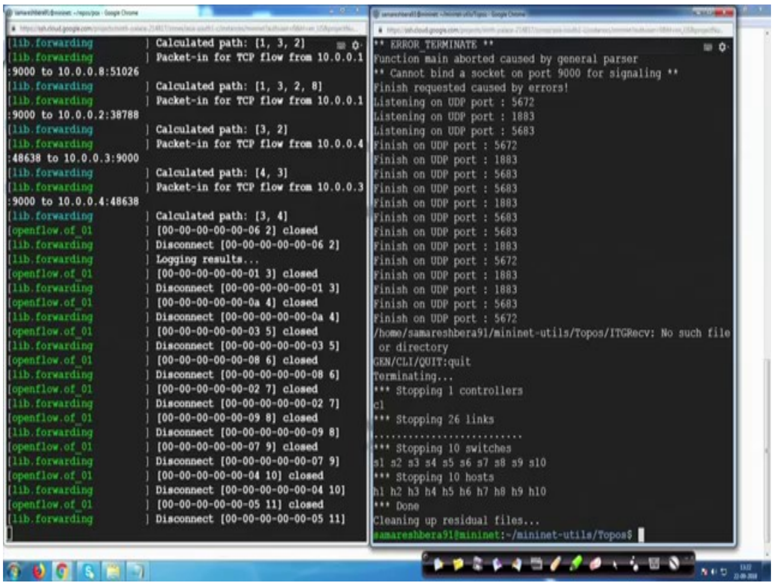


So, let us quit the Mininet emulator. So, in the left hand side you can see at the POX controller it is detected that the switches are disconnecting so, disconnected with the switch id number. Now let us show you the results.

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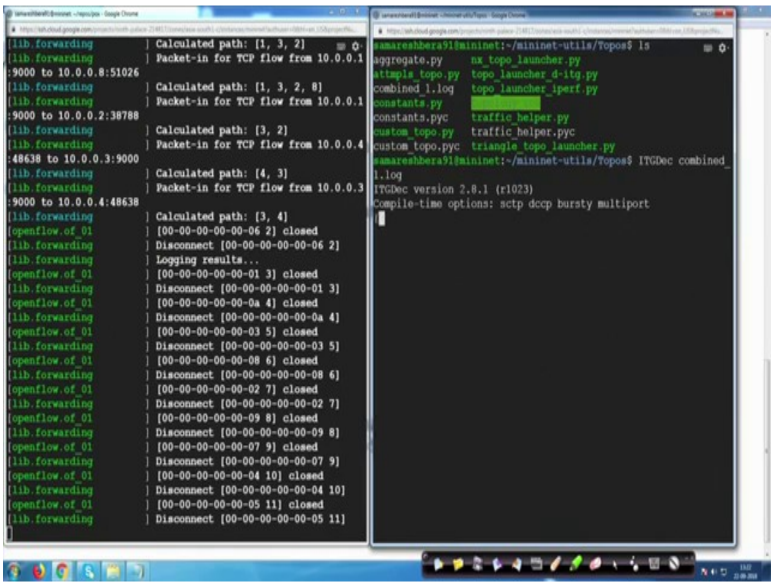

So, here you can see at the Mininet emulator a log is generated which contains the different network performance matrix. So, let me decode it so as we have generated the traffic using D-ITG generator. So, we have to use this command ITG Decode. So, the command is “ITGDec ___.log” (lig file name).

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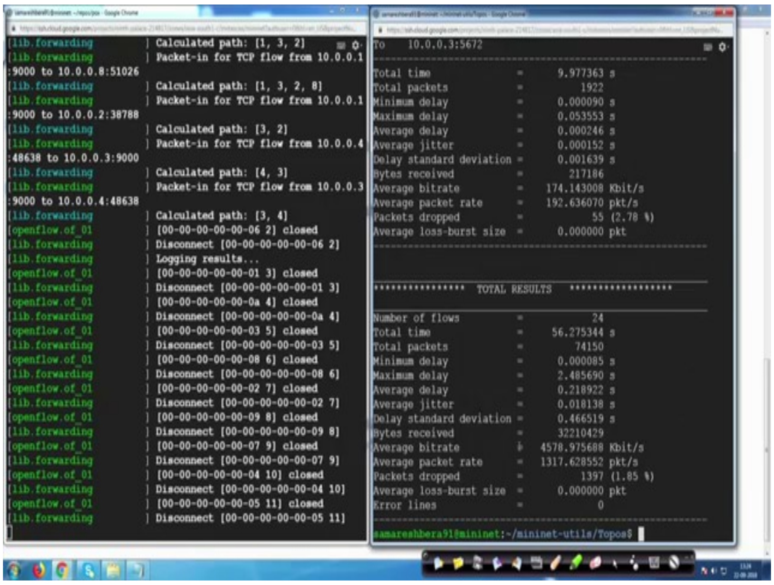


So, it is just compiling the entire thing. Now at the end you can see, we have generated the total number of flows which is 24, total time is 50 seconds. So, although we have defined 100 seconds within 50 seconds all flows are generated and routed in the network. And as I have mentioned the total number of packets is in the order of 1000s so, for 24 flows the total number of packets are generated 74,150.

And we can see different things like what is the average delay, that is 218 milliseconds, then average jitter which is 18 millisecond and then we have the average bit rate which is the throughput. So, we have got 4578 kbps and finally, at the end you can see average number of packets dropped which is 1.85 percent, which is very minimal. So, you can design your own benchmark and you can experiment it and accordingly you can measure the network performance. At the POX controller let us see what happened. I am exiting the POX controller.

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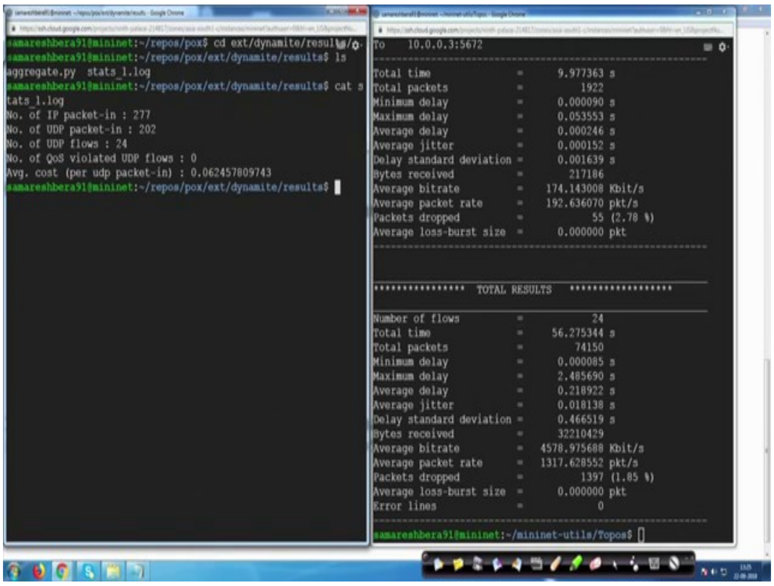


So, where we have stored the results let us see what we have obtained. So, "cat stats 1.log", we have generated this one. So, let me check what we have got here. So, total number of IP packet we have received 277. So, number of UDP packet we have received 202 because typical as Professor Misra mentioned that typically in IoT scenario you have UDP flows. So, that is why we have counted the UDP packet also and number of UDP flows is 24.

So, in the left right hand side you can see the number of flows is also generated which is 24, number of QoS violated UDP flow which is 0. So, although we have 74,150 packets in the network, but we have got only 277 packet in messages at the controller end. That means, according to the flow rules multiple number of packets which are matched with the flow rule eventually forwarded to the destination without generating the packet at the controller rate.

So, this is a small demo we have shown to you, so that you can emulate the IoT traffic and you can a monitor the network performance, also you can phase the real data which are coming from the sensors to the network and you can deploy your own routing algorithm using the SDN controller in the real time to have, let us say, minimize delay or minimum loss or, let us say, that we want to have the maximize the network efficiency.

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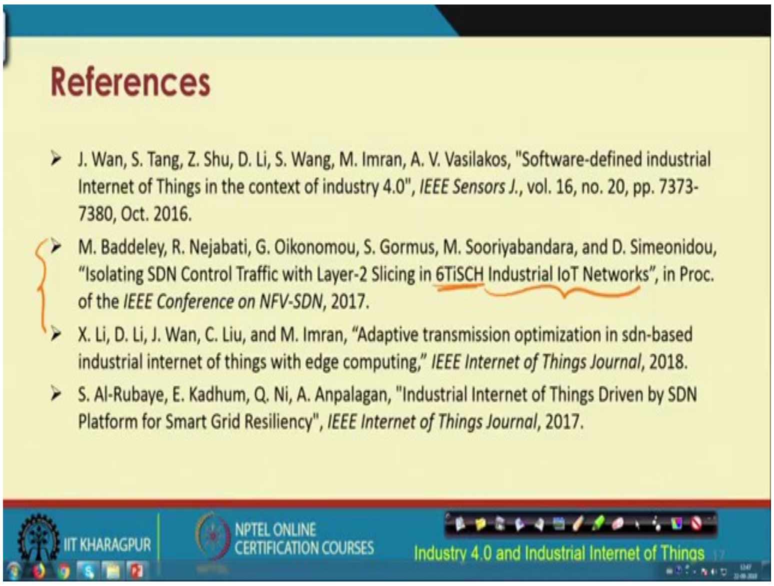


So, with this we come to end and this is a list of different references for you to go through further on IIoT and software defined IIoT. These references will give you a better idea about the different solutions and the different initiatives that are in place. This particular literature I would encourage you to go through in order to understand the 6TiSCH architecture and it is adoption for industrial IoT scenarios and how you could have the SDN enabled for the 6TiSCH architecture for IIoT. So, with this we come to an end of the entire lectures on software defined networks for IIoT.

Thank you.

**Introduction to Industry 4.0 and Industrial Internet of things**
**Prof. Sudip Misra**
**Department of Computer Science and Engineering**
**Indian Institute of Technology, Kharagpur**

**Lecture – 47**
**Advanced Technologies: Security in IIoT - Part 1**

In this particular lecture, we are going to focus on the security aspects of IIoT. So, this particular lecture will give a highlight of the different security issues, the vulnerabilities that exist due to the incorporation of IoT in the industrial sector, manufacturing plants and so on, and why these vulnerabilities arise and what are the main issues and so on. And at a very high level; what are the ways forward the discussions about those. So, this is what we are going to discuss in this particular lecture and the next.

So, when we think about IIoT. So, IIoT is industrial IoT as we have seen this in detail in the last several lectures. So, industrial IoT, when we talk about it is basically an integration of IoT to cater to the requirements of the industrial sector. So, every industrial sector has its own separate requirements. So, catering to those specific requirements for these different industry verticals is what IIoT should concern.

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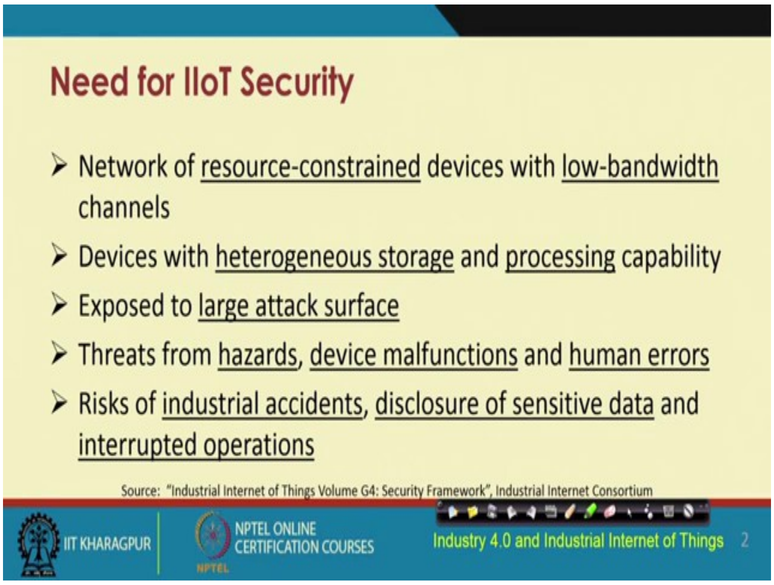


So, let us look at some of these different issues. So, when we talk about IoT as I was telling you that IoT is basically a resource constraint environment internet of things. So, this is what we have been telling time and again in the last several lectures that IoT.

Forget about IIoT, but IoT in general is a highly resource constraint environment with devices which operate in low bandwidth and in resource constraint environment such as devices having very low energy, the devices having very low computational power, the everything like even the storage the buffer etc.; everything is highly constraint. So, we have such a constraint environment.

Now you know when we talk about security, as most of us already know that security basically there are lot of different security solutions that are available right. So, security for IoT particularly in general is something that has been well researched. There are so many different security solutions considering different aspects of security and so on. System security, information security; lot of works are available, lot of different algorithms have been proposed. All these algorithms like you know RSA, Diffie-Hellman and many others right, even the digital certificates and so on; digital signatures and so on; all of these different works on security.

These have been proposed primarily for resourceful environments right; so, where there is no resource constraints. Now, when we talk about wireless networks in general. Wireless networks if we are talking about the traditional wireless networks like cellular networks and Wi-Fi etc.; these have some additional vulnerabilities over the wired counterparts, but still these are not highly resource constraint networks. So, the devices are not highly resource constraint. But when you are talking about IoT devices, these devices are operating in highly resource constraint environments right. So, all these sorts of constraints that I told you just now, so those constraints are applicable for these IoT resource constraint devices.

So, one thing is that IoT devices are primarily, but not necessarily wireless devices right. So, they operate in wireless environment. Secondly, they are resource constrained. And when we talk about IIoT, basically what we are talking about is the incorporation of these IoT systems into the manufacturing sector or the industrial sector. Now, the industrial sector has its own different characteristics, which basically adds to the list of vulnerabilities that were already existing with IoT. So, additional vulnerabilities because of this implementation of IoT in the industrial sector, there are some additional vulnerabilities that are going to be existing.

So, how you are going to deal with all of these different types of vulnerabilities; what are the different types of attacks and what are going to be the different solutions is what concerns security in IIoT. So, going back, as I told you that we are talking about a resource constraint environment, devices are highly resource constraint, energy constraint, processing power constraint, buffer constraint and resource constraint with respect to all kinds of computational resources that we can think off. Plus these IoT devices operate in low bandwidth channels; typically, low bandwidth wireless channels and all these different types of communication wireless communication, wire communication applicable for IoT these are the ones that we have already seen.

And we have always already seen that these different ones which are characterized with their own different features, they pose if you think little deeper, they will pose their own different vulnerabilities which will have to be addressed. Otherwise there could be attacks, security attacks that would be possible; so, that is number one.

Second thing is that we are talking about in the IoT world, not a homogeneous kind of environment, heterogeneous devices; devices following different standards, devices which have been developed through proprietary means using proprietary technology by different vendors, devices having different configurations with respect to storage, with respect to processing capability and so on.

So, these are highly heterogeneous devices, following different own proprietary standards, following different heterogeneous network protocols and other protocols and so on. So, you see that we have a highly complex heterogeneous environment which also adds to the different vulnerabilities that might already exist with IIoT.

Third is that because of all these vulnerabilities, wireless nature and so on and so forth, these systems are exposed to large attack surfaces. So, large attack surface means that there are so many different types of attacks that are possible because of the diverse nature of vulnerabilities that exist in these IoT systems integrated with the industrial systems and so on. So, there are different types of threats.

Additionally in IIoT systems, threats due to different types of industrial hazards; due to the hazards, due to the machineries and so on. Device malfunctions, malfunction of the networks, and human errors. Human is very important in the manufacturing sector, in the industrial sector. So, human errors, there are risks of industrial accidents, disclosure of sensitive data, interrupted operations and so on.

So, as you can see that in a typical IIoT environment, we are not just talking about IoT. We are not just talking about devices, networks and so on. We are not just talking about connectivity, we are also talking about the industrial machinery and their operations and the additional risks or vulnerabilities that come up due to the integration of these low power resource constraint devices in these industrial plants.

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So, the basic security goals with respect to IIoT are 1. Availability. So, availability means that only the authorized users must guest access to the data, but they must get access to the data whenever it is required; irrespective of whether there is any threat or there is any failure of any kind.

Integrity is the 2nd goal of IIoT security. Integrity basically talks about that from the point; the data was sent, till the point that the data was received by the receiver. The contents of the data, the nature of the data, the data as a whole has not changed. So, basically the data that are sent are exactly received in the same way at the receiver; so, that is integrity. 3rd is the confidentiality. Confidentiality basically ensures that only the intended users will get access to the data. So, only the intended users will be able to derive value out of the data and for all others, the data will either not be made available or if it is made available by any chance, then the data will not be of any use to the others.

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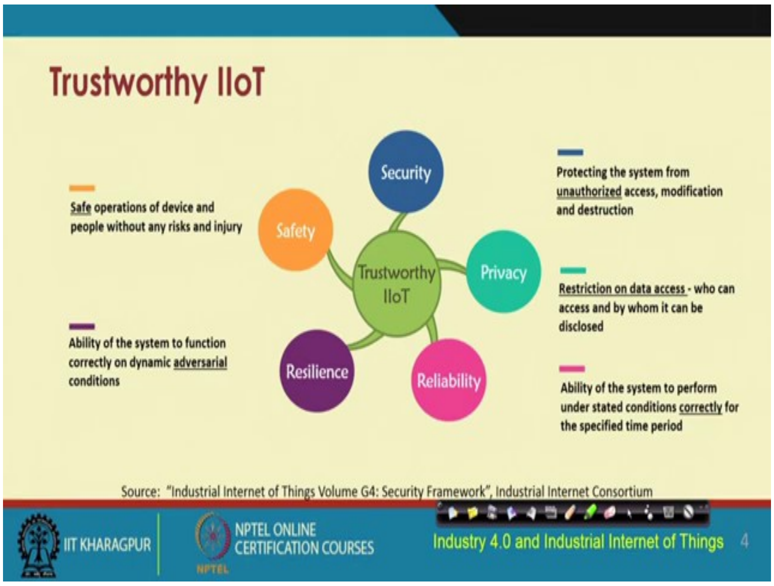


Now, IIoT systems must be trustworthy. Trustworthiness when we talk about has different facets. Trustworthiness with respect to security is what I have been talking about in the last few minutes. Trustworthiness with respect to privacy; that means, only the data will be made available to the ones that are the genuine recipients of it; the privacy of the data should be restricted; the access to the data should be restricted and so on. Only the intended recipients should be able to get access to it; others should not be able to. The privacy of the data should be maintained.

Reliability is very important. So, basically reliability ensures that the system has the ability to perform the under stated conditions correctly for the specified duration of time. Resilience is very important which basically ensures that the system is able to function correctly on dynamic adversarial conditions; if the nature of the adversaries changes, then also the system would be able to function correctly.

And safety; safety particularly is an important characteristics of the industrial IoT. Safety basically ensures that the machinery that are being used, the devices that are being used are not going to pose any risks or are going to not hurt or give injury to the users.

So, safe operations of the device of the machinery and the people without posing any risks and injury that is the safety component of the trustworthiness.

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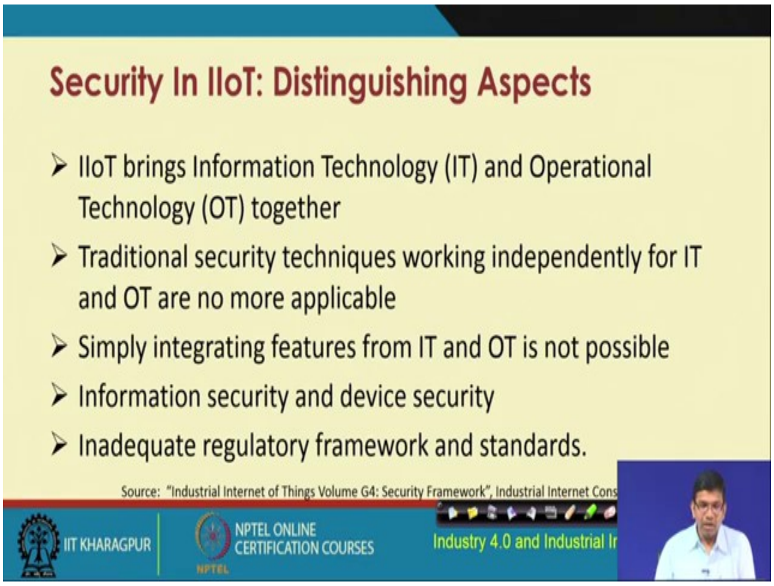


So, security in IIoT, there are certain distinguishing characteristics over the traditional IoT. So, when we talk about IIoT, as we discussed in a previous lecture we are typically at a very high level talking about the integration of information technology with operational technology. So, this operational technology component comes characteristic of industrial sector. So, this operational technology along with the traditional information technology from the traditional IoT, the integration of both of these is the distinguishing characteristic of IIoT.

Traditional security techniques working independently for IT and working independently of OT in the traditional manufacturing plants are no more applicable. So, we are not talking about independent operation of IT, we are not talking about independent operation of OT. It is an environment where IT and OT work hand in hand and that is where we have to consider the features the requirements and so on of both IT and OT and we have to come up with security mechanisms to for that converged set of for the converse set of requirements.

So, simply integrating features from IT and OT is also not possible and is not desirable. So, information security and device security will have to be considered together in order to come up with that IT or OT converged set of requirements for catering to the requirements of security in IIoT as a whole. In addition, we also have to take into consideration the regulatory framework, the regulatory standards that are existing because the regulatory issues are also a very important alongside to be considered for security.

Regulatory standards are very important because if you do not consider the proper regulatory standards, there might be some vulnerabilities that might come, some attacks might sneak in because of those non compliance of these systems with the regulatory standard. So, these are some of these distinguishing aspects of security in our IIoT.

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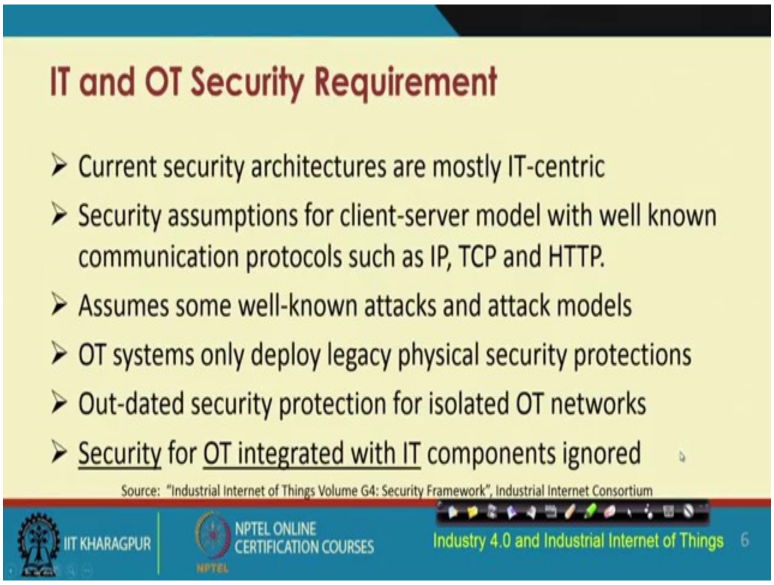


So, I have been talking a lot about IT and OT security requirement. We have seen that both sorts of requirements will have to be considered. Security for OT integrated with IT components is something that is required to be considered, but is often ignored. So, whenever people talk about IIoT, they simply think about IoT security not IT and OT security integrated as a whole. So, this is the most important requirement that will have to be considered, when we are talking about IIoT security.

So, the current security architectures that are available particularly for catering to IoT requirements are mostly IT centric. Security assumptions for client-server model with well known communication protocols such as IP, TCP, HTTP are no longer valid for IIoT, when we are talking about this IT-OT convergence. So, the well-known attacks and attack models that are there for traditional networks, for traditional wireless networks are also not sufficient to be considered for this kind of IT-OT converged environment.

So, you need to also find out the different other attack possibilities that might exist due to this particular integration of IT with OT. OT systems only deploy legacy physical security protections and IT ones will only cater to the requirements of the traditional IT centric equipments. So, the outdated security prediction are there for most of the isolated OT networks in the most of the industries. So, we need to come up with an integrated solution for catering to the requirements of both IT and OT.

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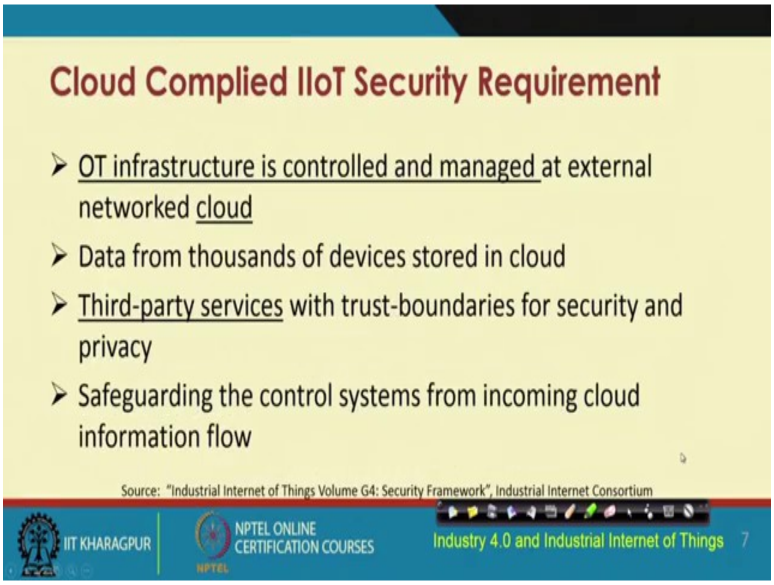


So, having said that let us first try to understand as a whole, what I have just mentioned. So, let us look at this trust issue in IIoT.

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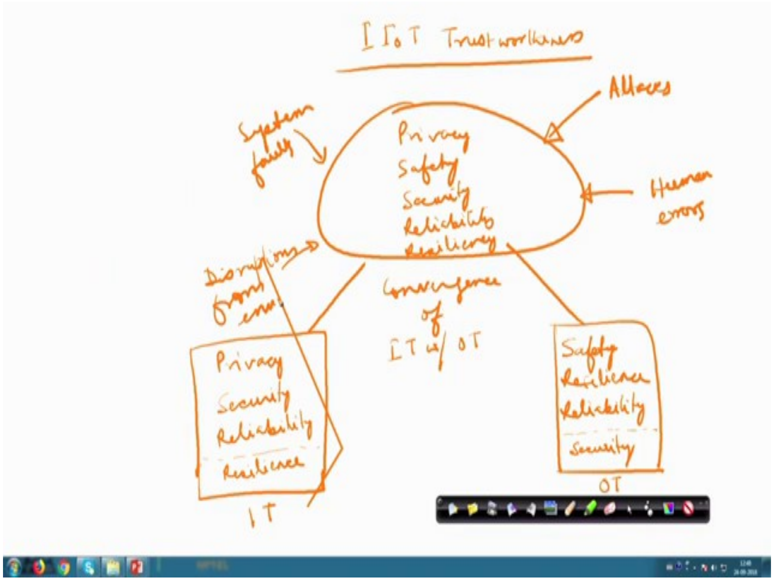


So, IIoT trustworthiness. This is very important. So, let us try to begin into this particular issue in little bit more detail. So, I have been talking a lot about the IT issues. So, we are talking about IT and OT convergence. So, this is let us say OT. So, whenever you are talking about IoT, then IT issues are important. But in industrial IoT, you have to also take into consideration the OT issues.

So, IT trustworthiness will take into consideration issues of privacy, issues of security, issues of reliability and to some extent resilience. On the other hand, if you are talking about OT trustworthiness, the main issues of concern are safety, device safety, machine safety and so on. Resilience is more important over here, and reliability; to some extent security is also important.

So, these are the issues of concern if we are talking about isolated IT systems and their trustworthiness and these are the issues of concern if we are talking about isolated OT systems and their trustworthiness. So, what is required in an IIoT scenario, we have to converge these two. So, the convergence of IT with OT has to happen.

So, for this basically we need to come up with an integrated set of requirements which will consider privacy, which will consider safety, which will consider security, which will consider reliability and resilience everything together. So, we have to come up with a trust model catering to all these requirements. So, as to make the system robust from different types of attacks; any kind of human or external machinery errors, different system faults and disruptions from environment. So, these are different considerations. So, now, we have also seen that cloud integrated IIoT solutions are very popular nowadays.

So, when you are talking about cloud; cloud is typically a third party service. Now whenever you are talking about a third party service, you also need to consider, you have to extend your existing trust boundaries to include the security and privacy issues that are existing with those third party services and you also have to safeguard the control systems in your IIoT from the incoming cloud information flow. Because it should not happen that there is some sneaking in that happens through the cloud due to some cloud vulnerability and there is some attack on the industrial machinery that is supposed to operate properly.

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So, IIoT security risks will have to be managed. So, for this many management there are these different considerations that will have to be made. Number 1 is it is required to avoid the risks; second is IT is required to mitigate the risks that will be still existing. First of all you avoid; second is whatever comes in you will have to mitigate and sometimes for risk management it is required to outsource the risks; outsourced to a third party and may be typically with at some cost right.

So, you have to pay some money to the third body in the form of insurance or something like that and that is how you basically outsource the risk to some third party. Then the fourth one is that accepting the risks. So, you know after doing all of these things, there will still be some risks that will be there and one has to accept those risks and not just accepting the risks, but those residual risks that will be there, somehow you will have to moderate those risk; you have to balance out those residual risks. So, this is this overall 5 step security risk management that is applicable for IIoT.

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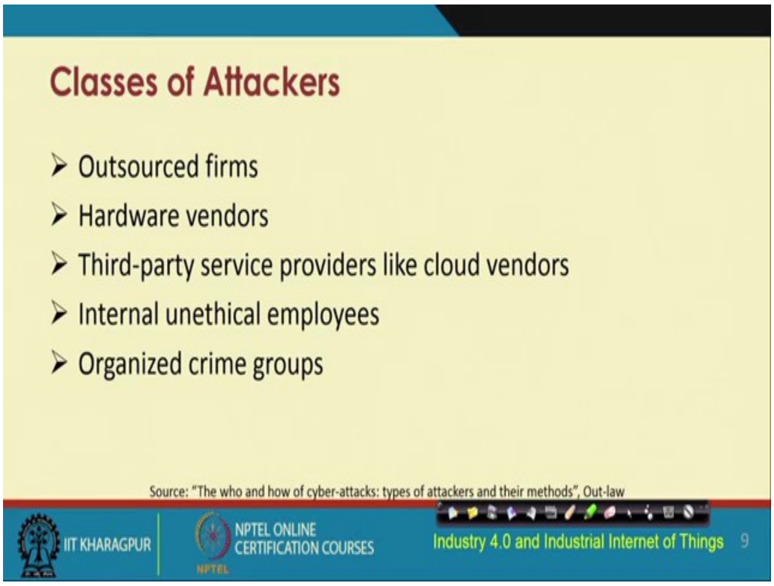


So, there are different types of attacks that are possible; different types of attackers that would be possible. IIoT basically scenarios, will involve outsourced third parties. So, those outsourced firms will be vulnerable points through which different attacks might be launched. So, outsourced firms might also pose as attackers directly or indirectly due to the vulnerabilities that might be existing in them or the vulnerabilities that arise due to the integration of those third party services to the services that are being offered in the mainstream.

Second is the hardware vendors. So, there are different hardware that are procured and are being used in IIoT. Those individual isolated systems might also have different vulnerabilities which might be points for entry for the attackers. Third-party service providers like cloud vendors would also be the attackers and internal unethical employees.

So, basically employees from within the organization who practices or adopts unethical practices, they might also be the attackers. So, these are basically the attackers from within the organization. And the last one is the organized crime groups, who intentionally want to launch different types of attacks on these IIoT systems.

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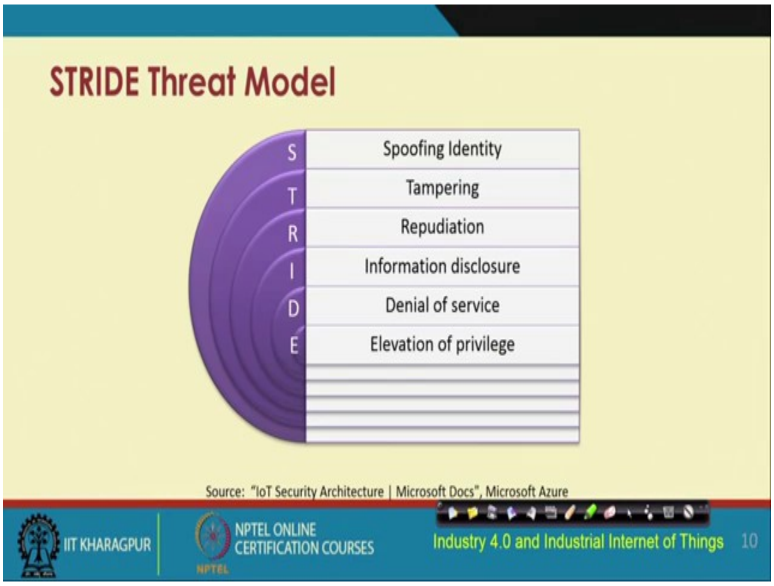


So, this is threat model and these different aspects of the threat model. So, STRIDE is the threat model. So, S stands for spoofing identity. So, basically somebody will be trying to act like a genuine user and we will try to spoof in. So, that is the spoofing identity. So, identity of a genuine user will be somehow hacked and will be somebody will be trying to pose as a legitimate user that is the spoofing identity.

Second is tampering; tampering means tampering with the system, tampering with the data to hurt the integrity of the data, to hurt the integrity of the system. Repudiation means like basically that you send the data and later on, you deny that you have sent the data. So, you know preventing from reputation is very important. So, you send the data, but later on you pose like as if you have not done anything, you have not sent the data, so, that is repudiation.

Information disclosure is well understood and denial of service; denial of service means like you send so many requests to a computational resource that after some time that resource is over flooded with the limited capacity it has and that is how basically the future requests that are sent to that particular computational facility, those are going to be denied. That is the denial of service. So, denial of service is a very popular form of attack and elevation of privilege is basically one tries to go beyond the privileges that have been given and try to get access to those different points of elevation.

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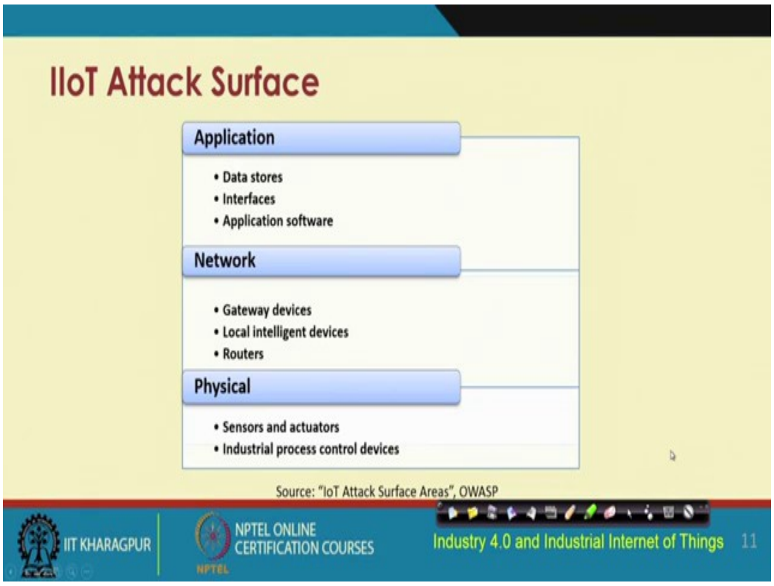


So, I was talking at the outset about the IIoT attack surface. IIoT attack surface is quite big, there are different points of vulnerability, points of attack and so on. At the application level data stores, interfaces, application software are there which are like different points of attack. At the network level the different gateway devices, routers, intelligent devices which are local to the network, those are different points of attack through the network and at the physical level the sensors, the actuators, the industrial process control devices, those are the different points of attacks.

So, IIoT attack surface is quite big. There are different diverse points of attack on the IIoT system due to the integration of so many different concepts, so many different technologies and particularly because they are heterogeneous and are quite diverse.

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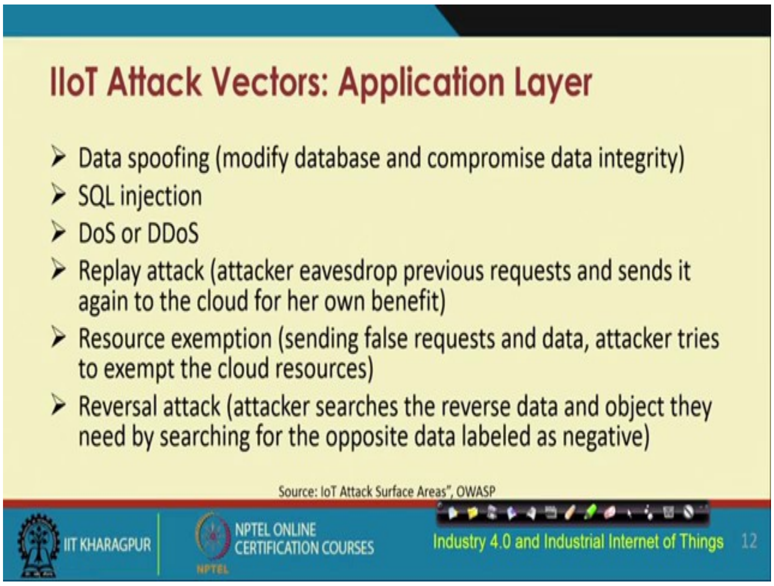


So, at the application layer, these attack vectors could be launching data spoofing attack; wherein basically the existing database the data that is resident in the database they are going to be modified, the integrity of the data is going to be hard and so on. So, that is that data spoofing attack. SQL injection attack basically is something like you sent different SQL queries to the database and thereby you try to get in through those queries to the data that normally should not be made accessible to you. So, intelligently you try to design your SQL queries in such a way that you get access to data beyond what you are supposed to get.

DoS or DDoS; Denial of Service and Distributed Denial of Service attacks. So, DoS attack, I have already told you and distributed denial of service attack is particularly relevant for IoT scenarios, where the machines themselves, the devices themselves are distributed and not centralized in one location. Replay attack basically here the attacker eavesdrop the previous requests and sends it again to the cloud for her own benefit.

Resource exemption attack here basically false requests are sent and the attacker tries to exempt the cloud resources. So, that is the resource exemption attack. Then, reversal attack; here, the attacker searches the reverse data and object they need by searching for the opposite data that is labeled as negative. So, basically through those negative data, the attacker tries to get in and get access to the legitimate data.

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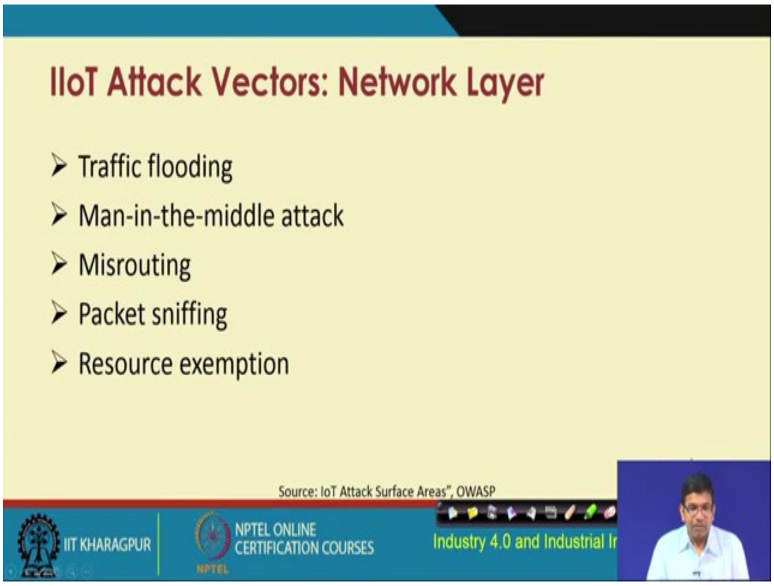


At the network layer, we are talking about traffic flooding, man-in-the-middle attack. So, basically man-in-the-middle attack means within the channel you know the entity is going to get in and get access to or going to sniff in the packets that passing through that particular channel that is the man-in-the-middle attack. Then, misrouting; so, the data are supposed to be sent through some legitimate route; but basically what happens is they are sent through some other route through which they are not supposed to be sent originally.

Packet sniffing; basically staying in between and trying to sniff the packets that are traveling in a communication channel. So, that is the packet sniffing attack and similarly resource exemption attack at the network layer is also possible and resource exemption attack I have already mentioned in the previous slide.

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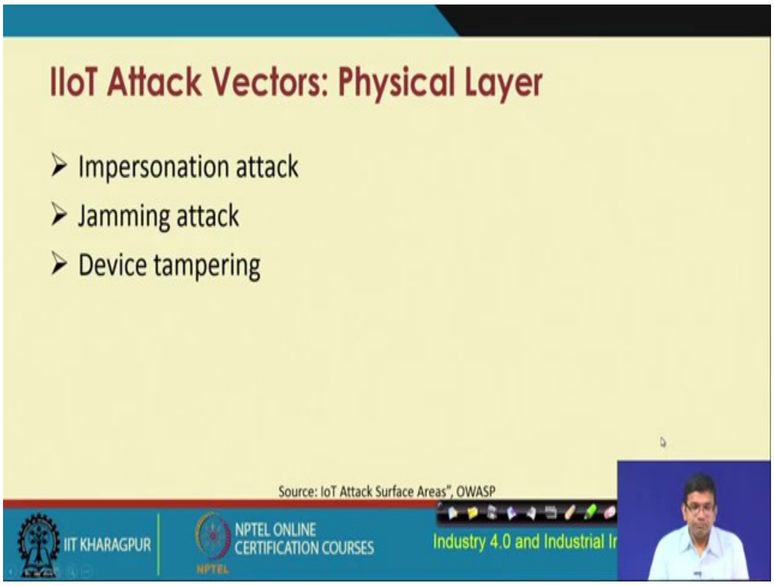


At the physical layer, impersonation attack, jamming attack, device tampering attack are all these different possibilities. I would like to mention to you about this jamming attack; jamming attack is particularly very prevalent and relevant and is of serious concern in IIoT not just IIoT even in IoT also. Because in IoT or IIoT we are typically talking about this resource constraint, highly constraint network environment and so on. Where, a high power jammer sending strong signals could be able to cripple the functioning of the system and the network.

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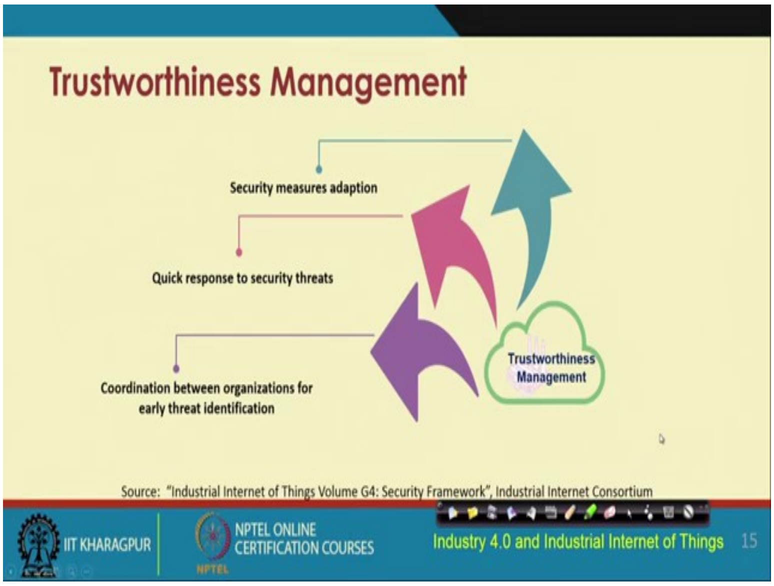

So, trustworthiness is very important and you have to manage the trust worthiness. For trustworthiness management, you have to consider 3 different things. Number 1 is security measures for adaption rather; then, the quick response to the security threats and the coordination between the organizations for early threat identification. These are the three different measures that will have to be taken in order to manage trustworthiness in IIoT.

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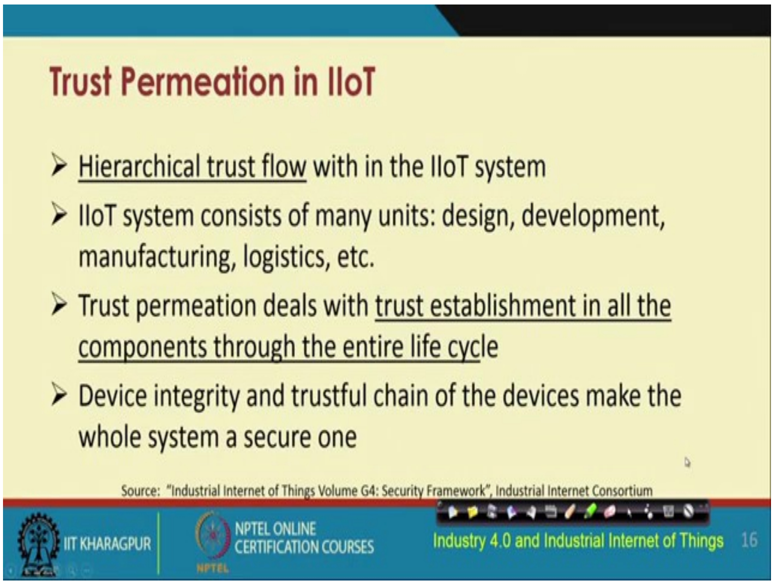


So, trust permeation in IIoT is important. We are talking about hierarchical systems in IIoT. So, in a hierarchical system, you also need to ensure that in all these different levels of hierarchy that the trust flows through these different layers of hierarchy. So, this is the hierarchical flow of trust that is important in a layered, hierarchical layered IIoT system. IoT system basically consists of many units; design, development, manufacturing logistics and so on. So, trust permeation basically deals with trust establishment in all the components through the entire lifecycle.

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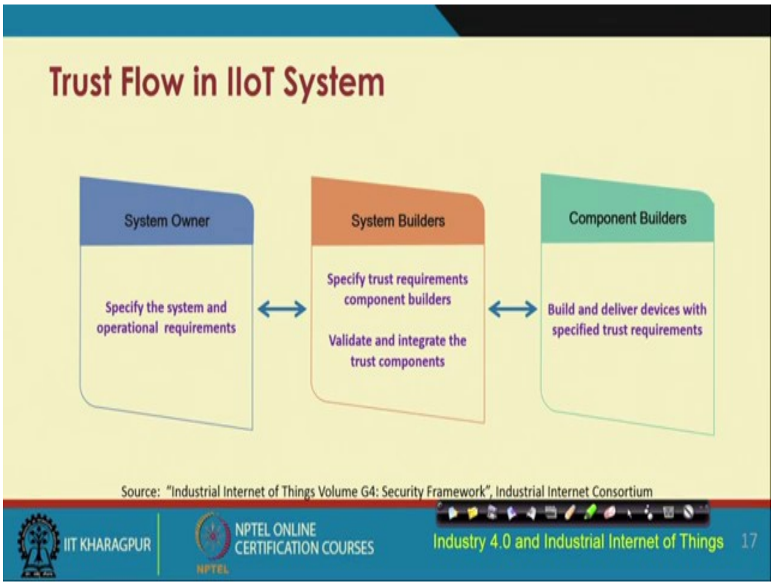


So, in IIoT system, trust flow happens between the system owner who basically specify the system and operational requirements; through the system builders who specify the trust requirements for the component builders, and validate and integrate those trust components to the component builders who actually build and deliver the devices with the specified trust requirements. So, it's a 3 component trust flow model that is relevant for IIoT. So, trust flow flowing through the system owner, through the system builders to the component builders. So, this is a very important consideration for trust flow in IIoT.

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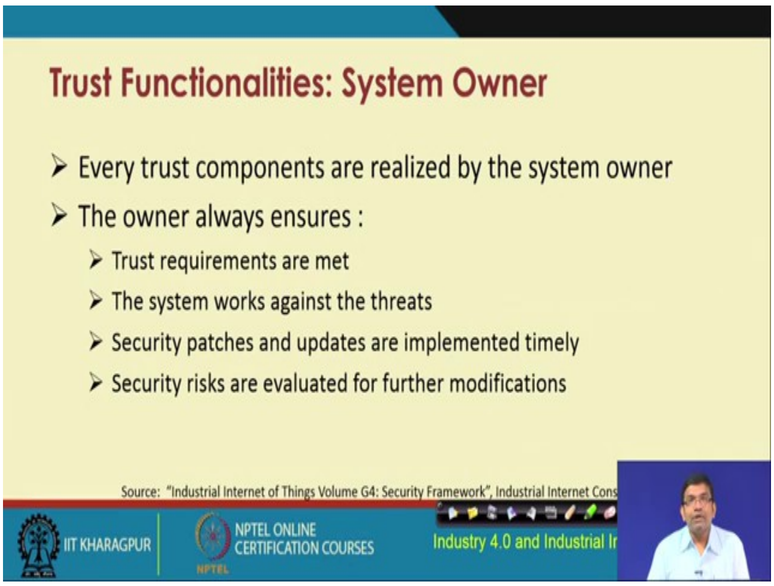

So, trust functionalities at the system owner level; every trust component has to be realized by the system owner. The owner always ensures that the requirements of trust are made. The system works against different types of identified threats and the security patches and updates are implemented in a timely fashion and are also installed in the relevant parts of the system and so on. And also the security risks are evaluated for further modifications of the system coming up with different additional patches to be implemented, to be installed in the system and so on.

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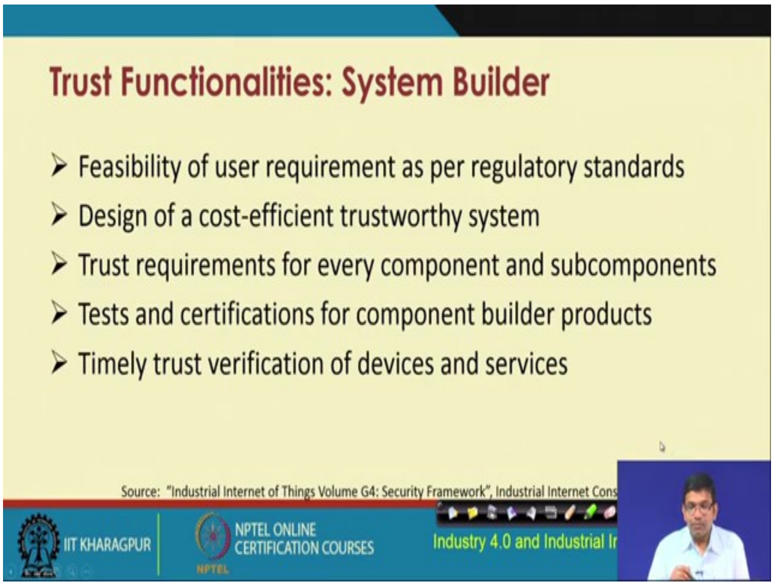


So, then comes the system builder; after the system owner, the system builder who is more concerned about building a cost efficient trustworthy the system. The trust requirements for every component and sub component has to be considered by the system builder and timely trust verification of the devices and services will have to be provided.

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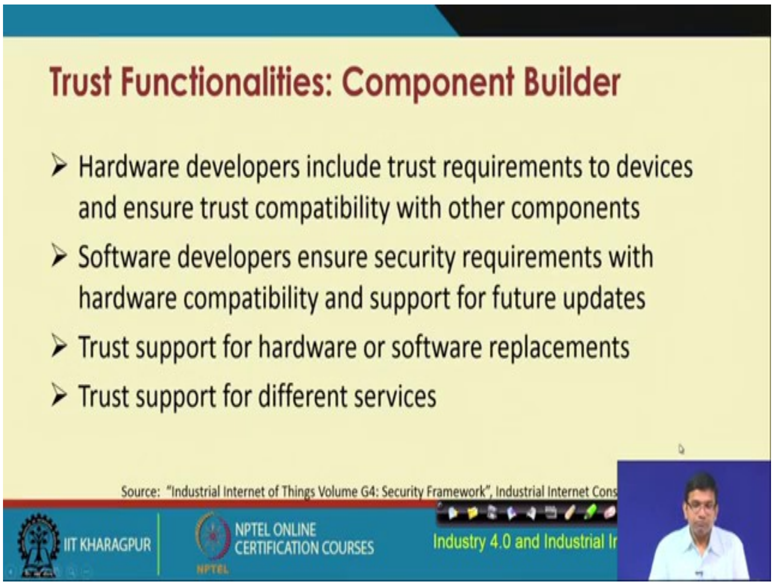


For the component builder; component builders deal with hardware developers and they will have to ensure that the hardware that are being used are trustworthy enough and the devices, the hardware, they are compatible with the trust requirements of the different ones with whom they are going to work. The software developers will also additionally have to ensure that the security requirements with hardware compatibility and support for future updates are provided.

And the trust support for both hardware or software replacements will have to be provided by the component builder. The component builder will also have to provide trust support for different services.

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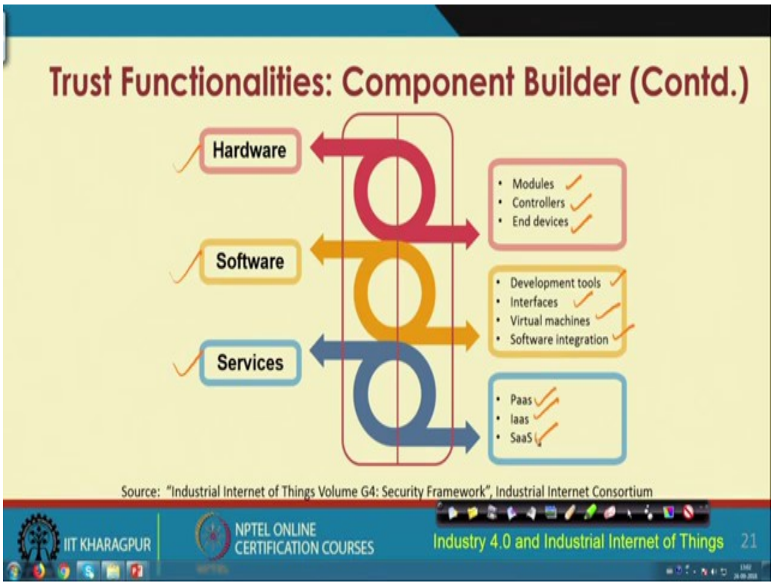


For the component builder these are the different trust functionalities; at the hardware level trust functionalities, at the software level and the services level. At the hardware level the issues of concern are the different modules, the controllers and the in devices that are being used and their corresponding trust issues and so on.

At the software level development tools, interfaces, virtual machines, software integration are of concern and their corresponding trust issues are of concern and at the services level different cloud service models for example like the platform as a service, infrastructure as a service and software as a service and their corresponding trust and not only trustworthy, trust functionalities are of prime concerned.

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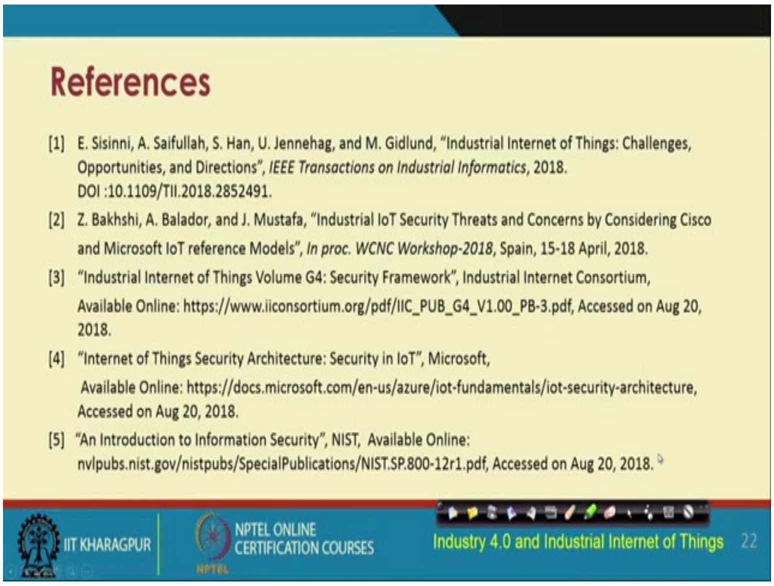


So, with this we come to an end of the introduction of security for IIoT. These are some of different references that have been provided to you, for your further reading.

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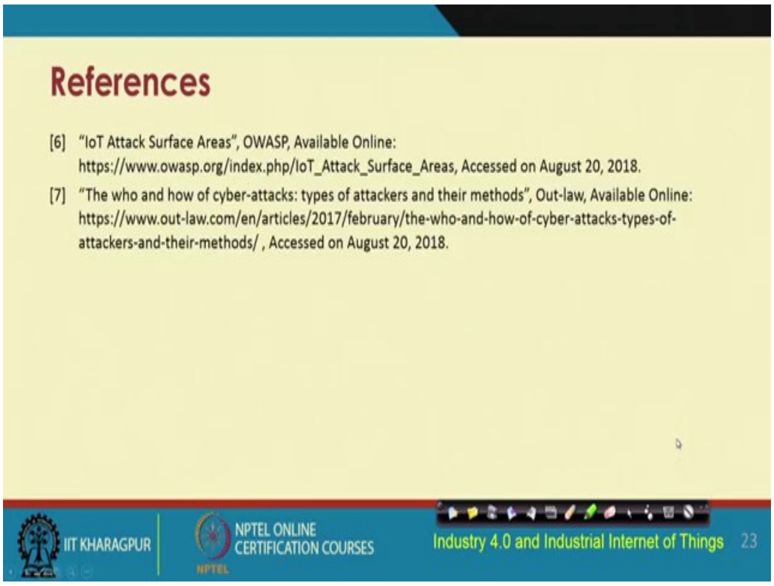


So, with this we come to an end.

Thank you.

**Introduction to Industry 4.0 and Industrial Internet of Things**
**Prof. Sudip Misra**
**Department of Computer Science and Engineering**
**Indian Institute of Technology, Kharagpur**

**Lecture – 48**
**Advanced Technologies: Security in IIoT - Part 2**

So, in the previous lecture on Security for IIoT we discussed about the security vulnerabilities in IIoT which is in addition to what already exists for IoT, we have seen that there is an integration of IT with OT in IIoT. So, consequently one needs to consider the security issues with IT and OT and their convergence separately. So, we have looked at all of these; now let us look at the few other issues.

So, before we do so I would like to go through a very high level schematic of the actual communication taking place in an IIoT scenario and this we have done in different perspectives in the previous lectures, but in order to keep things in the perspective of security let us revisit the whole thing from a different angle. Let us look at what actually happens with respect to communication in an IIoT setting.

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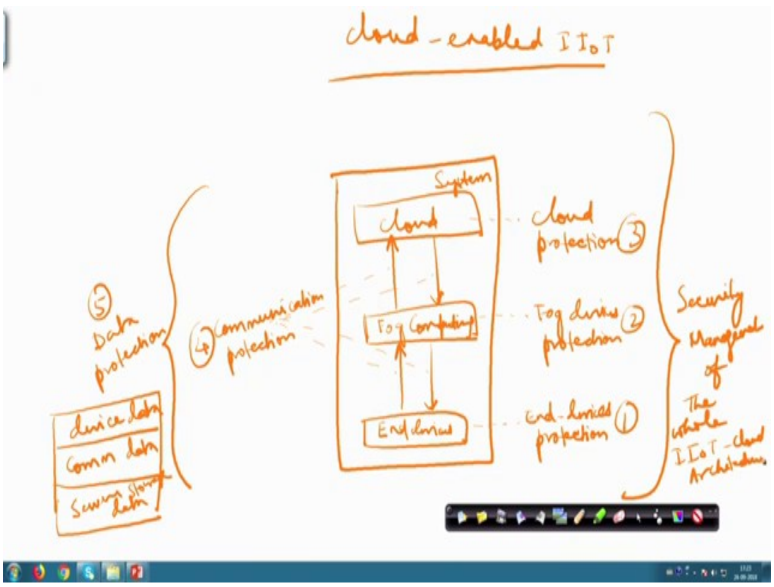


So, let us think about what actually happens, if we are talking about some cloud enabled IIoT system, so let us look at the cloud enabled IIoT system. So, at the very bottom or let us say that when we are talking about the system as a whole at the very bottom we are talking about different end devices.

Thereafter let us say that it is completely you know up to date with technology we have fog as well as cloud implementations, let us see that thereafter we have another layer of processing which is the fog computing layer, which actually does some processing close to the edge, so basically close to these devices from which the data are being retrieved.

And so we have two way communication between these two layer and as we have seen in the lectures on fog computing and cloud, that the rest of the data which can wait for the processing of would be sent to another layer which is basically the cloud right so this is the cloud layer and so we have b directional communication between all of these different layers; the end devices layer, the fog layer and the cloud layer.

So, holistically we have let us say that this particular box representing our system, this is our IIoT cloud fog enabled IIoT system. So, if you look at the security aspects we need security for everything. So, we need security for end devices, protection this is quite obvious, we need security for the protection of fog devices.

We need security for cloud; fog devices protection and this is cloud protection, cloud security and so on. And we have bidirectional communication everywhere we have these different communication links between all of these 3 different layers in the system as a whole.

So, these are all communication links, so we need protection for this communication system protection. So, we need communication protection and so let us number these. Let us say that this is number 1, this will be our number 2, this will be our number 3, this will be our number 4 and then what is happening is that from this system as a whole we are retrieving the data. So, the data is being retrieved and has to be protected. So, this we need as data protection.

So, data protection and so if we look at the data protection, then basically the data has to be protected at again the respective levels. So it can be your device data, so device data protection; communication data, so communication data protection; and then we have the server storage data, so server storage data protection.

So, these are respective components we have seen that these are mainly the 5 components where protection is required. Now holistically the whole thing has to be managed with respect to security. So, this is security management. So, we need a suitable architecture for security management. So, security management of the whole IIoT cloud architecture.

So, this is holistically what we need to do in terms of security management of a cloud fog enabled IIoT system. So, this is the holistic perspective that we have to keep when we discuss about the rest of the topics in this particular lecture. So, let us proceed further and see what we can do about this security protection.

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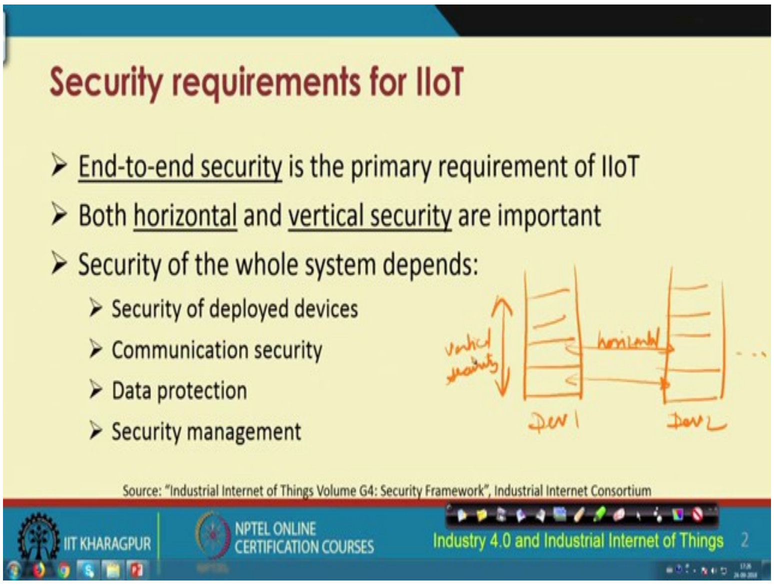


So, if we are talking about security in terms of the requirements for security in the IIoT context. We need to have end to end security between the end devices, so from the origin point of the data till the point of consumption or point of storage or whatever.

So, from the source to the receiver to the intended destination etc., end to end security has to be ensured otherwise if you do not have a system which has ensured end to end security the system as a whole is not going to work for all practical purposes. Next important thing is that holistic end to end security is fine, but think about it little bit deeper. So, when you talk about different devices these are the different devices that internally are composed of different layers.

So, you have one device following a particular stack you have one device following a particular stack comprising of different layers likewise you have different other devices having different layers and so on and you are trying to put them all together. So, it is something like this that you have one stack. So, this is let us say device 1, this is another stack let us say this is device 2 and this thing can continue like this all right.

So, we need to ensure horizontal security; that means, so basically what is going to happen is communication between these different layers are going to happen. So, we have to ensure horizontal security as well as we need to also ensure this one which is the vertical security; both are important. So, security of the whole system comprising of horizontal as well as vertical security ensuring end to end security is what we have to strive to achieve.

So, security of the deployed devices is required when you are thinking about the system as a whole communication security is important, data security is important, security management is important right. So, we are talking about all these different types of security issues and taking care of these component wise layer wise and so on for the system as a whole IIoT clouds, fog enabled IIoT system and its security.

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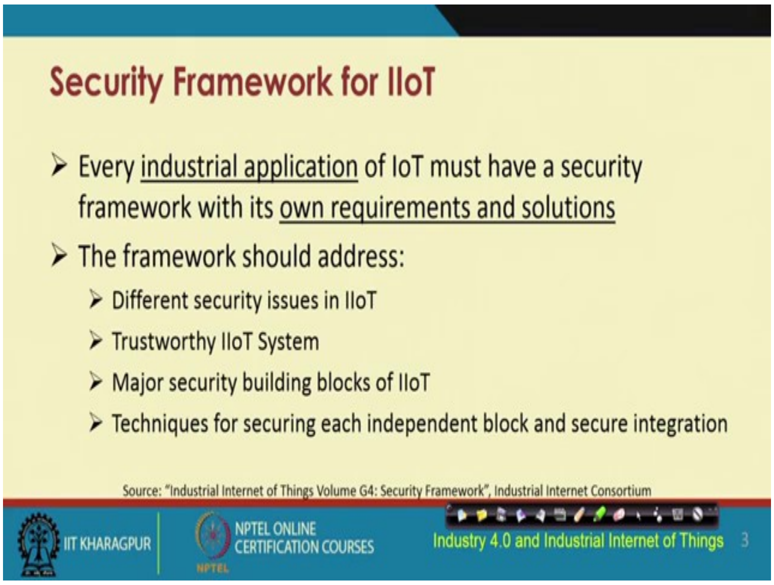


So, when you are talking about IIoT industrial applications of IoT we have to ensure that there are certain commonalities, there are certain commonalities across all IIoT applications which are fine. So, you can come up with a common security framework, but then there are specificities across different application domains even within an application domain also there are sometimes custom requirements that will have to be fulfilled for different industries.

So, all of these security requirements will have to be understood and then you have to come up with a security framework catering to the requirements which are general plus the custom requirements. So, the framework that we come up with for security has to address different issues in IIoT, has to ensure trustworthiness of the system, has to ensure that each of the individual building blocks have taken care of the different vulnerabilities and the security aspects.

And will have to ensure that the communication itself, the communication that takes place itself across the different independent and different other building blocks those are also secured. So, you need to have techniques for securing each of these individual blocks plus their integration and the communication between them.

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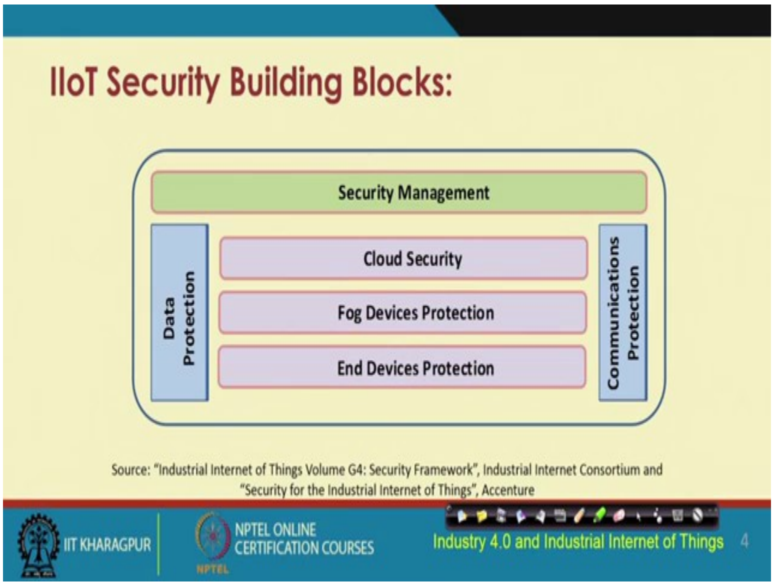


So, IIoT security building blocks would be like this, you need to have end devices security, fog devices security, cloud security, you need to ensure that the data that is coming in from this whole system that is secured and protected. The communication medium through which these different devices communicate that is also protected and secured and you need to have a holistic security management framework cutting across all these verticals and horizontals.

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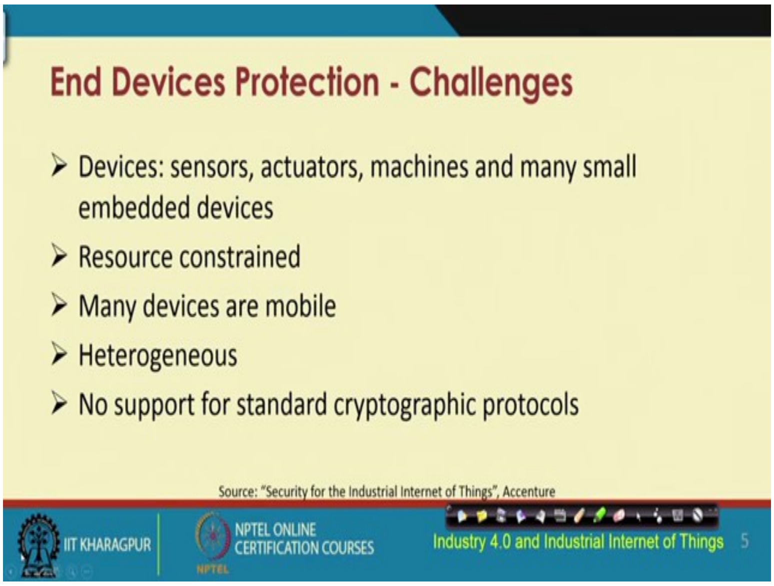


So, when we are talking about end devices protection of end devices we are talking about essentially sensors, actuators, their communication; the sensors and actuators they are hosts; that means, the machines where they are deployed, the embedded systems that are running them and so on. So, we need to consider the protection of all of these different components, additionally we also have to keep in mind what I was telling you in the previous lecture that we are talking about IIoT means that we are talking about a highly resource constraint environment.

So, resource constraint, energy constraint, processing constraint the network resource itself is constraint, bandwidth constraint, low data rate, low energy. So, we have a highly constraint kind of environment and we have to ensure the protection of the different devices, the different devices in isolation, the different devices in communication and the different devices that comprise the system as a whole.

Heterogeneity also we have talked about earlier the real challenge in IIoT is that we are not talking about homogeneous devices following homogeneous protocols homogeneous standards and so on. We are not talking about that IIoT essentially is featured to run different heterogeneous protocols, heterogeneous devices working intended and so on.

So, we need to take care of this kind of challenge to deal with heterogeneity. So, and there is no standard cryptographic protocols that are there to run for IIoT. I mean people are working on different protocols, they are trying to come up with lightweight protocols that are going to work in this kind of constraint environments, but cryptography itself is heavyweight.

So, original cryptography itself is heavyweight coming up with lightweight protocols, cryptographic protocols is a huge challenge and so there are lots of research work one would find which are trying to cater to cryptographic protocols and their design for IoT and IIoT.

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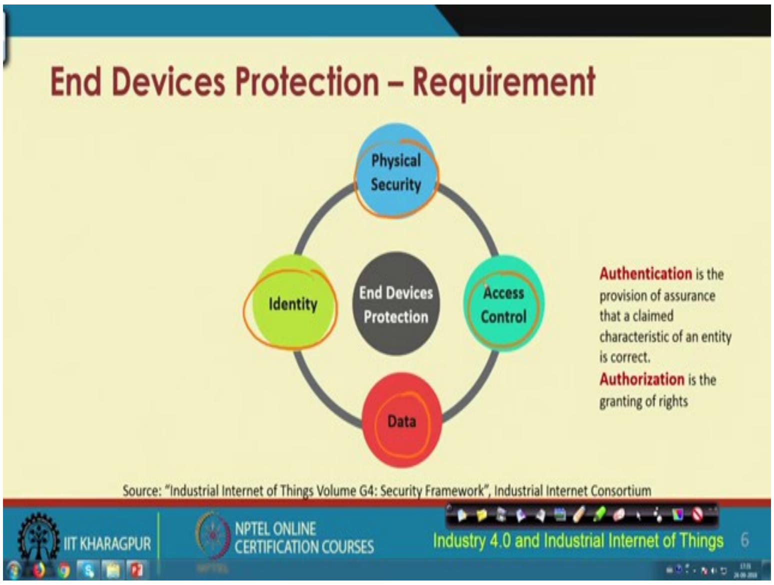


So, in terms of the requirements when we are talking about the end devices we have to ensure physical security of these devices, we have to ensure that the end devices have their identity and this identity will have to be protected, we have to ensure the protection of the data the and also the access control. We have to ensure that legitimate access control based on what actually the organizational policies are going to support so legitimate access control is has to be ensured.

So, it should not happen that a particular device gets accessed by someone in certain level of the automation hierarchy who should not actually have access to that device or it's data. So, not only within the organization, but also outside the organization also nobody should get illegitimate access to the devices and the data. So, all these 4 components can be summarized in this manner.

So, we have to ensure for end device protection that there is suitable authentication mechanism in place, which will give an assurance that a claimed characteristic of the entity is correct and suitable authorization is also in place in order to ensure that suitable rights are granted as per the requirements and as per what is desirable.

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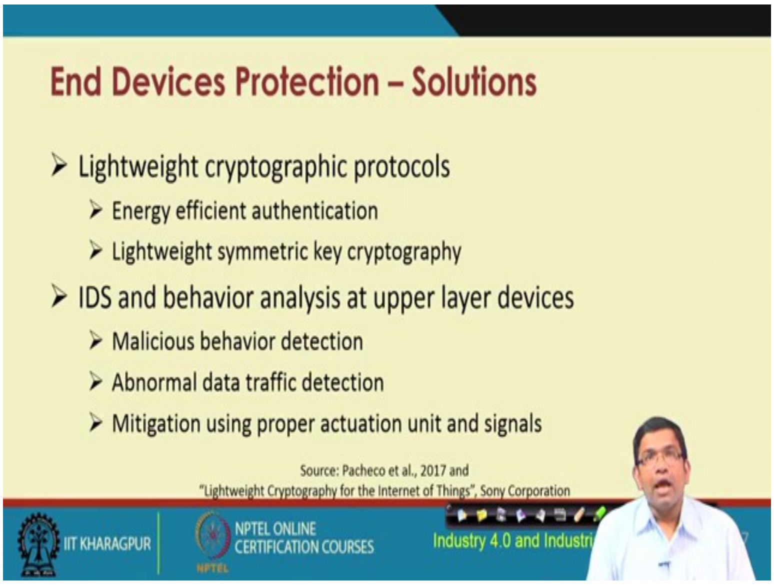


So, there are different solutions for end devices protection we need lightweight cryptographic protocols there are many that have been researched, there are a lot of research papers that basically come up with lightweight cryptographic protocols for IIoT. Energy efficient authentication mechanisms, lightweight symmetric key cryptography; symmetric key as you probably already know, here actually we are talking the same key being used at both the ends right, so the symmetric key.

And so lightweight symmetric key cryptographic mechanisms should be used and also intrusion detection; intrusion detection coming up with intrusion detection system, intrusion prevention systems based on behavioral analysis at different layers of the device basically analyzing the malicious behavior, detecting malicious behavior based on the data and it's analysis, abnormal data traffic detection, mitigation using proper actuation unit and signal. So, all of these things will have to be done in order to protect the end devices.

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So, in terms of protection of the fog devices; fog devices are deployed near to the end devices and these are also constraint, it is better than the end devices in terms of computing storage etc., but still it is more constraint than what actually exists at the server form or the cloud end. So, these fog devices because they are also like semi-constraint in terms of resources storage computing etc., will have to ensure that we have some suitable protection mechanisms in place for protecting these fog devices.

So, plus we have to come up with some cryptographic protocols that are going to do authentication, authorization and authentication of the fog devices and authentication between the fog devices and the cloud. So, basically the essence over here is to ensure that we come up with lightweight cryptographic and other security information system security methods for use in this kind of constraint environments.

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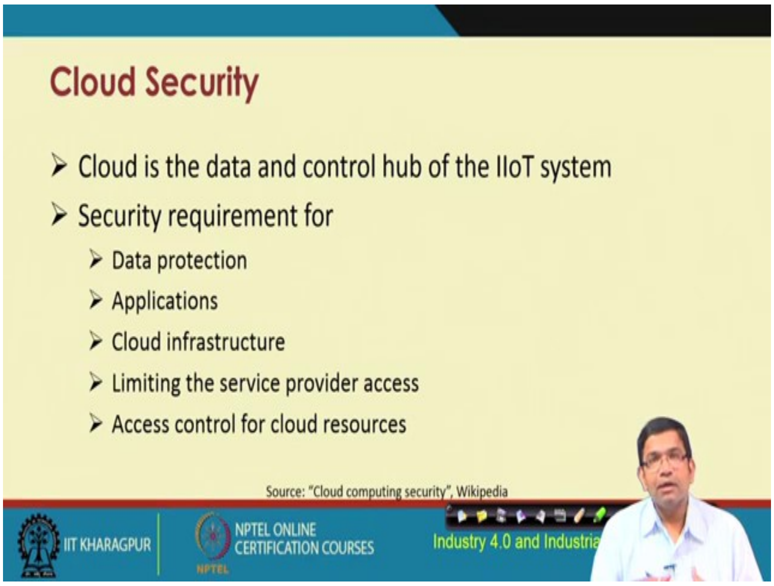


Cloud actually is the huge resource; so cloud security is of huge concern because it's typically a third party kind of service cloud, but at the same time cloud security and ensuring cloud security is of a lesser challenge than the fog security or the end device security.

So, for cloud level you need to ensure data protection at the cloud, applications that are running on the cloud and using the data from the cloud they will have to be secured the cloud infrastructure itself has to be secured and protected and also there has to be some policies for limiting the service provider access and also there has to be access control for the cloud resources. So, all of these different aspects of security and the requirements of security for cloud are very important and has to be considered holistically.

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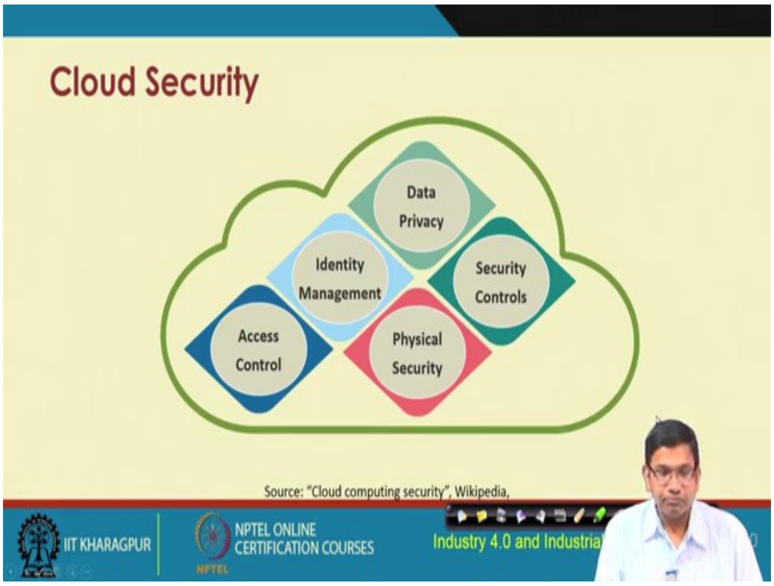


So, for cloud security then we have all these different issues that will have to be taken into consideration, the physical security, data privacy, security controls, identity management and access control. So, holistically all of these different issues will have to be taken into consideration for ensuring cloud security.

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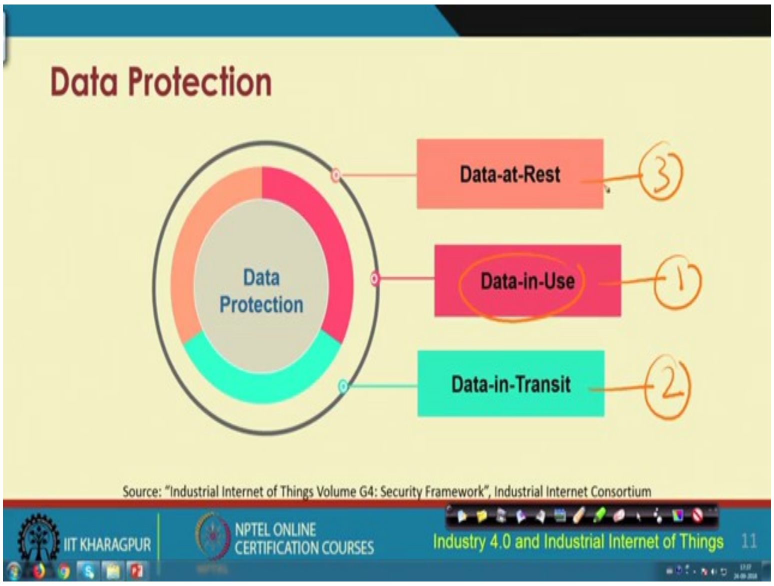


So, for data protection; there are different types of data, some data are in use, this is one kind of data then we have some data which are basically in transit and some data which are in rest. So, typically stored in the servers for future use so data at rest data in use the data that are currently being used and data in transit are basically coming to the channel and still they are not being used. So, all these different types of data will have to be protected with suitable levels of protection.

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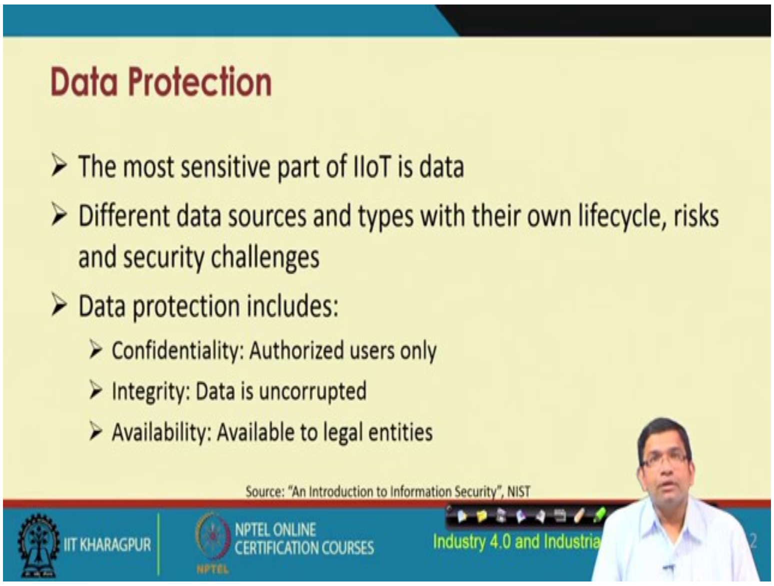


So, data protection is the most sensitive part of IIoT and so basically when we are talking about IIoT; IIoT it's all about collecting data and analyzing the data right. So, IIoT is this data and it is the most sensitive part of IIoT systems and you have to ensure suitable levels of protection of IOT data.

Different data sources and types with their own lifecycle risks and security challenges will have to be understood, will have to be analyzed and suitable mechanisms consequently will have to be brought in place. Data protection includes three different things -- confidentiality which has to ensure authorization of only the legitimate user's, integrity which basically talks about ensuring that the data is uncorrupted and it has not been tampered with, and availability which has to ensure that the legal entities are available.

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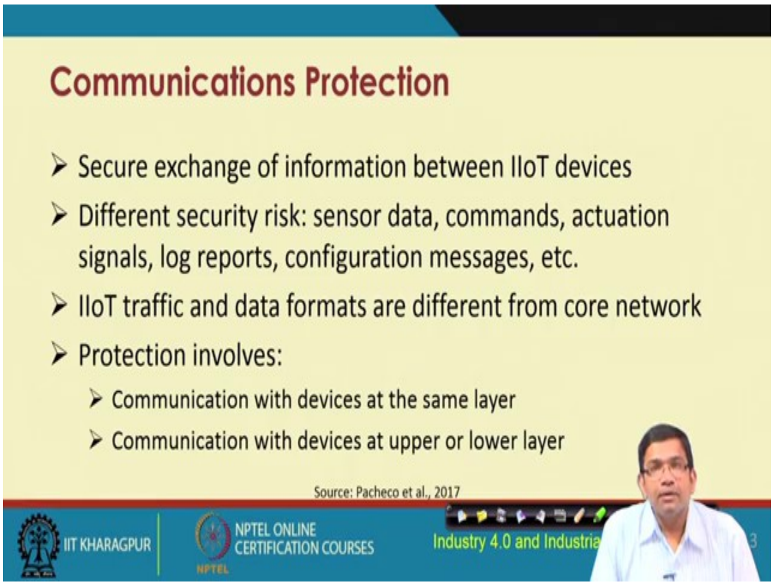


So, availability of the data whenever it is required to the legally entitled entities is very essential. So, these are the three different layers of data protection confidentiality, integrity and availability. Communication protection securing the exchange of information between the IIoT devices. IIoT: it's all about connectivity, so when whenever we are talking about connectivity. So, basically earlier I told you that IIoT code to IIoT is data, but the data has to come only if these devices are all interconnected right.

So, at the backbone is what we have is the communication channel the backbone network etc. So, that channel itself has to be secured so communications security and protection is very important. So, the different security risks that exist would be with securing the sensor data, securing the commands, securing the actuators and the signals that are sent for actuation, log reports and their security configuration messages and their security and so on.

So, all of these are different security risks and their security will have to be ensured adequately. IIoT traffic and data formats are different from the core network, so protection involves communication with the devices at the same layer which is basically the horizontal security that I talked about earlier and communication with devices at upper or lower layer which is the vertical security that also I explained earlier.

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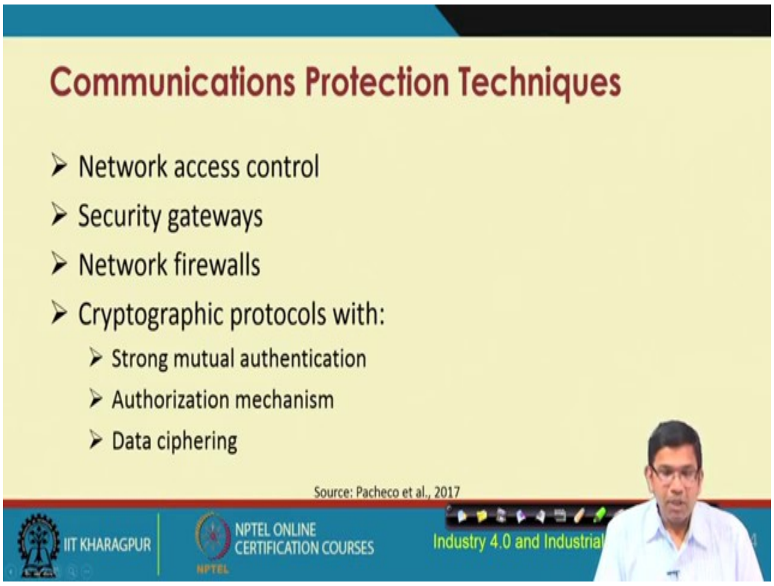


So, for communication protection, communication security you need to have suitable network access control you need to have security gateways, network firewalls and also different cryptographic protocols for authentication, authorization and data coding encoding.

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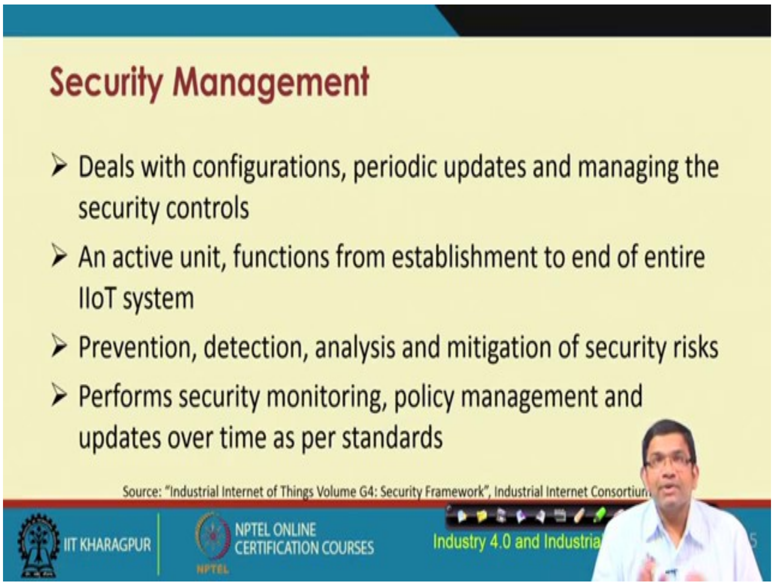


For security management we are talking about the system as a whole, we are talking about dealing with issues of configurations, periodic updates and managing the security controls. Security management is an active important function and this has to ensure that the whole system the IIoT system is secured.

So, the management of this whole system is what concerns the security management of IIoT. Prevention detection analysis and mitigation of security risks are very important when you are talking about security management of any system and definitely for IIoT systems.

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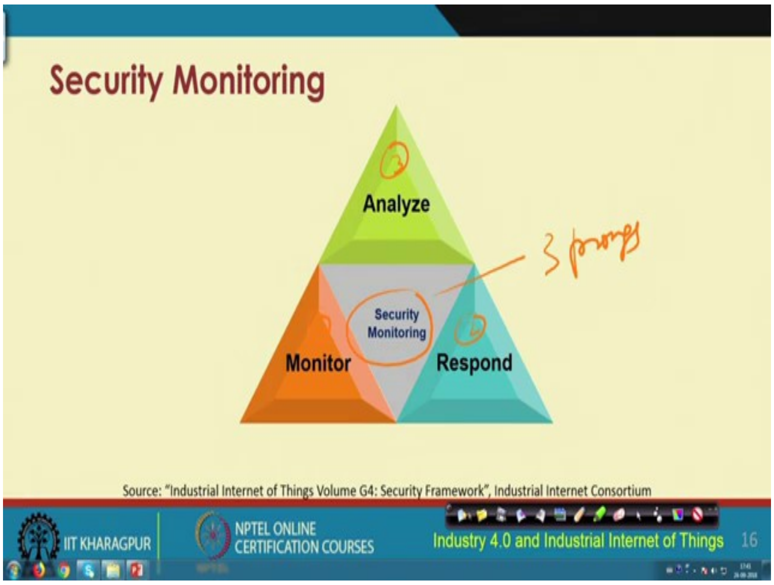


So, for security monitoring these are the three different prongs of the same problem, one is the monitoring, response and analysis. These are the 3 different prongs of security monitoring; monitoring, response based on what is being observed, and the analysis of the data. So, this is the security monitoring and its three different prongs.

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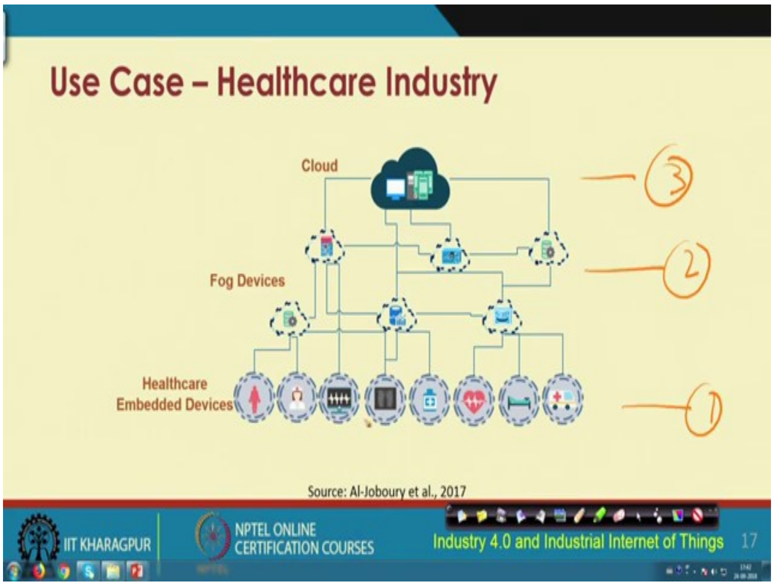


Now, let us look at this particular diagram which talks about a fog cloud enabled IIoT system for healthcare industry this is an architecture that I have taken from the source given below. So, look at the different layers over here so we have the healthcare embedded devices in this particular layer: this is layer 1, then you have the fog devices layer and the cloud layer.

So, holistically so these are basically the healthcare embedded devices such as SpO2, devices such as the different healthcare monitors, devices such as the glucose monitoring system, devices such as the blood pressure monitor like that all these different devices and their connectivity. So, these devices are basically in an IIoT scenario these devices do not work in isolation, they are all connected.

So, ensuring the security of all of these devices and their interaction between them is important and second is the fog devices layer here also the security mechanisms adequately will have to be ensured and finally, at the cloud layer also the data are being stored and adequate security mechanisms and adequate access control through the cloud will also have to be ensured.

So, access control and data protection at through the cloud at the cloud, through the fog at the fog and also through the healthcare embedded devices and at these devices -- these are all these different things that will have to be taken into consideration and analyzed.

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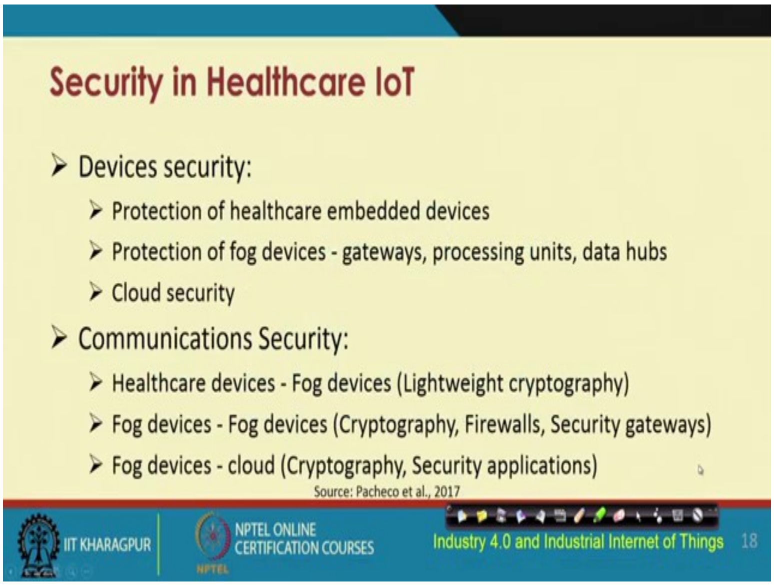


So, whenever we are talking about security in healthcare IoT we have to talk about the devices, their security, their protection, devices would include not only the sensors actuators and so on but also in the gateways the processing units, the data hubs and also the cloud to where most of this data are stored. The second is the communication security which is basically talking about security of these connected devices, these connected devices themselves, connected devices to the fog, connected fog to cloud.

So, the communication everywhere will have to be secured suitably using lightweight cryptographic methods, we using gateways secured gateways, using secured, using firewalls and different secure security applications. So, using all of these holistically communication security will have to be ensured.

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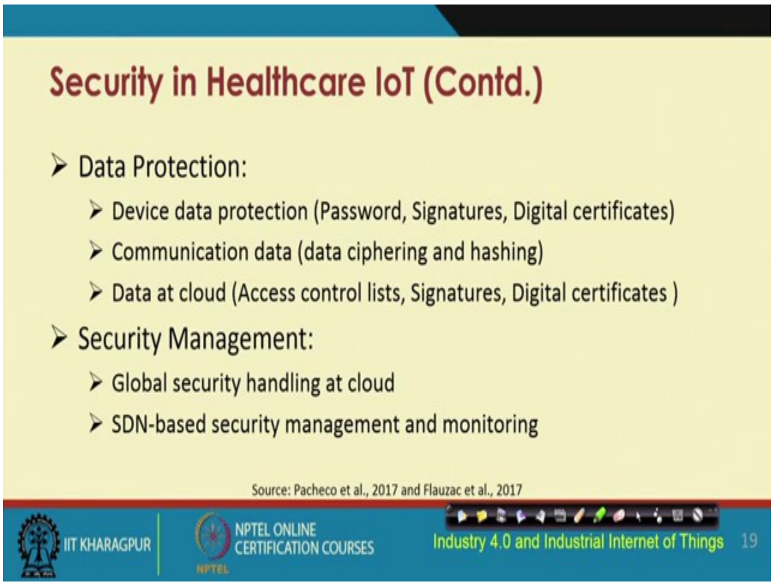


Device data protection using suitable password mechanism, signatures, digital certificates, communication data protection using suitable use of data ciphering and hashing and data protection at the cloud using suitable access control mechanisms, digital signatures, digital certificates and so on. Security management holistically global security handling at the cloud and SDN based security management and monitoring.

SDN is something that I have already discussed in detail in two different lectures I am not going to mention or elaborate it further over here, but I think this is quite understandable, SDN based security management and monitoring is basically what is desirable because most of these systems are going to be in the future SDN enabled and their security is also of importance.

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Regulatory standards for IIoT security is important not only all these technological issues, not only these technical issues, device level, fog level and cloud level and the communication level and so on. But also we are talking about ensuring that the regulatory standards that are in place the security of those.

So basically for IIoT we are talking about security standards, conforming to the requirements of IT and OT. Information technology and operation technology and there is unfortunately no security standards that is in place to ensure the security of IT and OT; that means, catering to the requirements of IIoT.

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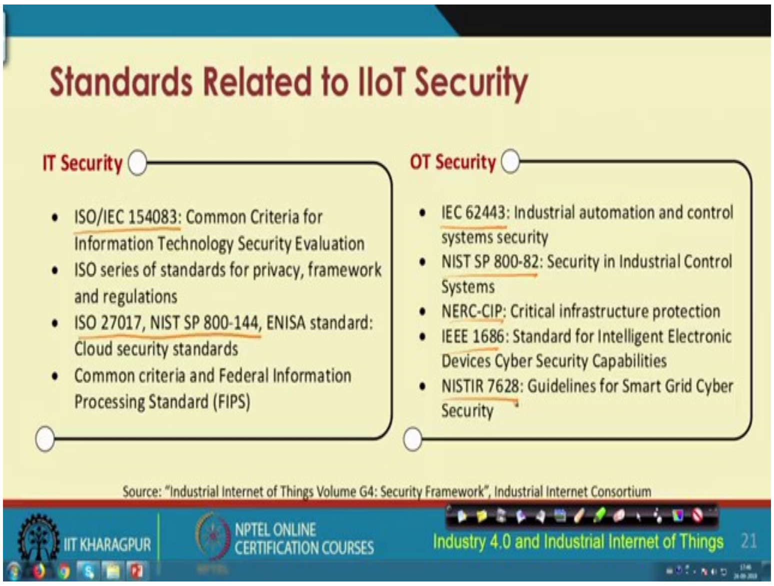


So, if you are talking about separately IT security, there are some regulatory standards that are there ISO/IEC 154083, this is a common criteria for information technology security evaluation, like this there are few other related standards for security of IT, for OT also separately there is this standard IEC 62443 which is a an industrial automation and control system security standard like this NIST also has its own and so on.

There are a few different other standards for OT which are in place, but in IIoT once again we are talking about IT and OT security requirements working together. So, you have to have a separate set of regulatory requirements for security of IT-OT convergence to be there. So, one is to come up with those regulatory framework for ensuring IIoT security.

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With this we come to an end of security concerns and their issues and their discussion surrounding. These are some of these different references that you can go through if you are interested to dig further into these issues of security in the context of IIoT.

Thank you.

**Introduction to Industry 4.0 and Industrial Internet of Things**
**Prof. Sudip Misra**
**Department of Computer Science and Engineering**
**Indian Institute of Technology, Kharagpur**

**Lecture – 49**
**IIOT Applications: Factories and Assembly line**

In this particular module I am going to take you through different case studies, different applications for examples of implementation of IIoT. So, different industries are trying to adopt IoT, IIoT solutions. So, I am going to take you through the collection of different adoptions and the stories behind this adoptions of IIoT technologies by different industries, I am going to do it domain wise.

So, in the first domain we are going to talk about smart manufacturing industries. So, manufacturing industries, the assembly lines and so on is the first one to be considered, smart factory more specifically is what we are going to revisit once again and look at which different industries have in adopting IIoT solutions and how their processes have improved consequently. So, let us look at manufacturing.

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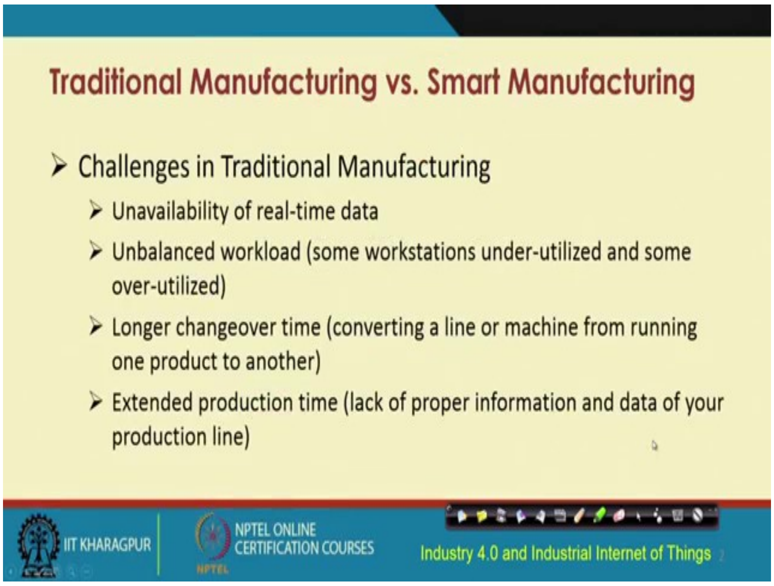


So, whenever we are talking about manufacturing, traditionally there were different challenges, this manufacturing machines deals to work in isolation, these machines were not connected, there were different other challenges such as because these machines were not connected with one another, there was unbalanced work load in this different machines. So, the work load across the different machines doing the same thing was not balanced.

There were other challenges also, challenges with respect to the availability of data in real time that was also another challenge with traditional manufacturing, with traditional isolated manufacturing machines which were not connected with one another and which were also not connected from one machine to some centralized entity or the controlled station.

There were challenges with respect to longer change over time; that means, converting a line or machine from running one product to another. So, whenever this changeover will have to happen it used to take much longer and so on, that is the traditional manufacturing, the drawbacks of it.

The other challenge with traditional manufacturing was that the production time itself used to be much more extended, this is because of lack of proper information and data of the production line. So, all of these different challenges, the 4 different challenges that I have just mentioned could be overcome with smart manufacturing solutions. So, smart manufacturing, smart factories, factories which integrate IIoT solutions to basically transform them to be smart. So, smart factories smart manufacturing is what we are going to talk about over here.

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So, smart factory: so whenever we are taking about smart factory, smart factory integrates IT and OT. So, you have this traditional machinery, the traditional equipments, the traditional operational technologies and their optimization, self optimization, automation and so on. So, not just having these machines run respectively in isolation, but also to optimize the processes automatically in through the connection of the different data that are coming from this machines about their health conditions and so on and also through the automation overall.

So, self optimization and automation so, benefits of this smart factories are going to be that one can, in real time get lot of data, data about different things particularly the data about the health condition of these different machines. This data will have to be analyzed and based on the analysis, quality control can be done and that is all of these things can be done only in a smart factory.

Smart factory results in reduced change over time, smart factory results in reduced production time and also smart factory has the features of flexibility; flexibility with respect to change over, flexibility with respect to adoption of newer components, newer technologies, integration, integration within and beyond the system and also ease of management. So, all of these are different benefits of a smart factory.

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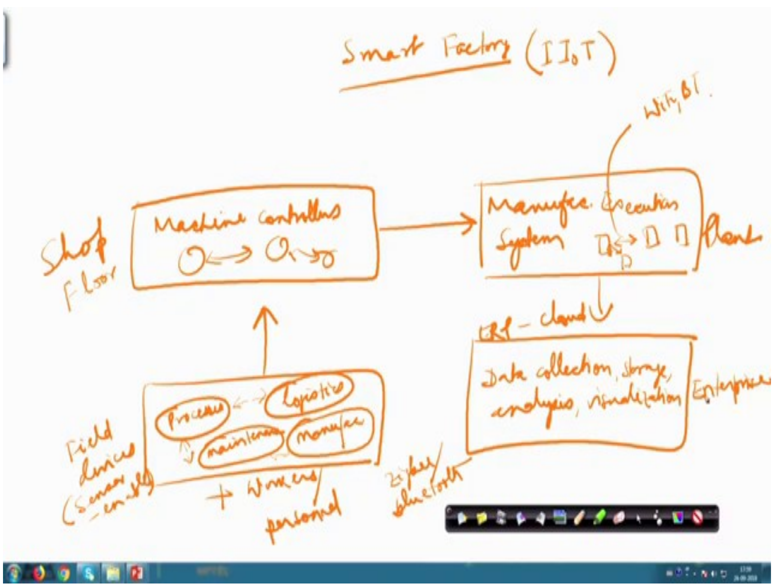


So, before I proceed let me show you some of the different features of a smart factory. So, smart factory is something that I have already discussed in a previous lecture, but let us try to go over this particular thing in much more detailed because IIoT a good application instance of IIoT is basically the building of smart factories.

So, whenever we are talking about smart factories we are talking about different field devices. So, field devices; these are basically sensor enable devices which will help in execution of different processes in a smart manner. So, different processes running on them the different other things can be done such as the maintenance of these devices, of the system, of the processes, logistics and manufacturing.

So, in other words we could have field devices improve the processes, improve the maintenance, improve logistics, and improve manufacturing holistically. So, these are the different things that can be done with the help of these sensor enabled field devices. So, this field devices are basically sensor enabled. So, let me also tell you that not only these field devices are enabled with the sensors, but these are also you know the sensors are also enabled with the different workers, or the different personnel that are involved.

They also will have different variable sensors which continuously are going to monitor there their work habits, their stress level and so on and so forth. So, all of these so monitoring the health of the different devices, monitoring the health and the working condition of this different workers and the work force the personnel so on, working in a smart factory all of these things are going to be done.

So, there after this data are going to be sent to the shop floor. So, these are like different units. So, if the manufacturing plant has a shop floor, different shop floors are there. So, these are like different units for manufacturing, different units catering to the different requirements within a particular factory. So, shop floor will have different controllers, these are machine controllers that might be there within a shop floor so machine controllers and so on.

So, these machine controllers will again be connected with each other. So, I forgot to mention over here that these different devices taken care of processes, maintenance, logistics, manufacturing and also these components between themselves they are all going to be connected with each other and this is going to happen through the use of different communication mechanisms like ZigBee or Bluetooth or the different communication technologies that I covered in the introductory lecture on IoT.

So, all of these are going to talk to each other. So, this is the shop floor and from this shop floor basically the data are going to be sent to the manufacturing plant. So, the manufacturing plant will have the manufacturing execution system right, manufacturing execution system which will again have different components like controlled rooms, you know sub controlled rooms and so on which will also have to be connected through this different communication mechanisms like may be Wi-Fi, Bluetooth, etcetera. And finally, the data will be sent may be to a system integrator like ERP right.

So, this may be the ERPs which is going to do the data collection, storage and may be analysis and this could be even cloud enabled. So, this could be ERP cloud, cloud enabled ERP not only just analysis, but also visualization is also possible so, all of these different things can be done. So, holistically so this is your enterprise level. So, we started with the field device level, then the next level higher up was the shop floor then the plant and finally, the enterprise level.

So, you know in a smart factory all of these things are going to be interconnected, these different devices throwing in lot of data being processed in the shop floor different controllers, connectivity between them, again sending the data to the manufacturing system and their execution at the plant level. And then at the cloud level the ERP and cloud together could be used for data collection storage analysis and visualization, this is holistically how a smart factory looks like this is the high level block diagram of how these operations go on in a smart factory. So, having understood this thing let us now proceed further and try to, we have already seen that these are the different benefits of having a smart factory.

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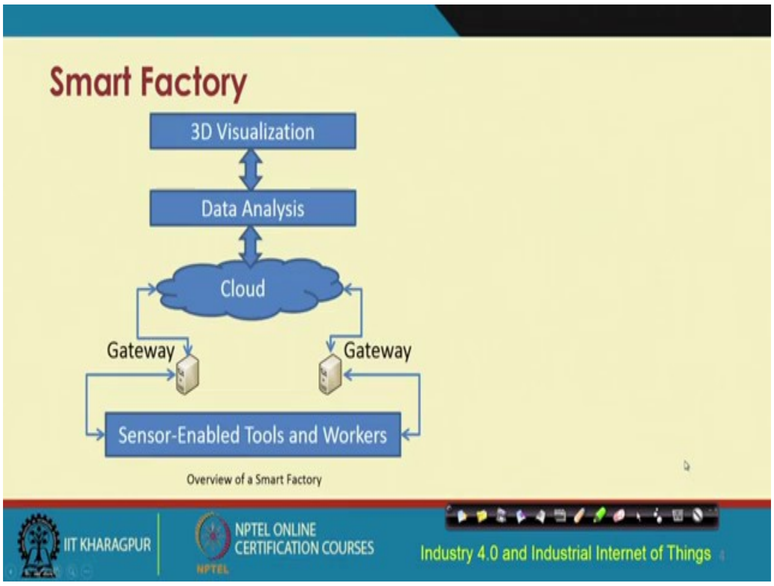


Let us now look at from a different perspective how this smart factory is going to work. So, at the very bottom we will have this sensor enabled tools and workers. So, this is what I was telling you earlier that your devices are going to be sensor enabled this is understood in a manufacturing plant in a factory and so on, but not only these tools and devices, but also the workers are going to be sensor enable.

So, both the tools and this workers are going to be sensor enabled, they are going to through in lot of data which are going to passing through this gateway to the cloud where further data analysis, data visualization, etc. are going to be done and the results are going to be made available to the respective stake holders based on their corresponding policies, their access control mechanisms takes place and so on.

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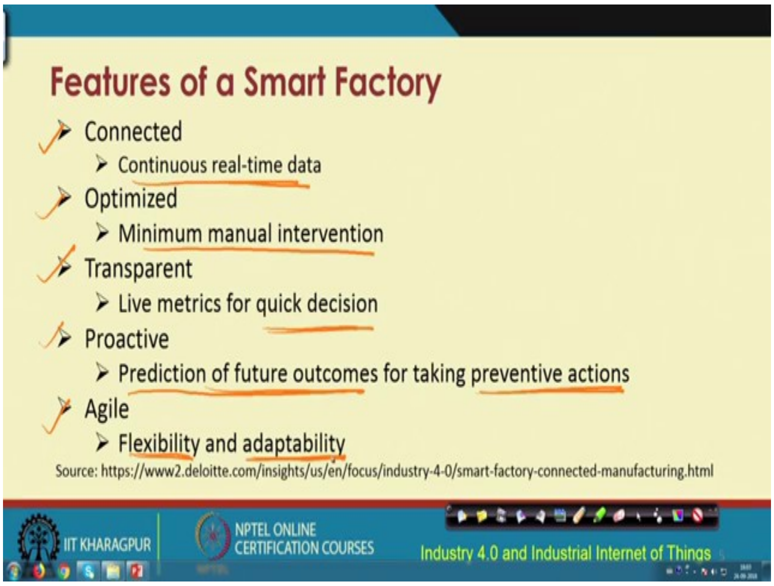


So, in terms of the features of a smart factory these are the some of these different features, in a smart factory we are talking about connected devices which are going to sent lot of data in real time continuously. Optimized components, optimized data without any human intervention or with minimal human intervention is a characteristic of a smart factory.

Smart factory is transparent in the sense that you are going to get lot of data, live data depending on the metrics that are implemented you are going to get all this live data and those data can be used suitably at different levels of management for quicker decision making so, transparency is also promoted in a smart factory.

Proactive feature means that you know proactively we can predict the future outcomes and take preventive actions depending on the situation and what is going on or what is going to happen in the future. So, proactively based on the prediction of future outcomes one can take preventive actions.

And finally, agility with respect to flexibility, flexibility to change adoption of newer systems components changes in terms of the versions etc. So, all of these things are possible in a smart factory.

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Let us now look at some of these case studies right. So, you know I will start with the Airbus Company which has state of the art implementation of IIoT. So, airbus basically has adopted something known as the factory of the future. So, before I talk about the factory of the future let me give you a brief highlight about airbus. So, airbus as you know is a major pair player in the aviation sector and airbus is a German or in general I can tell the it is an European aircraft manufacturer and it applies lot of IoT technologies in its production process.

So, essentially what happens is that consequently during the production; that means, during manufacturing productions so on in the floor of the plants and also after the products are deployed in a real aircraft lot of data can be collected. So, lot of data can be collected at the time of manufacturing production in the floor of the plants, but also additionally lot of data can be collected from the flight recorders, while the flights are in operation.

So, collecting data on flights will help to improve the in flight experience and the workers on the factory floor can use this IoT devices to improve their processes to get an understanding about the different positions in the manufacturing process and so on the I mean how much the manufacturing has processed what are the different gaps etc. in the process and so on. So, all of these things holistically the workers on the factory floor using this IoT enabled devices can get a holistic understanding. So, airbus, they launched this digital manufacturing initiative which is known as the factory of the future. So, this is how it looks like.

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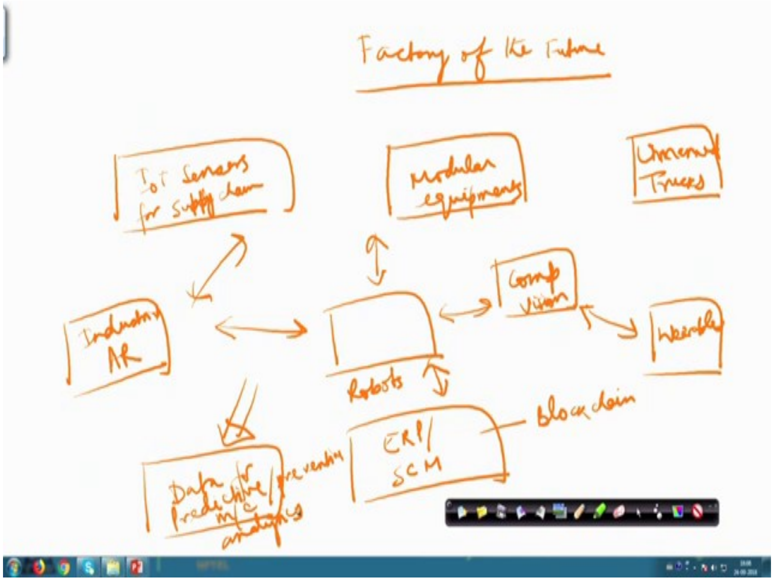


Let us look at this factory of the future. So, in a factory of the future, we are talking about different components; components such as IoT sensors for supply chain management. Then we are talking about modular equipments, use of different robots, robotic arms, etc., use of concepts of industrial augmented reality, use of computer vision, image processing and video processing in real time and so on.

Then use of logistics and trucks and particularly in an autonomous system which is a characteristic of the factory of the future we are typically talking about unmanned trucks and we are talking about workers and these different machines which have wearables. We are talking about ERP, then supply chain management, probably cloud enabled and also may be block-chain implemented, and these basically will be different components; randomly I am connecting them, but basically they are going to work together.

And also what is very important is finally, all of these are going to throwing this data this data will be used for predictive or preventive machine analytics. So, this is typically how it looks like, what it looks like in a factory of the future and as I told you that airbus has already adopted the factory of the future.

So, let us now proceed further and look at this different other implementations that airbus has adopted with respect to the factory of the future.

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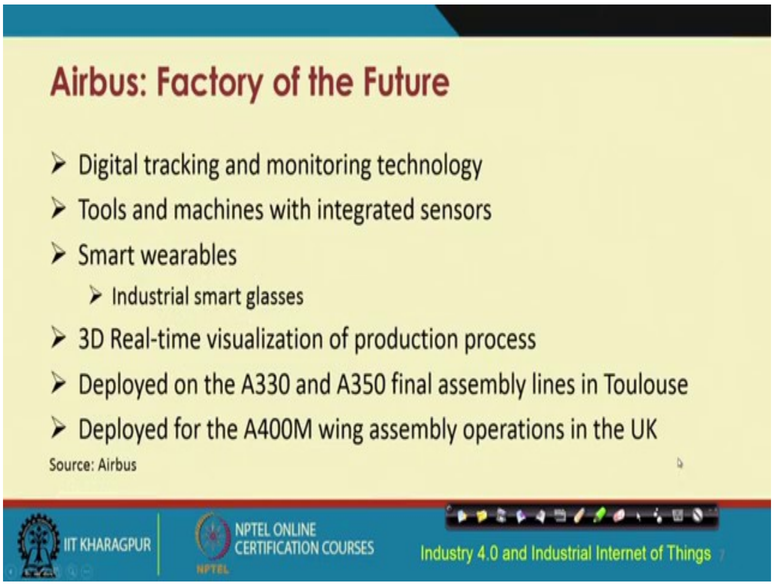


So, with respective the implementation of factory of the future, airbus now has mechanisms for digital tracking and monitoring, tools and machines with wearable sensors, sensors which are integrated to them not only those wearable sensors, but also equipments such as smart glasses can be use the industry grade smart glasses could be used with maybe augmented reality support, so, this smart glasses could be used. So, airbus is using all of these different things for its implementation of factory of the future.

So, 3D real time visualization of the production process is possible and all of these things are also deployed different sensors and all of these things are deployed on the A330 and A350 models and their assembly lines which are there in the Toulouse manufacturing plant and they have also deployed this factory of the future for the A400M model and their assembly operations in the UK.

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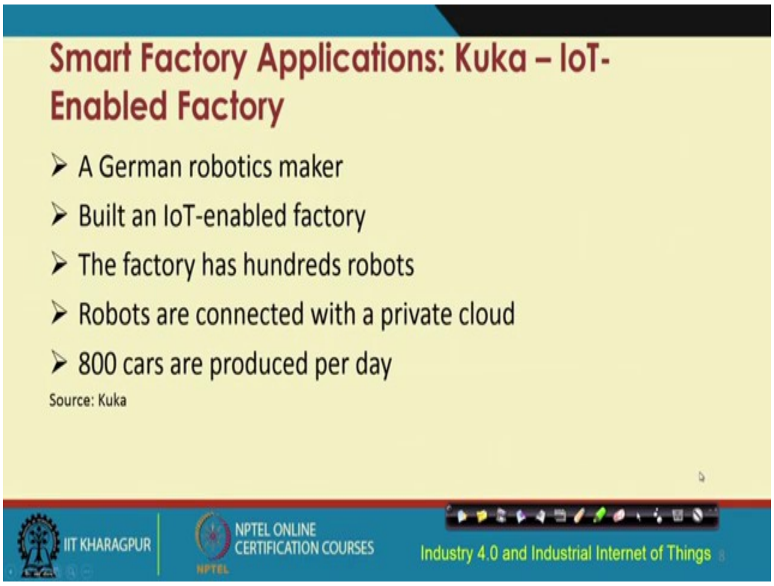


Another company of which is a germen robotics maker; name is Kuka, they have their IoT enabled factory which basically caters to having different robots their manufacturing of the robots and their connectivity between them etc. All of this things have been implemented IoT enabled connectivity between this different devices sensors connectivity and so on. So, all of these things are enabled in Kuka. So, basically these robots are connected with a private cloud and so, Kuka basically produces more than 800 units of these different devices per day.

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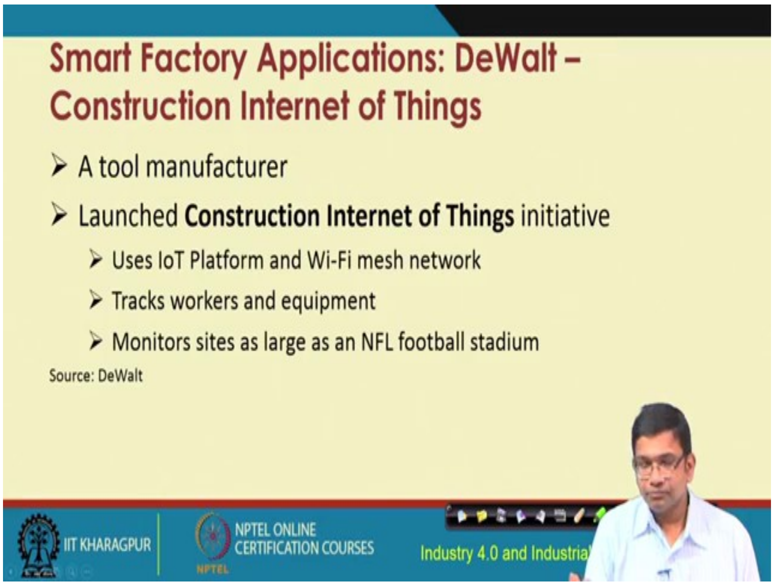

So, another application is the construction internet of things. So, by the company DeWalt; DeWalt is the tool manufacturer which launched this initiative of construction IoT. It uses the IoT platform and the Wi-Fi mesh network that tracks the workers and the equipments that they are using. The construction internet of things basically monitors the sites the construction sites which are very large, as large as the NFL football stadium.

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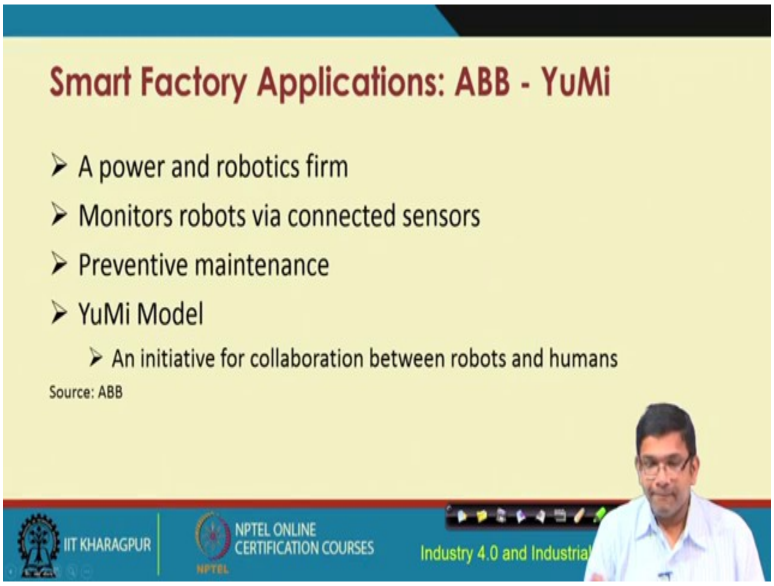


ABB came up with the YuMi model which is basically an initiative for collaboration between different robots, industry skilled robots and the humans YuMi model. And ABB is a power and robotics firm which has sensors and different robotic machinery enabled power systems, for monitoring the conditions of these machines and so on. So, these machines are all sensor enabled and also are connected through robots etc. and this YuMi model can help in the preventive maintenance of the ABBs products.

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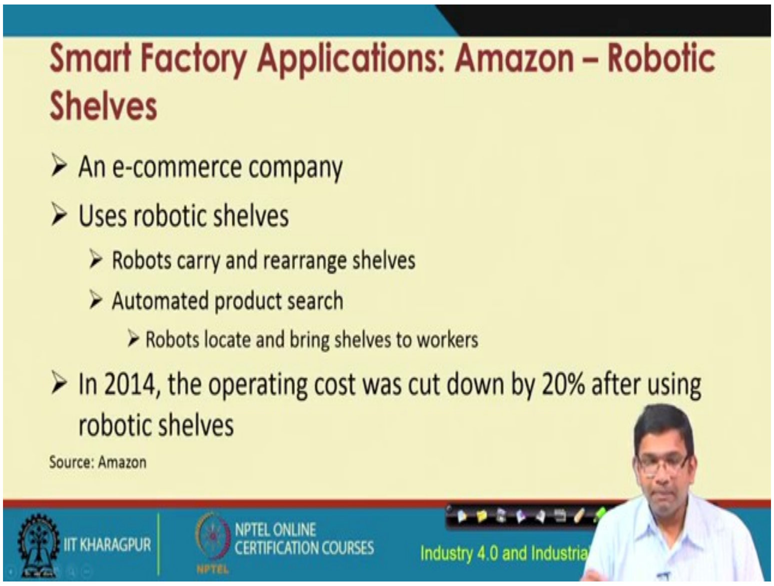


Amazon basically has the robotic shelves and as this name suggests basically Amazon uses different types of robots that will carry this shelves and rearrange this shelves. Amazon basically is the e-commerce company as you know and this shelves and their rearrangement robotically is very important and that basically makes the processes much more autonomous, efficient and so on.

So, the good part of this thing is that because it is an autonomous robotic system; using this system the robots can efficiently locate and search different items from their different shelves. So, basically in 2014 the operating cost was cut down by 20 percent using these robotic shelves by Amazon.

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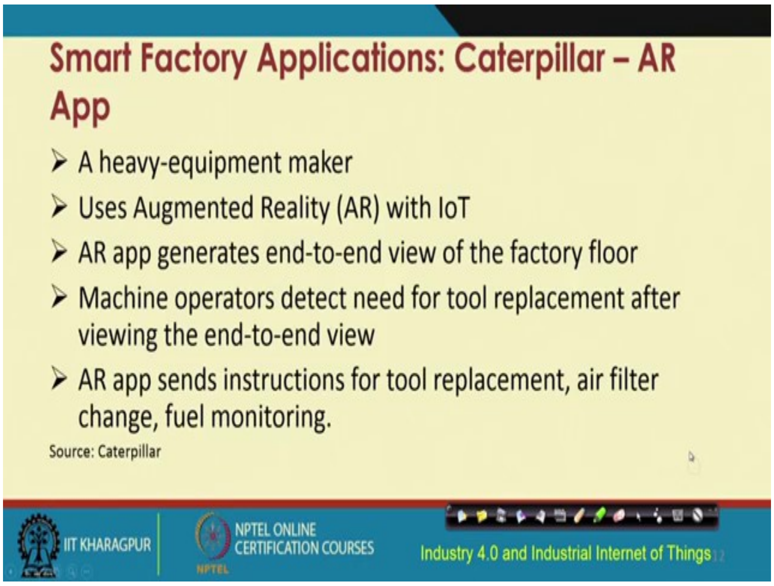


Caterpillar: caterpillar basically has the AR app augmented reality app which is integrated with IoT, caterpillar as you know is a heavy equipment maker and they have come up with the augmented reality app that generates end to end view of the factory floor. So, the machine operators can detect the need for tool replacement whenever it is required after viewing the end to end view through that particular AR app. The AP app basically sends instructions for doing things like tool replacement, air filter change, fuel monitoring and so on.

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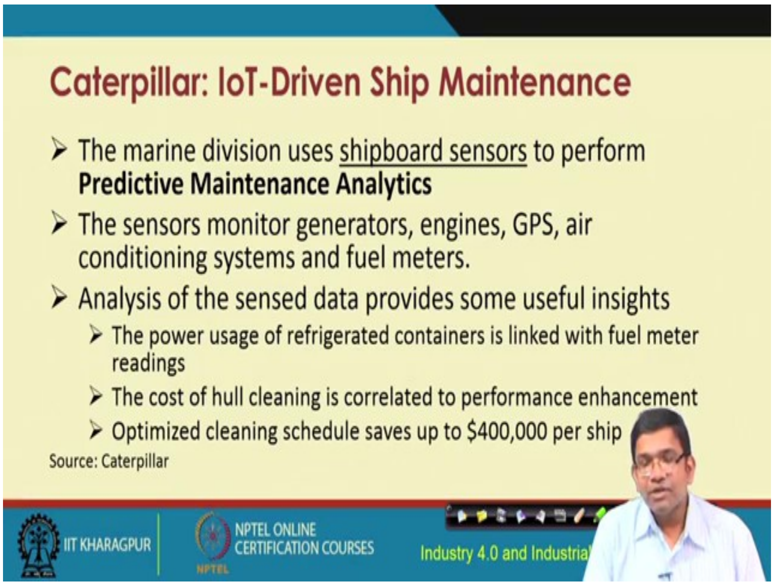

Caterpillar has the IoT driven ship maintenance and that is done by their marine division they use the ship board sensors to perform predictive maintenance analytics. The sensors that are deployed can monitor generators, engines, GPS, air conditioning systems and fuel meters. The analysis of the sensed data provides useful insights with respect to the insights about power usage of refrigerated containers, the cost of hull cleaning and optimized cleaning schedule and their data these are all provided through the analysis of the data that are obtained through these different sensors that are deployed in the onboard devices of the ships.

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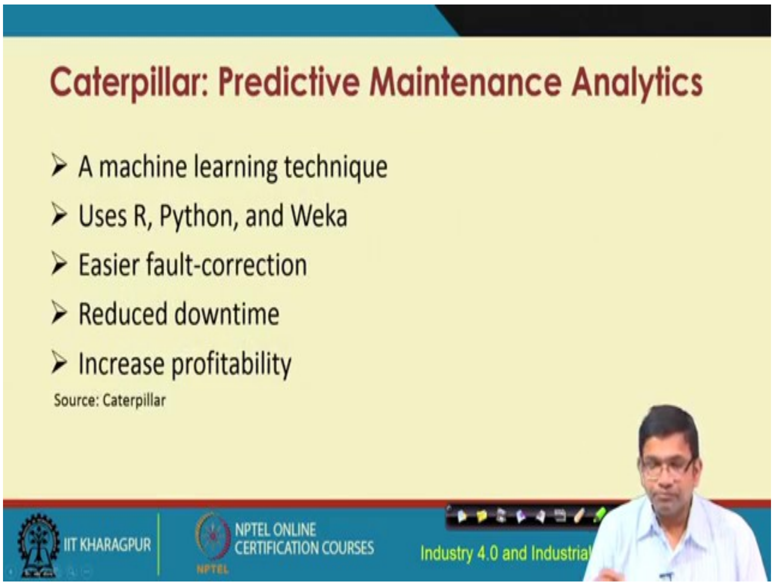


So, preventive maintenance analytics talks about use of all these machine learning techniques that we have discussed in a previous lecture. Tools and techniques like, are Python, Weka could be used to come up with these different analytics predictive analytics and so on. It is used easier to have easier fault correction, reduced downtime, and increased profitability, using the predictive maintenance analytics and this is what caterpillar is doing.

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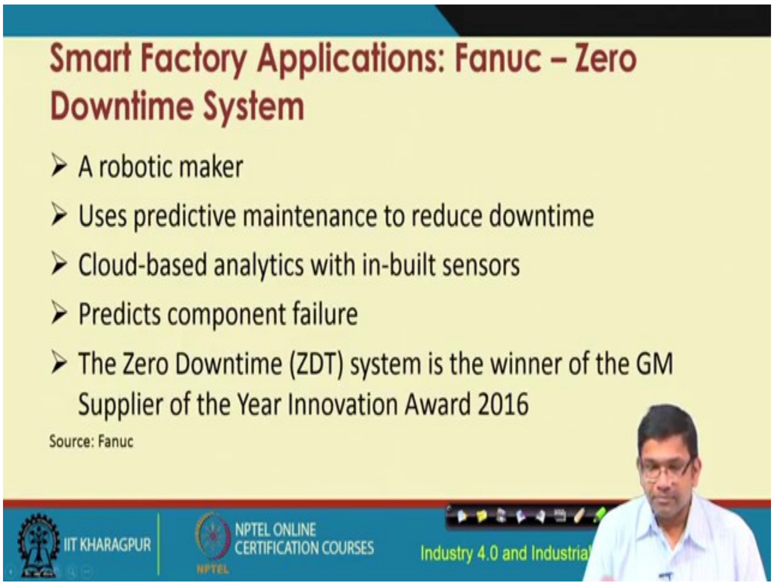


Fanuc is a robotic maker. It has the Zero downtime system, it uses predictive maintenance to reduce the downtime. It uses cloud based analytics with built in sensors, predicts component failure and the zero downtime system that Fanuc has is the winner of the GM supplier of the year innovation award 2016.

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Gehring is in the space of connected manufacturing. It makes honing machines, using cloud based analytics different types of predictive analytics is done with the data that are received from the machines in real time, thereby the productivity of the processes, productivity in the manufacturing plant of Gehring is improved, the optimization of productivity is done and so on.

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Hitachi has the Lumada system which offers IoT platform comprising of 5 layers, the layers of edge, core, analytics, studio and foundry which are used together in order to improve the manufacturing processes of Hitachi.

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Maersk is in the space of intelligent shipping. Maersk is a container shipping company that tracks the assets and fuel consumption using different sensors. So, this is another example of smart factory and it is implementation. It uses IoT for preserving refrigerated containers uses blockchain technology for supply chain optimization.

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Magna Steyr has the smart packaging system which uses IoT for tracking assets including tools and vehicle parts. So, smart packaging is enabled with Bluetooth. Bluetooth enabled packaging is there in their system and it tracks the components in the warehouses. In Magna Steyr the employees use wearable technologies in order to have end to end connectivity, improved connectivity, between these different machines, not only between these different machines but also the machines and the humans or the employees that are working in the factory.

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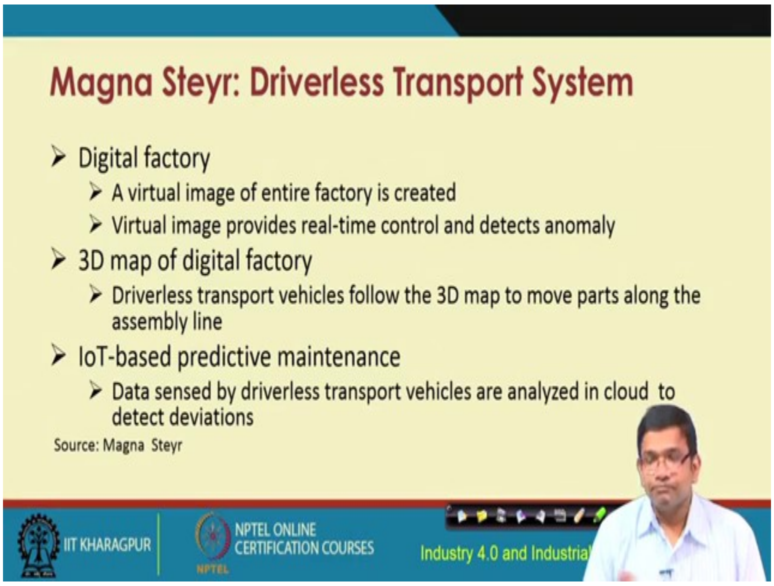


Magna steyr has the driverless transport system, they have the digital factory which offers a virtual image of the entire factory and that is done using advanced technologies this virtual image provides real time control and detects in the anomaly. They create with the help of the data collected, they create the 3D map of the digital factory and that basically helps in doing number of things efficiently including predictive maintenance of their transport vehicles using the data that is stored in the cloud.

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North Star BlueScope Steel uses IoT for worker safety. So, this particular company is a major supplier in the steel industry. It has different smart IoT devices, helmets, wristbands, etc. for the workers and their supervisors so that the supervisors can track the health condition of the different workers. The supervisors can give break for example, to the overloaded workers, the supervisors can monitor the condition of the workers and the working condition in which this workers are working. So, the supervisors can get data about you know the environmental parameters such as whether there is any radiation in the environment in which the worker is working or whether the worker is working in an environment a with different toxic gases.

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So, some other smart factory applications include the implementation of IoT by Rio Tinto for mining. So, Rio Tinto has driverless trucks and trains to pull ore from the mining sites and they also have the autonomous drill technology.

There are different other IoT applications in the power grid sector were IoT has been deployed to make the power systems much more smarter. The company bosch also heavily uses IoT and it basically deploys different IoT equipments in order to improve the working condition of the workers or and also to reduce the number of errors that happen in the work floor by the different workers.

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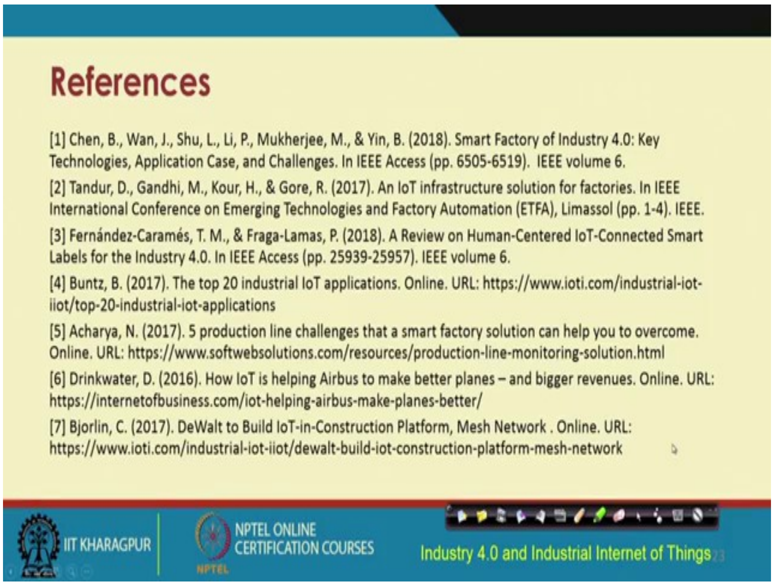


So, these are some of these different references that you could go through in this particular space of the smart factory and also the assembly line in the smart factory IIoT implementation in a smart factory and so on. These are all these different references and including the references talking about these case studies of the companies and their products that I talked about briefly in the last half an hour of lecture.

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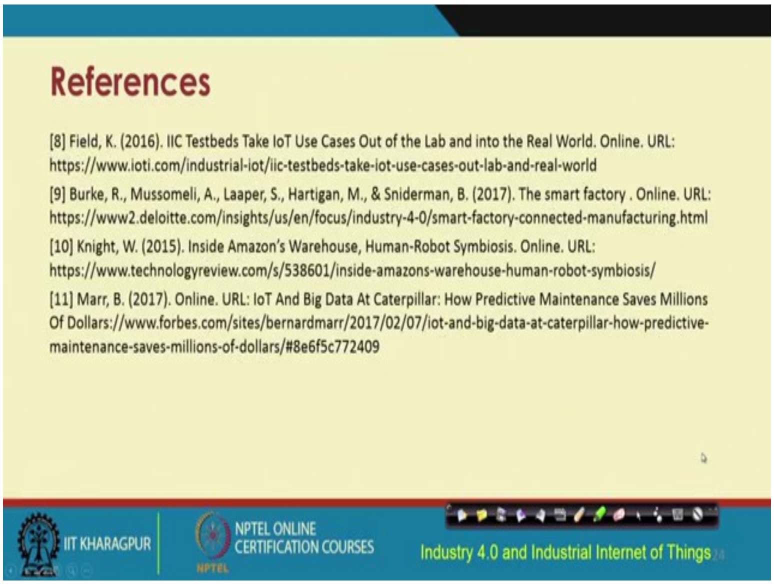


These are all these references for you to go through.

Thank you.

**Introduction to Industry 4.0 and Industrial Internet of Things**
**Prof. Sudip Misra**
**Department of Computer Science and Engineering**
**Indian Institute of Technology, Kharagpur**

**Lecture - 50**
**IIOT Application: Food Industry**

Another application of IIoT is in the food industry, agriculture and food industry. So, in the food industry let us first try to understand what actually happens. So, we have agricultural produce, those agricultural produce; they come from the field then those produces are basically taken through different processes and finally, the consumers basically consume the agricultural produce. So, let me elaborate this little bit further so, the process is well known as field to plate.

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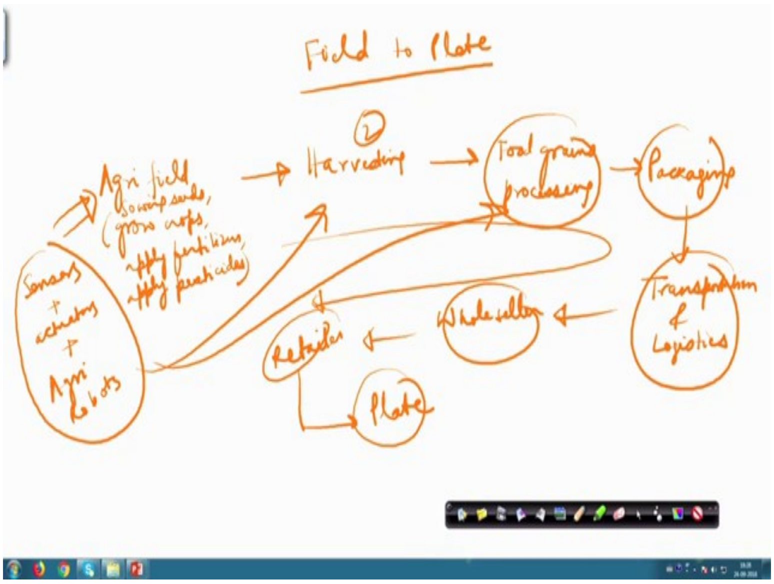


So, field to plate; what it means is that from the field, where the production is made to the plate, where the consumption is made, what is the supply chain? What is the chain of production?

So, let us say that it will start with the agricultural field. So, in the agricultural field you would be growing the crops. So, let us say that sowing of seeds, the farmers are going to sow seeds, grow crops, apply fertilizers, apply pesticides, etc. and then after the agricultural plans they become matured, then basically these crops are harvested right. So, these crops are harvested.

So, the next step is broadly is going to be harvesting. Following harvesting these food grains are going to be processed; food grain processing, after food grain processing we are going to have let us say the packaging, packaging of the food grains. After packaging of the food grains these packages are going to be transported; transportation and logistics. So, they are going to be transported typically to a wholesale market.

Then it goes to the retailer, the retail market and finally, the consumers are going to buy and cook the agricultural produce and they are going to consume. So, basically this is going to be the plate right. This is typically the chain from the agricultural field to the plate. So, this is typically the chain of activities that are followed; this is the supply chain let us say. So, supply chain comes because ultimately for each of these things the supply will have to be ensured through this entire cycle right. So, all these supply through these entire processes and the different steps will have to be ensured.

So, we are talking about this kind of scenario. So, in this kind of scenario sensors will have to be used; you have sensors, IIoT devices will have to be used in the agricultural field for monitoring the growth of the crops, the sowing of the seeds, for applying fertilizers precisely adequately and so on and also to precisely and adequately apply the pesticides.

So, sensors, actuators, plus different agricultural robots could be used over here. So, not only over here even in step 2 for harvesting also these could be used for food grain processing, again these could be used, for packaging likewise transportation, logistics, wholesaler, retailer, plate actually let us leave this aside. So, we still are not in a point of having a plate which is sensor enabled and robotic plate and so on. So, that is a far dream to be achieved so, but in retailer basically sensors, actuators, robots etc. these are all going to help the systems, or the machines that are helping in the processes and the different states etc. to be made much more efficient autonomous and so on.

So, let us now look further ahead and see what we have in terms of IoT implementation in the food industry.

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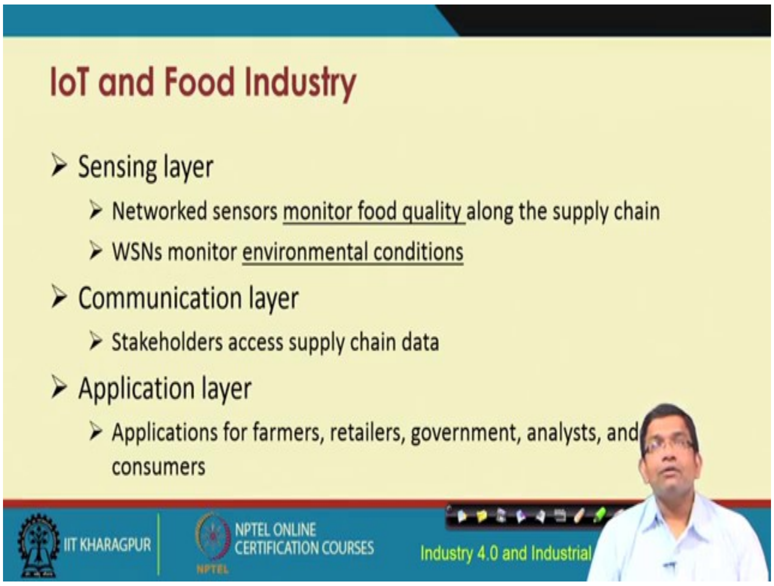


So, these sensors, actuators is something that I have already mentioned right, but they will have to be networked. So, we need to have network sensors for food quality monitoring along the supply chain that I have just mentioned, sensors and their networked sensors for monitoring the environmental conditions. So, food grains going through different warehouses whether the temperature of the warehouses have been properly maintained, monitoring of those temperatures, the crux carrying those temperature monitoring etc., those will also have to be done. So, sensors are very crucial over here in this entire food supply chain.

Communication layer basically talks about stakeholder access supply chain data etc., the communication between the different stakeholders, access to the stakeholders, communication between the different components of the supply chain, connecting different data to the use of sensors, from the sensors through the communication network, all of these things are required. And finally, that the application layer to have applications for farmers, retailers, government, analysts, consumers, insurance companies which have not written over here but very important for insurance companies also it is very important.

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So, you need sensors for doing number of things, sensors for monitoring humidity, temperature, composition of food products and so on. So, sensors can do number of these different things, but the sensors will throwing lot of data in real time which will have to be analyzed in real time as well in order to make the most out of those data that that have been retrieved. So, you need easier process control, increased food safety, etc. and it is also very important to have adequate end to end traceability.

So, I told you about the field to plate concept at the outset. I explained it. So, field to plate and the corresponding supply chain. So, if you have this adequately implemented using suitable IoT solutions it would be possible for example, to trace a rice packet back to the paddy field; that will be possible. So, as you can understand that this is going to be this is going to be very attractive if you can implement it properly.

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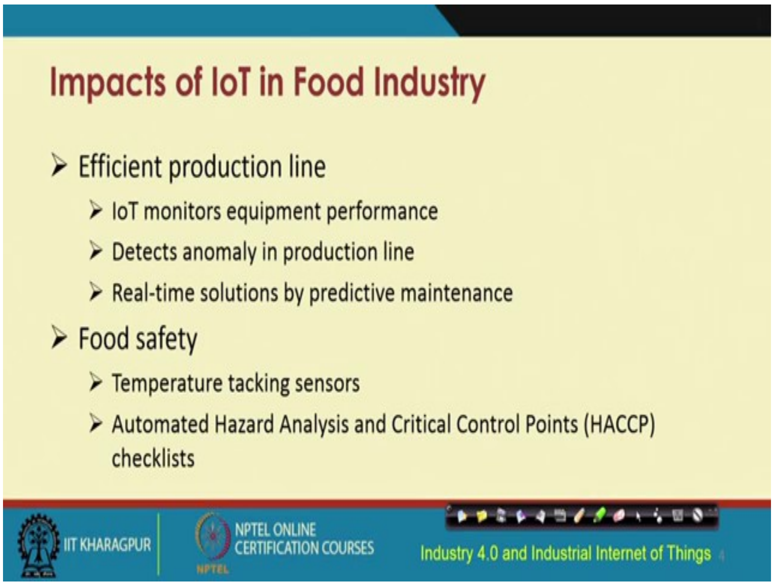


So, the impact of IIoT in the food industry is like this; that we are going to have efficient production line, we are going to have adequate, suitable, efficient food safety measures, the food safety regulation implemented.

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We are going to have transparency of the supply chain, we are going to minimize the wastage in the entire supply chain, we are going to have minimized wastage of food resources, and we can analyze in real time for example the information of food products and reduce the food wastage. So, all of these things are possible if you have IIoT implementation in the food industry.

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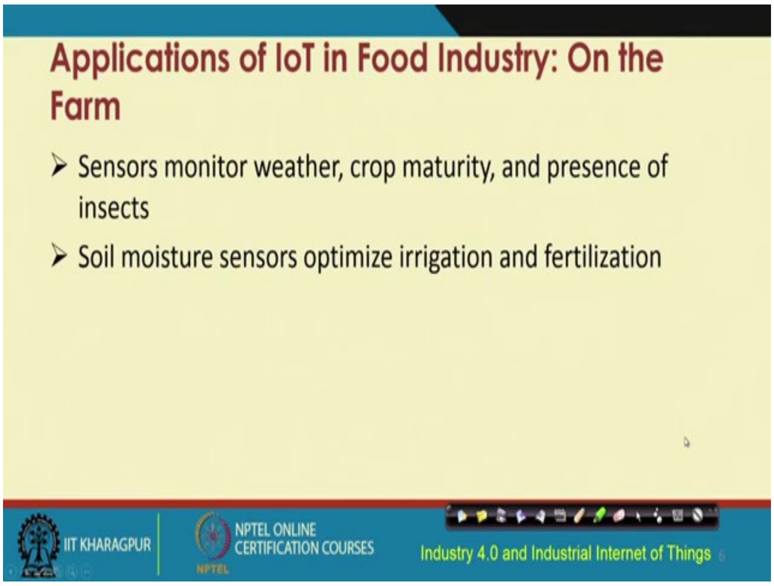


So, on the firm we can have sensors to monitor weather, to monitor the crop maturity, to monitor the presence of insects, to monitor the conditions of the field with respect to the soil conditions for example, how much soil moisture is there in the field, how much is the water level, how much is the fertilizer content of the field, the soil nutrient condition of the field. So, all of these things are possible with the help IoT implementation in the food industry. So, these are some of the different applications like wise you have large number of different applications that are possible for IoT implementation.

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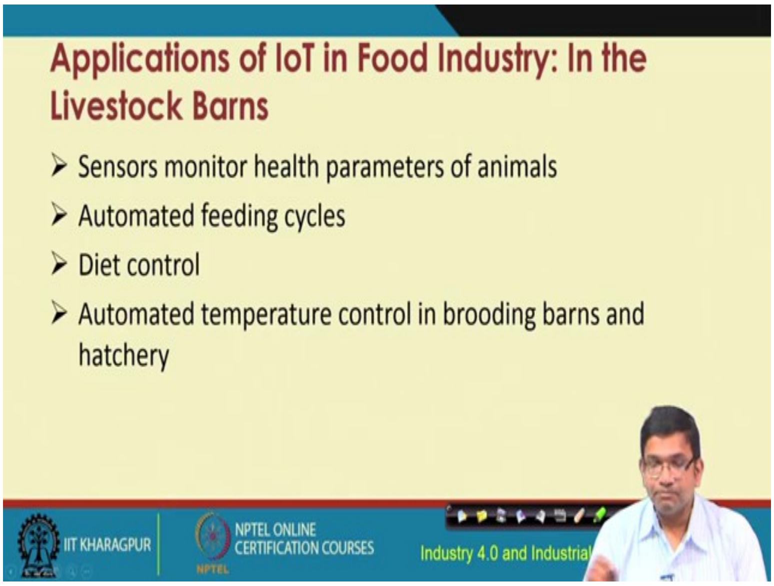


So, I am now going to give you some examples; in the livestock barns sensors can help in monitoring the health parameters of different animals, different live stocks such as cows, buffaloes and different other live stocks including sheep and goats and so on. So, all of the life monitoring, continues real time monitoring using IoT enabled devices is possible in the form.

Automated feeding cycles can be set up with the help of IoT implementation, diet control of these different livestock, the different farm animals is possible with the help IoT implementation. Automated temperature control in the brooding barns and hatchery these are also possible with the help of suitable IoT implementation.

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On the equipment, IoT enablement can be done in terms of you know GPS tracking whenever these animals are moving around their exact location their position etc. could be could be tracked. This is a just an example like this GPS could be used for tracking the movement mobility of different other components in the IoT in the food industry.

Drone-assisted field monitoring is quite common, drone assisted field monitoring applications in agriculture are quite common and are being implemented, we ourselves in the lab are working on different agricultural drone applications for doing number of different things.

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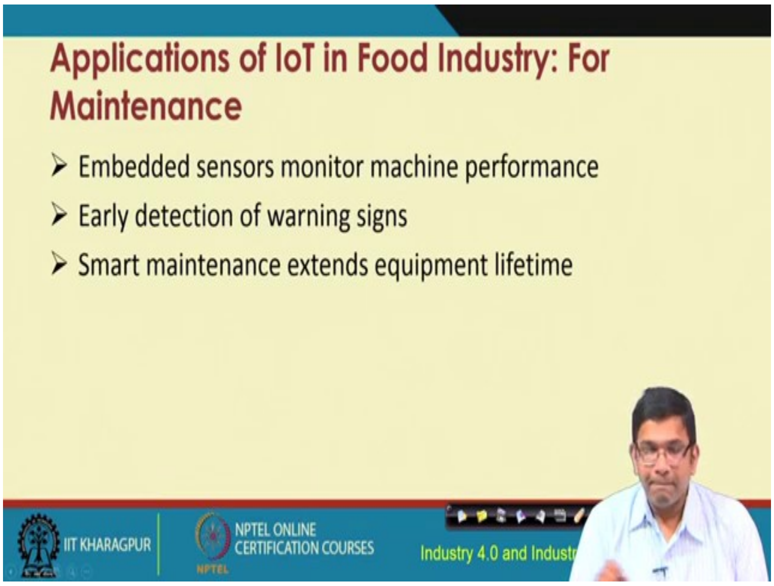


So, in the food industry IoT implementations can be done for maintenance embedding sensors to these different machines such as farm machinery, tractors, etc. to monitor their condition, to monitor their performance, to detect whether any machine is going to go down in the future. Early detection of warning signs, smart maintenance etc. of these machines extending the lifetime of these equipments all of these things are possible with respect to maintenance in the food industry through IoT implementations.

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IoT implementation in the food industry can improve the margins through predictive analytics, spotting early warning signs, making well informed decisions and maximizing profits.

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For the consumer, there are different initiatives, smart level is an initiative by the Grocery Manufacturers Association GMA, which uses QR code to provide product related information to the consumers. These consumers consequently can get information about the ingredient details of a particular food item, allergens exposure of that particular food item, nutrition, value and many different other Information.

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Consumers can scan the QR code to get details about the product; the product information includes nutrition, ingredients, allergens, third party certification, social compliance programs, usage instructions, advisories and also safe handling instruction.

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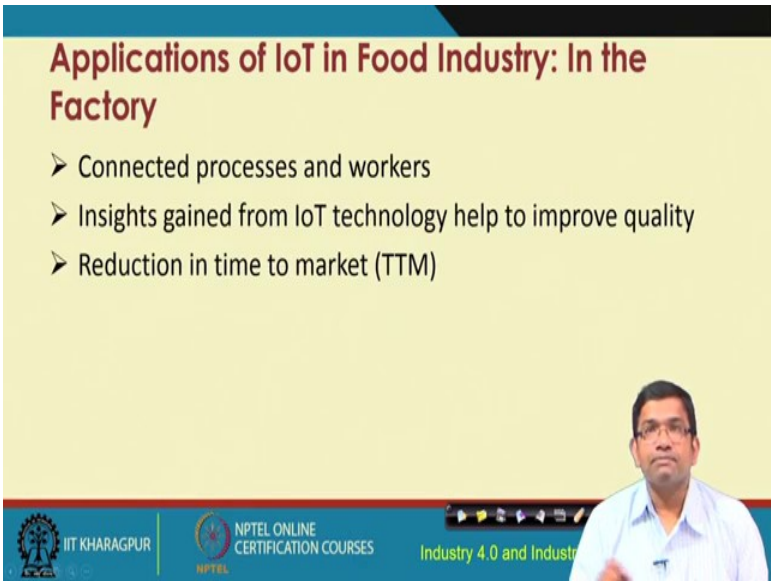


In the factory, IoT implementations can help the different machineries in the food processing industry, the different workers who are working in the food processing industry to remain connected autonomously. This connectivity can help in gaining insights to improve the quality of the food product, the quality of the food processes and so on and consequently they can also help in the reduction of the time to market TTM.

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So, IoT implementations can also improve compliance and safety of the food product, compliance to regulatory standard, compliance to best practices and also safe handling of the food products, these are all possible with the help of IoT implementation in the food industry.

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IoT implementation in the food industry can also help in empowering the workers through augmented reality safety glasses and other wearable, thereby increasing the overall productivity and efficiency of their processes, efficiency of the workers, and efficiency of the machinery that they are using.

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City crop is an intelligent indoor garden that provides intelligent indoor garden to grow fruits, herbs, vegetables, greens and edible flowers, they have implementation of automated climate control, automated livestock monitoring, automated smart notifications which can be sent to the concerned stakeholders and also to the plant doctors' automated notifications would be sent.

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Diagenetix has this product, the bio ranger which can help in detecting the presence of microbial diseases in the food. Bio ranger is a small handheld device that connects with android app and instantly detect pathogens in the food.

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Eskesso is a company that has the cooking sorcery the product which is basically for smart cooking. So, they have this Wi- Fi connected smart cooking device that can help in easy monitoring of the cooking status via the smart phone app. Smart cooking basically helps by placing the food packet and Eskesso device in a pot of water, selecting the recipe and starting via smart phone app you can get your food cooked in a smarter way through minimal involvement.

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Culinary science industries has the flavor matrix which basically infuses foods and beverages with unique flavors, they collect data on the food ingredients, collect user data and uses different implementations of machine learning and data analysis to enhance the flavor of dishes and provide user specific food and beverage pairing.

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Intellicup has the smart cups solution which basically is a smart beverage vending machine which reduces the waiting time and increases the profit at the beverage shops. These are sort of like IoT enabled cups which have NFC integrated chips at the base of the cup and they connect the cups to the mobile banking platform and IntelliHead which is a modular dispensing unit. So, this NFC chips basically helps in connecting each user to a cup. So, the cups are usable and made with biodegradable material.

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So, how the smart cup works? So, basically there are separate apps for the merchants and the customers, the customers create intellicup accounts using the app, they transfer the funds to the e-wallet us and linking there after the cups are linked to the e-wallet by scanning a QR code via the app and docking the cup on the dispensing unit using the intellihead. So, customers there after enjoy the beverage that is finally, produced through this smart cup.

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Likewise there are different other IoT solutions for the food industry by Spinn Inc for smart coffee brewing and farm shelf for smart indoor farming.

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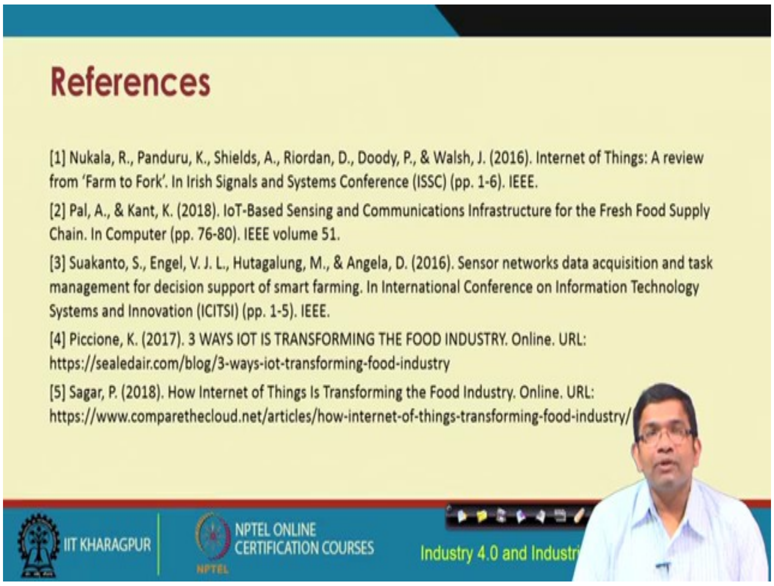


So, these are a list of different references talking in more detail about the solutions that I have talked about briefly, IoT solutions that have been used in the food industry, food processing industry and so on. So, if you are interested about any of these solutions that I just mentioned you are encouraged to go through these differences.

Thank you.

**Introduction to Industry 4.0 And Industrial Internet of Things**
**Prof. Sudip Misra**
**Department of Computer Science and Engineering**
**Indian Institute of Technology, Kharagpur**

**Lecture – 51**
**IIoT Applications: Healthcare**

The next example that I am going to give you of IIoT implementation is from the healthcare industry. IIoT implementation in healthcare is quite pervasive; there are large number of different IIoT implementation solutions in the healthcare industry that exist at present. So, I am going to give you the highlights of how IIoT can help in transforming present day healthcare and making healthcare much more affordable, much more efficient and much more autonomous.

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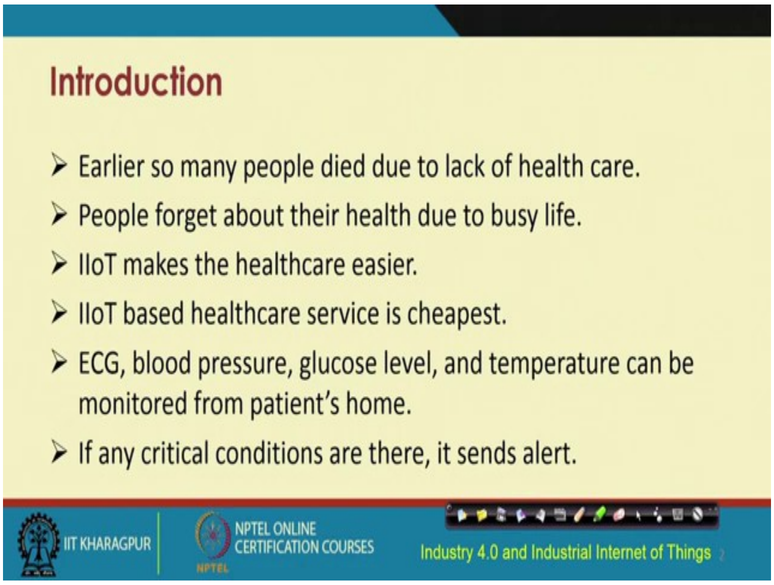


So, before I do so, let me give you some points of introduction. So, healthcare now a days have improved. Earlier days, people used to die due to lack of healthcare. People used to forget about their health due to busy life and this as also happened in the recent past. People basically tend to forget about their health and taking care of their health due to busy life and so on. Additionally, the number of diseases have also increased in the recent times. So, however, we have our IOT solutions, we have our IIoT solutions that could be used to alleviate some of the problems that are encountered by people with respect to health. So, IIoT solutions can help in making healthcare easier, affordable and so on.

There are different sensors such as the ECG sensor, blood pressure sensor, glucose monitoring sensor, temperature sensor etc. that are currently available in the market, that can be that are those are cheap affordable and can be procured can be purchased by the patients themselves for monitoring their health conditions at their homes or those could be also purchased by different healthcare facilities hospitals and so on. So, these systems would be further developed, these devices, these different sensors would be internet worth so that if any patient has a critical condition, different levels of alerts would be sent to the healthcare facilities or hospitals to which this patients are registered.

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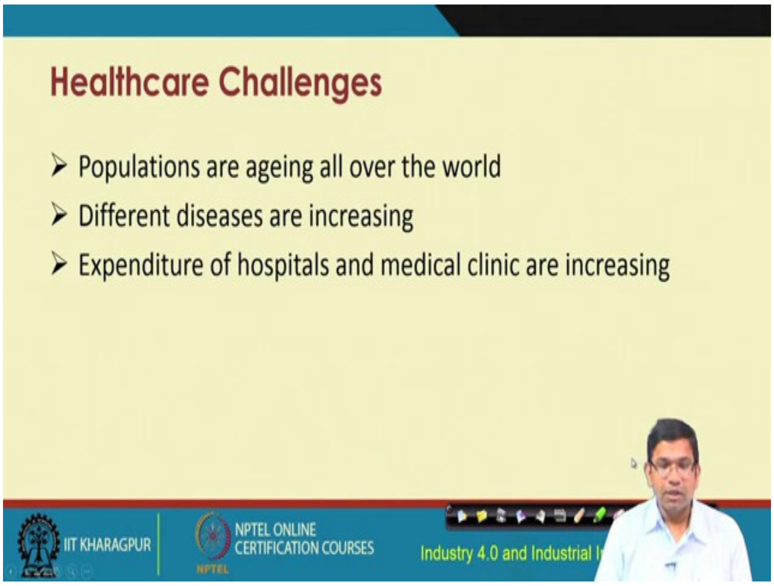


There are different healthcare challenges with respect to their implementation of IIoT. Populations are ageing all over the world; different diseases are increasing; expenditure of hospitals and medical clinic are also increasing. These are some of the generic healthcare challenges, but from an IIoT perspective as well. Catering to this going requirements is also a challenge; scalability of IIoT solutions will have to be taken into account both in terms of numbers, but not only in terms of numbers, but also in terms of diversity. Catering to different types of diseases; catering to different types of hospitals, different types of medical clinics having different facilities.

So, all of these challenges, the generic healthcare challenges also have implications on the IIoT implementations in the healthcare industry.

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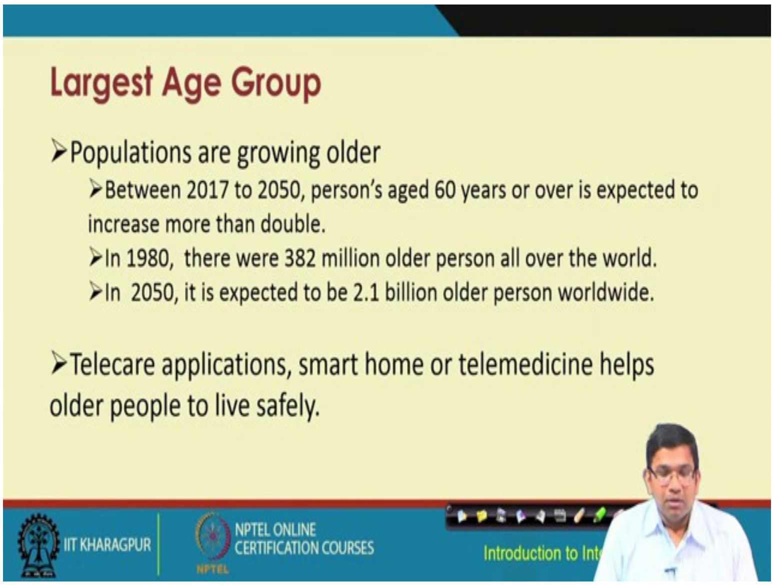


Looking at the age groups, populations are growing older, between 2017 to 2050; the persons aged 60 years over are expected to increase more than double. In 1980, there were 382 million elderly persons over the world, in 2050 that number is going to grow to 2.1 billion. So, you see that 1980, it was only 382 million elderly persons all over the world and by 2050, this particular number of elderly persons is expected to grow to 2.1 billion, worldwide. So, this is a huge number. We have a growing population and growing population also will invite taking care of their health. Elderly people monitoring their health condition etc. efficiently will have to be done. So, Telecare applications, smart phone or telemedicine basically can help elderly people to live safely.

So, you can have telemedicine solutions being deployed being implemented in the homes of these elderly persons so that the doctors can remotely monitor the condition of this elderly people from their home. Not only elderly people, I took the example of elderly people, but this also applies for the other population as well; other parts of the population as well.

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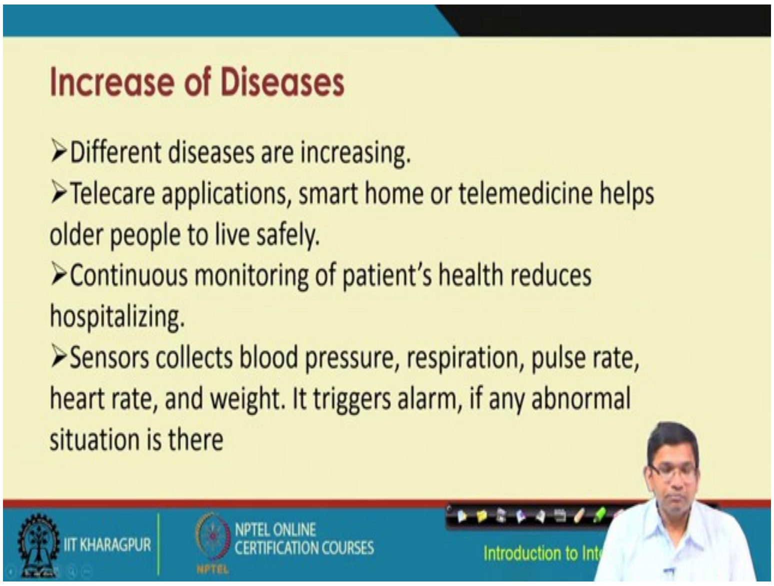


Additionally, the number of diseases are also increasing. Not only the number of diseases, but also the types of diseases are also increasing day by day.

So, you need to have suitable efficient large scale monitoring system that will cater to this particular problem and addressing that problem. So, now a days, we are talking about having Telecare applications, smart phone applications, and telemedicine applications for elderly people. We are also taking about these kind of solutions for catering to the other segments of the population. So, that continuous monitoring of patients health can be done and this can also help in reducing the number of cases of hospitalization.

Sensors can collect blood pressure, respiration, pulse rate, heart rate data, weight data continuously and as and when required, if any alarm has to be triggered this can be done this can be done in a much more efficient manner and this can be done if any abnormal solution is detected or any abnormality is going to arise in the future, predictively this can also be done.

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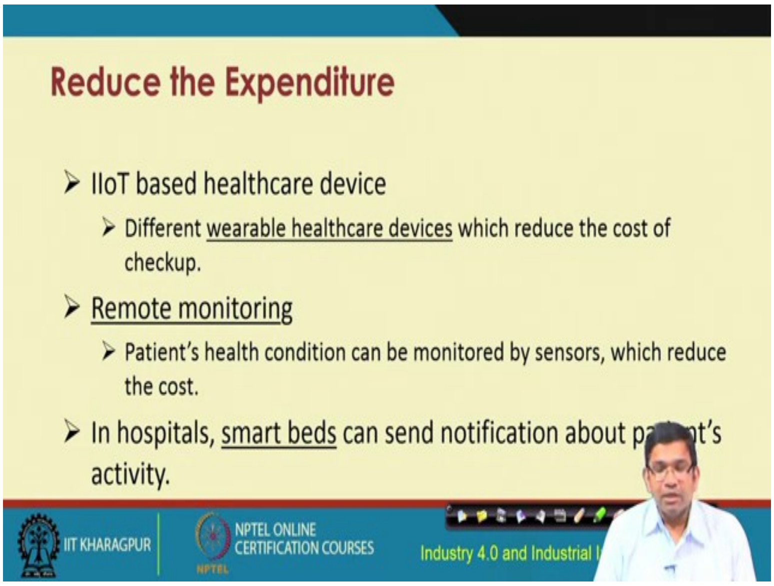


So, reduction in the expenditure is required. IIoT based solutions for health care can help in reducing the expenditure; different wearable healthcare devices can help in reducing the cost of health checkup; remote continuous monitoring of patients using different sensors, smart sensors, connected sensors would be made possible. In hospitals and other health care units smart beds can be deployed which can send notification about the patients activity.

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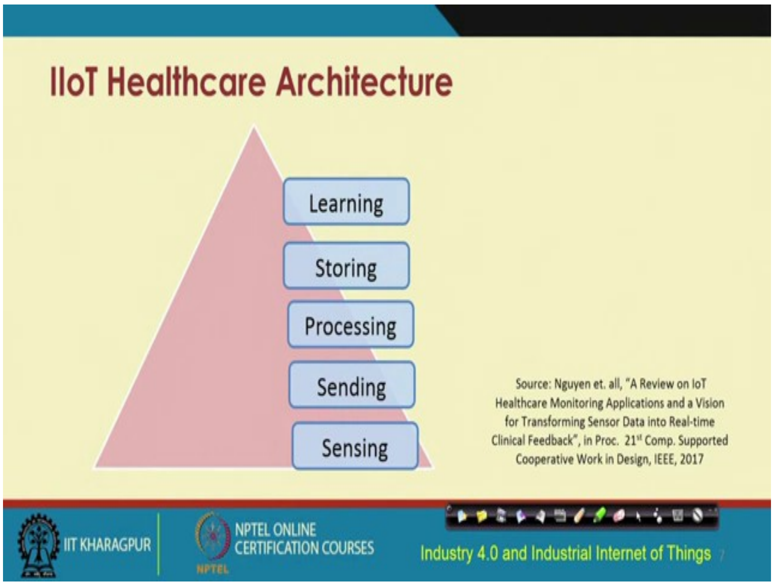

So, if we are talking about IIoT healthcare solutions, let us look at this particular architectural view point. This has been taken from this particular source that is given at the bottom of the slide. So, basically when you are we are talking about IIoT healthcare, these are broadly the different layers in the architecture. It starts from Sensing at the very bottom; Sending the sensed data; Processing the data; Storing the data and getting different information knowledge etc. about what is going on underneath from the data trying to make more sense out of the data, through information processing, knowledge processing and so on. These are all this things that are possible.

So, let me now elaborate this thing further.

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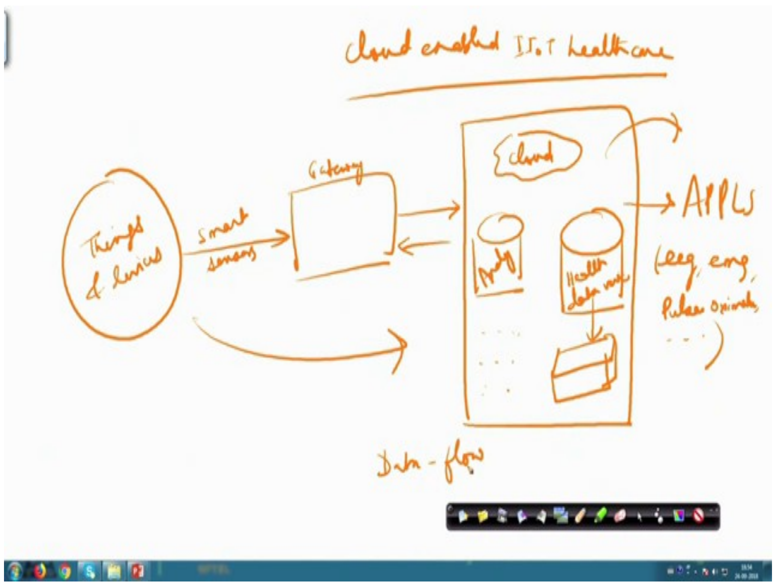


Let us say that we want to have a cloud enabled IIoT healthcare care solution. So, how it is going to look like? Let us look at the dataflow architecture of such a solution. On one end we are going to have all these different things and devices which are going to be typically sensor enabled, i.e. the smart sensors and then, some gateway. So, gateway devices, the data are going to be sent to the cloud platform; IOT enabled cloud platform where different analytics will be performed. Different other analysis for example not just analysis, but may be health data verification can be performed and the data can be stored and the data can in fact, be also processed in a computer or a computational resource in the cloud and so on.

And there is lot of other different things could also be done at the cloud and finally, we are going to have this is two way communication and finally, we are going to have this different applications, healthcare applications which are going to be the beneficiaries from all these analytics on the data that are coming in. So, this different applications are going to run.

So, you know at the application end, different patient data about their health condition such as ECG, EMG, then may be pulse oximeter data and many other different types of healthcare data could be made available after suitable processing suitable analytics and so on through these different applications, different portals, web portals and so on. So, this is going to be the dataflow architecture at very high level for healthcare IOT.

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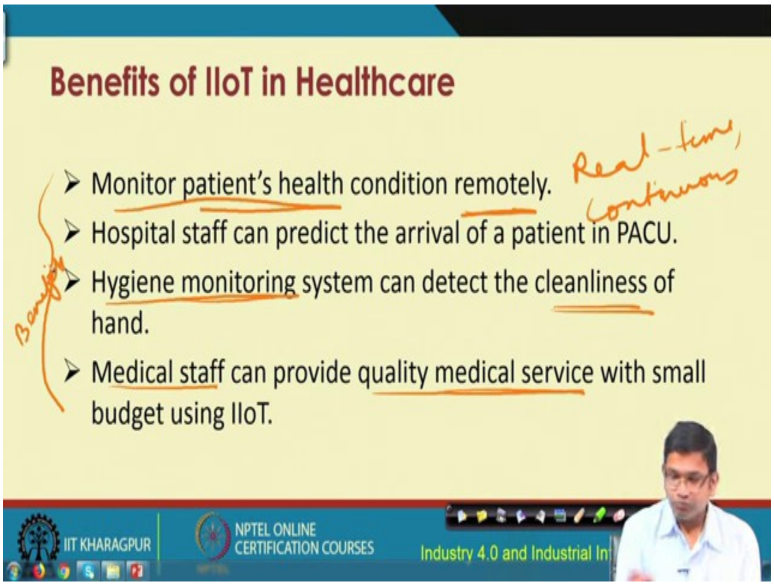


So, let us look further ahead and see what the benefits of IIoT in healthcare are. With IIoT, one can monitor the patient's health condition remotely. So, remote healthcare is possible. Remote real time continuous monitoring of patients health condition 24x7 is possible. Hospital staff can predict the arrival of a patient in their emergency units; it is also possible to have hygiene monitoring system which can detect the cleanliness of the hospital and the healthcare facility. Medical staff can provide quality medical services with small budget using IIoT. So, these are some of the many benefits that IIoT implementation in healthcare can provide.

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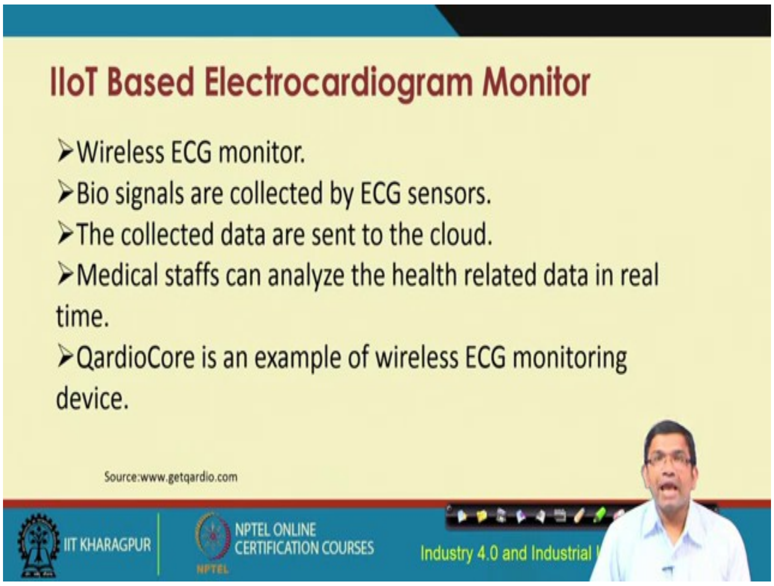


So, nowadays there are different healthcare devices. Wireless ECG monitors are there which can collect bio signals from this ECG devices, ECG sensors; the collected data could be sent to the cloud; medical staffs can analyze the health related data in real time. In fact, you could have some programs which can autonomously which can analyze the data that are coming in and can send alerts. So, one example of a wireless IOT enabled ECG sensor is QardioCore. QardioCore is a device for ECG monitoring; it is a wireless device.

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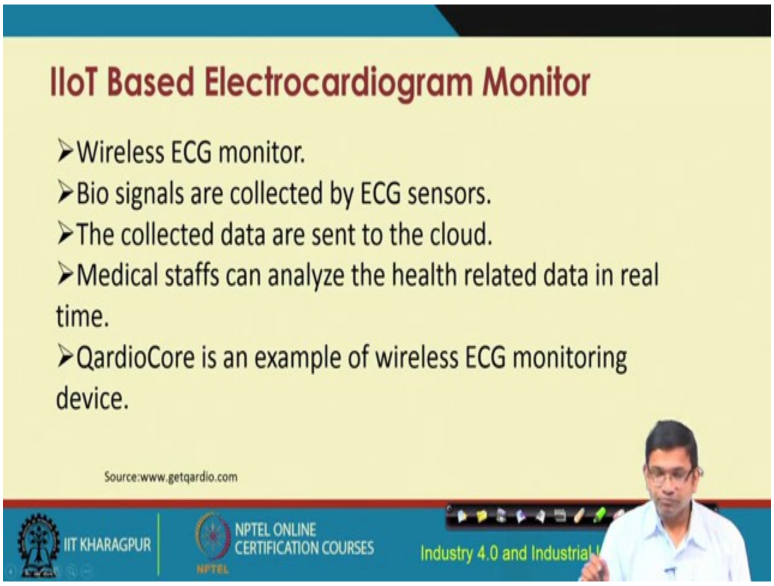

Similarly, for glucose level monitoring particularly for diabetes patients; diabetes patients typically need to check the glucose level quite often. Particularly, the ones who have higher degrees of diabetes; they have to they are required to check the blood sugar continuously, not continuously but quite often. So, if you have an automated IOT enabled system to which the patients can be fitted, then a automatically the data from this different patients can be made available to whoever can make sense out of the data such as doctors who are treating the diabetes patient and so on and example of continuous glucose monitoring device is the Dexcom. Dexcom devices can help in continuous glucose monitoring.

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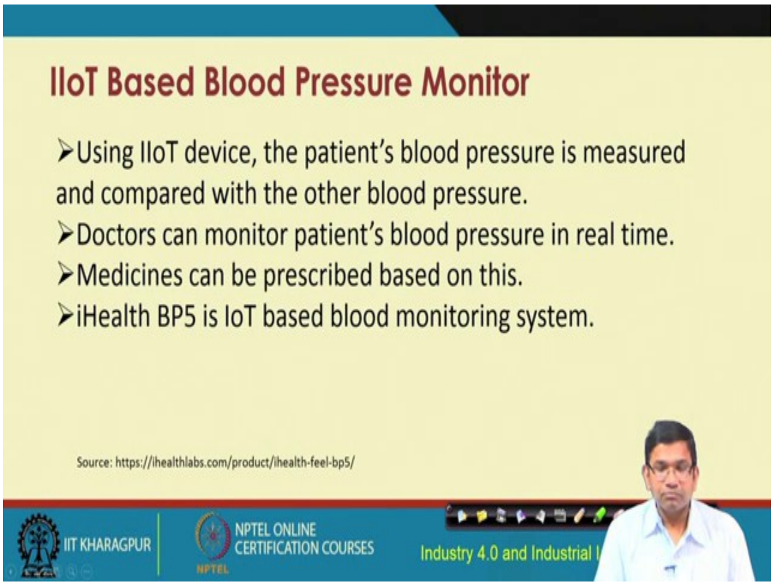


Similarly, we have IIoT based blood pressure monitors. Using IIoT devices the patient's blood pressure is measured and compared with the other blood pressures in real time. Doctors can monitor the patient's blood pressure in real time; can get alerts if the blood pressure process a particular threshold and depending on the blood pressure data, the doctors can prescribe medicines to the patients. One such example of blood pressure monitoring system is iHealth BP5.

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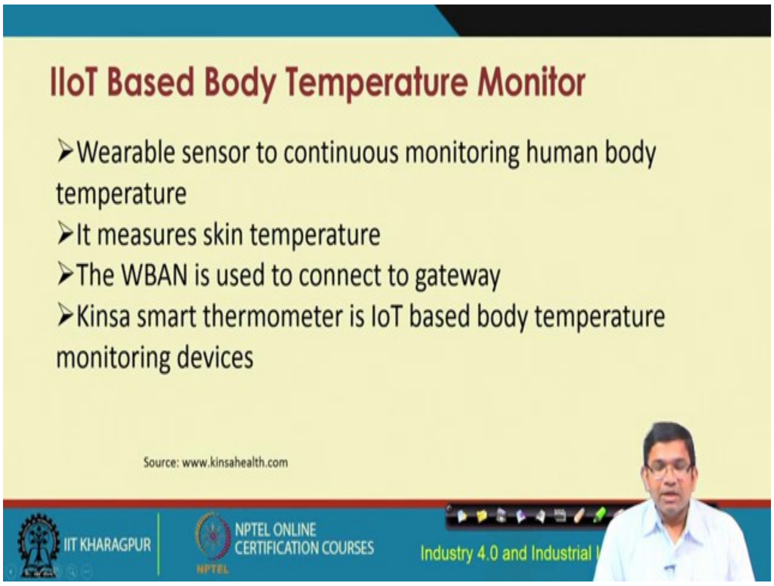


Similarly, body temperature monitors, wearable sensors to continuously monitor the human body temperature. This sometimes is very much required particular patients who are suffering from diseases which make the patients vulnerable to sudden increase in the body temperature or sudden decrease in the body temperature. So, there are different body temperature sensors in the market. One such body temperature sensor is by Kinsa. So, they have their smart thermometer which is an IOT based body temperature monitoring device.

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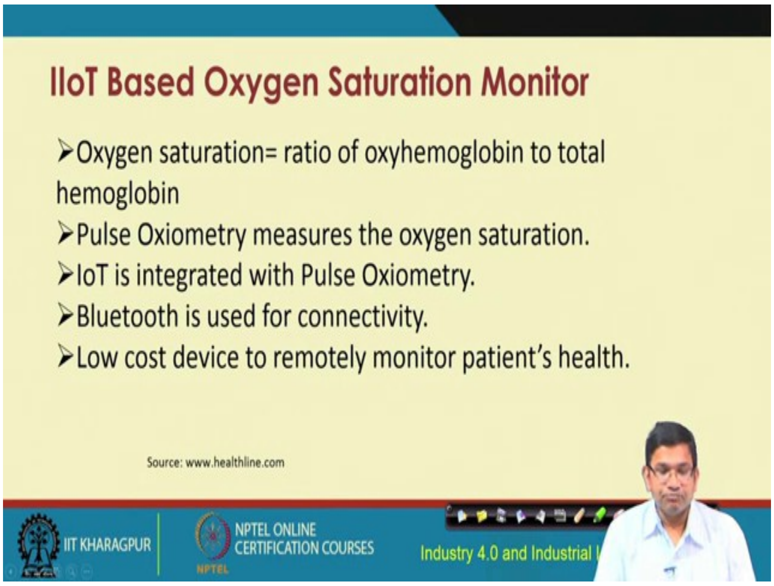

For oxygen saturation monitoring, particularly for asthma patients this is very important, oxygen saturation can be monitored with the help of IOT devices such as Pulse Oxiometer. So, Pulse Oxiometer can help in measuring the oxygen saturation so this Pulse Oxiometer could be integrated with connectivity solutions such as Bluetooth which can send continuously the data of the oxygen saturation level of the patient who is being monitored.

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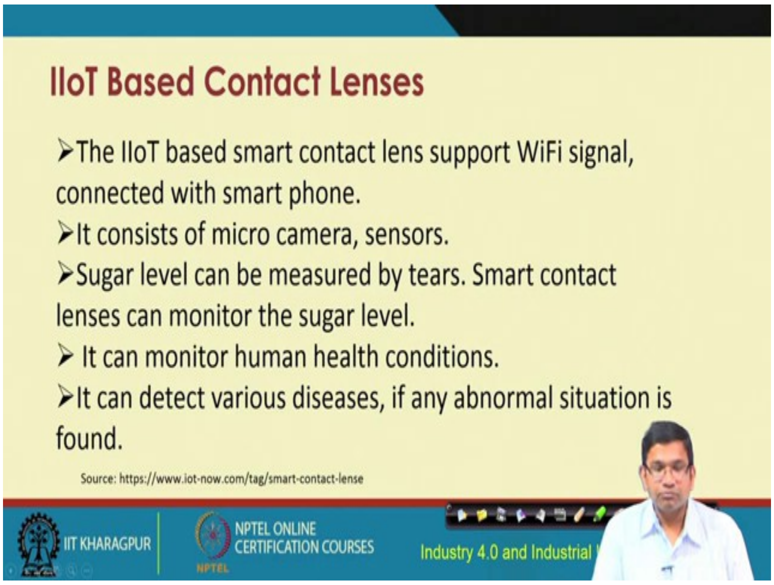


IOT based contact lenses are also there in the market. There are different IOT based contact lenses which are which also offer Wi-Fi connectivity with smart phones so that the condition of the patient, their eye condition, their sugar level etc. could be also monitored.

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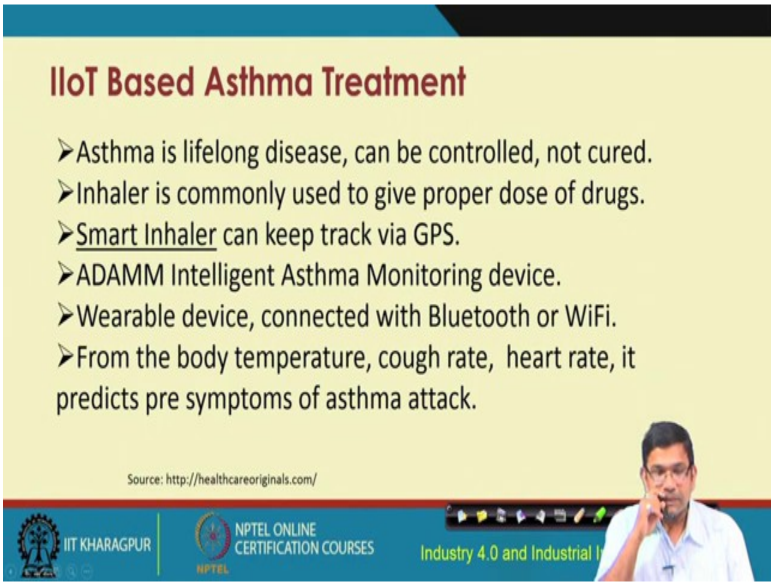


IOT based asthma treatment solutions are already in the market. Smart Inhaler; inhalers are a very essential requirement of asthma patients. So, Smart Inhalers have been manufactured. So, ADAMM is an intelligent asthma monitoring device that has been developed. So, this particular device can keep track of the body temperature, coughing rate, heart rate etc. which are basically preliminary symptoms of an asthma attack.

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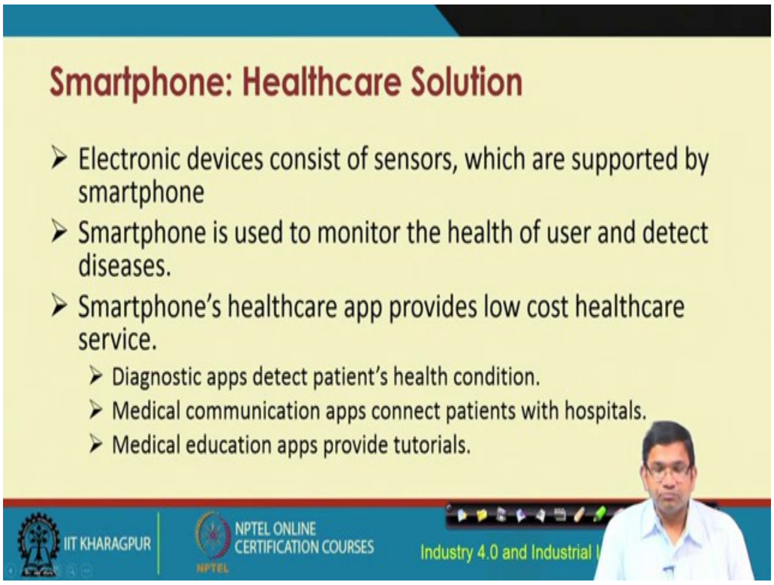


Different smart phone based healthcare solutions are already available. So, smart phone devices connected to electronic devices such as sensors can help in collecting the data of the patients. Smart phone is used to monitor the health of users and detect the diseases. Smart phones healthcare app basically provides low cost healthcare devices which are sort of like diagnostic apps that help in detecting the health condition of patients; can also help in medical communication between the patients and the hospitals and can also offer medical education in the form of tutorials to the patients.

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Health assistant is one such app which keeps track of health condition of the patient. Google Fit is another solution which keeps track of different physical activities of the patient. ECG Self Monitoring is another solution which serves as ECG device, based on the "ECG Self Check" software. Likewise there are different other solutions that I have listed over here and there are many more that I have not listed.

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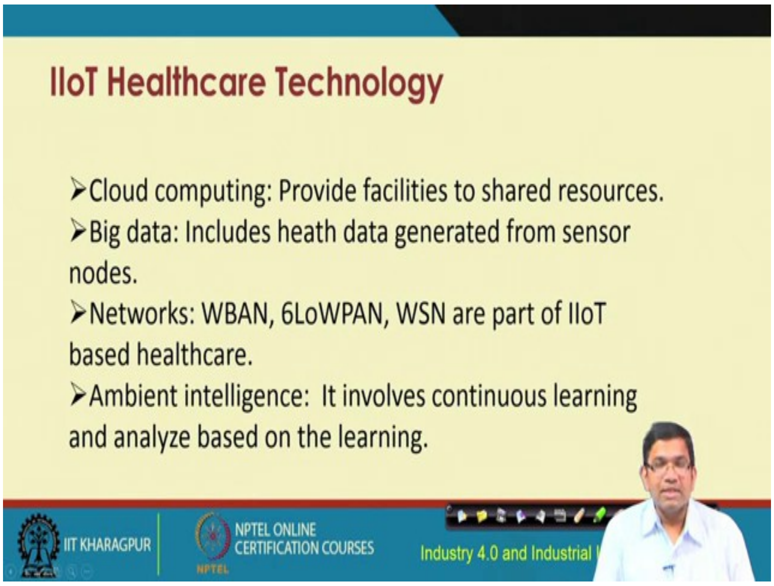


So, I would encourage you to basically explore the different solutions that are there in terms of healthcare and the IOT implementations in healthcare. Cloud enablement, dealing with big data because most of this data that is generated from these healthcare sensors have the nature of big data. So, cloud enablement big data analytics etc. are very important in healthcare and IOT implementation in healthcare.

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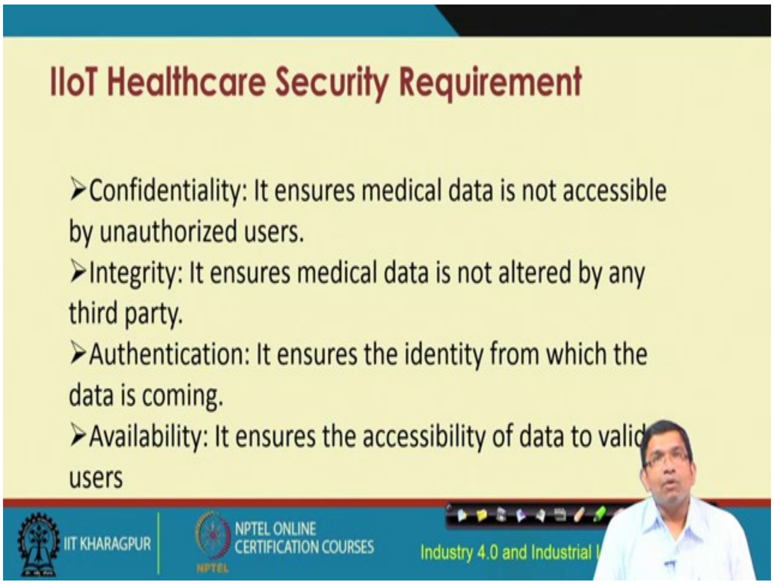


So, security is paramount in the healthcare sector. Privacy of the individuals is very important because the data that are being carried forward from one device to another through a particular communication channel should not be hacked and basically unauthorized users should not be able to get access to the data. So, ensuring the confidentiality of the data, integrity of the data, authentication mechanisms and their implementation and availability of the data are very important in terms of security requirements and their implementations in IIoT healthcare.

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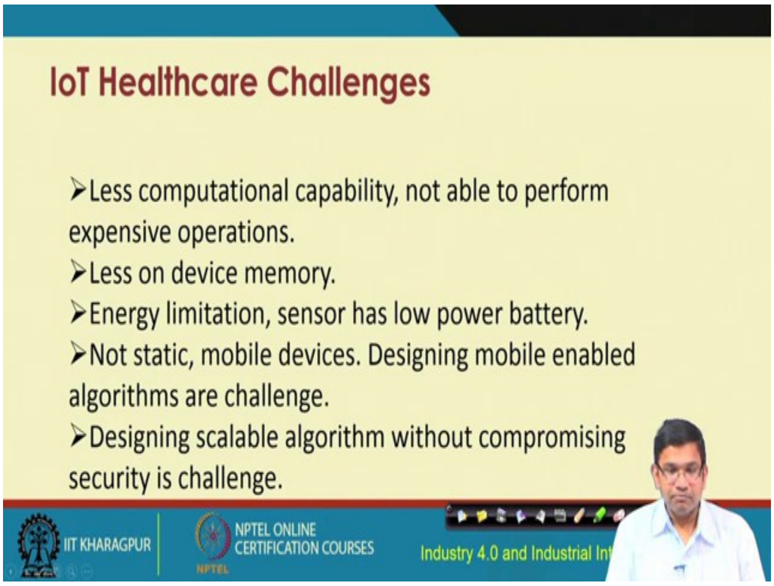


IoT or IIoT healthcare as different challenges; challenges with respect to limited computational capability, not being able to perform expensive operations, challenges with respect to having very less device memory, energy limitation and also taking care of the mobility of these different devices because the patients themselves are mobile.

So, consequently this devices themselves are wearable devices, the sensors themselves are also mobile. So, taken care of mobility of these different devices from a technical point of view is a challenge; both from a communication and algorithmic point of view there are different challenges. So, taken care of all of them are different challenges that basically are important for consideration.

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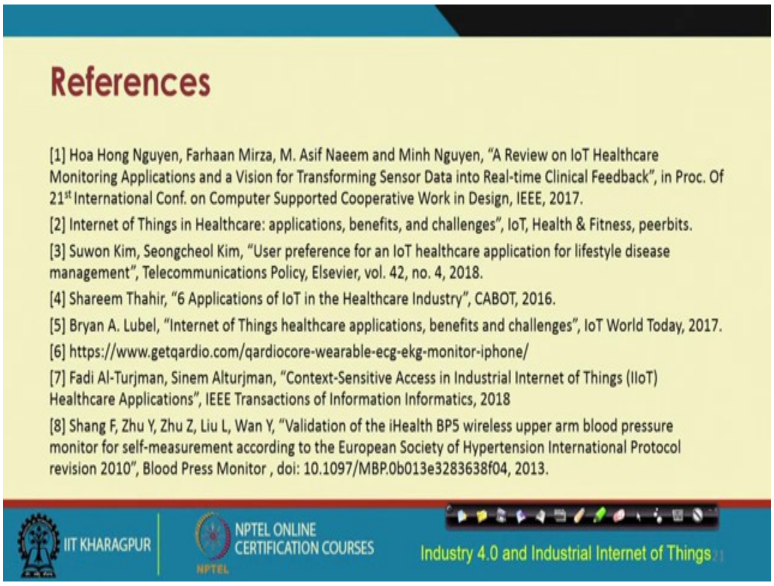


So, finally, we come to the references. Once again as usual, these are some of the references that you are encouraged to go through. With this, we come to an end of the healthcare implementation or IIoT implementation in the healthcare industry. The different references, we have talked about; different solutions that are there, we have talked about. So, I would encourage you once again to go through these different solutions to get an understanding about how IIoT implementation has been done in the healthcare industry to solve different challenges that plague this particular industry.

Thank you.

**Introduction to Industry 4.0 and Industrial Internet of Things**
**Prof. Sudip Misra**
**Department of Computer Science and Engineering**
**Indian Institute of Technology, Kharagpur**

**Lecture - 52**
**IIOT Applications: Plant Security and Safety**

In the previous lectures, we have seen the applications of IoT and IIoT in different application domains such as food and agriculture, healthcare and so on. We are going to continue further and we are going to look at different other applications, applications of IoT and IIoT in the power sector more specifically in the power plants.

So, just as a recap when we talk about IIoT basically it is the integration of information technology with the conventional operation technology in the manufacturing or power sector. So, IT-OT convergence is what characterizes IIoT. So, here also in the power plant we are going to experience the same thing.

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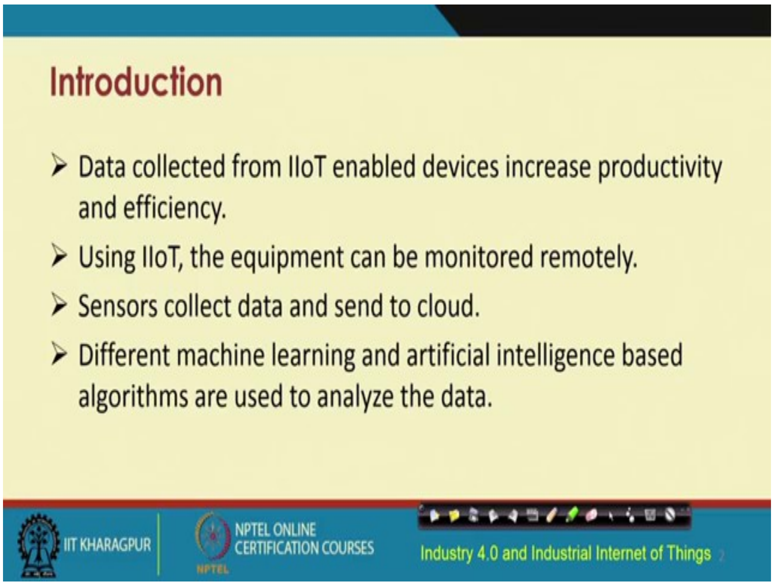


So, let us look at some of the advantages of the adoption of IoT solutions in the power sector. So, basically when we are talking about IIoT once again we are talking about smart devices, devices which are sensor equipped, actuator equipped and so on and these smart devices have connectivity between them internally and also between each of these internal each of these devices in that internal network to the external world.

So, basically what happens is, the data are collected from these IIoT enabled devices in the case of power plants from these power sector IIoT enabled devices and these data are sent for further analysis to improve the productivity, to improve the efficiency of operations of the workforce that is working in the power plants and so on. So, essentially what is going to happen is, we can also have remote monitoring and remote control; this is very important; remote monitoring is fine, but remote control of the different machinery of the different equipments that are working in these power plants.

So, essentially what is happening is from these different smart power devices the sensors that are embedded in them are going to collect different types of data, data about their health, data about the temperature, the operating condition, etc. of these different machinery and these data are going to be sent through this connected system the network to the cloud for further processing. Different machine learning algorithms, artificial intelligence algorithms and so on could be used to analyze the data at the remote end at the cloud. So, let us look at their different advantages of the use of IIoT in the power sector.

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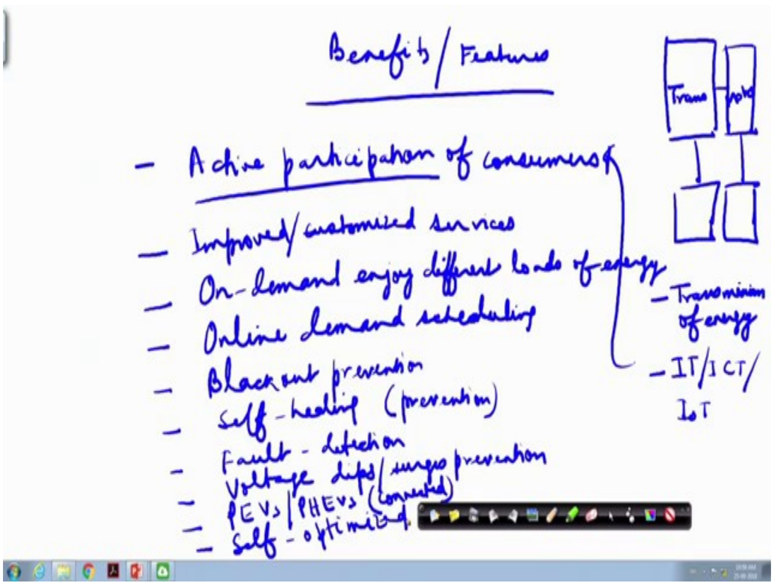


So, if we are talking about the benefits or the features of incorporation or integration of IoT and IIoT in the power sector this is what would happen. So, we are going to get these different benefits, we are going to get the advantage of active participation of end consumers possible. And this would be possible because essentially in the power sector we are talking about these different machinery machineries like transformer machineries like different motors, etc. So, different motors etc. and there could be different other power systems machinery which could be basically connected together.

So, these machinery; number one is this connectivity between these different machinery can help in the transmission of energy or electricity which is there traditionally in all power plants; all the traditional power plants have the capability of transmission of energy. Transmission of energy maybe right from the point of generation through different grids, micro grids and so on to the end consumer devices, station substations and so on to the homes and offices of the end consumers. So, all these connectivity helps in the transmission of electricity in a traditional power plant.

So, that is there, but in addition with IIoT it is also possible to integrate information technology, information and communication technology or IoT. So, this will basically help in 2 types of communication happening between these power machinery, one communication is the transmission of electricity and the second form of communication is basically the transmission of the information that are collected from these different power machinery in the power plants. So, 2 types of communication are going to happen.

So, the incorporation of IT, ICT and IoT can essentially help the end consumers in the homes and offices to actively participate in the entire process. So, they will not be just the passive recipients of the electricity or the power that is generated, but they can also be an active participant in the process; thereby many things can be achieved. So, what are those many things?

So, first of all improved or customized services can be enjoyed by the consumers, the consumers can on-demand enjoy different loads of energy that is a possibility like this there are different possibilities. It is also possible through the integration of IT, ICT and IoT with the traditional power grid to have online demand scheduling. So, online demand scheduling means like let us say at your home you have different appliances.

So, through online demand scheduling it would be possible to have some of these devices operate autonomously in certain parts of the day and in certain other parts of the day other devices may be operated without any human intervention. So, the demands consequently in different parts of the day are going to change from the individual customers. And holistically as well when you take all the customers together the demand on the micro grids and the power grids holistically that is also going to vary over time throughout the day. So, online demand scheduling would be possible with the integration of IT, IoT and ICT with the traditional power grid.

Other possibilities are to have different features of let us say black out prevention, it is possible to have self healing system that means, that if some part of the system goes down there are other parts of the system that can take over without any human intervention so self healing.

We could also have in a smart IIoT enabled power system, we could also have automated fault detection, and fault prevention is something over here captured through self healing. And also different other things such as let us say voltage stabilization in the form of taking care of voltage dips and surges and their prevention could also be done. It is also possible to integrate plug in electric vehicles and plug in hybrid electric vehicles and their connected systems, it is also possible to basically have a self optimized system and so on.

So, self optimized means like, if something can be improved over time the operations could be improved based on the data that are collected from the sensors that are integrated to these different power machinery. So, the analysis of that data over a period of time can help in the optimization of the processes of the machinery their operations and so on so, self optimization that is also possible. So many different benefits exist from the integration of IIoT with power system.

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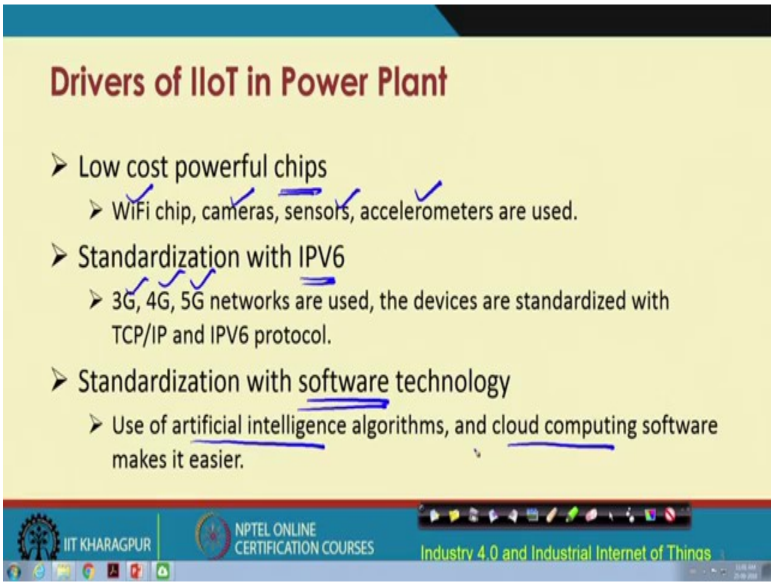


So, let us now look at further and try to understand the different drivers of IIoT in the power plant. So, what are these drivers? We have seen that traditional electrical systems, power systems and their integration connectivity not only to transmit electricity, but also to transmit information between these different components in a power plant and also externally from these different components to the outside world.

This is what basically looks like in an IIoT enabled power system. So, there are different so, for this connectivity we need low cost powerful chips, Wi-Fi enabled chips, cameras, sensors, different other sensors, accelerometers, etc. these could be used these are like end devices acting as drivers.

Then standardization in the form of use of IP, 3G, 4G, 5G technologies and so on. Standardization of software technology, use of artificial intelligence, cloud computing, etc. and to have overall integrated application supporting different layers at the very top would be these AI and ML supported applications or maybe standalone other applications as well and thereafter we have the cloud layer at the bottom of the application layer. We may have a fog layer, we may then have at the very bottom the devices layer, the field layer and so on. So, all of these different layers are possible. So, let us look at how the architecture is going to look like in a smart grid.

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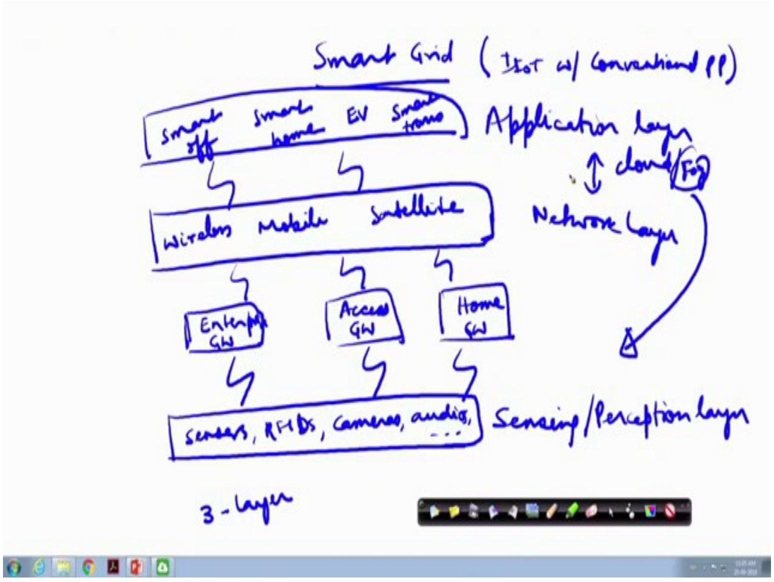


So, in a smart grid which is going to result in through the integration of IIoT with the traditional power plant this is what is going to happen. So, we are going to have kind of a layered architecture typically like a 3 layered architecture, where at the bottom layer we are going to have this sensing. So, this is going to be our sensing or perception layer.

This layer will consist of different sensors, RFIDs, cameras, audio devices and many more. So, the data that are collected from these sensor enabled machinery are going to go through different types of gateways; some gateways will take care of the enterprise requirement. So, enterprise gateway, we can have normal access gateways, we can have home gateways for home customers and so on. So, we have all different types of communication. So, this is basically our gateways.

So, through these gateways the data are going to be sent to the network layer; the network layer. In the network layer we are going to have different network technologies such as wireless networks, mobile networks, satellite networks and any other different type of network that you can think of. And finally, this data from this layer is going to get to the application layer; supporting different applications for smart offices, smart homes, applications for electric vehicles, plug in electric vehicles, plug in hybrid electric vehicles, etc., applications for smart transmission and so on and in between we can have this cloud and fog implementations.

So, fog implementation can be done closer to this sensing; so, fog implementation can happen over here. So, cloud basically implementation can be done just below the application layer. So, this is how an IIoT enabled electrical power grid is going to look like and this is our smart grid. So, these are these different drivers that we talked about and then let us talk about the benefits of the digital power plant.

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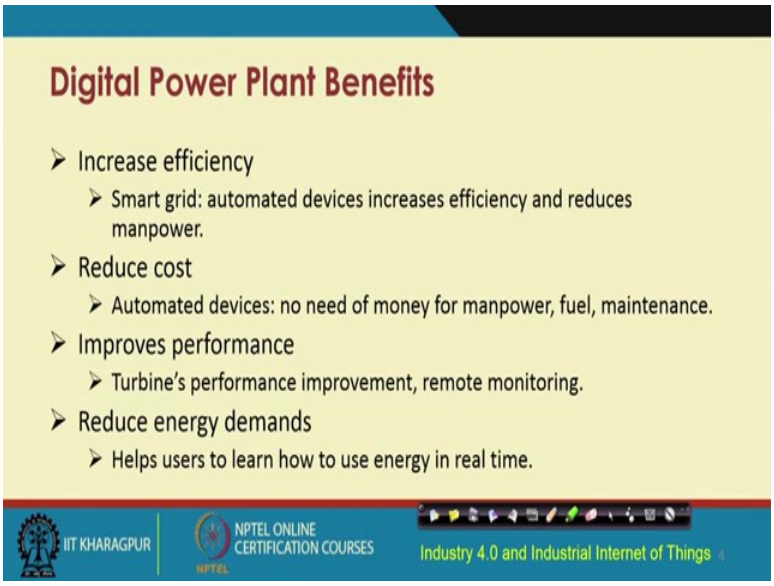


A digital power plant can help increase the efficiency so we can have smart grids which can help in automation of these devices, connectivity between them, overall increasing the efficiency, reducing the involvement of human resources, manpower and so on. So, overall improvement in efficiency is what can be achieved through these digital power plants.

Reduction in cost can happen because we are talking about reduced human resources. So, automated devices would be deployed and you can have reduced manpower consequently reduced wages and so on to be incorporated and also reduced fuel reduced maintenance and so on. So, these are these different reductions that can happen through the incorporation of digital technology with the power plant.

The other features would be improving the power the performance of different turbines, wind turbines, remote monitoring. So, all of these improved performance remote control, remote monitoring can be possible and also reduced energy demands. So, this basically will help the users to learn how to use the energy in real time in an efficient manner. So, these are these different benefits of digital power plants.

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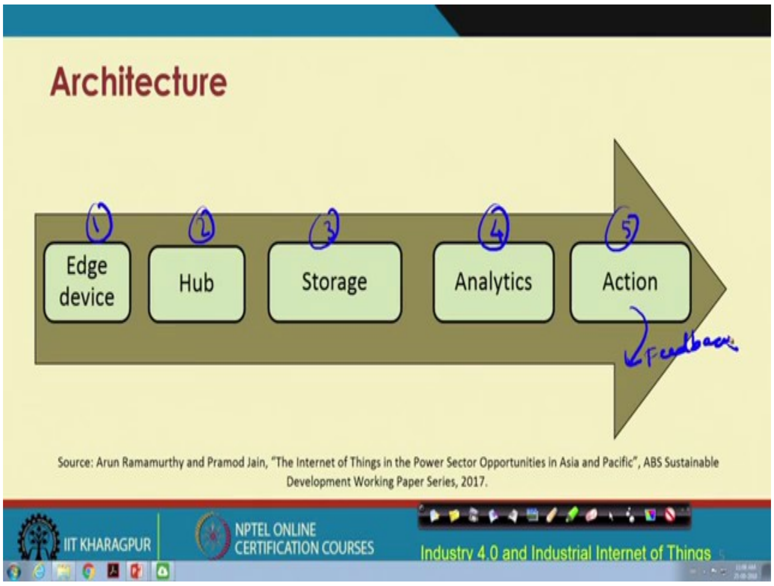


So, architecturally these are the different components of an IIoT enabled power plant. So, we will have all these different components edge devices, hubs and gateways, then we have storage maybe in the form of cloud etc., then analysis of the data analytics maybe at the cloud. And then the corresponding actions maybe some kind of a feedback control will have to be sent; a feedback signal will have to be sent to the machinery to control certain components in the desired machine. So, these are the different components of in the architecture of a smart power plant.

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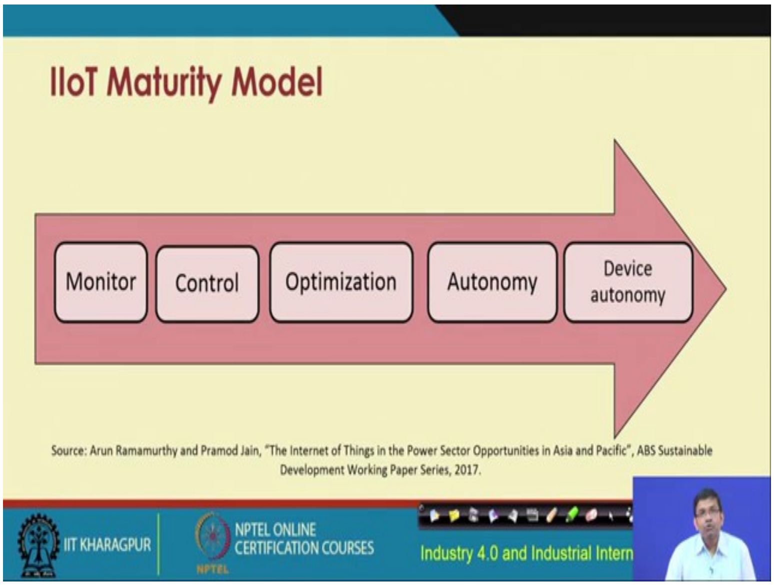


So, IIoT maturity model has gone through all of these different layers in the power sector. So, it starts with monitoring, monitoring is very simple because if you have the connected sensors, actuators then this monitoring would be possible, for the control you need to take help of the actuators and for the control basically you need to send a signal, a feedback signal back to the machine or a component in the machine.

So, monitoring, control these are all possible through the integration of IIoT and optimization over time using or analyzing the data that is received; autonomy overall can be achieved autonomy in all respects device level, system level, application level and so on. So, all levels of autonomy would be possible so this is this IIoT maturity model.

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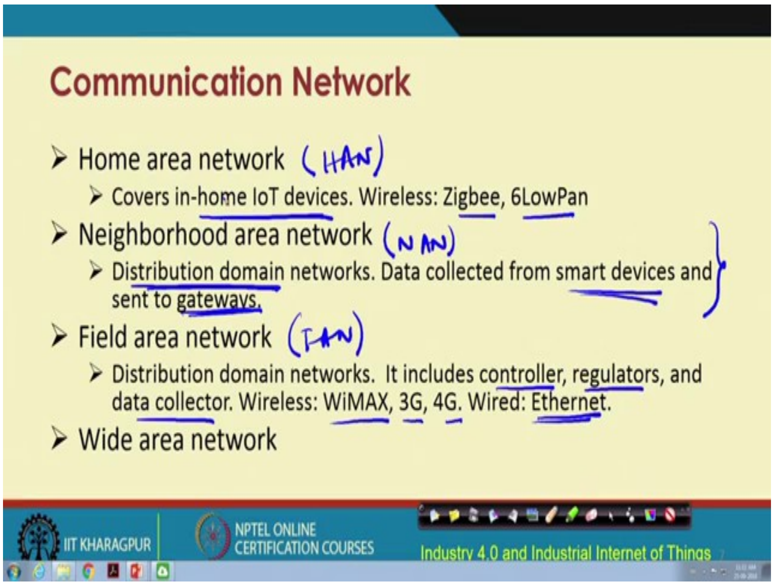


In terms of the communication network, because communication network is the core in a smart grid or a smart power plant so, the communication network has different parts. So, these are some of these different parts; this is the well known ones are home area network, which is basically IoT devices in the home and for these communication technologies like Zigbee, 6LowPan and are often used and these are these different standards and technologies that we have already discussed in detail in an introductory lecture on IoT.

So, this is something that we have already discussed. So, after home area network, we will have this never neighborhood area network in short it is also known as the NAN and so, this particular network basically talks about the distribution domain in the networking of the distribution domain. So, the data that are collected from the smart devices are then sent to the gateways in the neighborhood area network.

So, neighborhood area network basically just concerns the distribution system. So, basically these smart devices are going to send the data to the gateway and that is basically the scope of the neighborhood area network. Field area network also known as FAN, this basically concerns distribution domain networks as well, but here it includes the connectivity of the controllers, the regulators, the data collectors, etc. and typically wide area wireless technologies such as WiMAX, 3G, 4G, etc. are used and for wired, Ethernet is also used.

And then we have this traditional wide area network in the conventional network and communication system. So, these are these different communication networks that one would encounter in a smart power plant.

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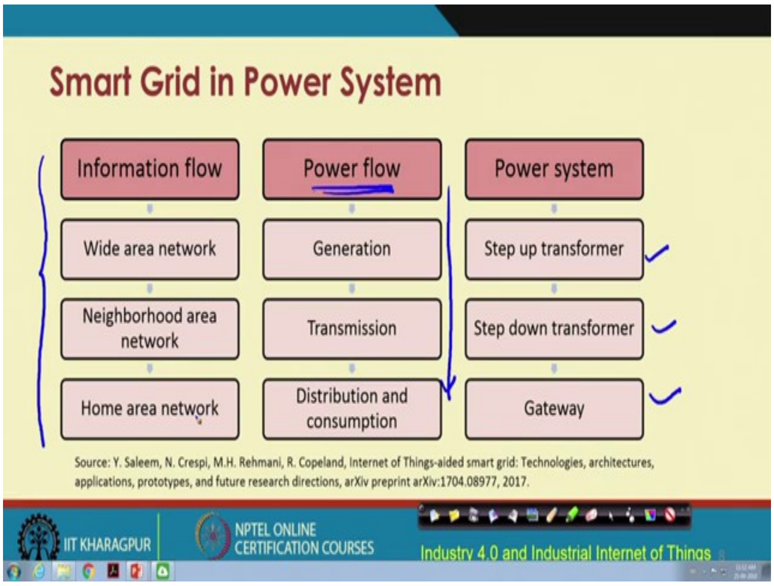


So, if we are talking about the smart grid, there is power flow, that is traditional, that has been there already. So, power flow; starting from the generation station through the transmission to the distribution and consumption units, the power flows like this. Power system basically setting up of the transformer then stepping up of the transformer, stepping down of the transformer and sending the energy through the gateway; this is the power system.

And the third component is basically this information flow, through the wide area network, neighborhood area network and the home area network. So, these are these 3 different components of a smart grid in a smart power system. So, information flow, power flow and power system together holistically works to offer, to deliver a smart grid.

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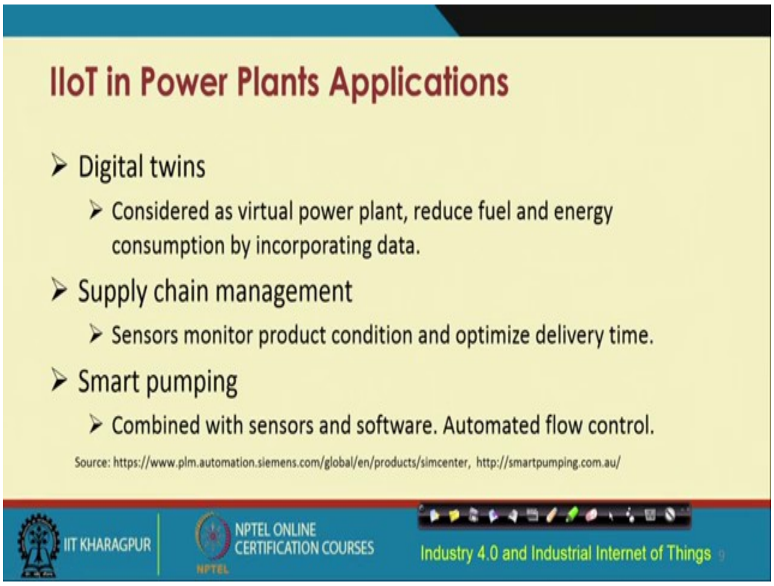


So, for IIoT implementation in the power plants different technologies such as digital twins such as supply chain management, smart pumping.

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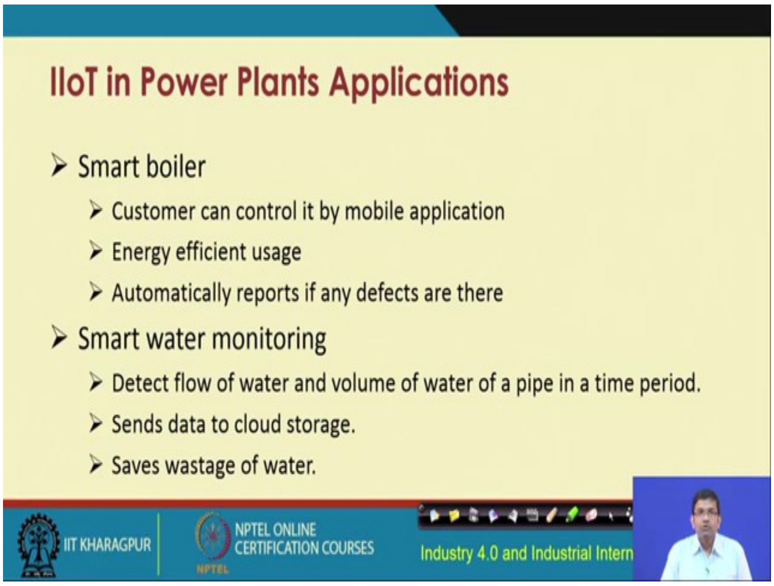


Then smart boilers, smart water monitoring and so on. So, all of these different types of applications are often used.

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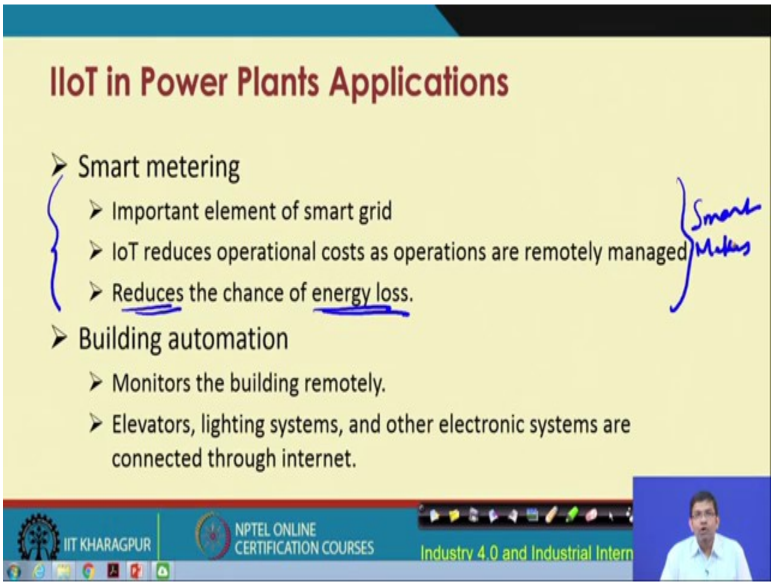


Concepts for smart metering, building automation are also quite popular. Smart metering; particularly I would like to emphasize this smart metering, basically is an important element of smart grid, where IoT is used to reduce the operational cost as the operations are remotely managed; this basically reduces the chances of energy loss and optimum use of energy. So, reduction in energy loss is basically achieved through the smart metering concept.

So, the deployment of smart meters basically has already happened throughout our country in India. So, in different parts of the country smart meters are already in use and particularly in other countries also smart meters are quite widely used building automation, smart phones, smart offices etc. So, basically you want to monitor the condition of the building remotely, in a smart building there would be sensors that would be fitted to elevators, lighting systems, other electronic systems, etc. and they are all going to be connected and monitored through the internet.

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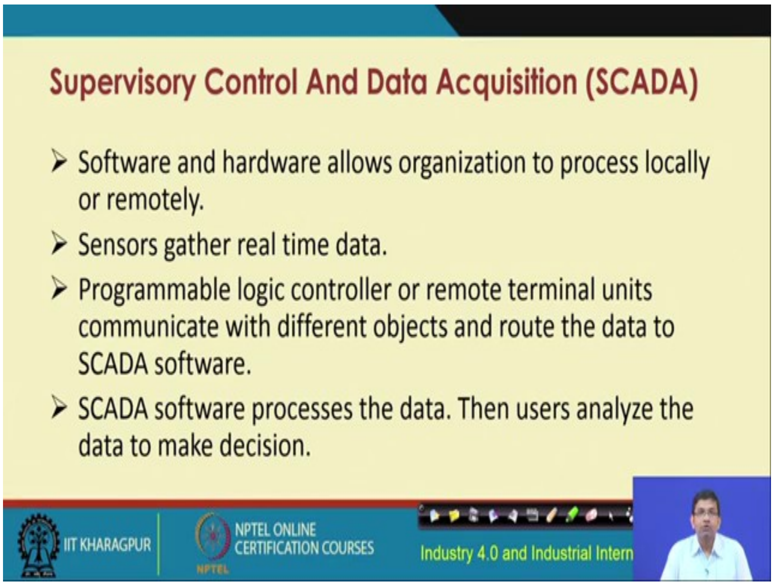


SCADA based control, supervisory control, supervisory data acquisition and supervisory control so, SCADA based power plants are a reality now. So, SCADA software are used or deployed in order to process the data, then the users analyze the data to make the different decisions and this decision making can also be automated, different rules could be implemented in order to make the decision making automated and the system fully autonomous.

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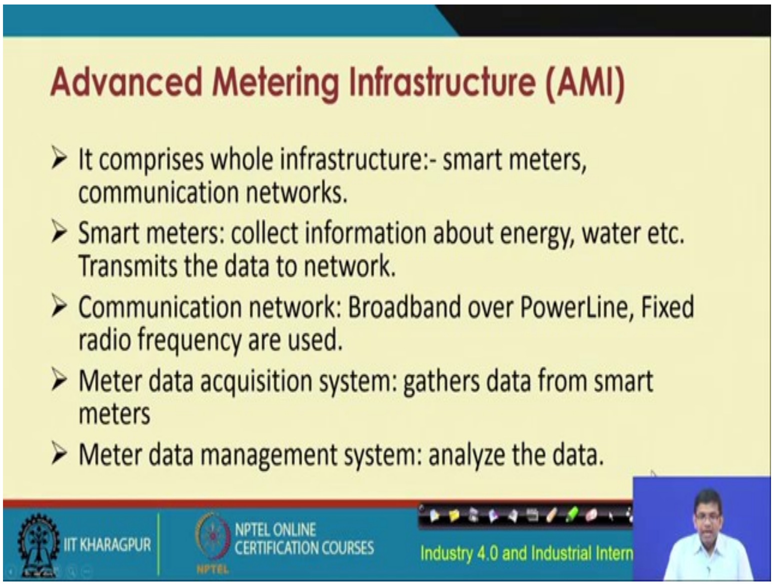

AMIs: Advanced Metering Infrastructure it basically comprises the whole infrastructure, smart meters, communication networks etc., smart meters help in the collection of energy, collection of information about the energy supply, water supply, etc. depending on what distribution network we are talking about; if we are talking about the traditional energy distribution the meters in those. So, then it is the smart energy meter if we are talking about the water sector, water distribution network, then we are talking about the smart water meter.

So, irrespective of that AMIs and particularly the smart meters are core to the implementation of this particular concept. So, communication network broadband over power line, fixed radio frequency, these are some of these communication medium that are used for the connectivity of this metering infrastructure. Smart meter data acquisition system which is basically the MDAS, the MDAS is basically helps in gathering of the data from the smart meters. And the meter data management system which is the MDMS; this MDMS basically helps in analyzing the data that are collected from these smart meters.

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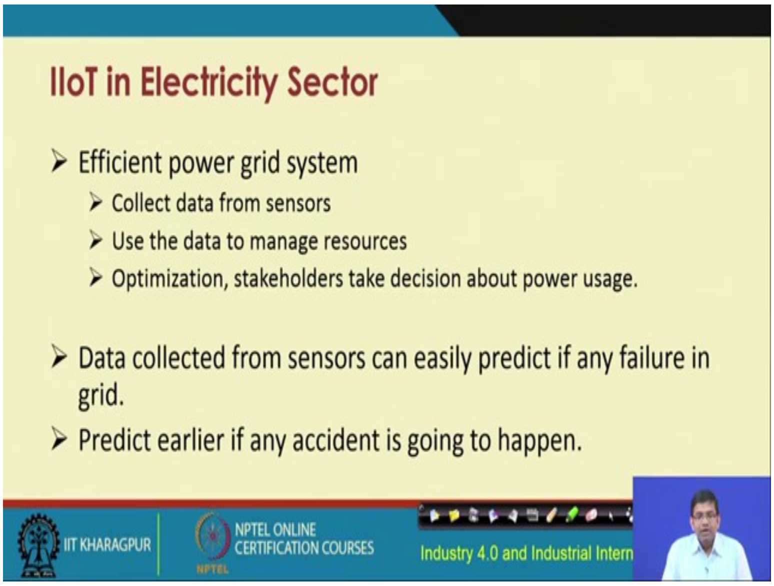


So, IIoT in the electricity sector in different parts of the electricity sector not only in the power plants, but also in the different parts starting from the generation point till the consumption point IIoT implementation can help in making the processes the systems overall smart. So, efficient power grid system would help in collecting the data through the sensors, use the data that are collected from the sensors to manage the resources and then self optimize and take automated decisions for overall improvement of the power system and reduction of power usage. The data that are collected from the sensors can help in performing different predictions through the implementation of different statistical techniques, machine learning techniques, and different AI techniques and so on.

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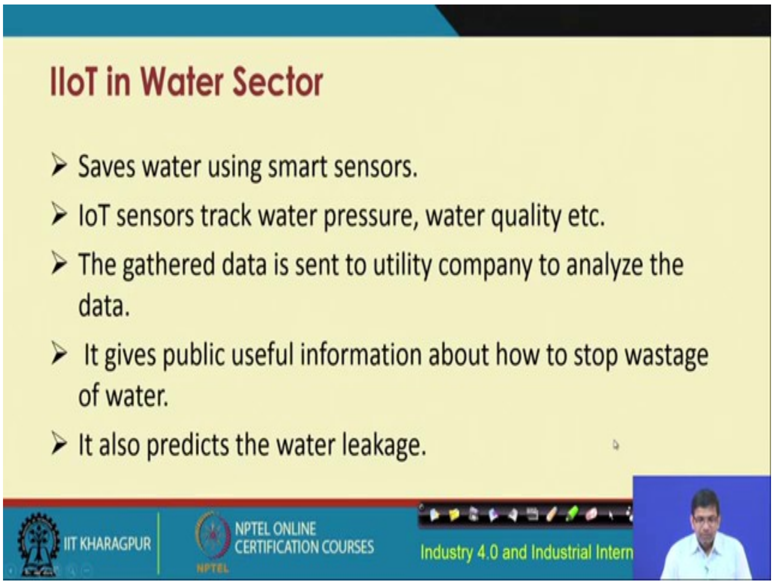


In the water sector IIoT could also be used to save water using the data that are collected from the smart sensors that are deployed in the water distribution system. IoT sensors can track water pressure, water quality etc. So, I have already shown you in a previous lecture one of the deployments of a model water distribution system and how a SCADA based monitoring system can help in getting and the idea about the quantity and also theoretically the quality of the water that is flowing through different junctions of that water distribution system.

So, basically different features such as prediction of water leakage, then optimization of water usage, all of these things could be done with the deployment of IIoT in the water sector as well.

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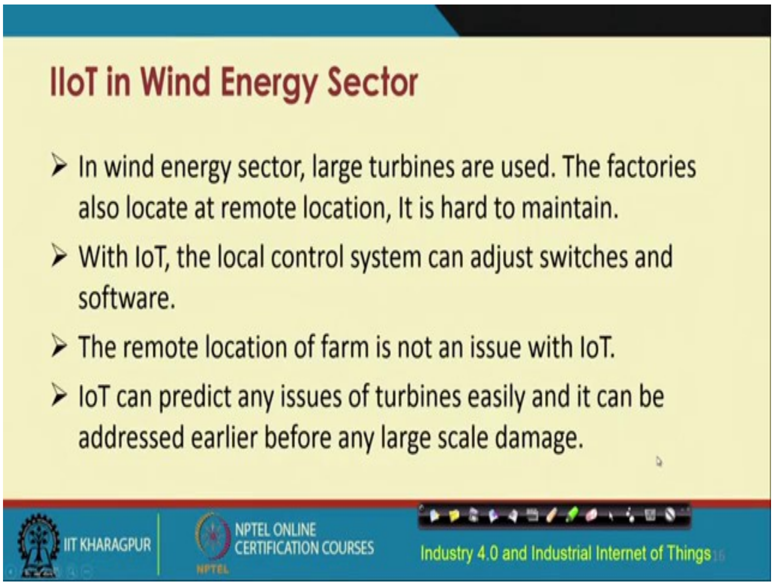


In the wind energy sector likewise IIoT deployment can help in improving the efficiency this can also help in remotely controlling the different wind generating turbines these could be controlled remotely over a network from some control station. So, both monitoring as well as control could be done in an IIoT deployed wind energy platform.

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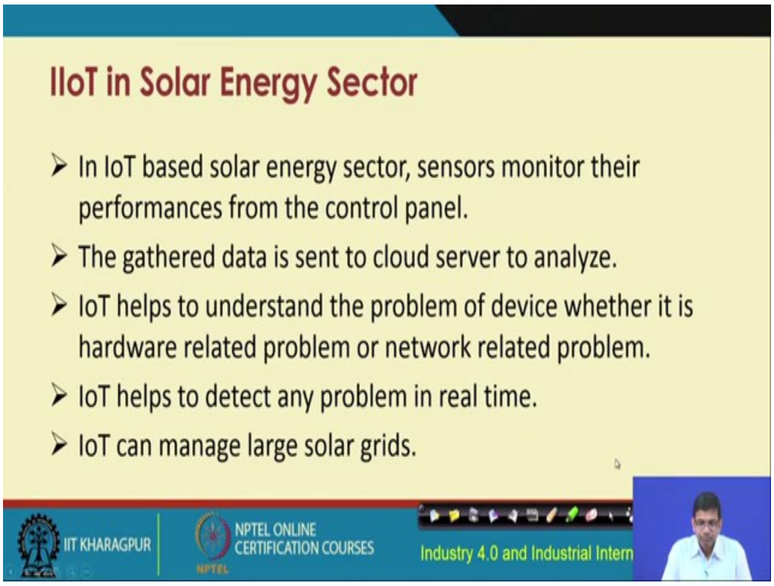


So, wind energy, solar energy as well IoT based solar energy sector sensors would monitor the performances from the control panel, the gathered data will be sent to the cloud server to analyze and this IoT would help to understand the problem of device whether it is the hardware related problem or the network related problem. So, overall the solar grids could be managed much more efficiently in an optimized fashion.

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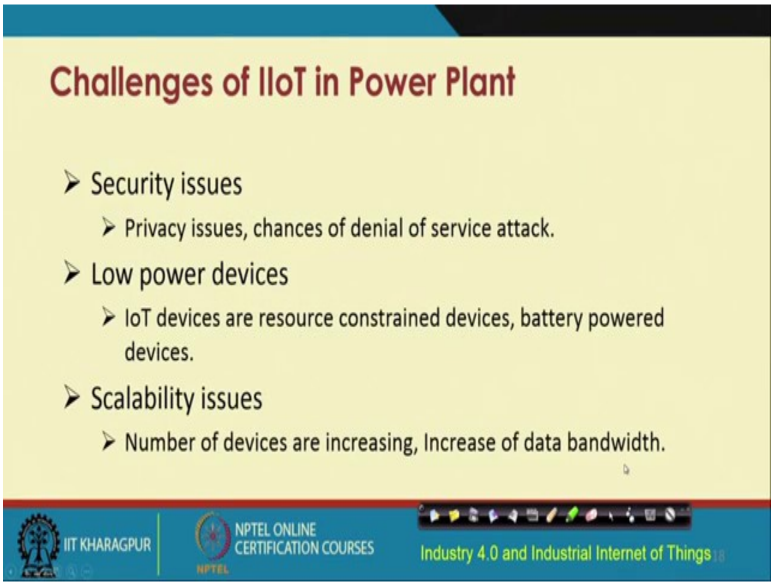


So, there are different challenges of implementation of IIoT in a power plant, there are security issues because now we are not just talking about the operational technology that has been existing the transmission of energy, the transmission of electricity, but now we are also talking about transmission of information, transmission of data that is collected.

So, security of the data, privacy of the individuals so, these are all different issues that will have to be considered through the integration of network and communication with the traditional power supply. So, low power devices, IoT devices, resource constraint, energy constraint, battery power and so on.

So, all these different features and the challenges that we have discussed previously, these will also make the implementation of security issues a challenge. So, there are scalability issues as well as. So, the number of devices that are connected are going to increase over time. So, this basically will require an increase in the data bandwidth which is itself a challenge. So, these are some of these broad classifications of challenges with respect to the security privacy having low power devices, their security in turn and the scalability in terms of increasing the number of IoT connected devices.

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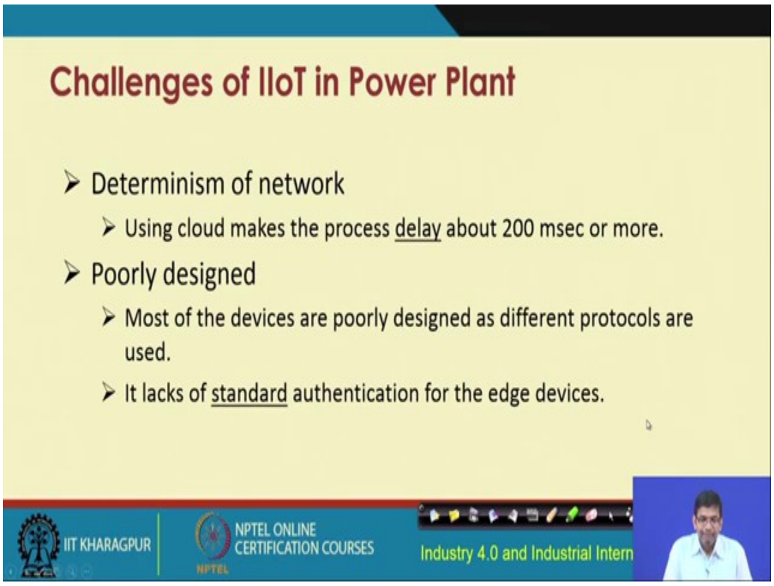


Determinism of the network is also important we are talking about integration with cloud, but throwing the data out to the cloud and getting it back. So, all of these basically increases the processing delay by about 200 millisecond or even more and this basically reduces the overall efficiency in the decision making process and taking different control actions consequently.

Poor designing with respect to implementation of non standard protocols, non standard authentication mechanisms, non standard security mechanisms etc. So, these are some of these different other existing challenges of IIoT implementation in the power plants.

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So, we come to the end of this particular lecture, we have seen highlights of the benefits and features of implementation of IIoT and IoT in the power sector. We have seen that there are many different types of benefits, but the challenges are also huge, we have also looked at the overall architecture for the implementation or the deployment of IoT in the power plants.

And holistically the power sector which basically takes care of different machinery and the supply chain overall from the generating point of the power to the consumption point. So, taking care of the automation of the whole chain is what is of concern in the IIoT deployment in the power sector. So, these are different references.

Thank you.

**Introduction to Industry 4.0 and Industrial Internet of Things**
**Prof. Sudip Misra**
**Department of Computer Science and Engineering**
**Indian Institute of Technology, Kharagpur**

**Lecture - 53**
**IIOT Applications: Facility Management**

In this particular lecture, we are going to focus on the application of IIoT for inventory management and quality control. Conceptually, whatever we have discussed about the implementation of IIoT in the previous application domains, those concepts will not change. We are going to still borrow, those concepts that we have understood, the technologies that we have understood are core two IIoT. Those core IIoT technologies we are still going to borrow over here as well, but we are going to relook at it from the different angle from an inventory management and control viewpoint.

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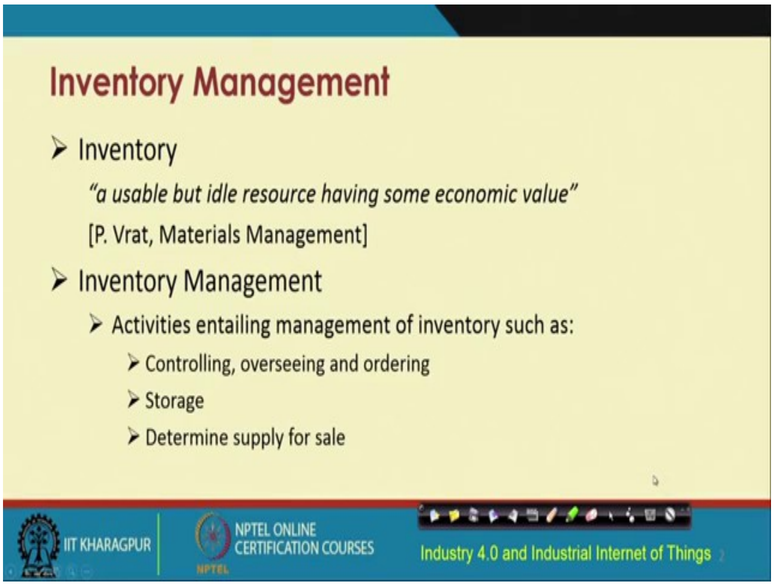


So, think about what is inventory control? So, first of all we need to understand what is inventory? So, in inventory basically the dictionary meaning of it is that inventory is a usable, but idle resource having some economic value. So, it is basically some kind of resource having some economic value that is going to be managed in inventory management.

So, some resource typically in a manufacturing industry these manufacturing resources, so these are basically are going to be the inventories and these inventories are going to be managed they are going to be used to have some value added products, value added services.

So, how you are going to manage this inventory? Inventory management is a huge thing in manufacturing plants is a huge thing there are separate teams which take care of inventory management and their control. So, activities that would entail the management of inventory would include controlling, overseeing, ordering, storage, and then determining the supply for sale.

So, because you do not want to sell anything that is out there right, you need to determine that based on your supply how much you are going to sell; how much you are going to sell? So, determining the optimum sale that can be achieved through the supply; you do not want to even stock the items, it is not like you procure everything stock it up and then you sell as and when it is required not like that, so everything has to be done optimally. So, that is where inventory management and the control of the inventory is required for the overall profitability of the business.

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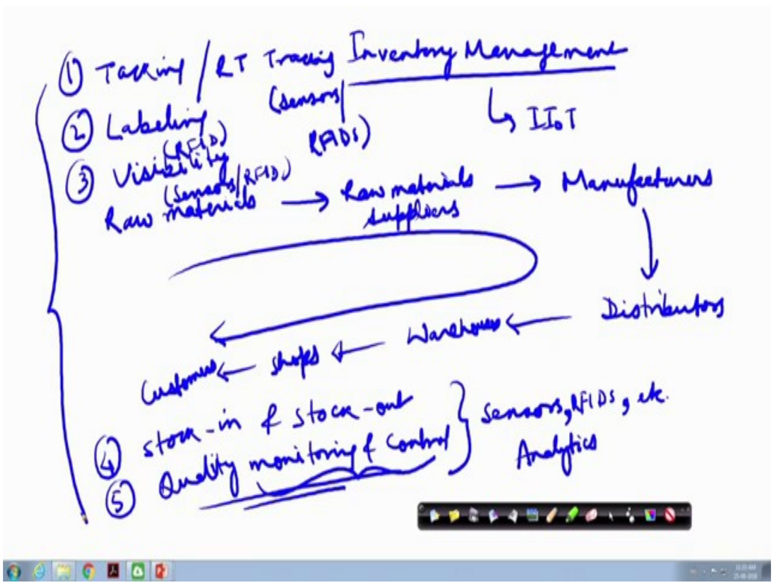


So, let us look at the different activities in inventory management. So, for inventory management we are typically talking about let us say first starting with raw materials, these raw materials in the supply chain are going to be supplied to the raw materials suppliers, they are going to procure or they are going to get it through some other service party. So, suppliers which are going to be sent to the manufacturers.

So, basically this could be this manufacturing firm which are going to use the raw materials and are going to transform that into different products. So, from this manufacturing plant by the manufacturers these materials are going to be sent to the distributors, the manufactured products from the distributors are going to be may be sent to the warehouses and then to the different retail outlets or shops and finally to the end customers.

So, as you can see this is the whole supply chain; it starts with the raw materials, procurement supply use being delivered to the manufacturers, the manufacturers use those raw materials to produce the goods, then the manufactured goods are then distributed sent to the warehouses finally, to the little shops and then are basically purchased by the customers.

So, in this entire process what are the things that are important? Number 1 is tracking and I would say ideally it should be real time tracking. So, real time tracking if we can have this would be a good feature. Labeling; labeling of these raw materials, labeling of the manufactured goods etc.

So, labeling is important then we can have you know it is very important to have visibility through the entire process visibility of the products, their expiration dates, the item locations where they are stored, where they are stocked forecasting their demands etcetera., so visibility. Then number 4, optimally stocking in and stocking out.

And then it would also be nice to have in this kind of supply chain or inventory management process it would be also nice to have some kind of quality monitoring and control mechanism and like that there are different things that could be achieved.

So, you see that for tracking and particularly real time tracking we can use different sensors or RFIDs, we could use those different devices, for labeling, RFID-based labeling would be attractive then for visibility again this different sensors and even the RFIDs could also be used. Then similarly, for the stocking in and stocking out and also for quality monitoring and control.

So, stocking in and stocking out and quality monitoring and control here also you could use the sensors RFIDs etcetera, but additionally you should also have particularly for the monitoring and control part of quality, you should also have the implementation of different analytics, so different analytics engines should be implemented.

So, as you can see this entire process we can automate we can make efficient through the implementation of these different concepts that we have learnt over time through different lectures on IIoT such as sensor, sensor networks, RFIDs, different connectivity technologies because ultimately you need to have this connected system holistic connected system which is going to retrieve the data and this data has to be sent through the network, to the cloud for analytics right.

So, this is this inventory management and how we can make it much more efficient through the implementation of IIoT. So, IIoT based inventory management this is what we are going to achieve if we can you know implement it using suitable technologies.

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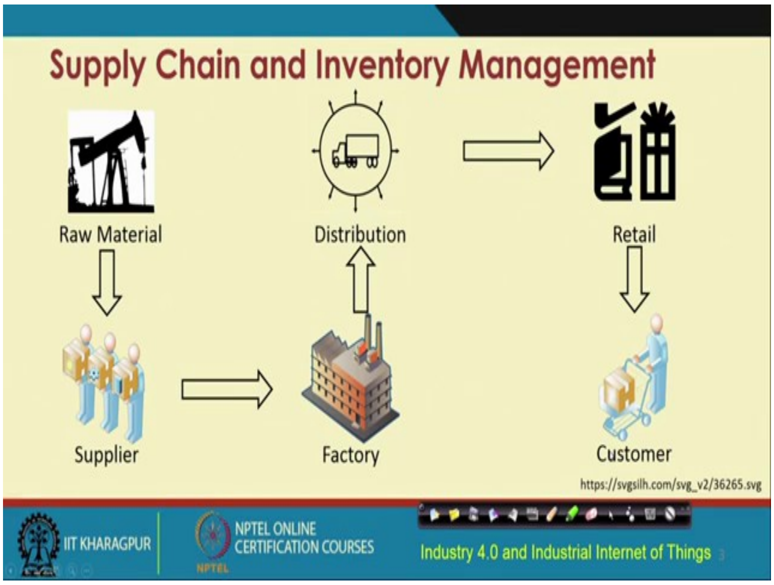


So, going forward, the supply chain once again is going to take the raw materials, send it to the supplier, goes to the factory, to the distribution centers, to the retailers, the distribution centers basically are going to send the finished goods, that are produced by the factories to the retailers and finally, the customers are going to use it this is this whole supply chain that we have already seen in the inventory management process.

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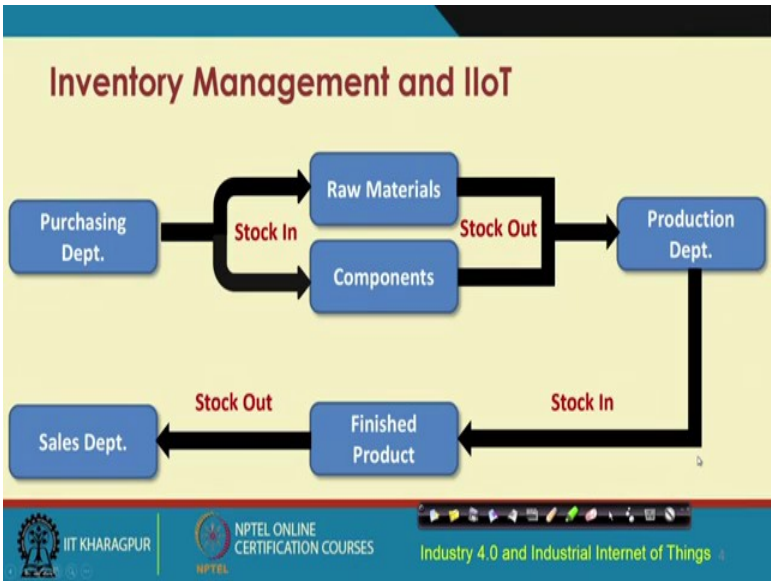


So, with IIoT all these different things the components that are involved in this inventory management such as, the purchasing department, the raw materials procurement, different other components getting involved there they are stock in of those components etcetera, sending to the production department, finished product, sales department etcetera everything can become connected.

So, the stocking in and stocking out over here, stocking in of the finished goods and stocking out over here of the finished goods. So, all of these things can be done efficiently with the incorporation of IIoT in the inventory management process.

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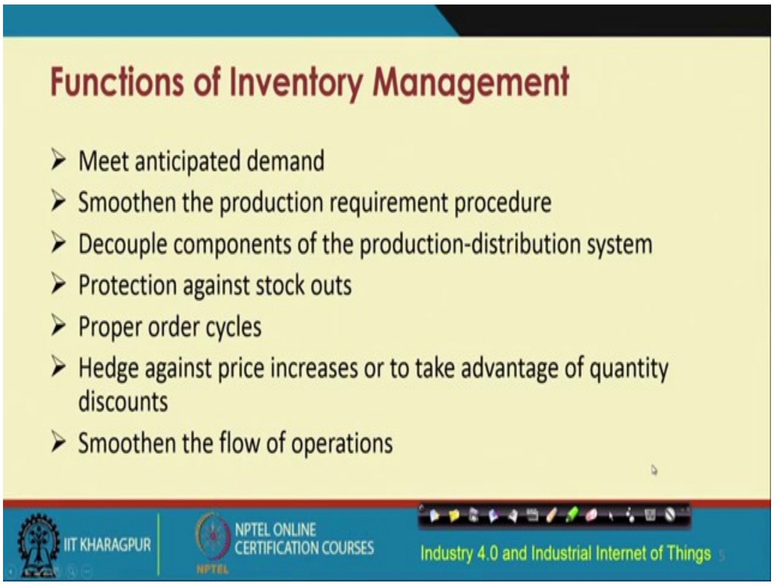


So, now let us quickly go through some of the functions of inventory management I am not going to elaborate this because these are quite self explanatory. So, the first one is meeting the anticipated demand, smoothening the production requirement procedure, decoupling components of the production distribution system, protecting against stock outs, properly ordering the cycles, hedging against price increases or taking advantage of quantity discounts, smoothening the flow of operations, so all of these are different functions of inventory management. And if we go little deeper down, so with the incorporation of IIoT we can have efficient inventory management through the implementation of all these IIoT devices and systems and applications.

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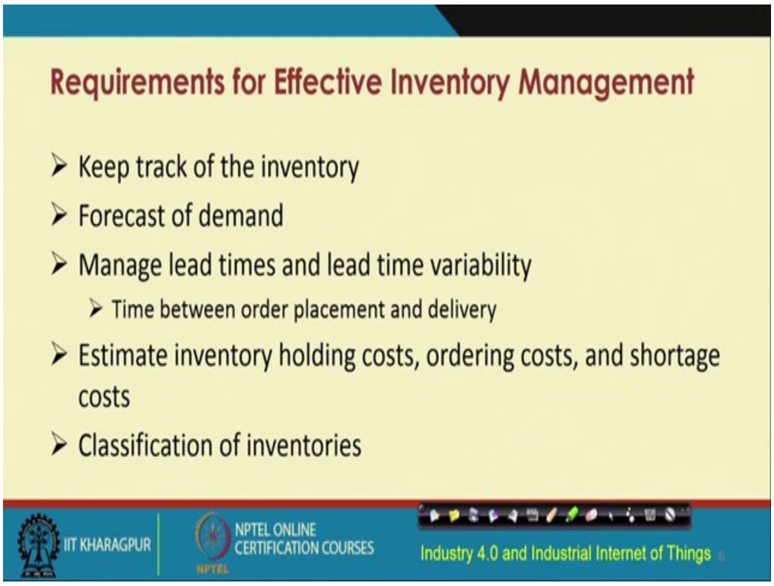


So, for effective inventory management it is required to keep track of the inventory, to forecast the demand, to manage the lead times and the lead time variability. So, what is this lead time? So, basically this is this latency that the lag between the placement of the order and the delivery of the order. So, basically managing that particular latency, that particular delay and the variability of that delay is what concerns the lead time.

So, effective inventory management should have effective lead time management, estimating the inventory holding costs, ordering costs, shortage costs etc. and classification of inventories these are the requirements for effective inventory management.

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Now, let us switch our gear and come to quality control. So, quality is very important; quality of the product quality of the services. So, this quality is important because ultimately we are talking about purchase by the customers and if the customers purchase, but then the customers are not satisfied, then that basically results in the failure of the product that is made, that is manufactured and is delivered. So, quality control of the products quality control of the services is what is very important.

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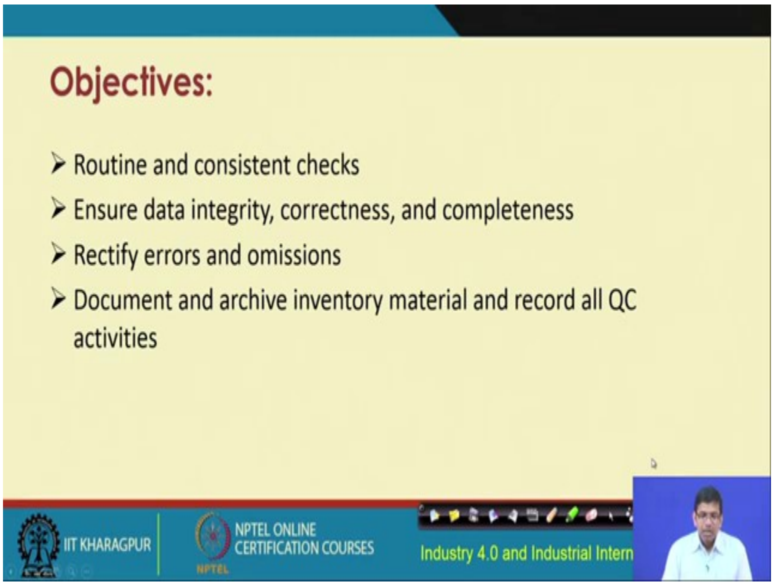

So, the objective in quality control is to routinely and consistently make different checks about the standard of the products that are being manufactured or the services that are being offered. Ensuring integrity of the data, correctness of the data, and completeness of the data that is also part of quality control. Rectifying any kind of error any omission incompleteness etcetera these are also part of the objectives of quality control.

And documenting and archiving inventory material and recording all the quality control activities, this documentation recording archiving and so on. These are also very important objectives of quality control; it is not just performing the quality control, but also the proper documentation and archiving of all these different activities data and so on that is also an important objective of quality control.

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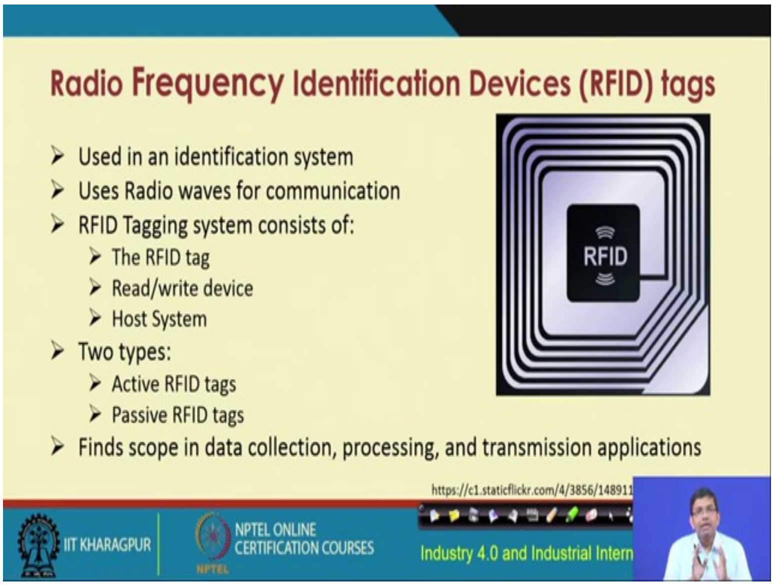


So, now very quickly we will go through as a recap of the technologies that are involved primarily in inventory management and quality control. We have talked about a lot about sensors, connected sensors, networked sensors, and sensor networks. We have talked about a lot in the previous lectures. We have also discussed briefly about the RFIDs. So, RFIDs basically are used heavily in the industry; in the industry for inventory management and control.

So, RFIDs basically will have two components and this is something that we have looked at in a previous lecture on RFIDs in detail. So, there are primarily two components one is the RFID tag which will have different data that are basically embedded or stored in them and the RFID reader which will come in the close proximity of the RFID tag and would be able to extract out the information that is stored in the RFID device or the RFID tag.

So, RFID uses radio waves for communication. So, in RFID the technology is radio communication technology, so there are radio waves that are communicating and this RFID tagging system will have these different components the RFID tag, the reading or the writing device and the system on which the RFID tagging system is deployed. So, there are two types of RFID tags, the active tag and the passive tag. So, there are two types and these different tags would be able to collect the data which will be further processed and would be sent to the applications that need the processed data.

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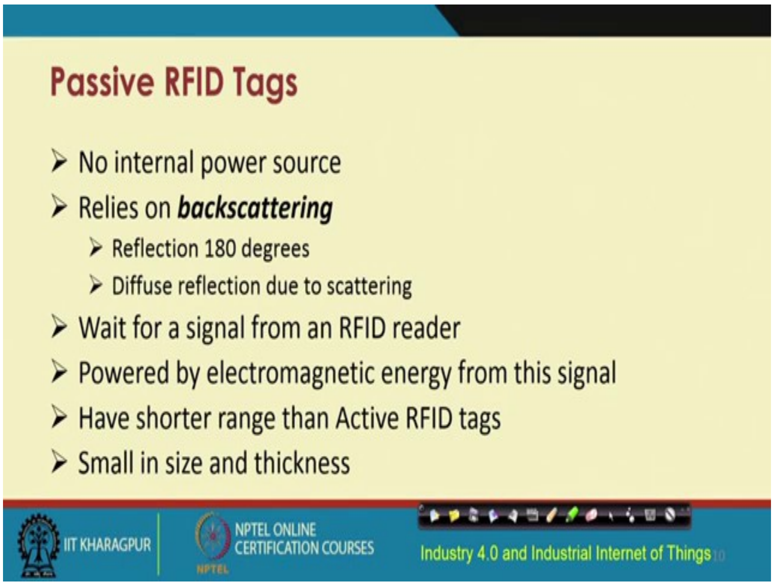


So, passive RFID tags do not require any internal power source, these tags basically work on the principle of backscattering. So, backscattering in communication basically talks about getting certain signals on the rays or the electromagnetic waves and these waves are going to get reflected back 180 degrees. So, basically what is happening is some kind of diffuse reflection that is going to happen due to the scattering and the back scattering.

So, the reader basically will wait for a signal from these tags and basically as I said that these tags do not have any internal power source and they are basically powered by electromagnetic energy from this backscattered signal. So, they are small in size and also very thin in terms of thickness. So, basically it's the chip that is embedded in these tags that makes the entire mechanism function.

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In active RFID tags on the contrary we have separate battery units, power units that can power these tags. So, these active tags would broadcast the information signal in the form of beacons and they have longer range and memory than the passive RFID tags that I discussed previously. So, these active RFID tags compared to the passive ones are much more expensive, much more bulky and are not as much portable as the passive RFID tags.

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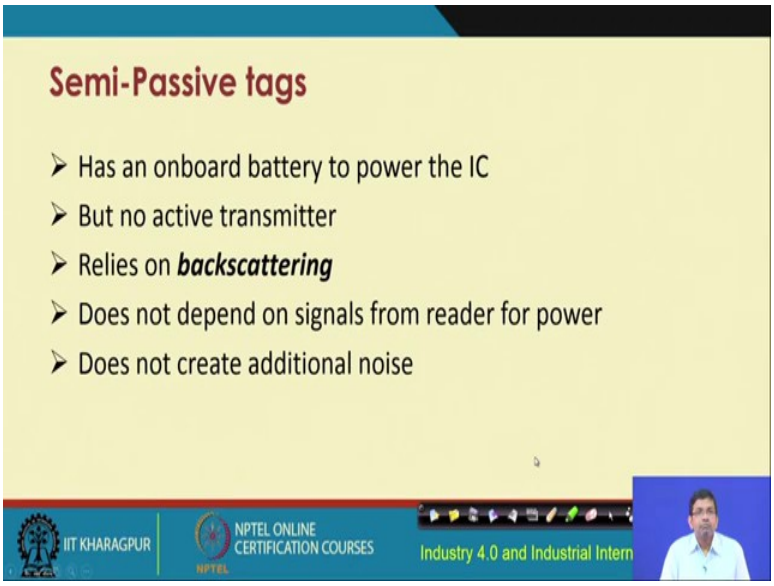


So, there are semi passive tags as well which has an onboard battery to power the IC, that is inside these tags and there is no active transmitter, but this mechanism also relies on backscattering concept that I discussed previously for the passive RFID tags.

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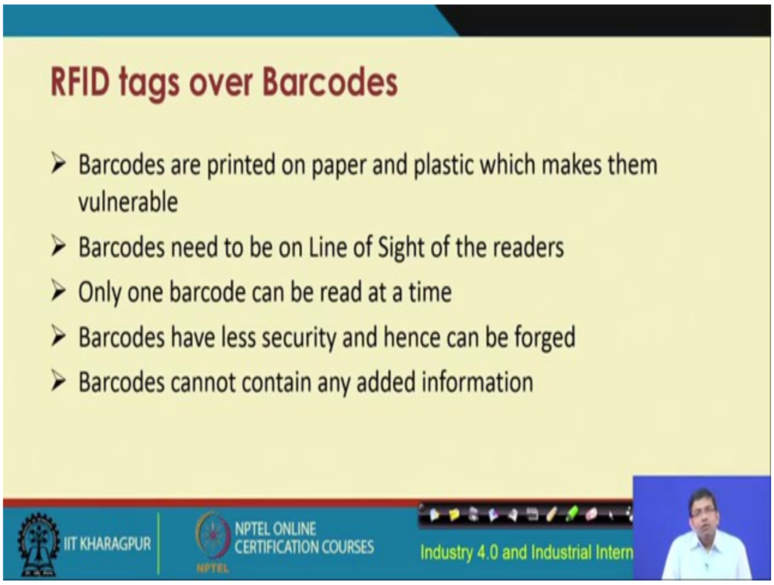


So, compared to RFIDs, bar coding mechanisms could also be used, both RFID tags and barcodes they could also be used but RFID tags over barcodes is something that is very interesting. These barcodes are basically printed on some device some goods may be paper or whatever paper or plastic and etc. So, barcodes need to be on the line of sight of these RFID readers and only one barcode at a time can be read and these barcodes have less security and hence can be forced.

So, barcodes cannot contain any added information beyond what is actually encoded in these codes. So, RFID tags over barcodes is a mechanism that is popularly used, but is not the only mechanic; this is an alternative way of basically using these RFIDs.

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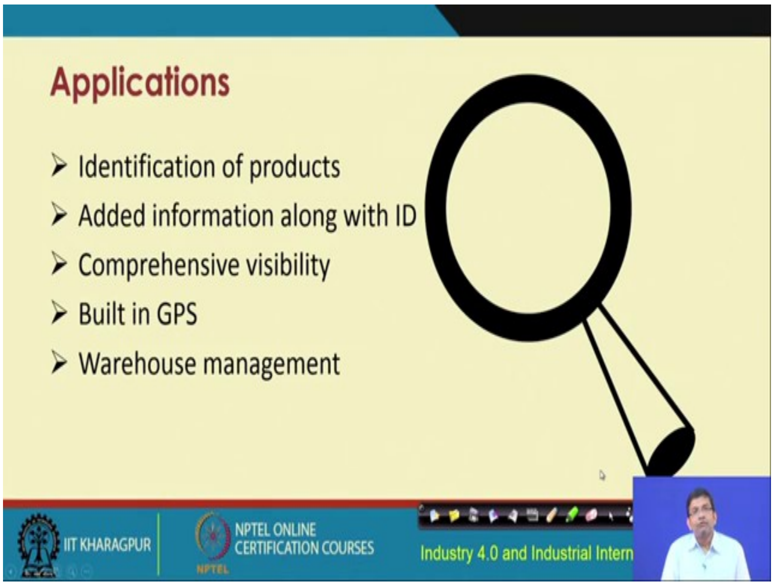


There are different applications of RFIDs in the inventory management and control process. So, basically identification of the products; products that are shelved in the warehouses, in the management of the warehouses, then adding information along with the ID, then having comprehensive visibility of the different products that different stocked items, shelved items and so on. These are some of these different applications of the use of RFIDs in inventory management and control.

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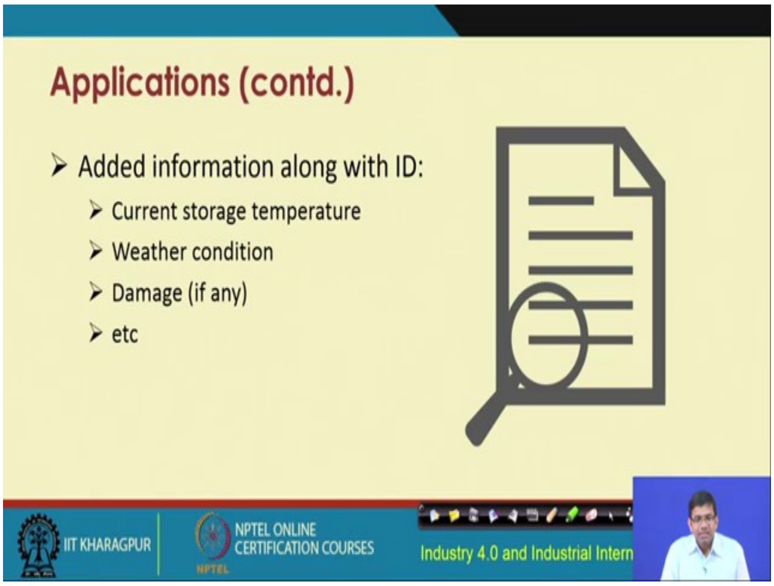


There are other different applications such as, weather condition monitoring, damage assessment, storage temperature monitoring and control; these are also the different other applications of use of IIoT applications in inventory management and control application.

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Getting comprehensive visibility, inventory levels, getting idea about the expiration dates, item locations, then about the demand forecasting. So, basically if in the future if you are going to get some more demands than what how much is the stock? So, demand forecasting, so these are some of these different other applications of the use of IIoT in the inventory management and control sector and particularly using RFIDs.

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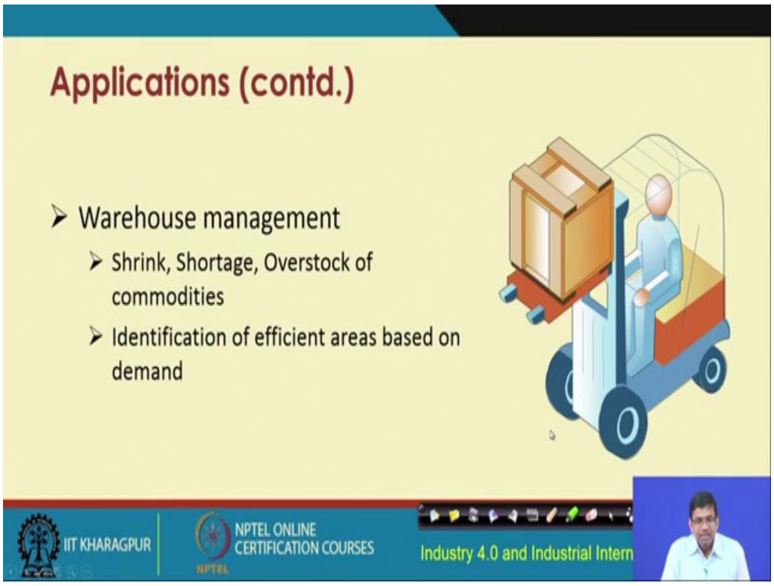


Similarly, warehouse management, shrinking of the stocked items, shortage overstock of commodities, and identification of efficient areas based on demand. So, these are also the different other applications of use of RFIDs for IIoT implementation in an inventory management application in a smart factory.

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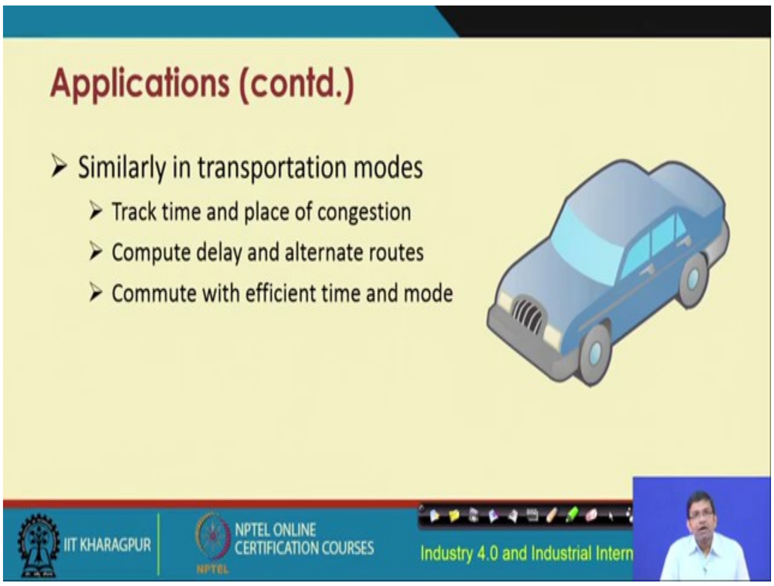

So, different other applications such as in the transportation sector basically tracking the time and place of congestion, computing the delay, and finding out alternate routes, commuting with efficient time and mode.

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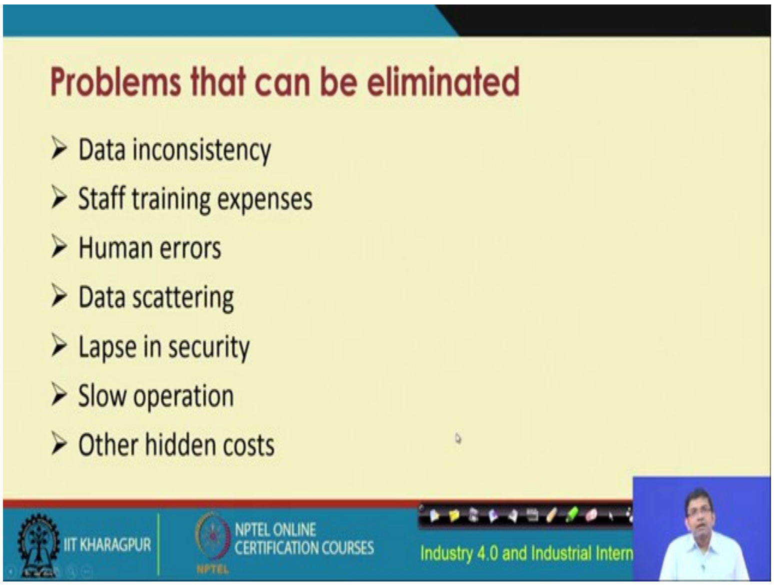


There are different problems that can occur through this IIoT implementation in inventory management and control. Problem such as data inconsistency, staff training, the expenses behind this kind of training, human errors, data scattering, lapse in security, slowing of operations and other hidden costs and incurring those hidden costs. So, these are some of these challenges that have to be overcome.

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So, in this particular lecture I have given you an overview of the incorporation of IIoT and the infuse meant of IIoT devices such as RFID sensors and the network RFIDs and sensors for making the inventory management and control process much more efficient and smarter. These are some of these different other differences that I have given you as usual, for your further reading in case you are interested to know further about the implementation of IIoT in the inventory management and control process in manufacturing sector.

Thank you.

**Introduction to Industry 4.0 and Industrial Internet of Things**
**Prof. Sudip Misra**
**Department of Computer Science and Engineering**
**Indian Institute of Technology, Kharagpur**

**Lecture - 54**
**IIOT Applications: Oil, Chemical and Pharmaceutical Industry**

When we are talking about a manufacturing plant, at a very high level we are talking about 2 distinct entities one is the workers, who are working in that plant and second is basically the equipments that are there in the plant, the machineries that are there in the plant. So, securing both of these entities and ensuring their safety, safety: the physical safety and security of these and also their operations is what is very important. So, plant safety and security is very important in all modern manufacturing plants.

So, now the question is that it is important, but now in the modern world how you can make things smarter and now that we are talking about IIoT and industry 4.0 and their implementation. How you could use IIoT technologies to make smart plant safety and security monitoring and control system. So, let us look at a case study first.

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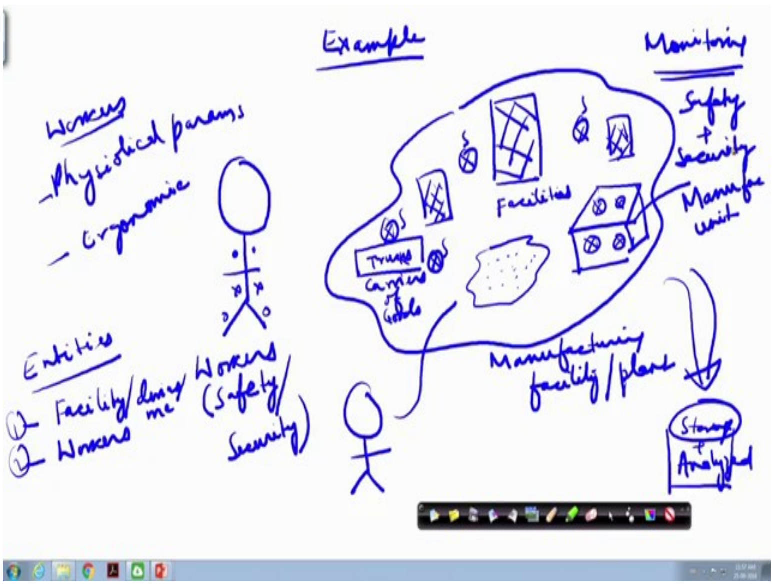


So, let us say I am going to run you through an example, let us look at this particular example. Let us say that in a typical manufacturing plant this is your manufacturing plant. A typical manufacturing plant would have different facilities, different buildings, for doing different stuff, all right are going to have different facilities.

We are also going to have let us say a manufacturing unit these manufacturing units can be in multiples. So, these manufacturing units can be connected with one another so that the output from one unit goes as an input to another unit and the process continues. So, different manufacturing units might be there which again are going to be connected.

So, output from one unit goes as input to another unit, again the output from the second unit goes as input to the third and the process continues. So, you are going to have manufacturing units, you are also going to have different logistic facilities such as trucks, different trucks or the different other carriers of goods and you could have maybe some ecological facilities such as water pond etc. So, this is at a very high level how a manufacturing facility or a manufacturing plant basically is going to look like.

But one thing I have missed in this I have talked about only nonliving things, I have talked about only the goods, about the buildings, about the manufacturing units, those are the ones I have talked about, but the essential component that I have missed out so far is this worker. And we have many such workers like this who are basically doing the work over here in this manufacturing facility. So, we have these different workers and it is very important to ensure that these workers are safe and they are secured.

So, as I told you at the outset in a manufacturing facility we are talking broadly about 2 types of entities, one is the workers and second is basically the different facilities that are there, the different devices, the machinery and so on and so forth. So, these are the 2 main entities in a manufacturing unit, in a manufacturing plant.

So, you see that you have to monitor you have to ensure the safety and security of both of these. So, again our IoT sensors and other techniques, technologies that we have learnt previously could help us in doing. So, for the worker's safety we could have these workers fitted with different sensors for monitoring their physiological parameters. So, for workers we can monitor their physiological parameters, we could have different sensors to monitor their ergonomic conditions of work and likewise these different workers could be fitted with diverse types of sensors for continuously monitoring their activities, their health status, their workplace and so on.

Like this there are other sensors that could be used and could be deployed in this manufacturing facility itself, these are different other sensors, these trucks could be fitted with different sensors, these manufacturing units would comprise of different sensors, different machinery in these units are going to be fitted with different sensors. So, these all these sensors from these nonliving things plus the sensors fitted to these living things they are going to send lot of data and as we have seen previously this data can be collected, stored and analyzed, storage plus analyzed in order to gain insights about what is going on.

So, this is the monitoring process in the manufacturing plant for ensuring the safety and security of different objects, different machinery, the workers working in them and so on and so forth. Control is also possible so, remotely it is possible this is the maintenance part that I have told you. So, we are not only monitoring these different entities, but also we can have control over certain machinery remotely. We can send some signals; some feedback signals back to the source from where the data originated to make the machine tool work in a much more efficient manner or do certain things in a certain way or know something that has already been done as a mistake. So, like these different things are possible.

So, having understood this let us now go back and try to understand the basic concepts of plant security and safety and how IIoT can help us.

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So, if we are talking about safety and security, there are 3 different prongs. So, this is basically the 3 different corners of the intrusion triangle, the famous intrusion triangle, the popular intrusion triangle has three different corners, three different features that will have to be taken into account. Number 1 consider that we have an intruder, so the intruder will have some kind of motive; some motive must be there for the intruder to do certain thing.

Second thing that the intruder would consider is the means how? So, motive is there, but then how the intruder is going to intrude that is the second thing, the means. And third is the opportunity, merely having the motive to intrude and nearly having the means is not going to make the intruder successful, the intruder should also have the opportunity for intrusion.

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So, when we are talking about plant safety specifically as I said before 2 entities humans and plant resources, their safety, their well being is very important. It is also very important to ensure that these different machinery they do not malfunction and cause hazards to the workers that are working surrounding those machinery or along with those machinery. So, plant safety is very important.

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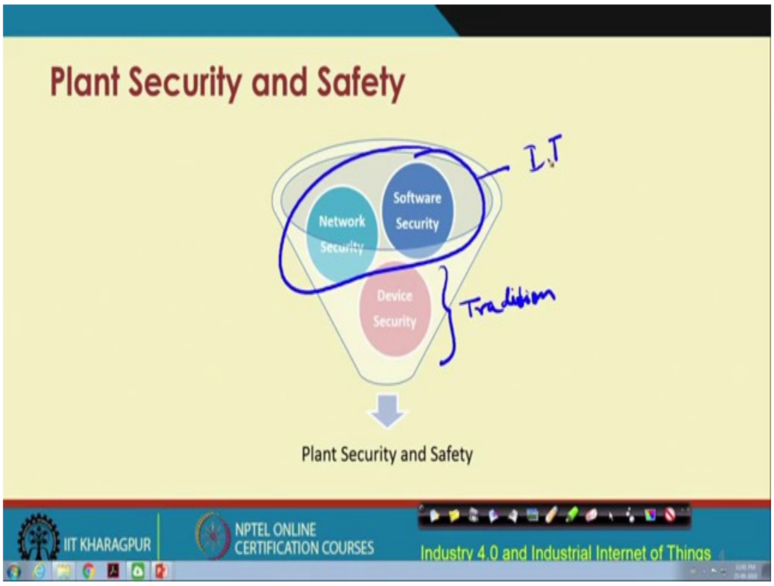


So, when we talk about security and safety in the plants these are the 3 main things that we will have to consider if we are talking about an IIoT implementation. Recall from a previous lecture what we discussed about IIoT. In IIoT we are talking about going beyond the operations, incorporation or inclusion of information technology and improving upon the operational technologies. So, IT-OT integration once again we have to relook at.

So, the security of these operational technologies would include the device security, the machine security, and the sensors that are embedded in them, their security and so on. So, all these machinery, their device security, but when you talk about IT additional things such as the network, the software, etc. also come into picture; so, network security, software security, addition additionally in addition to the device security are also important. So, we will have the device security this is from the traditional device security, and newly due to the integration of IT we have the concerns about network security and software security.

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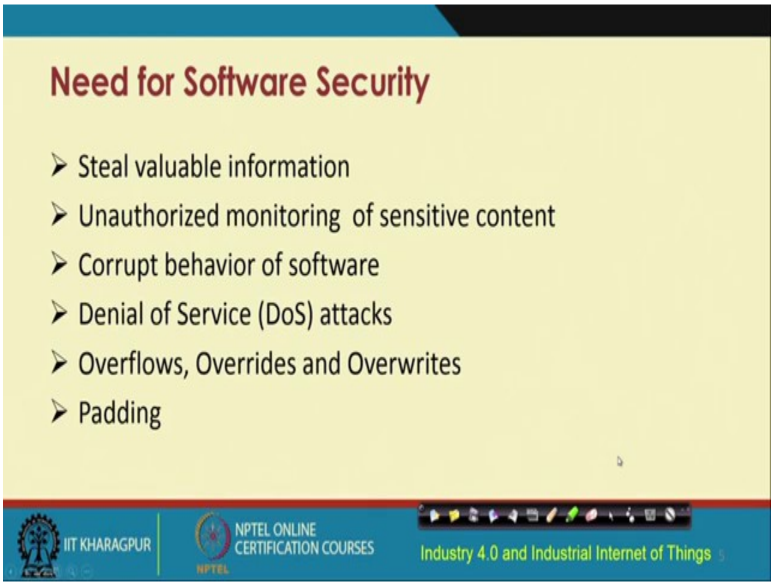


So, there is need for software security, because if the software that is implemented and is running in the automation process, if that software is not secured that can pose as a vulnerable point to steal valuable information. So, this authorized monitoring of sensitive content is important, it is important to ensure that the software does not become corrupt or does not behave corrupt, denial of service attacks should be prevented by the software. So, software security is very important.

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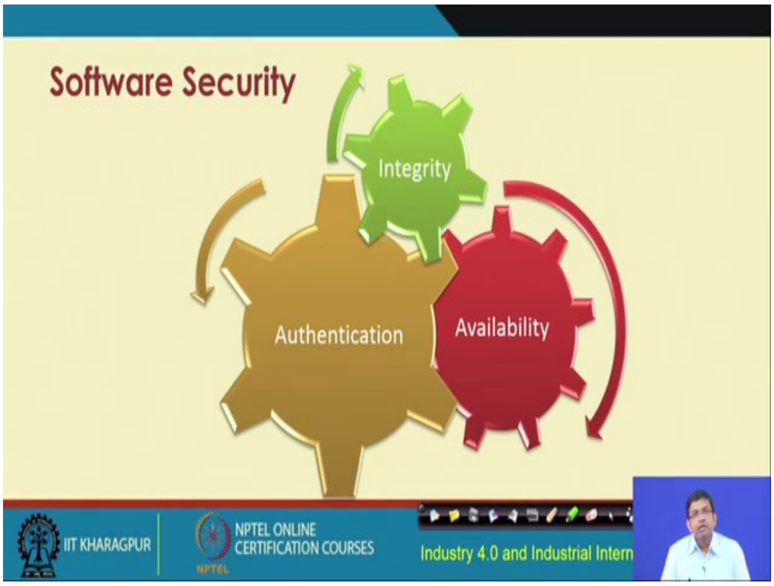

Software security involves ensuring authentication, integrity and availability. In the lecture on security in IIoT, I discussed these different features in adequate detail. So, this software security will have to ensure all these 3 different features of authentication, integrity and availability and their implementation.

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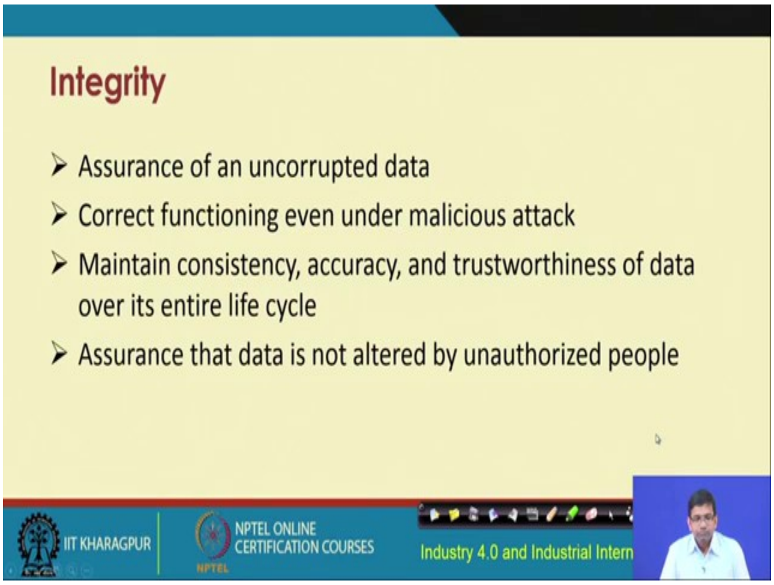


Integrity talks about assurance of an uncorrupted data.

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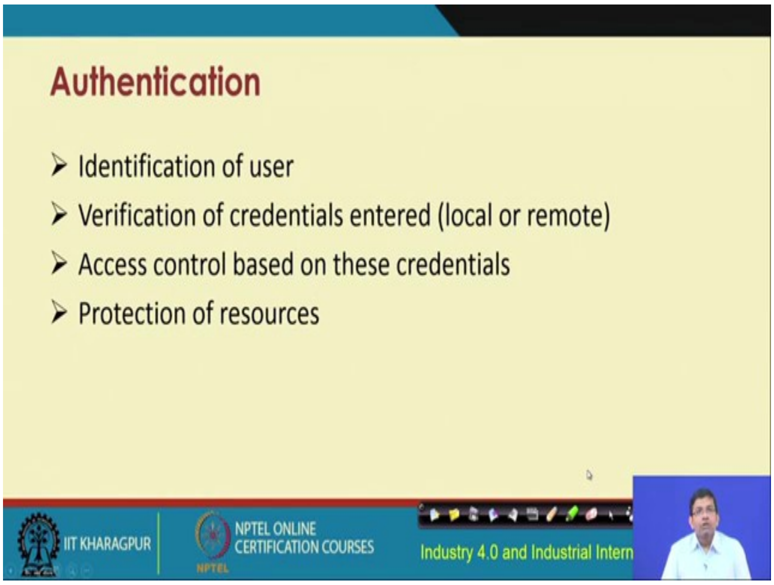

Authentication talks about identification of user correctly and ensuring that the credentials that are entered locally or remotely through the machine by the user are all correct and we are given, we are authenticating a particular user to be a legitimate one.

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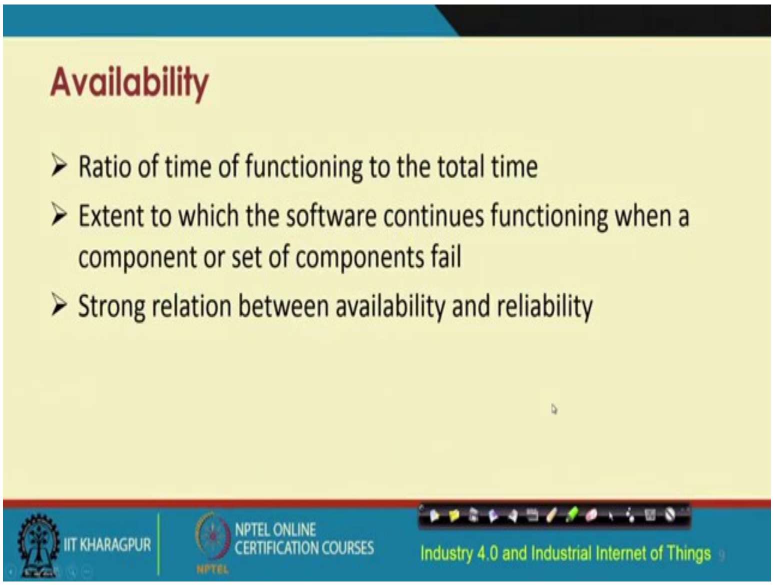


And the third one is availability, which talks about the ratio of the time of functioning to the total time. So, ensuring that the machine is made available, the software is made available as much long as possible.

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There are different requirements with respect to ensuring good programming techniques, installing good firewalls, detecting intrusions, good preventive measures, etc. these are some of these techniques for ensuring the security and safety in an IIoT enabled system.

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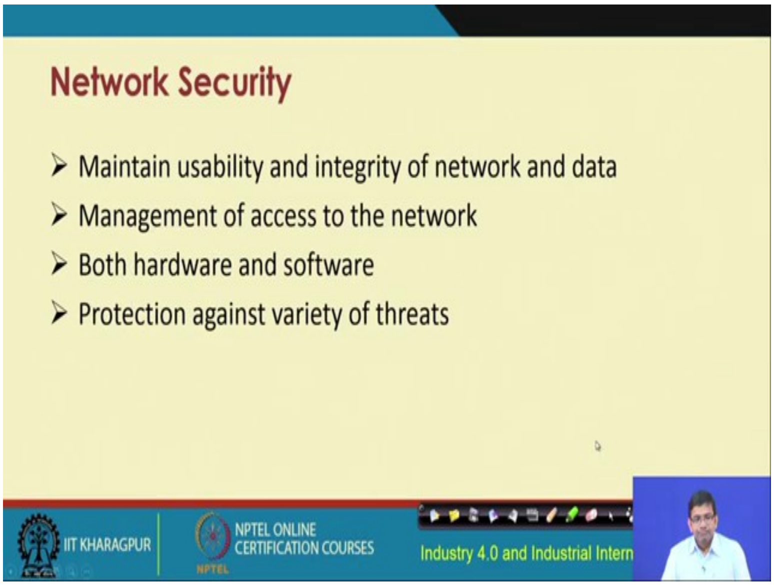


Network security talks about securing the entire network so that the vulnerabilities in the network, the vulnerable points in the network are minimized.

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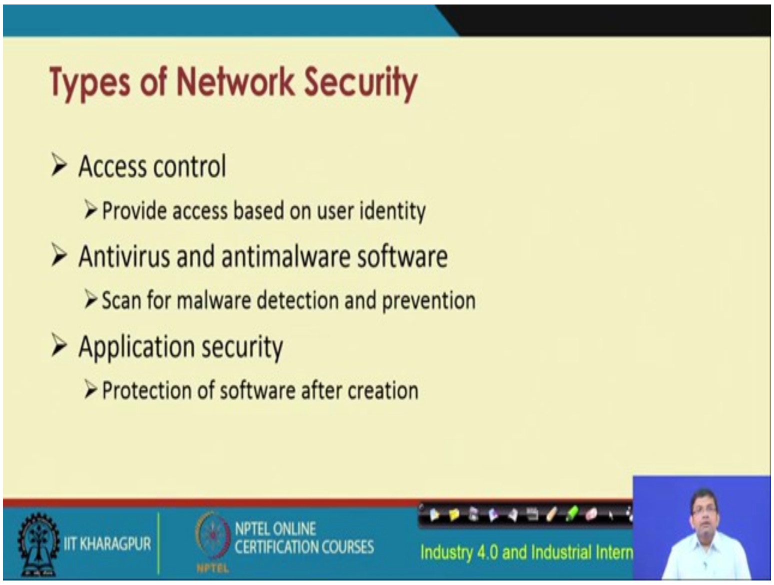


There are different types of network security: access control based on who the actual users are and how much access this should have in the system, not that all users are going to have 100 percent access to all the different components of the system. Certain users are going to have access to certain components other users are going to have access to the other components of the system and so on.

So, controlling this access based on the privileges that are dictated through the policy documents, those should be implemented. Antivirus, antimalware software should be should be used in order to protect the network, then application layer security for protection of the software after it is development that also should be done.

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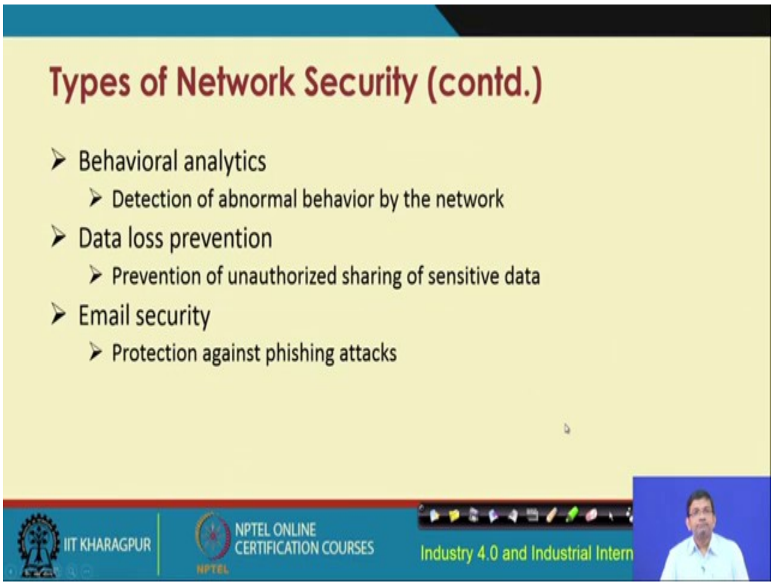


There are different types of security issues; behavioral analytics for detecting abnormal behavior by the network should be done. Data loss prevention should be ensured and email security should be ensured to protect against phishing attacks.

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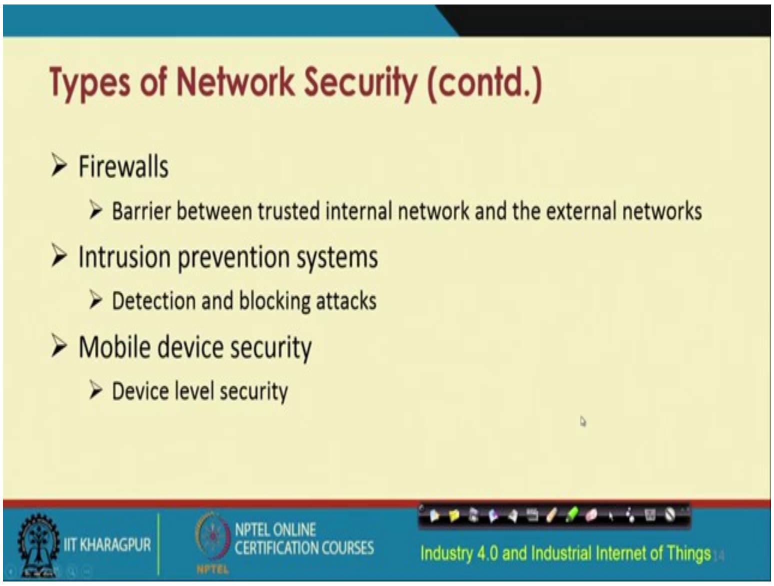


Firewalls, intrusion prevention systems, intrusion detection systems, mobile device security, these are also other concerns of network security.

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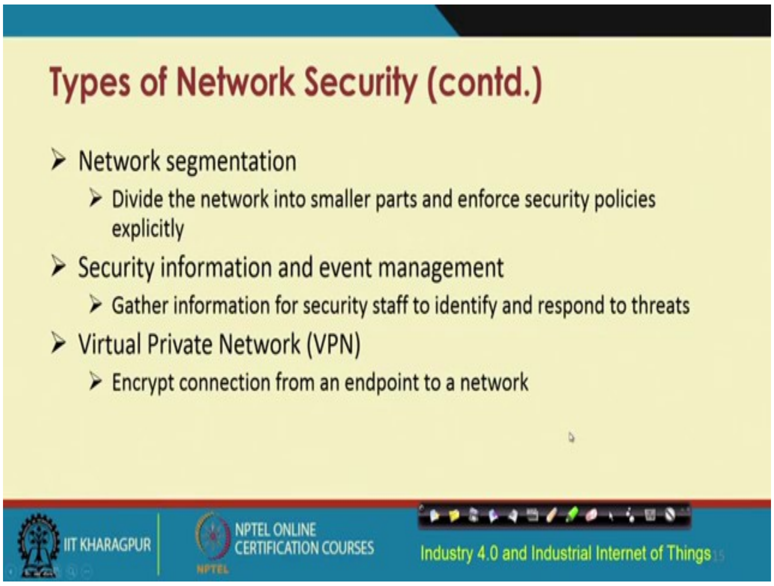


Network segmentation, which is basically dividing the network into smaller parts and enforcing security policies explicitly in those different subdivided parts that is network segmentation. VPN security; security of information and event management these are all the different other concerns in network security.

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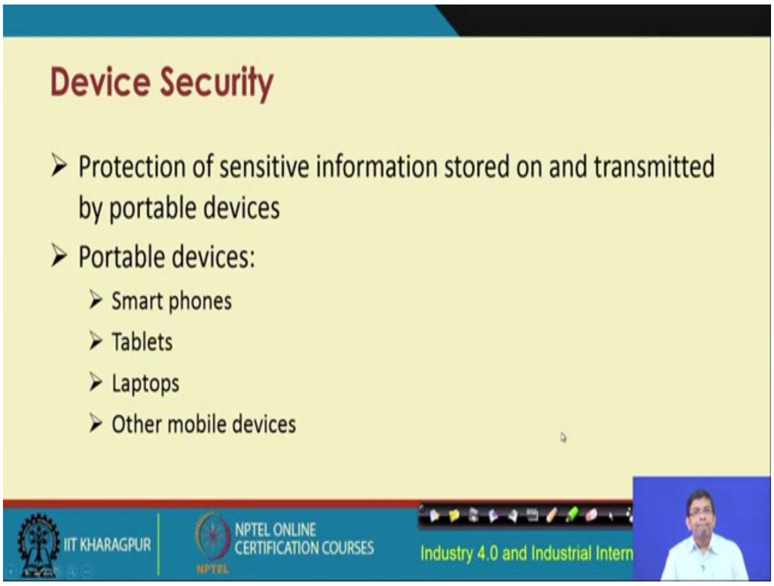


Device security is very important, protection of the sensitive information that are stored in the devices and the different devices such as smartphones, tablets, laptops, etc., their device security is very important.

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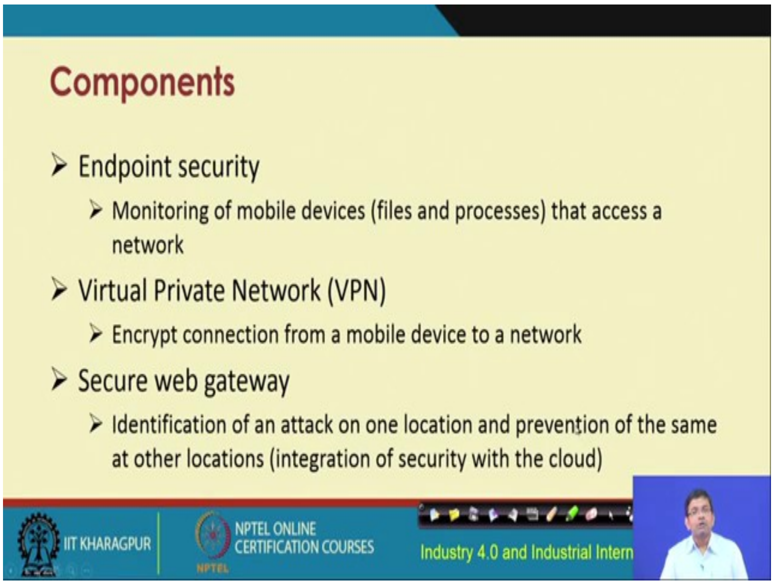


Components in a particular network which improves the different devices, their security, endpoint security, VPN security, you know the gateway security all of these different network components and their security are very important.

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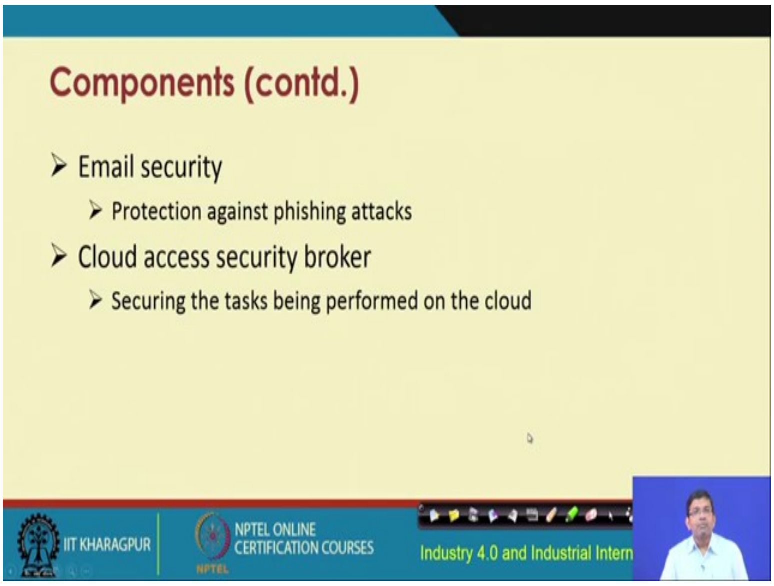


Email security also likewise and cloud security, because cloud is like a third party service in most of the cases. So, securing the cloud and ensuring the integration of the cloud to the home system and the communication between the home system and the cloud, and their security these are also different other components of security in IIoT implementation.

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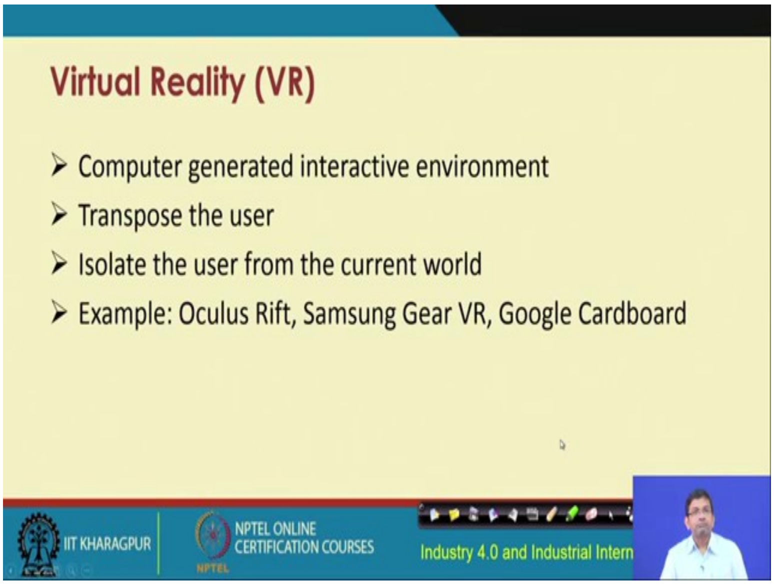


Now, let us talk about virtual reality, virtual reality and augmented reality we talked about a lot in a separate lecture and if you recall that these are very important components that could be used in the industry in order to improve the efficiency of the processes to offer training to the workers and so on. So, augmented reality as well as virtual reality we have discussed in length in a previous lecture we are not going to do that once again over here, but one thing I would like to highlight over here.

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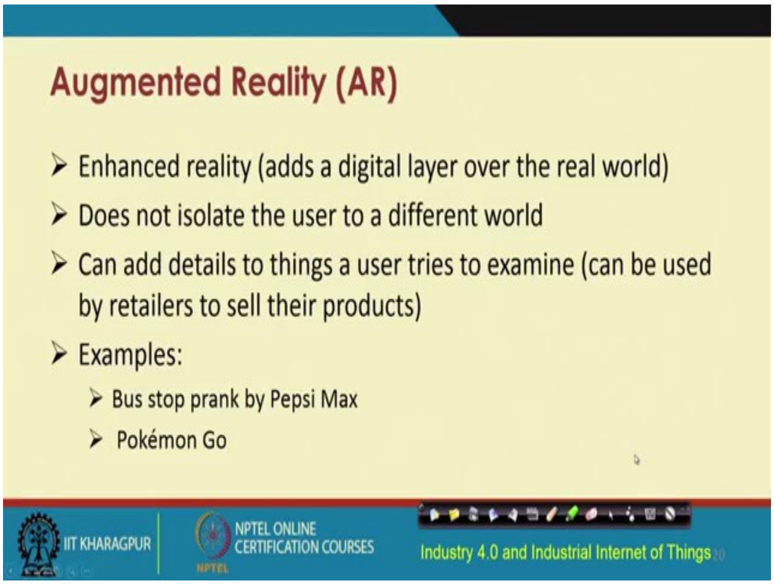


So, virtual reality and augmented reality is something that we have understood, but let me show you, let me draw a schematic of how augmented reality would help in ensuring safety and security in a manufacturing plant.

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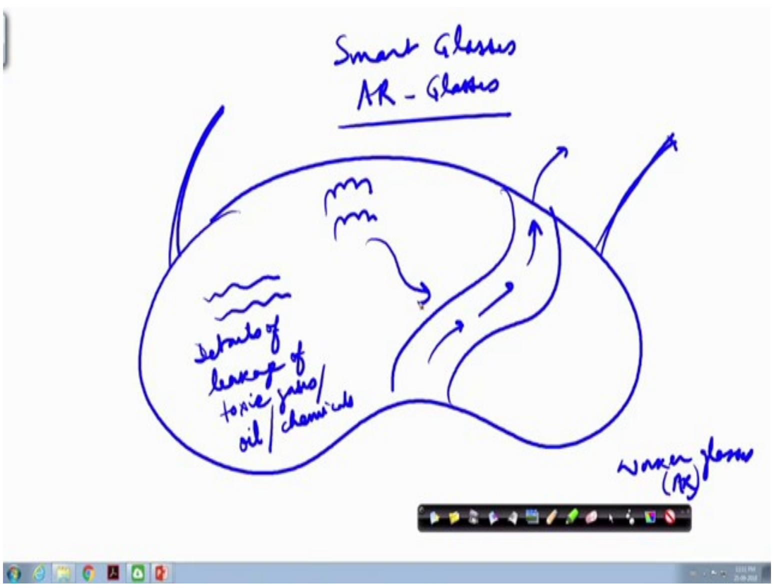

So, all of us have heard about smart glasses. So, smart glasses and augmented reality enabled glasses, AR glasses could be used to improve the safety and security in a manufacturing power plant. So, let us say that we have a glass like this. So, this glass could be basically fitted to the different workers. So, these are the worker glasses, these are the AR glasses, let us say AR or smart glasses which could be owned by the workers.

So, these glasses could help using suitable augmented reality implementations to get details of, let us say details of leakage of toxic gases, leakage of not just toxic gases, but also may be leakage of oil in a manufacturing plant maybe in some machine some oil is getting leaked and so on or maybe some other chemicals leakage of other chemicals, these are some of these examples. So, leakage could be detected by wearing these AR enabled glasses, smart glasses. So, these are possible. If there is a leakage, let us say that there is a leakage right, it would be possible to get the directions a safe way out from this facility so that the worker is not affected due to this kind of event. So, the safe passage way out basically can be directed to this AR enabled glass.

So, like this you could have different other implementations, let us say that if there is a fire or maybe if there is some other event, undesirable event that has happened. So, then taking the requisite action that direction the guidance can be offered by these AR enabled glasses. So, AR enabled glasses lot of research work is going on some industries are already in this space they are working on development of these AR enabled glasses, implementing different functionalities, custom functionalities are implemented in these different AR enabled glasses. So, these could be owned by the workers to ensure their safety and security.

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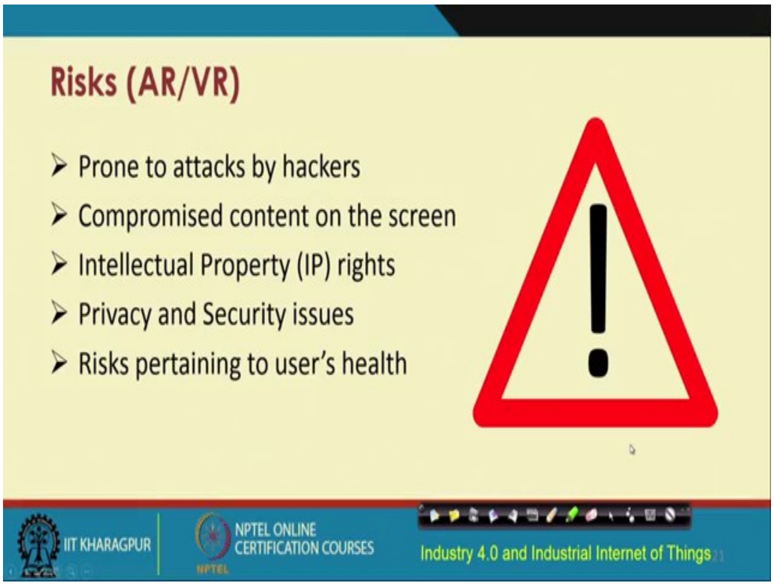


However this AR/VR enabled solutions, these are new IT based solutions. So, they are prone to IT attacks by different, so there are different attackers who could be performing different attacks. So, it might so happen that the content of the screen due to an attack might get compromised and that is going to pose additional risks to these different workers who would be using these different devices.

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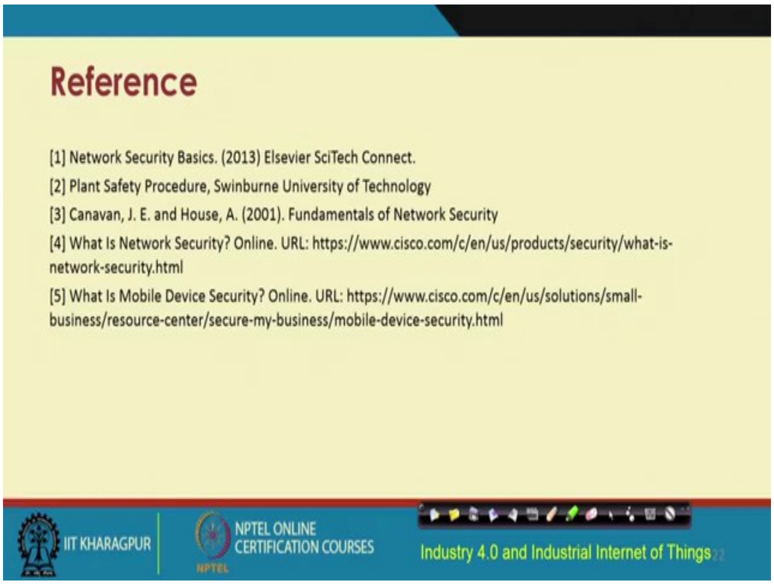

So, in a nutshell this is what I have covered. So, this is basically how these augmented reality glasses could help in improving the safety and security in these manufacturing plants is what I discussed at the end.

I started discussing about what are the security and safety issues in a manufacturing plant and how IIoT can come as a rescuer for implementing these safety and security issues in a manufacturing plant so that the devices can be safely and securely managed and stored and also they the human resources the workers could also be having a safe working environment a secured working environment. So, these are different references once again as usual and with this we come to an end of this particular lecture as well.

Thank you.

**Introduction to Industry 4.0 and Industrial Internet of Things**
**Prof. Sudip Misra**
**Department of Computer Science and Engineering**
**Indian Institute of Technology, Kharagpur**

**Lecture - 55**
**IIoT Applications: UAVS in Industries**

Our next discussion in this lecture will focus on facility management, which is a very important aspect in manufacturing plants. So, how IIoT can improve facility management applications of IIoT for facility management is what we are going to discuss briefly. So, as I told you in all these application lectures, we are essentially talking about the same old thing whatever we have learnt in the previous lectures in the other modules, but we are implementing them. I am just showcasing you how we could implement them in order to make these different domains smarter and to have different facilities which are going to be smarter.

So, what is this facility management? We need to understand this. What is facility first of all? So, facility is a general purpose term which means buildings, precincts which could mean community infrastructure. So, facility in the context of manufacturing plants would basically imply the company infrastructure that is there, the manufacturing company their infrastructure, their buildings, their machines, different machinery, the different trucks, the fleet, etc. all these different types of infrastructure buildings, machinery, etc. all are these different types of facilities.

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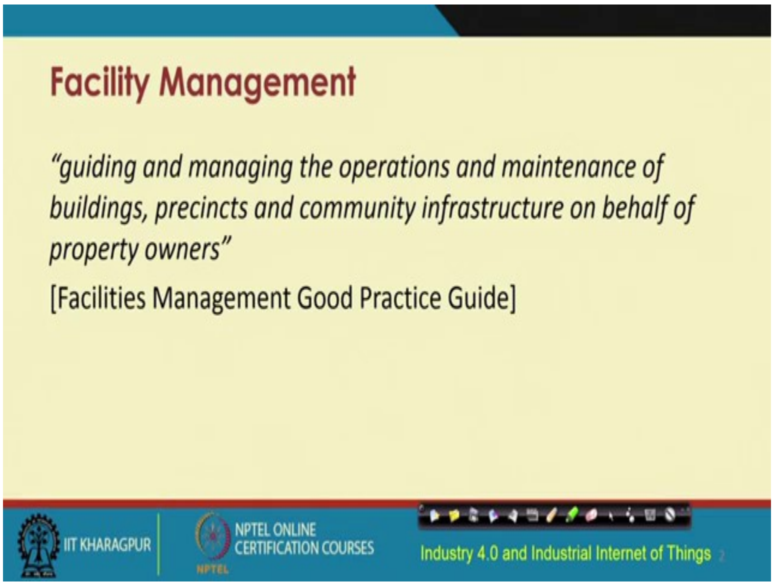


So, management of these facilities is what is required. So, essentially what facility management talks about is captured through this particular definition, it is basically the guiding and managing of the operations and maintenance of different facilities such as buildings, precincts, community infrastructure on behalf of property owners we need to manage all of these. So, once again let me draw and try to analyze what this facility management is going to be like.

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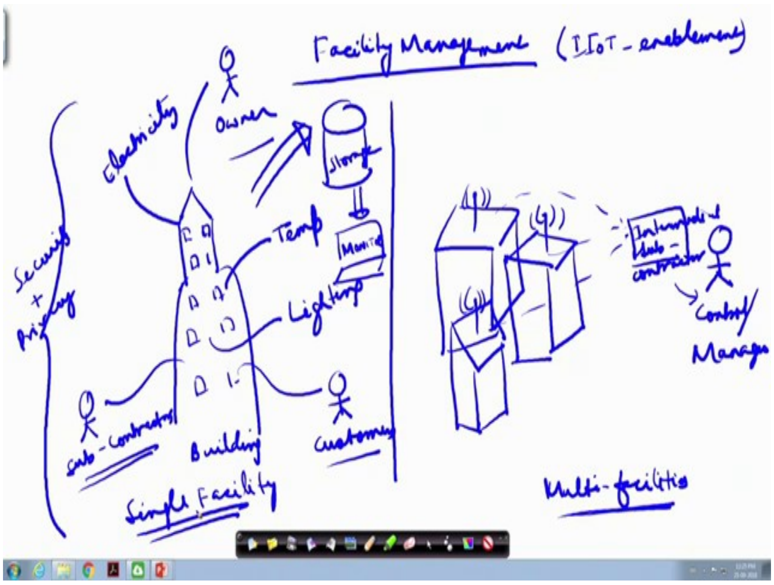

So, facility management and in this particular lecture our focus will be on IIoT enablement. So, IIoT enabled facility management. So, if we are talking about, let us talk about 2 types of facilities. It could be a single facility, we could have a single facility where we could have some kind of, I am just taking an example let us say that we have some kind of a building, a facility having different floors, different rooms, etc. and so on. This building let us say, will have an owner, has different rooms, different departments different offices, different infrastructure in them.

So, these different units are going to be powered through electricity. There could be different rooms which will have to be temperature conditioned. So, temperature conditioning of these rooms, these rooms are going to be lighted; so, lighting of these rooms is important. There are going to be different not just the owners, but there could be different other actors who are going to use this facility like, let us say customers. There could be different in an industrial facility, there could be different let us say contractors or subcontractors who could be using.

So, whenever we are talking about facility management you know we need to have a department, a facility management department which will take care of the management of all of these different entities that I have talked about, particularly this fixed infrastructure, these machinery, the buildings, the floors, the rooms, their temperature conditioning, the lighting conditioning, monitoring control all of these things plus the different users and the different actors who are going to perform different actions on this particular facility or using this particular facility.

So, owners, customers, subcontractors are examples of the different users or the actors of these facilities. So, now, if we are talking about this kind of system ultimately we need to have these different units, these different actors, work much more efficiently in order to have improved facility management. For improved facility management again as usual we need to have sensor enablement; IoT devices will have to be enabled. So, we need to have these devices which will be enabled depending on the use cases being implemented and so on. These different devices which are monitoring the condition of these different facilities, they are going to throw in data which will have to be stored; this is your storage of the data in the common database.

And finally, there is going to be some kind of a monitoring station, a control station from where this monitoring is going to be performed. So, this is going to be a common monitoring station for monitoring the facilities in the buildings using IIoT implementation. So, once again we should not forget that if you are doing all of these things; we should not forget about the security and the privacy issues. So, this was the single facility examples. Let me now give you another example, this is the multi facility so, where you have multiple facilities being monitored.

So, here we are not just talking about a single building, but we are going to have maybe a cluster of buildings and so on which all will have to be monitored. So, we are going to have different antennas fitted with them to send the data out of these buildings and so on. So, we have this multiple collection units and each of these buildings have their own subcontractors and finally, this data will have to be sent to the manager, manager or the control station. So, there could be a manager sitting in the control station, who is the facility manager taking keeping an eye on the entire facility.

In between because we are talking about multiple subcontractors and so on, in between again you could have an intermediate subcontractor, who could be sitting in between and could help this controller or the manager to monitor the facilities appropriately. So, this will be for multi facilities; multiple facility scenario and the single facility scenario and IIoT enabled facility management in both of these scenarios is what I just showcased you.

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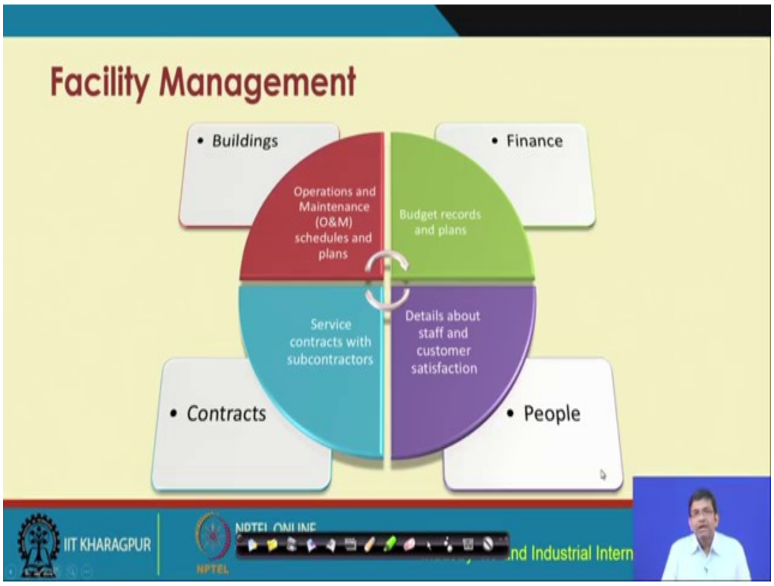


So, let us now go forward and try to understand the different concepts in facility management. So, whenever we are talking about facility management we are talking about buildings, finance, people, and contracts and so on. So, all of these will have to be managed it is not merely buildings; it is not merely people; facility includes all of these different dimensions and their management is what facility management talks about.

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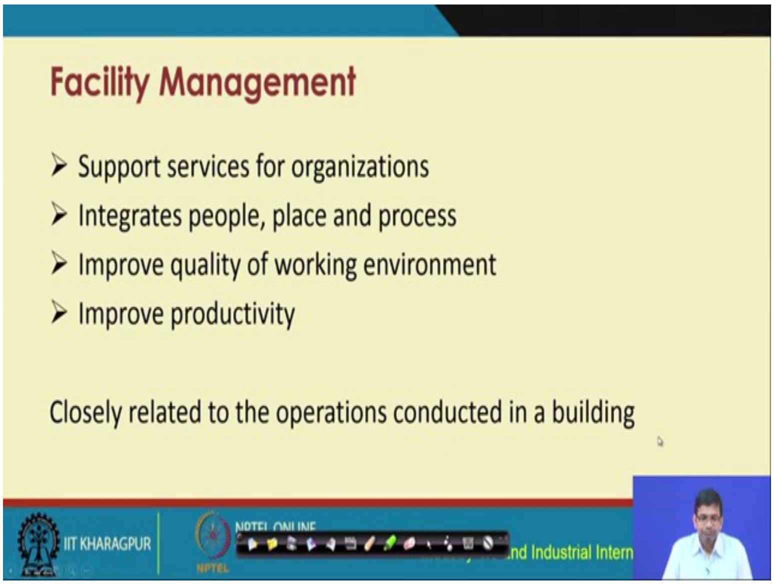


So, facility management would offer support services for organizations, would integrate people, place, process, would improve the quality of the working environment, would improve productivity and these are closely related to the operations that are conducted in a building and monitoring, managing those different operations. So, facilities manager is going to do all of these different things.

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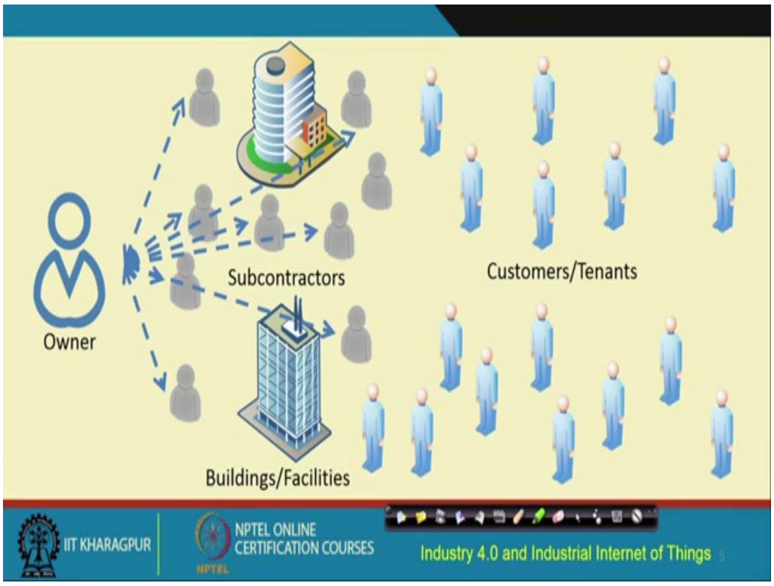


So, let us run through this particular example; I am going to now show you step wise how we are going to have this facility management. So, let us say that we have all these different ones like buildings, facilities, etc. like the ones that are shown in the figure in front of you. We also have a building owner and we have different customers, tenants of these different buildings. We may have the different subcontractors performing different things like different buildings, different floors could be handled by the subcontractors and what is required is to have this owner manage all the subcontractors and through these subcontractors manage these facilities, these buildings and so on.

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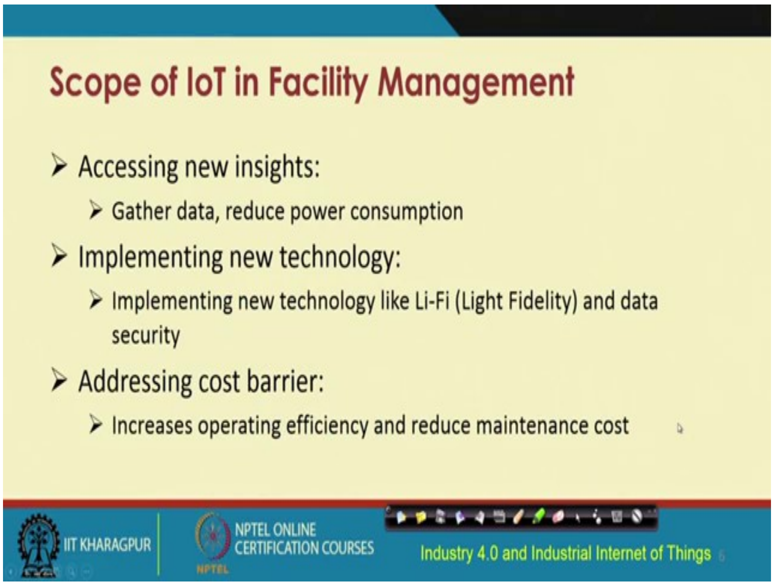


So, scope of IoT in facility management basically concerns the deployment of these different IoT devices, to get new insights through the access or gathering of the data, reducing power consumption in these facilities. Implementing different newer technologies such as LiFi, advanced security mechanisms and many different other technologies. Addressing the cost barrier, increasing the operating efficiency, reducing maintenance cost, these are the scopes of IoT implementation in facility management.

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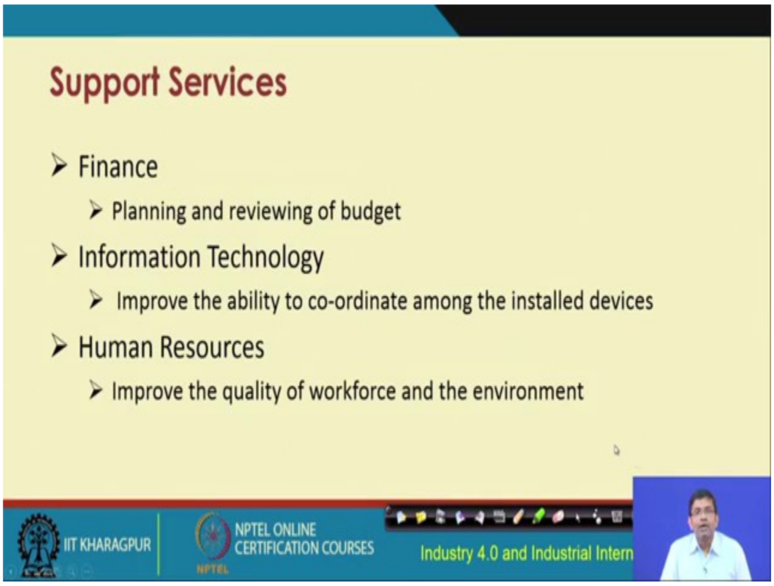

Support services will have to be offered in terms of finance, IT, human resources, management of all of these different support services is also of concern of facility management.

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Facility management also talks about administrative support, offering administrative support, marketing, knowledge management, and business development and so on. So, these are the broader services offered as part of facility management, but these are also inclusive in facility management.

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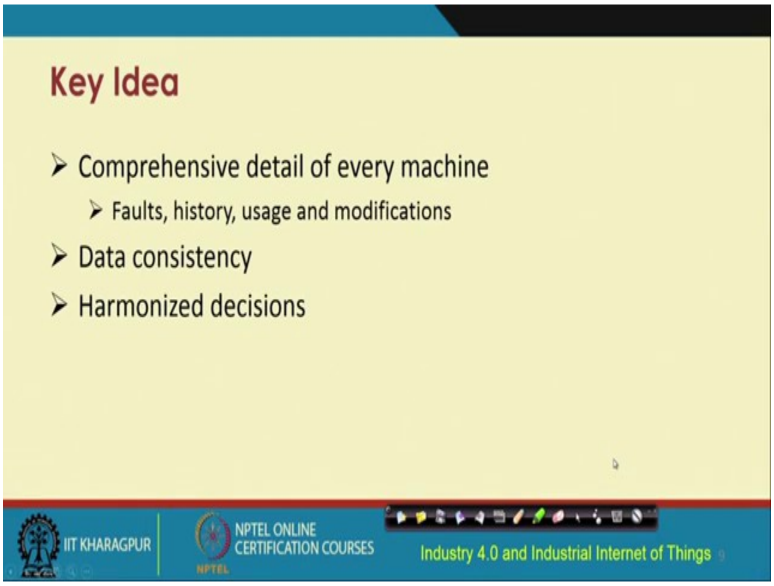

So, basically the key idea of facility management is to get a comprehensive detail of each and every infrastructure, every facility, every machine, the faults, the history, usage, modification. So, obviously, without this IoT implementation efficiently effectively getting all of these types of information, managing these information over a connected system would not be possible. So, IoT implementation is paramount for improved efficient facility management. Ensuring data consistency, making harmonized decisions is what a facility manager should also deal with.

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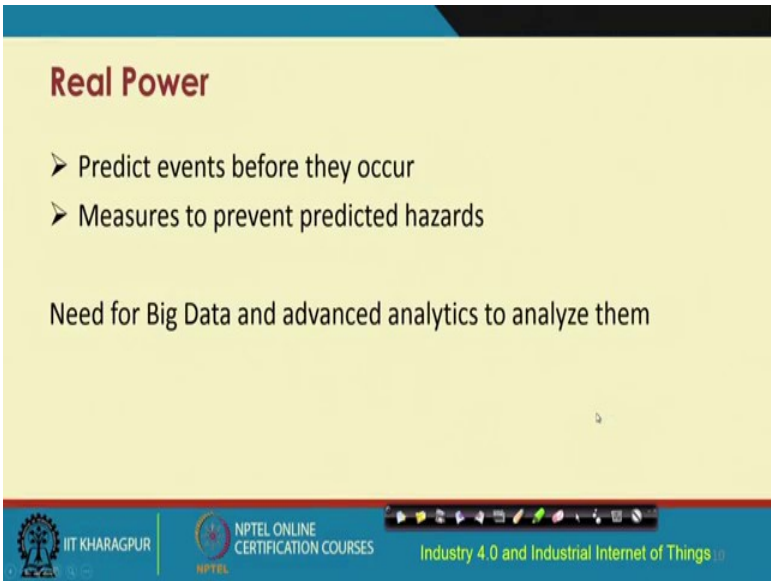


So, the real power of facility management is to predict the events before they actually occur and to measure and prevent the predicted hazards. So, advanced analytics, big data management needs to be implemented because actually the nature of the data that we deal in facility management through the IIoT implementations are basically the big data.

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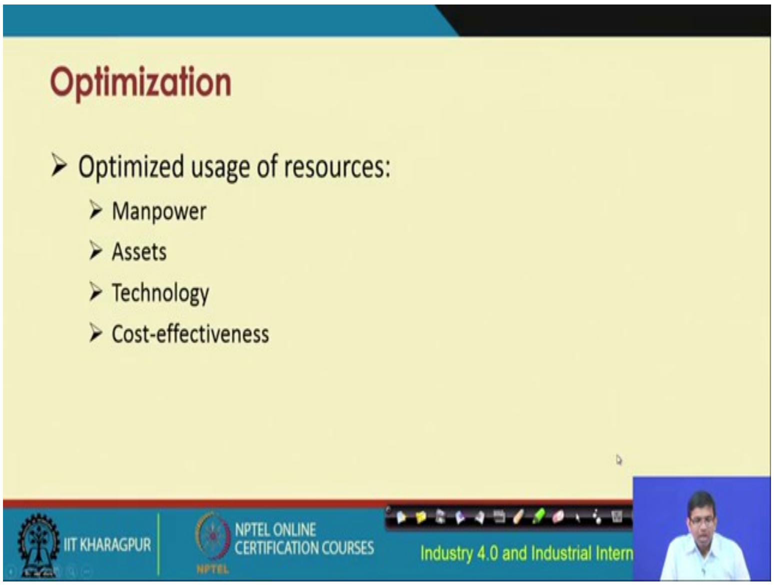


Optimization of different resources, manpower resources, assets, technology, cost effectiveness these are also different optimization issues that a facility manager deals with.

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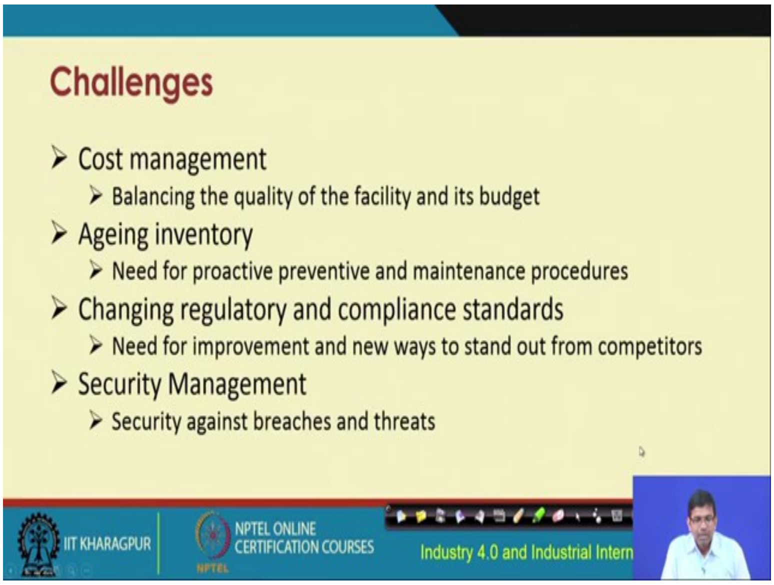


Different challenges with facility management include cost management; that means, balancing the quality of the facility with respect to the budget, aging of the inventory so, taking proactive and preventive maintenance these are also part of this facility management. Changing regulatory and compliance standards and enforcing those within the facility; these are also part of the facility management, security management to protect these different infrastructure facilities, machinery against security breaches and threats that is also part of security management, but is a challenge.

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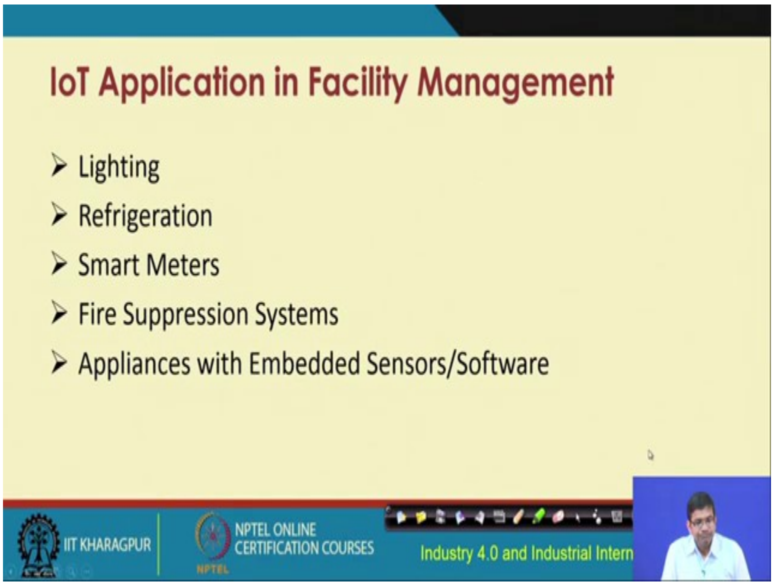


So, IoT application in facility management would include; using these IoT devices to have smart lighting, smart refrigeration, use of smart meters, smart fire suppression systems. If there is a fire that occurs then detecting that in a smart way, controlling that fire, suppressing the fire in a smart way these are also part of the IoT application, improved IoT application in facility management.

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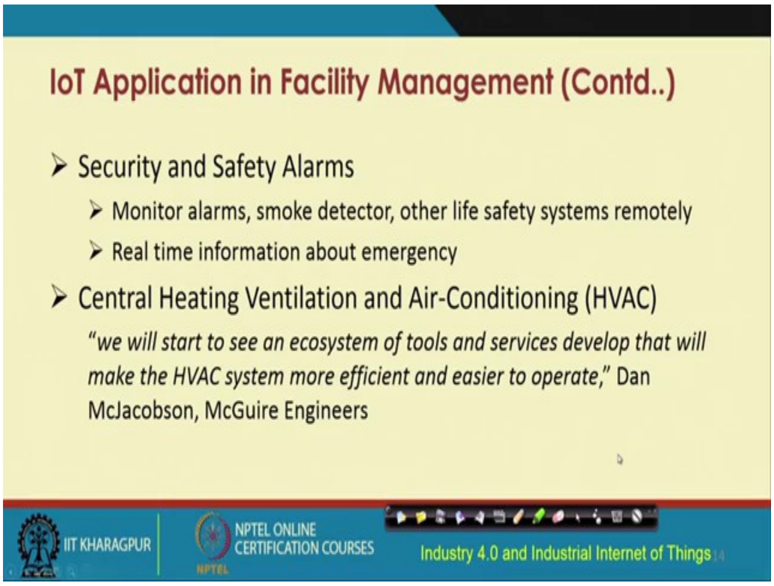


Iot application in facility management also includes installation of security systems; safety alarm systems and so on. Dealing with the HVACs, which are basically the Central Heating Ventilation and Air Conditioning systems and these are the systems which are like central systems for air conditioning, central ventilation and so on.

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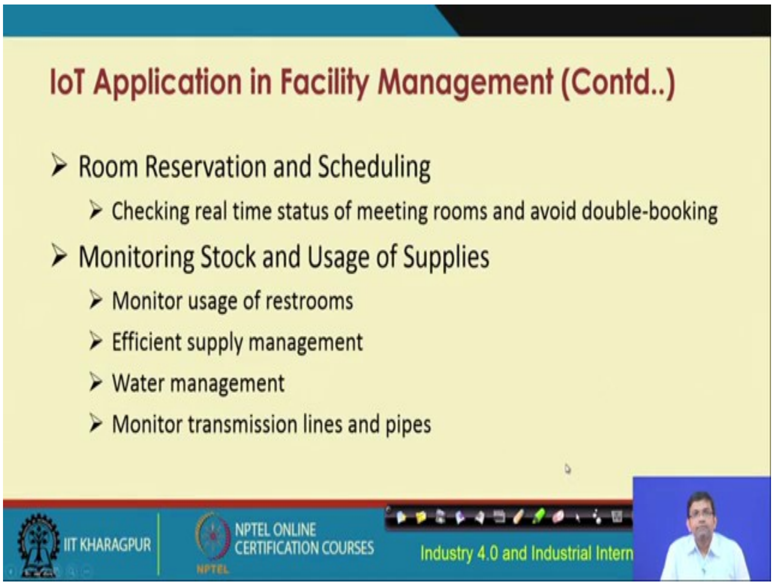


Room reservation, scheduling that is also part of facility management, using IoT real time status updates of the meeting rooms to ensure double booking this is also done. This is just an example of IoT enabled facility management that can be achieved monitoring of the stocks, usage of supplies, these are also possible efficiently these could be done with IoT application.

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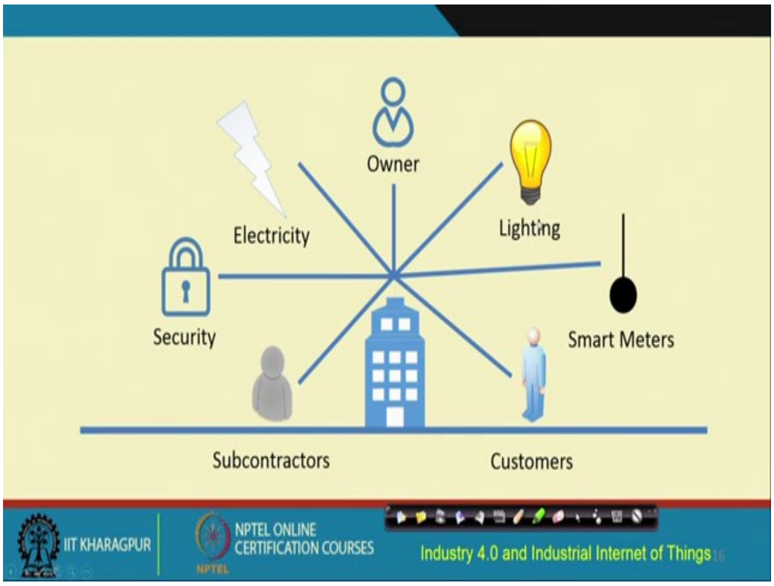


So, we are essentially talking about facilities like this these buildings which have their owners, they have electricity, lighting, different power meters, etc., managing this whole thing, having smart electricity deployment, smart lighting systems, smart temperature control and so on. So, all of these are the concerns in a single facility, smart facility management system using IoT.

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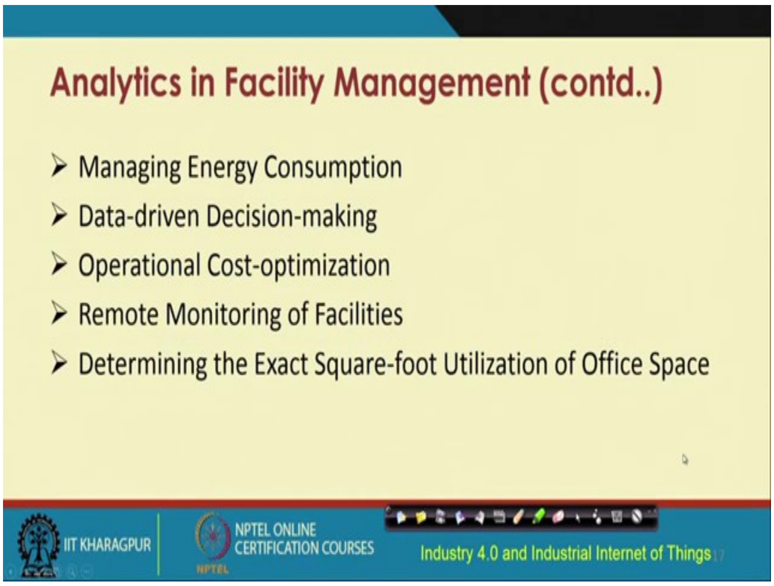

Analytics is very important because there is no use of this data that are collected through the deployment of these IoT devices if you cannot deal with this data and try to get insight out of the data; means then this data is going to be useless. So, managing the energy consumption, making data driven decisions, operational cost optimization, and remote monitoring of facilities, etc. these are of concerns with respect to analytics in facility management.

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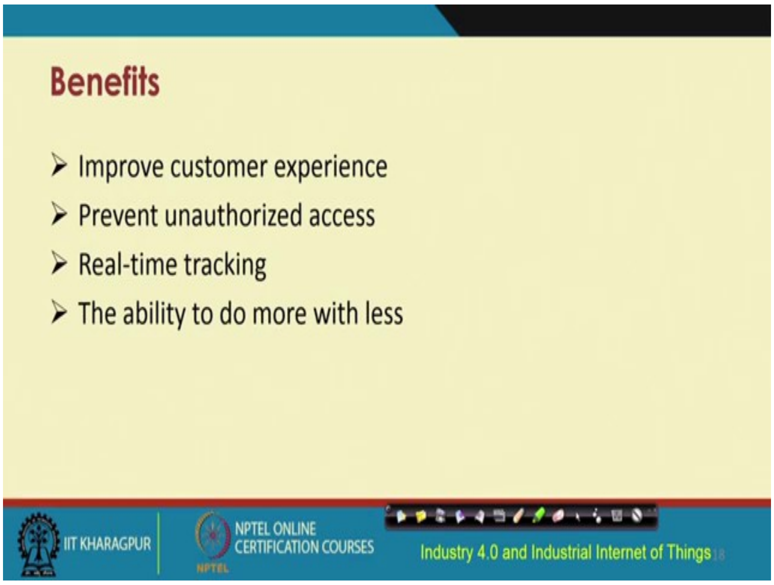


The benefits of facility management would be having or offering improved customer experience, preventing unauthorized access, real time tracking of different things, different activities that are going on within the facilities; real time tracking of those real time tracking of intruders, surveillance. Surveillance is also something that I did not mention, but that is also part of facility management surveillance using different cameras, the CCTV cameras and so on. Then most importantly optimize; that means, ability to do more with less resources, optimization of resources and improved productivity this is also within the purview of facility management. So, this is an important benefit of facility management.

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So, IoT enablement for facility management improved customer experience and so on this is what this particular lecture concerned about, I have given you highlights about the different concerns in facility management, how IoT can help in improving these different concerns, addressing these different concerns and so on. So, for further reading these are different references that have been given to you and in case you are interested you can go through them to get further insights about facility management and facility management using IoT and IIoT.

Thank you.

# Introduction to Industry 4.0 and Industrial Internet of Things

**Prof. Sudip Misra**
**Department of Computer Science and Engineering**
**Indian Institute of Technology, Kharagpur**

## Lecture – 56
## IIOT Applications: Oil, Chemical and Pharmaceutical Industry

In the previous lectures, I have given you different examples of application of IIOT in different domains such as healthcare, food, food processing, facility management, inventory management and so on and so forth. I would like to briefly expose you to the different applications of IIoT in the Chemical industry, Oil industry and the Pharmaceutical industry. As I told you earlier as well that in all of these different application domains, the core technology, the core technological ideas remain the same; they cannot be changed and they are basically the ones that we have discussed in the previous modules.

So, the only thing that changes is basically the type of sensors that would be used. The specific requirements that a particular industry has and certain industry specific industry, vertical industry domain specific requirements, but that is basically mostly dealt with in the application level and at the network at the device level more or less the concepts remain similar. So, in this lecture also consequently, I am not going to talk about anything new drastically. But I am going to expose you to some of the requirements that are specific to these industries oil chemical and pharmaceutical and how these specific sensors and their interconnectivity can help address the issues that these industry space face.

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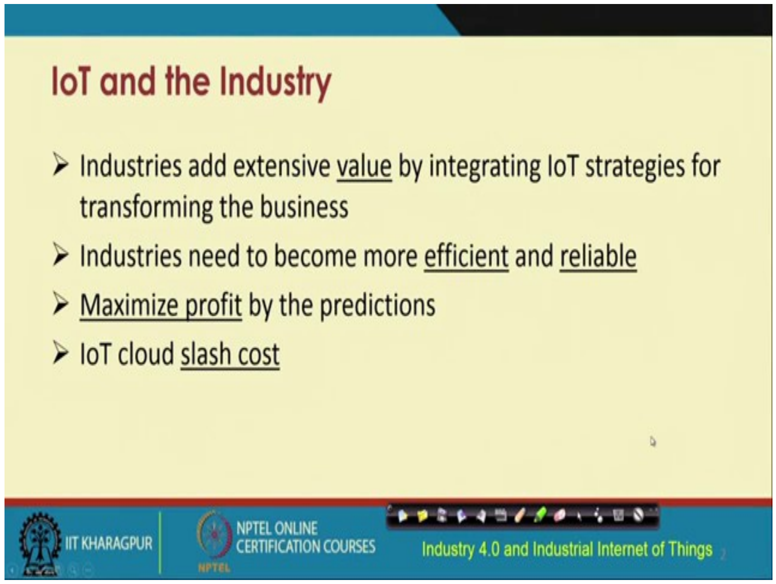


So, let us look at these issues in detail, but before we do that I would like to have a recap because this is going to be the last application that I am going to expose you to in this particular section on applications. I am going to take you through a recap of the issues that are there and the advantages that can be obtained from IoT implementations in the industry. In other words, in a nutshell; let us talk about the specificities of industrial IoT once again. We have looked at it in different levels of detail earlier, but now I am going to expose you to the summary of the different requirements that are there.

So, we want to industries have been operating in their respective fashions since ages; whether we are talking about the oil industry; whether we are talking about the chemical, pharmaceutical or manufacturing industries; things have been going on since ages, since decades, things have been carried on using traditional methodologies. But only now we are talking about the use of IoT or IIoT solutions and we are doing that in order to improve certain things.

We want to improve the efficiency; we want to improve the overall cost effectiveness operations and so on and so forth. In other words, what we want to do is that we want to add value; we want to add value to the products and the processes that are already there, the traditional ones. We want to add value by integrating IoT strategies, IoT solutions to these products and services.

So, value addition should come out through this incorporation or integration of IoT solutions. Essentially, what is going to happen? We are going to improve efficiency; we are going to increase the reliability, safety, security; maximize the profit, maximize production and at the same time, we are going to slash the cost; the cost of production, the cost of manufacturing, the cost of the goods in turn. So, improving the productivity, reducing the cost is essentially in a nutshell we can say that are the benefits of integration of IoT solutions in the industry sector.

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Now, let us come to the specificities in terms of Oil and Gas Industry.

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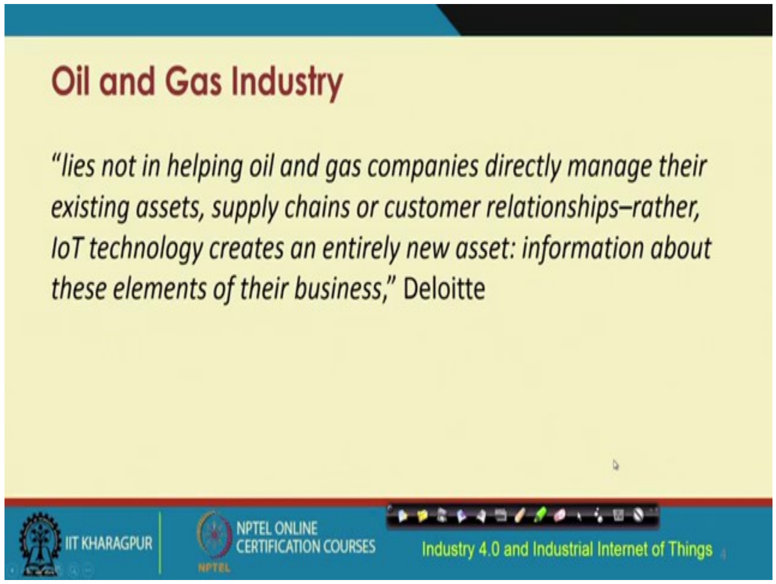


So, there are different efforts globally that are going on in this particular industry domain oil and gas industry domain; lot of efforts are going on, lot of these different industries operating in these spheres. They are talking about having solutions where integration of IoT with their existing processes, machinery etc. are going to happen. The benefits is something that, I have already told you at the outset, but what is going to happen is through the integration the oil and gas companies would be able to directly manage their existing assets, supply chains or customer relationships and that basically will help the business overall..

The productivity of the business is going to improve, the customer relationship is going to improve, the asset management is going to improve, the cost reduction is going to happen and so on. So, overall this is what is going to happen in the oil and gas industry through the integration of IoT solutions. This is a quote that I have taken from a Deloitte literature.

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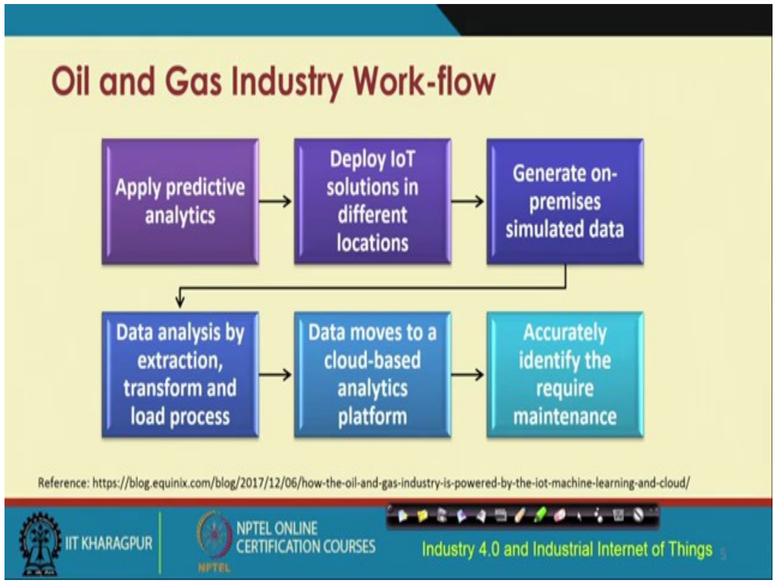


So, this is something that you are already familiar with. We have looked at it, relooked at it in different ways, but essentially as I told you earlier everything remains the same. The only thing that changes is basically the industry domain specific requirements, but from a technology point of view, from an IoT deployment point of view and IoT solution point of view things are essentially the same. But still for completeness sake for getting a bit of idea about implementation issues in different domains, let us still have a relook at the entire process of integration of IoT.

So, ultimately, what we need? We need data; we need data for doing different things, we need data for predicting something that might happen in the future, miss happenings in the future events and miss events that are going to occur in the future. So, this is what might happen.

We need data about different parts of the process, we need data about the health condition of the machines, we need data about the workforce the employees that are working and so on. So, we need data. We need data to do predictive analytics. So, depending on what analytics, we would like to do the specific objectives that we have, we means the specific industry that is implementing the oil and gas industry that is implementing this solution, they would have some specific analytics objective.

So, based on that objective different IoT devices are going to be deployed; sensors, actuators etc. are going to be deployed in different locations. Different locations in the plant, within the plant also in different machines that are going to be involved in the process, in the supply chain and so on. So, different IoT devices are going to be deployed. Thereafter, these devices would generate lot of data. These data could be even augmented with certain simulated data as well. Those data the real ones plus the simulated ones could be together used to analyze, they could be used, they could be analyzed a priori to extract transform and load the processes, the etl processes could be implemented thereafter.

The data thereafter can be moved after this basic processing etl processing the data could be moved to the cloud-based platform where in depth analytics is going to be performed and these analytic solutions are going to be commensurate with the analytics objectives that were set at the outset. And finally, based on the results of the analytics, requisite actions are going to be taken. For example, the devices that need future maintenance would be identified. Also the devices which would need immediate maintenance, they would be identified.

The segregation of the data, segregation of the machinery consequently based on different criteria are going to happen. So, this is overall the entire lifecycle of IoT deployment till control of machinery this is over all the lifecycle. The workflow that is going to be implemented and this is going to be implemented in the oil and gas industry and this is what is already happening, this is what is already happening, there are existing works, initiatives that are focusing on implementation of this kind of solution in the oil and gas industry.

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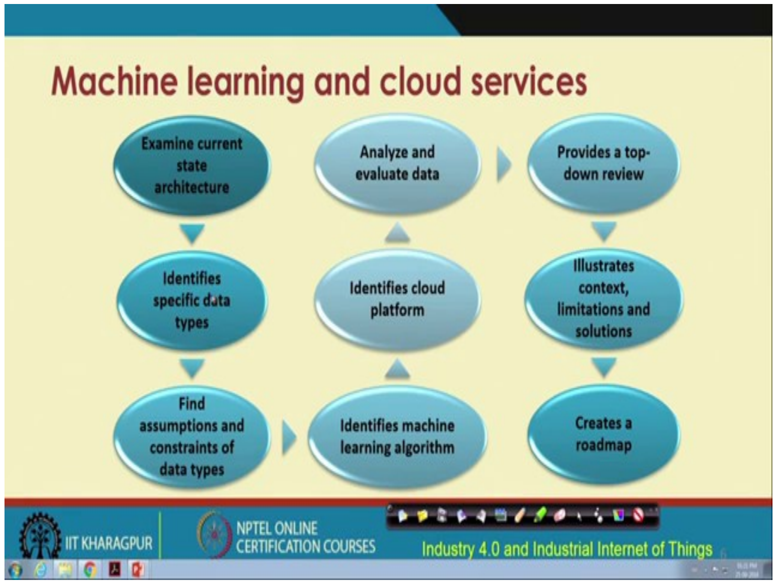


So, for analytics we need what? We need huge processing capabilities, we need adequate intelligence in the form of machine learning AI algorithms which in turn are going to be executed at the cloud. So, we need all of these. So, these are the steps in the machine learning and cloud-based services that are going to be integrated with the IoT solutions for the oil and gas industry. So, this is already something that is happening. Different systems are being deployed in these industries globally in order to realize these solutions.

So, basically it starts like this that it starts with examining the current state of the architecture, thereafter the next step is going to be identifying the specific data type, finding the assumptions and constraints of the data types, identifying the requisite the suitable the targeted machine learning algorithm that is applicable, identifying the cloud platform analyzing and evaluating the data, providing a top-down review and illustrating the context limitations and solutions and creating a roadmap. So, it is in these phases that we could also implement a certain a suitable visualization engine for appropriate monitoring and understanding of the results of analytics.

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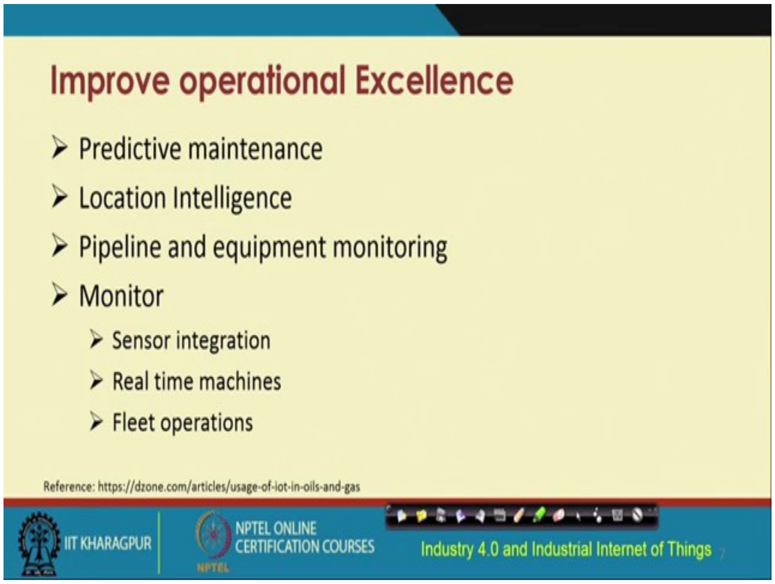


So, overall we want to improve the operations. Different attributes such as predictive maintenance, location intelligence, pipeline monitoring, equipment monitoring, monitoring of the different sensors that are integrated to the pipelines though the machines etc. Real-time machines taking part in these industries in the different processes their execution and so on and fleet operations all of these their operations and so on the performance overall could be improved with the incorporation or integration of IoT solutions.

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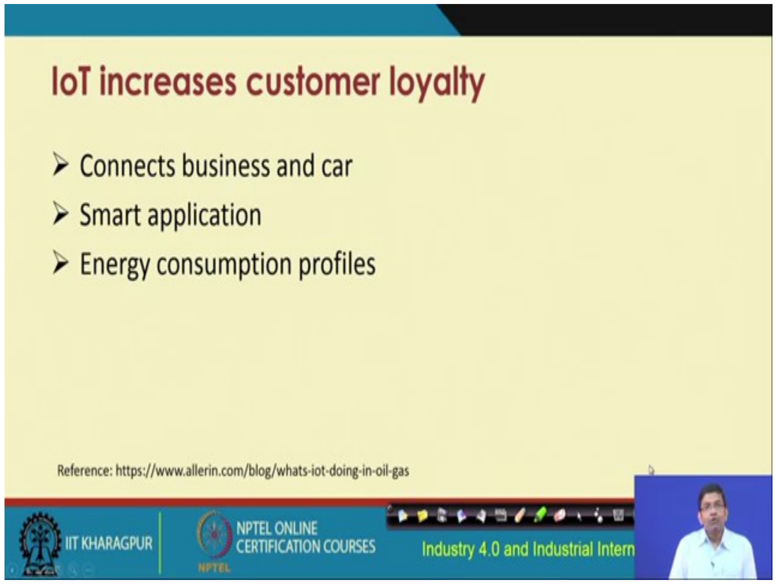


IoT not only does what I just told you, but IoT is also capable of increasing the customer loyalty. Connecting the business, connecting different businesses and different other components, smart applications energy consumption profiles and so on. So, all of these things could be improved and could be made handy and available to the IoT to the customers that are there in these different industries.

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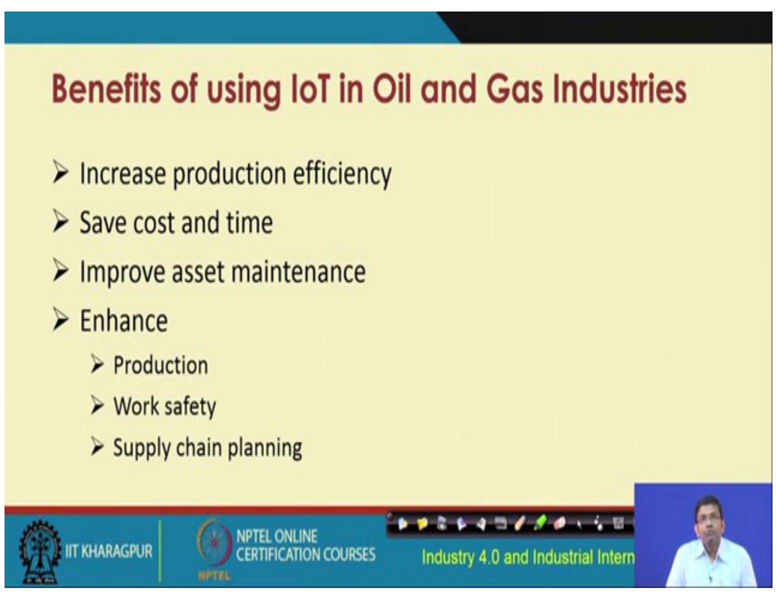

So, the benefits of using IoT in oil and gas industries is already quite apparent, but essentially let us recap and try to summarize what are the different benefits. Benefits include increase in production efficiency, saving on costs, saving on the time, improving asset maintenance, enhancing product productivity, work safety, supply chain planning and so on.

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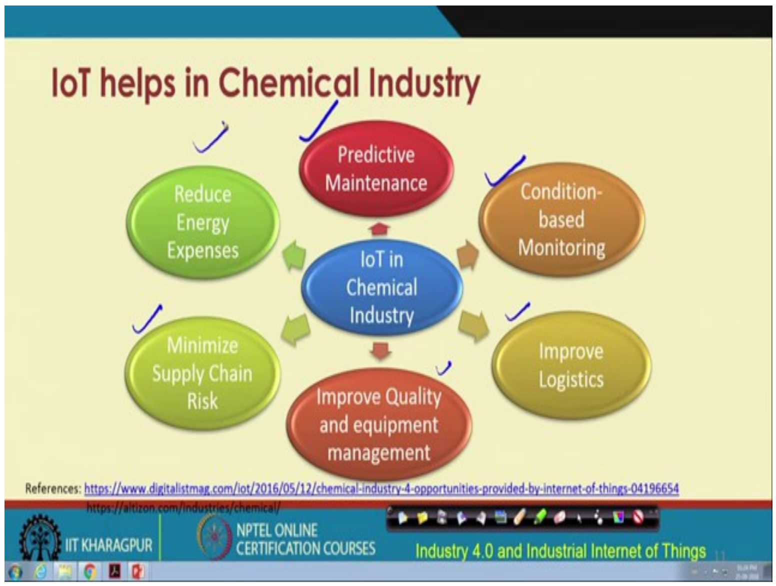


In the chemical industry likewise IoT could be used for improving the overall processes, productivity reducing costs and so on and so forth. So, in the chemical industry once again, let us have a look at these different benefits. We can have predictive maintenance; we can have condition-based monitoring of different machinery that are taking part in these industries to carry out different processes to execute them and so on; improvement of logistics could also be done; improvement of the quality; improvement of the management of the different equipments in these industries; minimizing the supply chain risk and reduction of energy expenses, these are the different benefits that could be achieved through IoT integration in the chemical industry.

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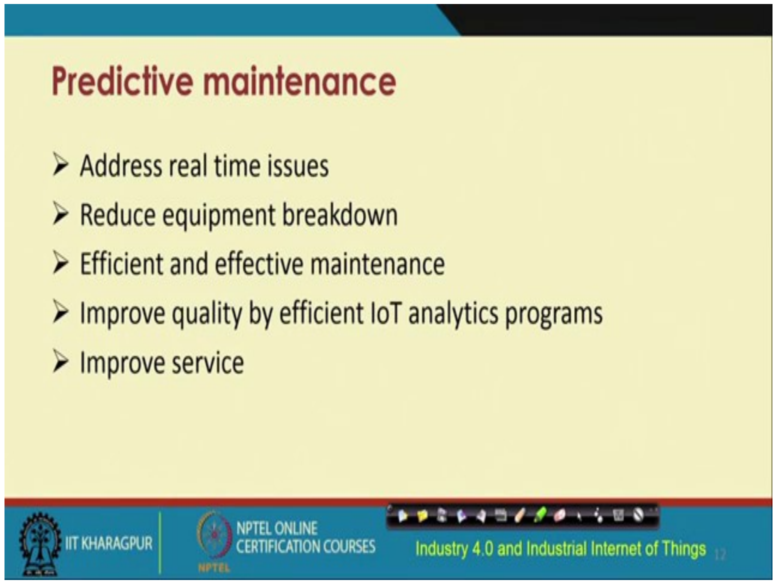


Predictive maintenance such as addressing different issues, that are going to happen in real time in the future now and also in the future. So, seconds later, two minutes later, two hours later, things that can happen. So, predicting those in advance is what predictive maintenance concerns. Reducing the equipment down breakdown and downtime is what is going to be the benefit out of predictive maintenance.

So, what is required is through appropriate predictive maintenance through IoT integration, we are going to have efficient and effective maintenance and improvement of quality by efficient IoT analytics programs and in turn improving the overall services that are delivered.

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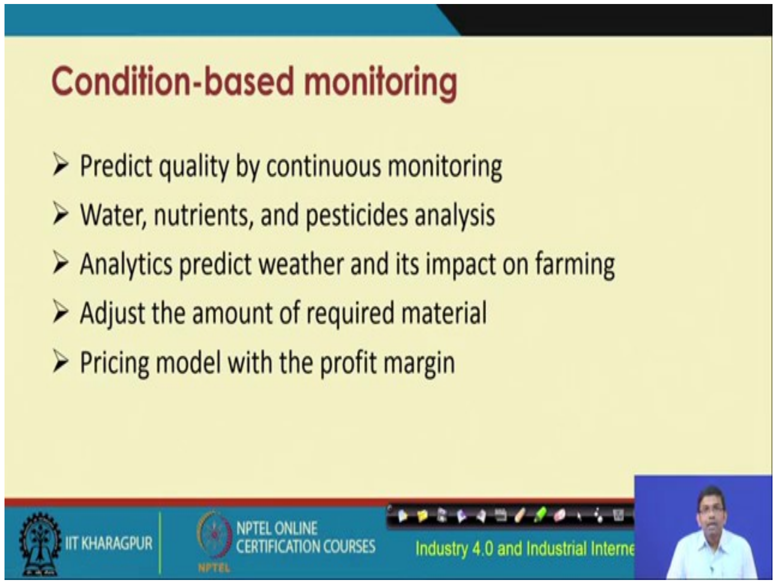


So, condition-based monitoring is going to be possible. It is going to be possible to predict the quality by continuous monitoring, water, nutrients, pesticides, their analysis and analysis in real time is going to happen through the integration of IoT solutions. Analytics predicting weather and their impact on farming and adjusting the amount of required material, pricing models with profit margin; these are the different attributes of condition-based monitoring which are going to be implemented through the integration of IoT solutions.

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Improving logistics, ensuring product location through sensors or RFID tags tracking of assets to prevent loss. Detection of contamination or attacks, alert notification warehouse monitoring are the different things that can help improve the logistics.

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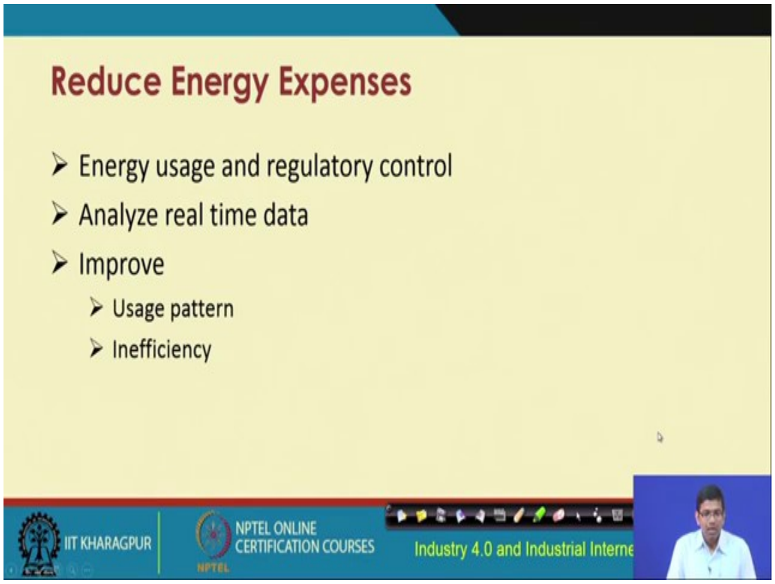


Reducing energy expenses, energy usage, regulatory control. Analyzing real time data, improving the usage pattern, behavioral pattern of users, inefficiency, reduction of inefficiency.

So, these are the different characteristic different things about the energy expenses and reduction of energy expenses is of concern.

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Minimizing supply chain risk. Chemical manufacturers can respond immediately to the required process whenever it is required as and when it is required based on the specific requirements that might be there. Real-time monitoring in the supply chain of equipment, materials being used, raw materials, finished products, finished goods processes, workers environment, everything in real-time, monitoring in real-time of the entire supply chain and the participants in the supply chain; be it the humans, the workers the laborers and so on or be it the different machinery, everything is going to be possible to be monitored in everything in the supply chain is going to be possible to be monitored in real-time.

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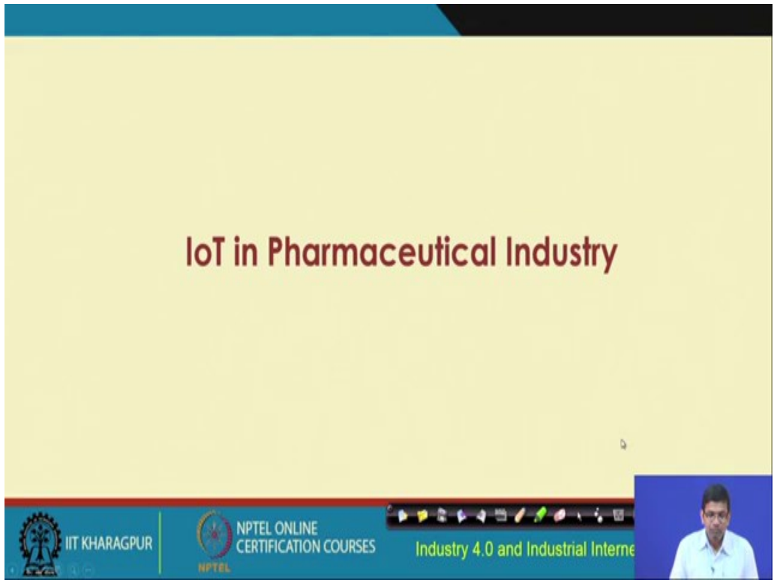


So, before I talk about IoT in pharmaceutical industry, let me see whether we understand this in detail enough. So, let us try to look at this particular thing. Let us say that we have, so we want IoT implementation in the oil and chemical industry.

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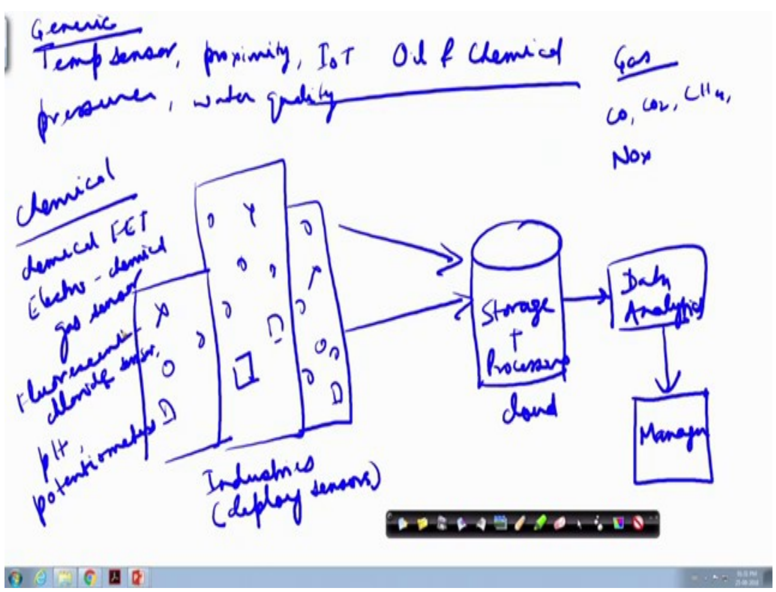


So, we are essentially talking about what; we are talking about different industries, different industries etc. in this domain. These are let us say the industries that would deploy different sensors; different sensors in these different parts of these industries in the different industrial floor, the fields the field equipment and so on. So, all of these different sensors are going to be deployed. So, these data are finally, going to reach some server or some cloud service let us say which has storage plus processing capability and this data would be analyzed and would be made available to let us say the manager.

So, manager at a high level I am mentioning. So, it could be any type of manager. Whoever needs access to that data so, this is holistically how it is going to happen and so, for chemical and oil industry these different sensors I have given different levels for different sensors that could be used.

The different sensors that could be used could be your traditional ones, the common ones like your temperature sensor, different other sensors like proximity sensor, pressure sensor maybe water quality sensor. So, these are these different types of sensors and also some specific chemical sensors could also be used. So, some these are the generic ones, generic sensors.

And some chemical sensors could be used. For example, So, we could have the chemical field effect transistors. We could have electrochemical gas sensors or different other types of gas sensors also, fluorescent chloride sensors, pH sensor is a very common one. Then, potentiometers, potentiometer sensors. So, these are the chemical sensors likewise gas sensors could be any of the gas sensors like carbon monoxide, carbon dioxide, methane, gas sensor; there is those NOx gas sensors and so on.

So, there are different sensors. So these are some of these different sensors, the chemical domain and the gas domain that I have mentioned. If you recall, when we talked about sensors in the industry scale, we also talked about the development of a gas cells sensor and I had shown you one of the facilities in our institute which basically deals with the gas sensor fabrication and how gas sensors can help in monitoring the concentration of different gases. So, we have talked about that.

So, those gas sensors are actually also applicable in these different industries; oil and gas industries. So, they could be used and for oil and gas industry, what also happens is typically from the point the oil and gas are procured or may be generated typically you will find that there are different ways of transporting that oil and gas. So, there are different gas pipes; big thick gap gas pipes of large diameters that can help in carrying the gas from one point to another. These are quite common. So, particularly the big oil industry is the back big gas companies, they deploy these gas pipes for carrying the gas for carrying oil from one point to another.

So, one of the common problems with these gas lines the distribution lines is leakage. So, gas leakage, pipeline leakage or even the oil leakage might happen in any of the points in these transmission lines and so, leakage detection, leakage monitoring is also very important.

So, basically the deployment of appropriate sensors for gas pipe monitoring is a very well-known problem and that is an application of IoT to improve the production, the transmission, the generation and so on. So, this is just an example like this different sensors could be used to solve different problems in the oil and gas industry. So, let us now take a brief look at IoT in the pharmaceutical industry, this is also very similar.

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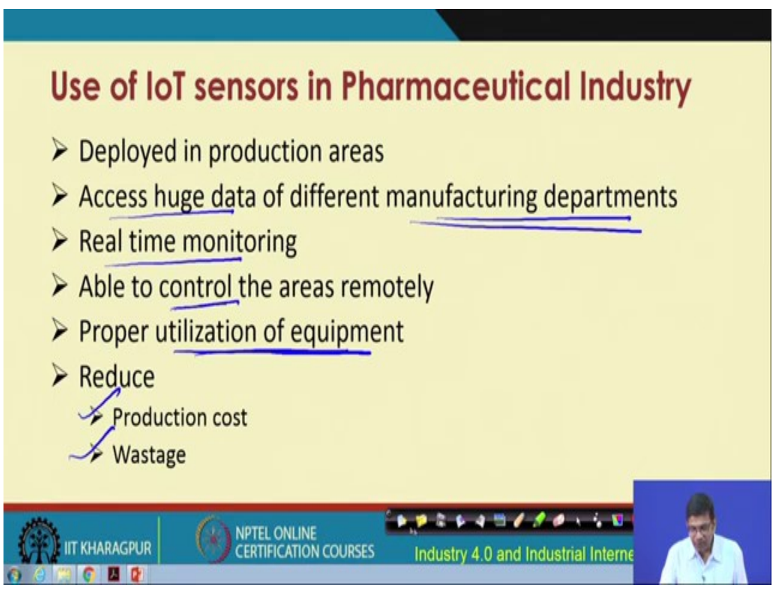


So, the thing is that there are in the pharmaceutical industry, you have different plants which are making different drugs and so on. These drugs are also used for the drugs and their monitoring of the drugs on different subjects, different animals and so on is also quite often done. So, IoT can help, IoT can help in doing these trials for the production process of the different drugs and so on monitoring those in a much more efficient manner. For example, production of a vaccine, it goes through different steps so and finally, it goes through certain trials if different sorts of trials happen.

So, these pharmaceutical companies, these pharmaceutical companies. They take these different drugs through different equipments, these drugs are tried out in different phases they are manufactured in different phases and finally, tried out in through different subjects and so on before these drugs are released in the market. So, for this entire production process, in this entire production process the supply chain and so on, sensors and IoT solutions could be deployed in order to improve the processes to monitor the quality of the drugs, the intermediate steps monitoring the quality of these intermediate steps and so on.

So, everything could be done in a much more efficient and precise manner. So, IoT sensors could be deployed in production areas could help in getting huge data from these manufacturing departments in these pharmaceutical industries can help in real time monitoring, can help in controlling these areas remotely, can improve the utilization of the equipments the machinery etc. And can help in reducing the production cost and wastage. So, these are some of these uses of IoT sensors in the pharmaceutical industries.

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So, IoT applications in pharmaceutical industry includes examination of the drugs and not just the final drugs, but also the intermediate ones through which the processes that are incurred in between in order to transform these raw materials into the final drugs. So, throughout from the raw materials to the final drugs, examining the quality, the quantity etc. also monitoring the different chemical reactions that are required in order to transform one part of the chemical to another part and so on.

So, all of these basically in this entire process, IoT solutions could be deployed. IoT solutions could be also deployed in order to detect adverse drug reactions effects of pharmaceutical excipients, detecting allergies, other complications that might be meant might be effort might be happening. So, all of these drug reactions and allergies etc. etc. monitoring those, detecting those everything could be done in the pharmaceutical industry. These are being done with the help of different appropriate sensors.

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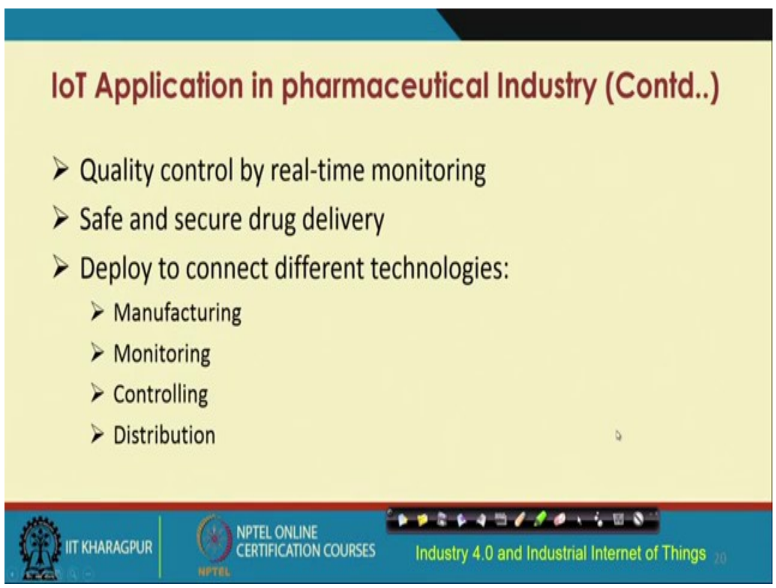


So, Quality control by real-time monitoring; safe and secure drug delivery deployment of different solutions to have improved manufacturing, improved monitoring, controlling, distribution. These are the different other requirements in the pharmaceutical industry.

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Improving logistics; tracking the movement of pharmaceutical goods. Improving warehousing, Optimizing routing, Maintenance of machines and equipment, Inspecting the machines of medicines and vaccines. These are also going to improve with the incorporation or integration of IoT in the pharmaceutical industry.

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Before I end, I would like to list these different types of sensors that we are going to use in the pharmaceutical industry.

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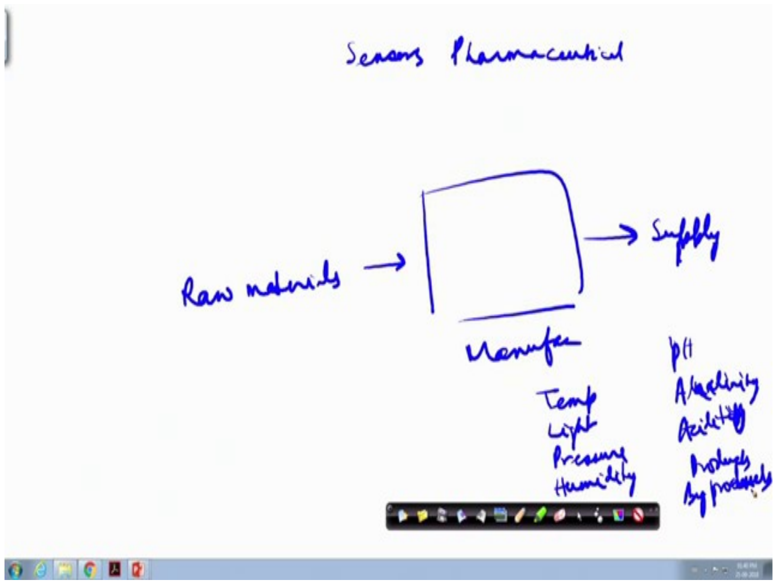


So, for the pharmaceutical industry also for first of all what happens is let us say that a pharmaceutical industry makes certain drugs. So, there would be different raw materials. So, raw materials are going to be used. These raw materials are going to be taken through certain manufacturing process, and finally, the final products are going to be supplied.

So, these are going to be delivered through trucks and other logistic means etc. So, these raw materials undergo different types of processing. These raw materials we would be subjected to different chemical treatment. These raw materials are going to be subjected through different pressure, under certain pressure condition, temperature condition, in certain humidity condition and so on.

Performing different reactions with different agents, reagents under certain temperature humidity lighting condition and so on. So, all of these things are going to happen. So, what sensors are going to be used? In addition to certain chemical, specific chemical detection, specific chemicals, specific sensors other sensors such as temperature sensor, because you need to conduct a certain reaction or maybe a titration under certain temperature settings in a certain lighting condition;, light sensors, temperature sensor light sensor, pressure sensor in a certain pressure condition these reactions have to happen. So, pressure sensors. Like this there are different other sensors that would also be used in the pharmaceutical industry.

So, let me just write. So, the names of some of these sensors, temperature sensor, light sensors, then you have pressure sensors, maybe humidity sensor and if you have some kind of chemical reactions these different chemical sensors for detecting maybe the pH level. So, pH level. So, you could have the pH sensors; detect the alkalinity, or the acidity of the different products or the byproducts in the chemical reaction. And the transformation process. So, some of these different sensors that could be used.

So, finally, we come to an end or in this lecture and as usual these are these different references. I would encourage you to go through these different references. There are lots of videos that you could also use to get better understanding of these the applications of IoT in this different industry; even in the oil industry, gas industry, pharmaceutical industry, there are a lot of different videos. You could try it out in different open media such as YouTube etc. lot of different videos exist. So, these are these references and finally, we come to an end.

Thank you.

**Introduction to Industry 4.0 and Industrial Internet of things**
**Prof. Sudip Misra**
**Department of Computer Science and Engineering**
**Indian Institute of Technology, Kharagpur**

**Lecture – 57**
**IIOT Applications: UAVs in Industries**

In this module on Applications, I have included a special lecture on the use of UAVs. UAV as the full form of UAV is Unmanned Aerial Vehicle. So, UAVs; drones for example, which most of you have heard of are good examples of UAVs. So, UAVs have become very popular.

So, consequently there are so, many different initiatives happening worldwide, which are basically targeting the use of these autonomous unmanned vehicles to conduct, to carry on certain activities in an efficient manner. UAVs have lot of different applications. Applications in the industries are particularly useful; in our country and different other countries UAVs are being explored to do number of different things.

UAVs are being explored in the industry to autonomously in an unmanned manner to reach out to places, which are basically difficult to be reached or accessible by humans. Maybe because there are toxic wastes and it is dangerous for the human beings to basically go over there.

So, you UAVs could be designed in such a manner, that these flying objects would fly from a safer location, and land up in a remote location and could collect different data could collect different samples from that remote location, which presumably is hazardous, which presumably cannot be made accessible to humans and so on. UAVs likewise have different types of applications we will talk about the different other applications in detail.

UAVs have application in health care, UAVs have applications in agriculture, UAVs have applications in manufacturing plants. In steel plants, in nuclear power plants where there are hazards of nuclear radiation and maybe close to the nuclear reactors, where there is hazard of nuclear radiations and their exposure and it is difficult for humans to go and take samples or collect samples or do certain types of monitoring activities. So, UAVs can come as a helping hand to do all these different activities remotely, which would be otherwise difficult to be done by human beings. So, UAVs are very helpful.

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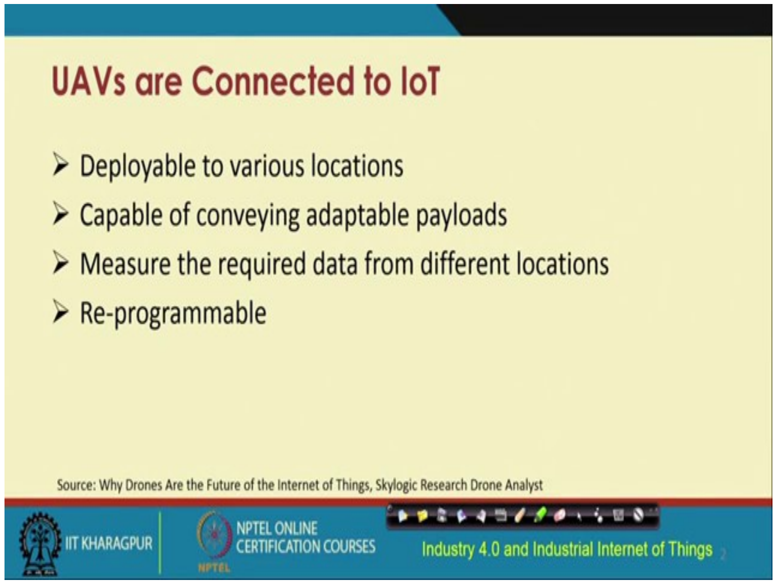


So, UAVs in the industry can help in doing number of different things and in the industry we are not just talking about single UAVs, we are talking about connected UAVs, swarms of UAVs; that means, UAVs which can talk to one another, UAVs which can send messages from one UAV to another UAV and maybe then back to the terrestrial control station and so on.

So, UAVs and the connected UAVs are very attractive. So, UAVs can extend the networks the terrestrial IoT networks to the aerial IoT networks. So, UAVs can extend beyond the terrestrial domain and carry the information from the ground; that means, from the terrestrial domain to the aerial.

So, connecting the terrestrial IoT networks to the aerial IoT networks and then sending back the signals from the aerial once to the ground; so, all of these could be done with the help of UAVs. So, use of single UAVs are quite common use of swarms of UAVs connected UAVs is also becoming quite popular. Because, these connected ones can do activities can do achieve certain tasks in a much more efficient manner than the single UAVs. So, UAVs could be deployed in various locations in the power plants, in the manufacturing plants, in the different industries and so on.

They would be capable of conveying adaptable payloads depending on the requirements different payloads could be adjusted adaptable payloads could be carried by these different UAVs. UAVs could lift the load from one point in the industry and could send and could release the load to another point in the industry, and maybe it can do that in a much more efficient manner than the conventional means of transporting load in an industrial plant or a power or a manufacturing plant. So, UAVs can help in measuring different data, from different locations particularly collecting data from remote locations hard to reach locations, locations which could be hazardous for human beings and so on.

UAVs can also be made reprogrammable so; that means, these UAVs can help cater to certain requirements and then dynamically those requirements if they change, they can be reprogrammed, many different things can be done with these UAVs and these connected UAVs or swarms of UAVs.

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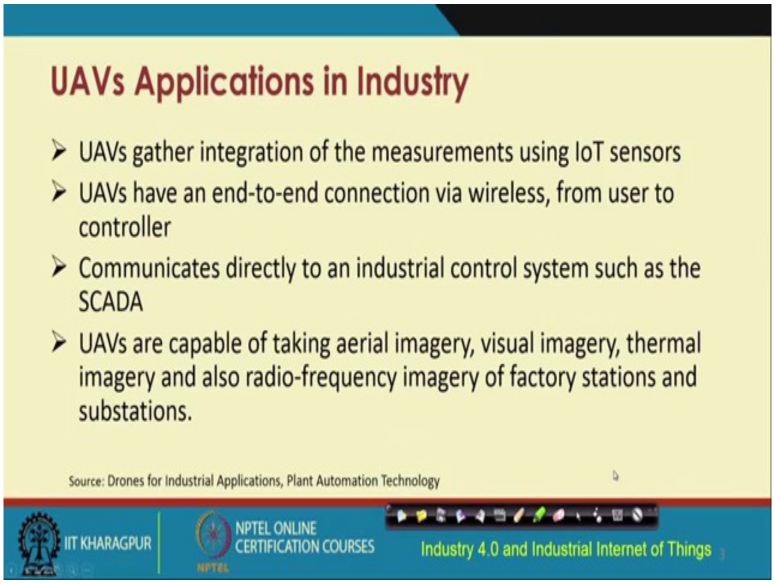


In the industries, UAVs can help gather different data, collect different measurements, using different sensors that could be integrated to these UAVs. UAVs can help in achieving end-to-end connection, as I was telling you not only terrestrial connection, but also terrestrial to aerial, aerial to terrestrial and so on.

So, UAVs have an end-to-end connection typically via wireless from the user to the controller. UAVs can help communicate directly to an industrial control system such as a SCADA and details of SCADA we have already understood in another lecture.

So, it is basically for supervisory control, supervisory data acquisition and so on. So, scatter devices and their integration with UAVs are also a reality that is happening in the industrial IoT sector. UAVs are also capable of taking aerial imagery, visual imagery, thermal imagery, and also radio-frequency imagery of factory stations and substations. So, before I go any further I would like to show you two different things. So, let me just show you how a UAV looks physically.

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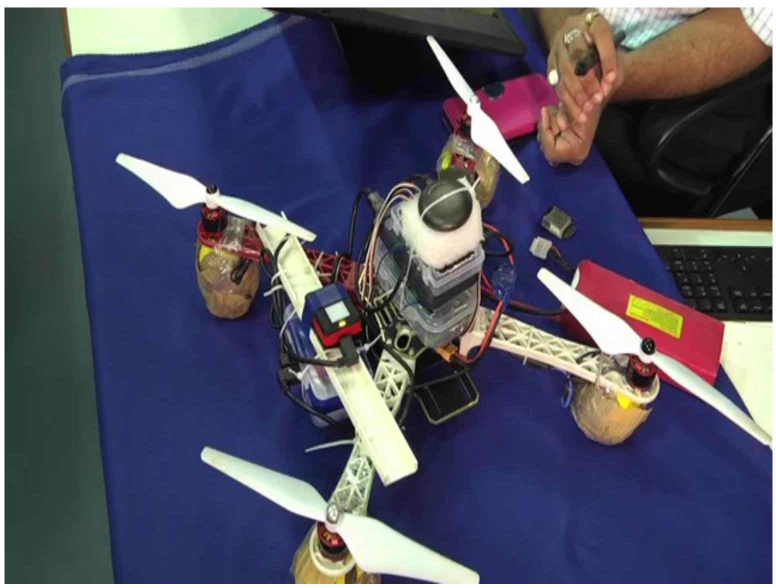

So, this is an example of an UAV and this is an example of a UAV. So, as you can see over here, this UAV has different parts. This UAV has this is a propeller; this is a propeller of an UAV as you can see so, there are this is a quadcopter; so this is a quadcopter. So, which has four different rotors, four different propellers so, there are four ones. So, there could be hexacopters, quadcopter octocopters which means that there could be 6 propellers, 8 propellers and so on.

So, these are these different propellers and these propellers they rotate by virtue of the rotation of the motors. So, these propellers are connected to these motors, this is a motor. So, underneath as you can see this is a motor this is the small one, the red colored one is a motor. So, the propeller is connected to a motor, this is actually UAV we actually in our lab the swarm lab in our Department CSE, Department at IIT Kharagpur we do a lot of work with UAVs. And, this is one such UAV that we work with and this is actually for agro-imagery we use it for agro-imagery.

And, so, this is a quadcopter UAV and this UAV is a fully autonomous UAV; that means, that you do not need any remote control to operate it. And, we have in our lab we have made it fully autonomous. And so as I was telling you let us continue explaining the different parts. So, this is basically one propeller likewise there are 4 different propellers. So, connected to these propellers are these motors the red coloured ones that I showed you.

So, there are 4 different motors; motors can come in different specifications you can have higher capacity motors and so on. So, if you have higher capacity motors that will give higher altitude, the higher thrust, bit better payload carrying capacity and so on. So, these motors and then you have this one is something known as the APM, this is a controller.

So, this controller basically controls all these different motors. These motors basically rotate in there are 4 different motors. And, these motors they rotate in two different directions. And one set of motors will rotate like this one and this one, these two motors will rotate in a counterclockwise direction whereas, these two motors rotate in the clockwise direction.

So, consequently the propellers also one set of propellers will rotate in the clockwise direction, the other set will rotate in the counterclockwise direction. And, this basically will help this UAV to take the lift. So, this is very important in the design of a UAV. So, as I was telling you that this is this APM controller which basically will control these different motors that we have. And, this is this GPS unit, which will help in getting the GPS position of this device when it is in flight.

There is also a raspberry pi an intelligent controller, I mean or an intelligent devices server, which can do lot of computation. And, this computation will be performed locally on certain data that are being received or procured by this UAV.

So, certain computation will be done by this device this raspberry pi and this raspberry pi can also help in sending the other data that it cannot process over here through the communication channel it can be sent. So, like this UAV could be fitted with different sensors, this is one such sensor to which it is fitted. So, it is a basically a solar sensor, which can basically detect the intensity of the solar radiation. So, this is the solar sensors a sun sensor and so on.

And like this there are different other sensors depending on the application specific requirements, these other sensors could also be attached to this UAV. There could be if it is for gas monitoring different gas sensors like methane sensor, carbon monoxide sensor and so on. All these different gas sensors could be fitted to this UAV.

And these gas sensors when this UAV flies these gas sensors will be collecting the gas concentration data not just in one place, but because it is flying over a large area over which this UAV is going to fly, this gas concentration and the data about the gas concentration in these different locations of flight could also be retrieved. So, consequently what is going to happen this is going to be like a mobile sensor unit? It is going to be like a mobile sensor unit, which is going to collect lot of data while it is in flight.

So, this is an advantage of the use of UAVs and fit these UAVs with these different sensors. So, these this UAV could also be fitted with cameras, this is one camera as you can see over here I do not know whether you are able to see it properly.

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This is a camera this is fitted with a camera, over here as you can see this is a camera. And, this UAV could be fitted with cameras to collect images while it is on flight. This particular UAV can and this camera can collect images while it is on flight over agricultural fields to understand different crop conditions and so on and so forth.

As I was telling you this is an agro-UAV that we have in our lab we use this UAV for collecting crop data and so on from agricultural fields. So, like this there are different other components. So, this camera basically sends this data to, this data could be sent to a mobile phone like this.

And so, in our lab the swan lab in the Department of Computer Science and Engineering at IIT Kharagpur, we work a lot with UAVs. We do designs of UAVs, network UAVs, we also cater to the requirements solving different application level challenges in different sectors, agriculture, healthcare, surveillance and so on.

So, we do a lot of research using UAVs. So, I thought that let me take it as an opportunity to show you a UAV how it looks like. So, this is a sample UAV that I have brought for you from my lab, this particular UAV is for catering to certain agricultural monitoring application. This UAV we use for agro-imagery taking images of agricultural field.

So, this particular image UAV is a quadcopter. So, as you can see over here there are 4 propellers; 1 2 3 and 4 there are 4 propellers. So, this is a quadcopter UAVs do not necessarily have to be quadcopters, UAVs could be of different types. There are so many different types of UAVs that are there. UAVs could be hexacopters having 6 different propellers, could be octocopters 8 propellers and so on.

So, irrespective of what type of UAV it is, UAVs could be monitored or UAVs could be run using some remote control device, which is quite common. And, these remotely operated UAVs are quite common in the marketplace; whenever you go and buy a UAV, you will mostly get the remote control ones

So, this particular UAV is not a remote controlled one it is an automated UAV, a fully automated UAV. So, this particular UAV does not need any remote control. So, there is no remote control to operate this UAV. So, going back I was talking about this quadcopter having 4 different propellers. So, there are two sets of propellers. One set of propellers this, this one and this one, they rotate in a counterclockwise fashion whereas, the other set these two would rotate in the clockwise fashion.

So, because of this combination of counterclockwise and clockwise rotation of these propellers the lift of the UAV takes place. So, UAV lifts up from the ground and goes for a flight, this is one of the reasons like this there are many other reasons why the lift happens. So, a combination of counterclockwise and clockwise motion basically lifts this UAV. Now, these UAVs and their propellers are basically powered through the motors, powered in the sense like there are different motors which make these propellers rotate. So, there are 4 propellers so, 4 motors.

These motors can be of different specifications, some of these motors can be of higher specification. So, they can have better capacity for lifting payload for improved thrust and so on. Some motors can be of lower capacity, depending on the requirements different capacity of these motors could be used for these UAVs. So, there are four different motors let me show you how this motor looks like. So, this is a motor.

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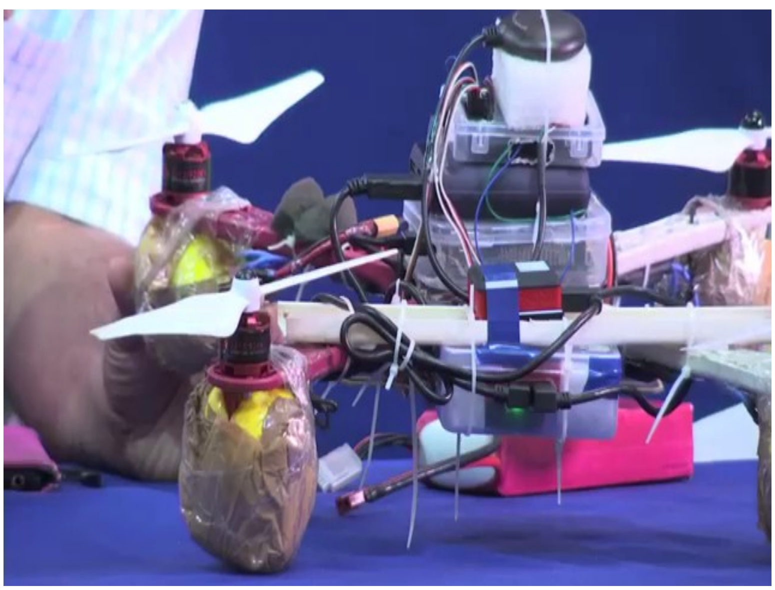

So, as you can see this red colored one is a motor. So, this is this motor, this is this motor as you can see over here like this all. So, this is this propeller and below it is this motor. So, like this there are four different motors.

Now, let me show you the other parts of the UAV. This whole UAV has to be powered for it to operate. So, there are different batteries that could be used to power these UAVs this is one such battery. So, this is known as the lipo battery, this is a very powerful battery, medium powerful I mean it is not extremely powerful, but it can make these UAVs fly for several minutes.

So, these lipo batteries are good for flying these UAVs for several minutes like 7, 8, 10 minutes, 14 minutes and so on. So, these batteries so, I can show you that this battery is fully charged. So, that how much is the charge content in these batteries could also be could also be tested with the help of this (Refer Time: 18:34) device as you can see this is giving you how much is the charge content, how much is the volts. So, this could be done with the help of, the testing could be done with the help of this particular device.

So, this battery is attached to this UAV. So, it will be attached like this I am not doing it now, but it could be attached to this and the UAV along with the battery is going to fly. And, this UAV also has an intelligent device.

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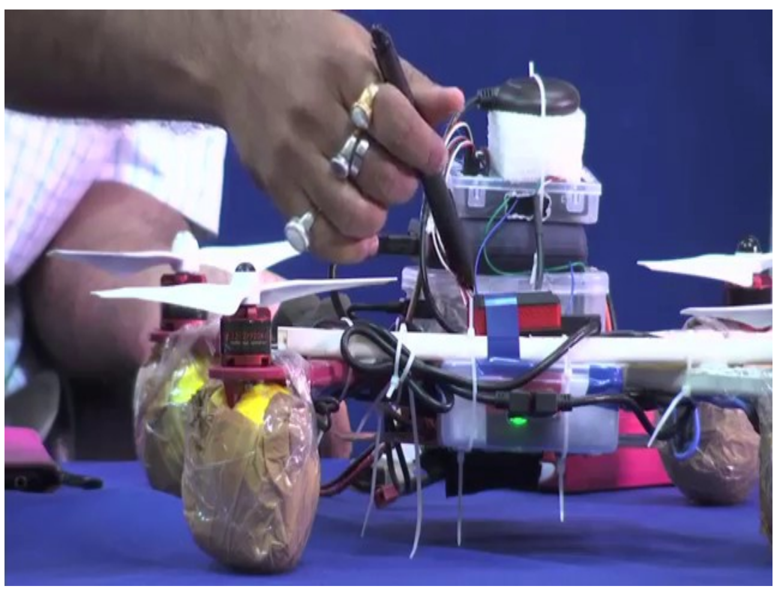

So, it is basically over here it is the raspberry pi. So, this is this raspberry pi that you can see over here this one, this is this raspberry pi. So, raspberry pi is inside this one. So, this particular device this raspberry pi it does some local processing. So, it is basically a mini computer and which can do certain processing, depending on the application specific requirements. Now, this one as I was telling you this particular UAV has been designed for catering to agricultural agro-imagery requirements.

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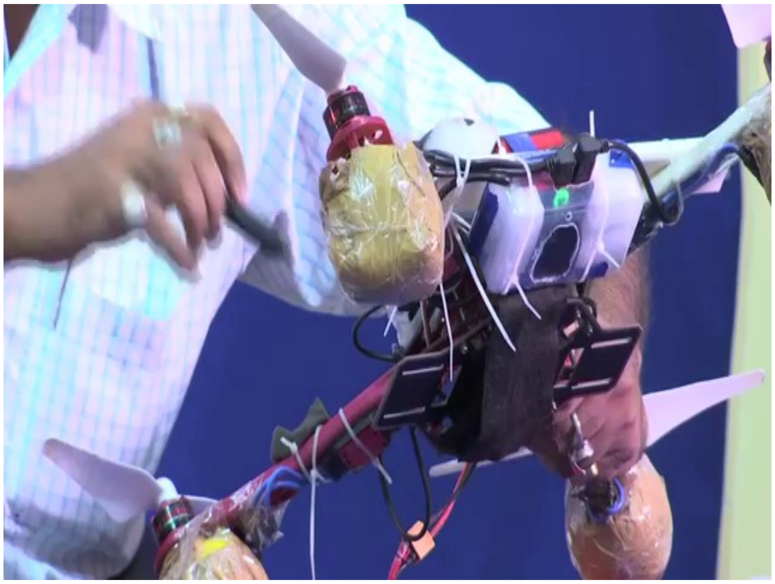

So, agro-imagery requirements so, there is this camera as you can see, there is a camera that is fitted to it this is this camera. And, this camera basically takes the images of the field from the top and some of this can be processed locally, in this raspberry and the other could be sent to the cloud. And this is this camera and this camera and the images could also be retrieved or what could be received in your mobile phones the smart phones and so on.

So, there are certain apps that are already installed here, which can help you to view the ground images that are being taken on this mobile phone or any other remote device can also show, the ground images that are retrieved through this camera. So, this particular camera is even again powered using another external power source, which is a power bank and that an additional power bank that is required to power powering this camera.

And on the top what you have is the GPS device for getting the GPS position while this UAV is on flight, getting the GPS position dynamically this particular device can help you do that. And, below this GPS is this APM controller and it is this controller which basically makes or controls these different motors to operate.

So, this APM controller not only the motors the flight of these UAVs with the help of the APM controller is performed. So, this is how an UAV looks like and I just wanted to show you this. So, that you can get an idea about how these UAVs are and how they look like and next let me show you an interesting thing we do as I told you that we do a lot of research using UAVs. So, let me now show some of our UAV based experiments that we have this is let me start with this one.

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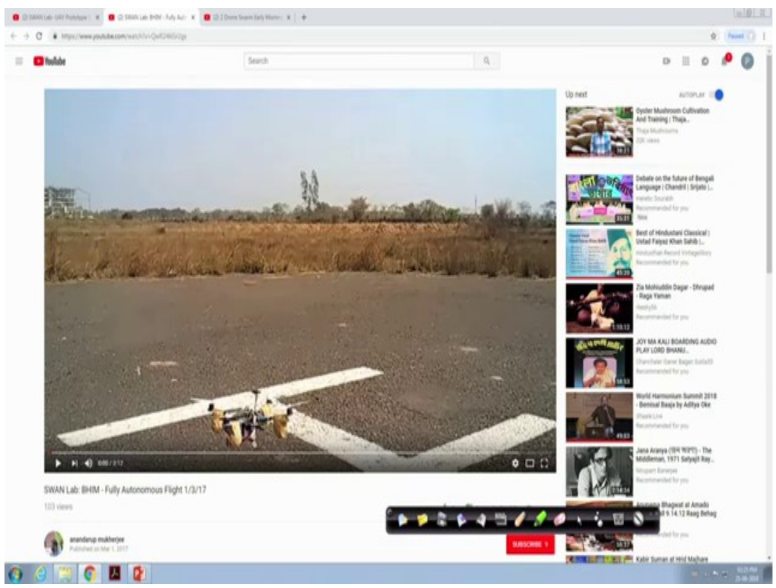


This is this agricultural field where we conduct not the agricultural field sorry this is a this is the field which is little outskirts of our campus, it is basically for helipad; it is a helipad for helicopter landing. And we do some of our experiments over here small scale low flight experiments we perform, and this is this UAV it is in flight, it is flying in the air.

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And, as you can also notice carefully that the one set of propellers is rotating counterclockwise the other set is rotating clockwise. And this is how these UAVs fly, this is an example of the UAV that I had shown you, how it is going to be when it is flying.

And depending on what you are doing with this UAV you can capture images, you can capture different sensor data. So, it might so happen that you need certain in an industry environment, you need to capture different data about the gas concentration. May be gases such as toxic gases such as methane, carbon monoxide etc., their concentration etc., in an industrial plant, you could use these UAVs.

But, those UAVs are going to be different those are going to be the indoor UAVs; indoor UAVs and outdoor UAVs are little different. So, this is an outdoor UAV, but for industrial indoor monitoring of industrial plants etc., indoor UAVs could be used. And, these UAVs could be fitted with different sensors and these sensors could be of different types depending on what you want to monitor well the UAV is on flight. So, it could be different gas sensors, temperature sensor, different other types of sensors could be fitted to these UAVs.

So, this is one such flight that, I showed you let me show you that UAV. So, I told you that we use these UAVs for agricultural purposes.

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So, this is our agricultural field over here. And this UAV basically helps in taking the different images and can also act like a mobile relay node, which can help connect different base stations to each other through this UAV. So, this is our agricultural field and it is being this UAV is flying and capturing the different images from this agricultural field.

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So, the last one is basically a small network of UAVs. Let me now show you two UAVs, which are networked with each other flying. This is also from our lab some experiments that we have performed, these are all there in YouTube if you want to search further you can search with our lab name swan lab UAVs. So, you would be able to see different videos of testing that we often do. So, these two UAVs, it is a small network these two UAVs are able to talk to each other and are able to pass information from one point to the other.

So, let me now go back and continue with our discussions so I was telling you that UAVs are very attractive in the industry; UAVs could help in monitoring the conditions, different types of conditions in the industrial power plants, in the different industrial settings. UAVs could help in reaching out to areas in the industries, which could be hazardous for human beings to go UAVs could help in collecting different data for acquiring different images of different units in a manufacturing plant. For example, chimneys; chimneys accessing the chimneys as you know, chimneys which throw a lot of exhaust gases accessing those chimneys is very difficult.

So, UAVs could help in collecting images for maintenance of these chimneys in a much more efficient manner and much more easily the maintenance the images could be collected of these chimneys to understand how much maintenance what would be required, when the maintenance has to be carried on and so on. So, likewise these UAVs could be fitted with different sensors to understand the ambient conditions around these chimneys. So, like it is there are different applications of UAVs for sensing for acquiring images for control and many others.

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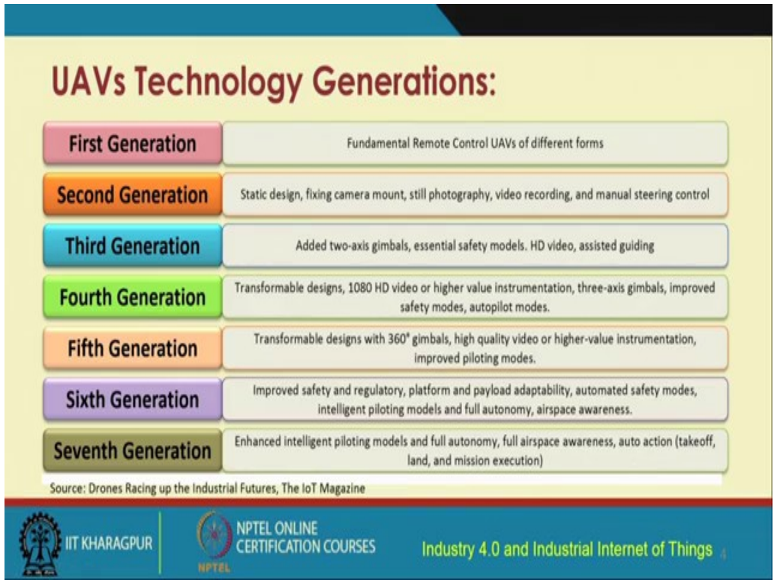


So, let me now go quickly and run you through some of the different other concepts. These are the 7 generations of the transformation of UAVs; that means, the UAVs have gone through 7 generations. So, first generation UAVs had fundamental remote control of different forms, then came the second generation UAVs which had a static design, a fixing device for camera mounting for taking still photography, video recording, manual steering control and so on.

That was the second generation like this these UAVs have evolved over the years third generation, fourth generation, fifth generation, sixth generation and at present we have the seventh generation UAV which have intelligent, which have different intelligent systems fully autonomous systems in place for doing different things. So, currently we are in the seventh generation of UAV technology transformation.

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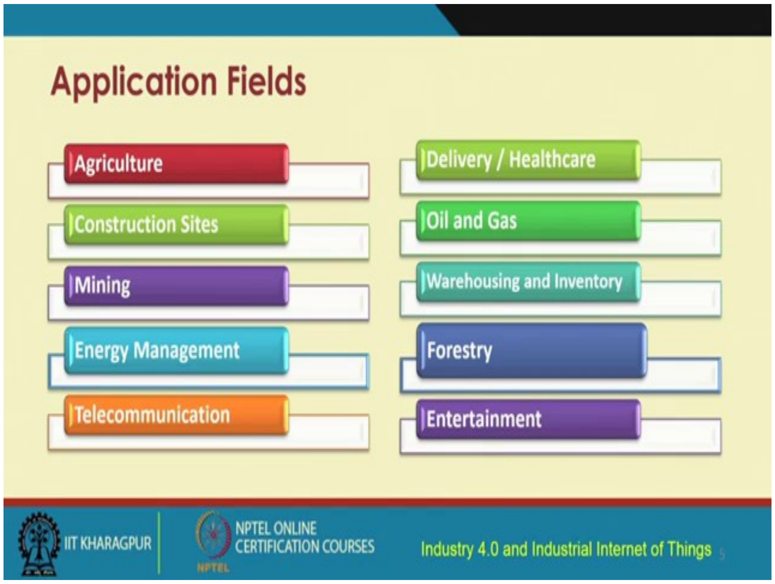


UAVs as I was telling you would be used in different industries; in agricultural industry construction sites mining industry, energy management for telecommunication industry, for offering connectivity between different remote places UAVs could be used.

So, where existing communication infrastructure is not already there UAVs could be used to offer connectivity between two different points. UAVs have also lot of applications not only in the civilian sector, but also in the military sector as well. The UAVs could be used to carry out different missions military missions in a much more efficient manner. UAVs could be used in the military for carrying out different reconnaissance surveys and reconnaissance activities.

So, in the other industries also UAVs could be used healthcare industry oil and gas, warehousing and inventory, forestry and entertainment industry. These are some of the names of different industries where UAVs find applications.

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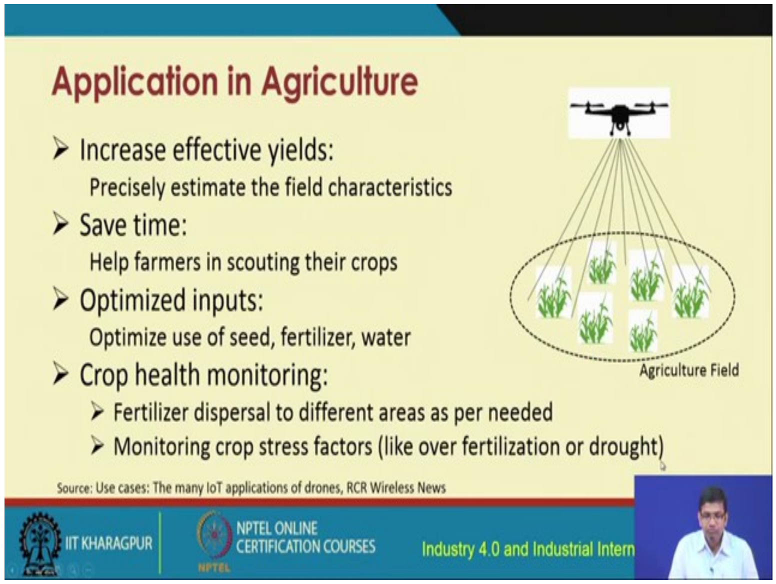


So, UAVs in agriculture there are diverse applications and particularly in our country, use of UAVs in agriculture is very much required is very much there are a lot of different efforts from different research labs, in the academic research labs and so on.

And also there are a lot of startup companies on UAVs which are focusing on agricultural application. UAVs in agriculture would help you to get agricultural images, monitor the condition of the crops, monitor whether a particular crop is stressed in different ways water stress nutrient stressed. So, lot of analytics will have to be superimposed on top of these images that are collected through these UAVs. Like this the UAVs can also help in sending payloads from one point to another. UAVs in agriculture could help you in spraying of pesticides in the agricultural field. So, UAVs could also help in spraying fertilizers like this UAVs can do number of different things in agriculture. So, this is the use of UAVs in the agricultural industries.

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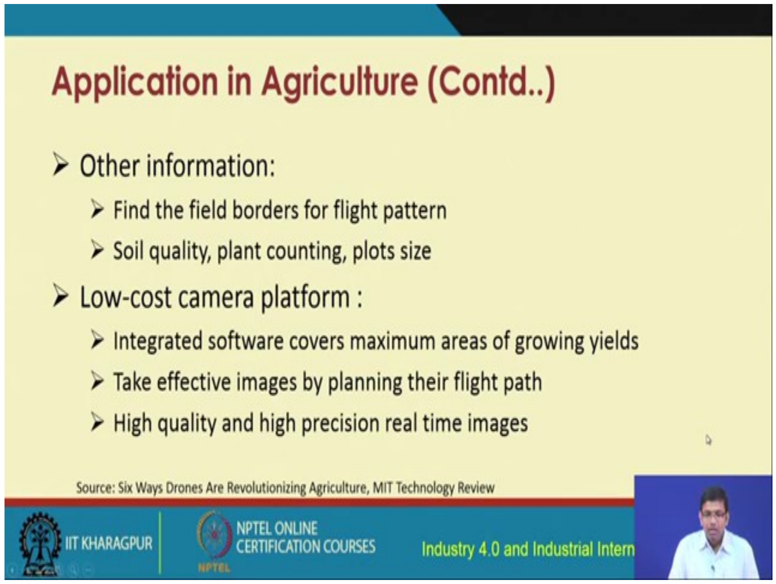


There are lot of different other use of UAVs in agriculture, particularly if you mount these UAVs with a camera. These cameras and the images that are captured either the static images or the real time video images, all of these could be analyzed and effective decision making about their the crop condition and that the requisite action that has to be taken based on these collected images the collected data could be made.

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In construction sites UAVs could be used like this; this is a construction site where the UAVs could be used to monitor the construction sites and whether there is any hazard, whether there is how much is the progress in terms of construction, monitoring the progress of the work. The safety standards the safety, measures that are being taken by these different, workers in these construction sites all of these could be done, inspection of the construction structures could be done continuously, remotely this monitoring could be done in a real-time continuous manner.

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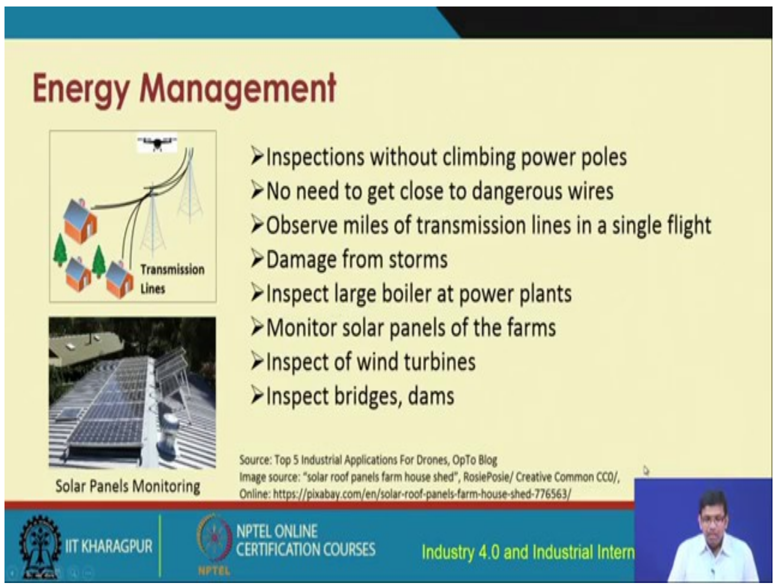


For energy management also UAVs could be used; UAVs could be used to monitor the power transmission lines. So, the monitor that the periodic monitoring of the power transmission lines is something that is done typically and that is done manually. So, UAVs could be used to do real-time continuous monitoring of these transmission lines.

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In the mining sector as well there are lots of use of UAVs particularly in opencast mines use of outdoor UAVs is very common. For indoor mines UAVs could also be used; that means, but those the specifications of those UAVs are going to be different.

So, indoor mining use of UAVs will require specially designed indoor UAVs for catering to the requirements of the mining sector, but in the mining sector whether it is open cast or indoor mines, the UAVs could be used to monitor to monitor different things for surveillance.

So, for monitoring the safety of the operations that are being conducted to surveil a particular area, to explore the site how much of extraction and extraction of the minerals extraction of the metals or the minerals are being taken how much is left. So, autonomous automated efficient monitoring of these extractions of these minerals like coal etc. could be done. Like this there are different other applications of use of UAVs in the mining sector.

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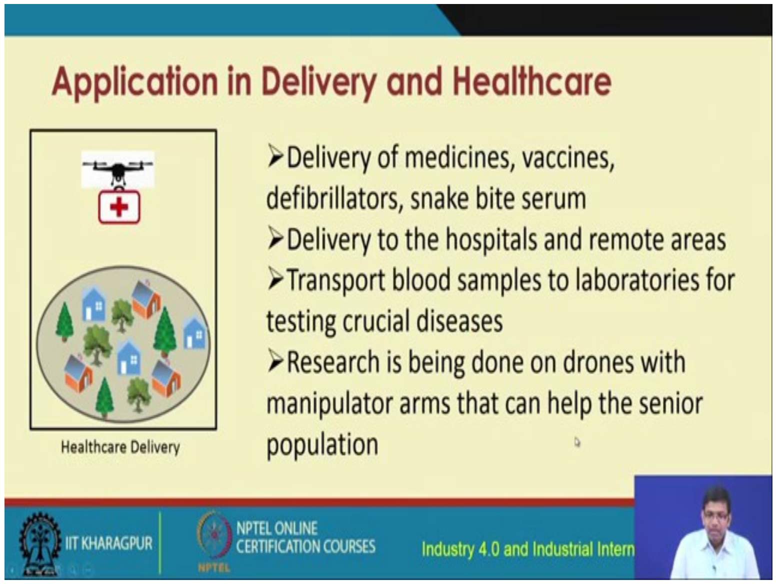


For the healthcare sector and drug delivery etc. also UAVs could be used particularly in our country drug delivery from a tertiary care hospital, which is already equipped with lot of amenities, lot of different drugs lot of facilities. UAVs as per requirement can be flown from a tertiary care hospital, to a remote primary care hospital, a village hospital, where maybe there is no drug. So, like this there are different vaccines medicines etc. depending on the requirement, specific requirement could be transported from one location to another.

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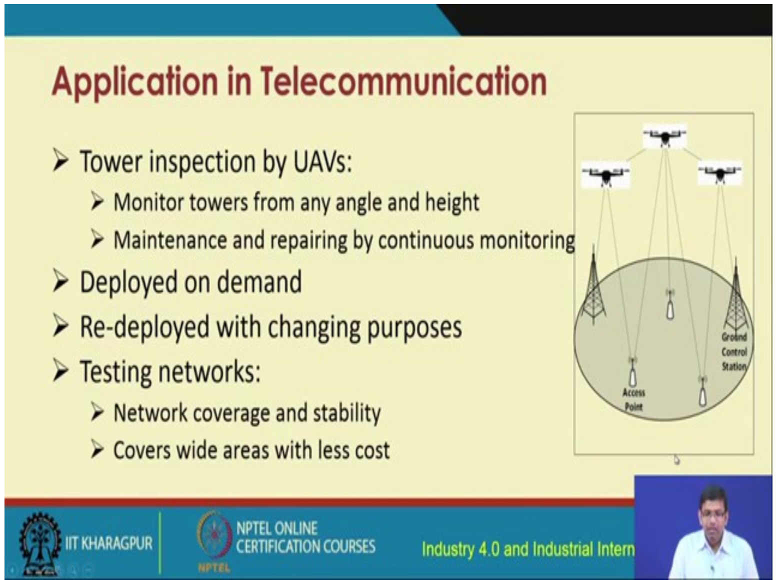


In telecommunication industry also UAVs could help in connectivity, UAVs could be like aerial gateways, they could act like aerial gateways or aerial access points, which can help in connecting two different points which otherwise may not be within their range. So, offering that kind of connectivity is possible with the help of flying UAVs.

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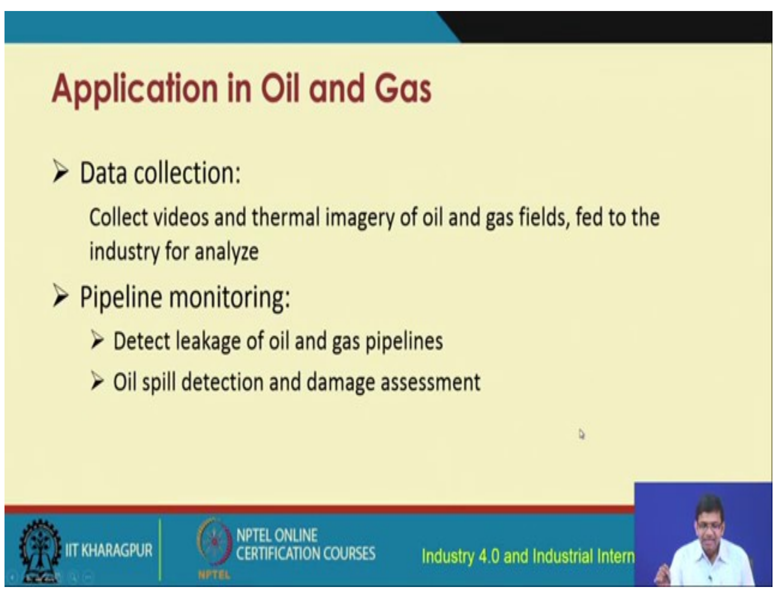

In the oil and gas sector as well for pipeline monitoring for detecting leakages, for collecting images about the distribution network all of these could be done with the help of UAVs.

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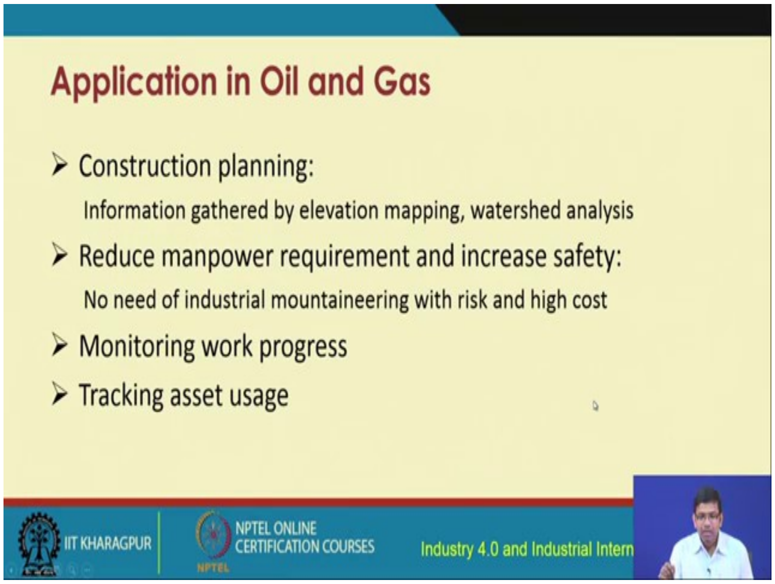


Similarly, construction planning, reduced manpower requirement, monitoring these chemical plants or the oil and gas plants their machinery etc., while they are in running condition. So, monitoring those equipments in a remote fashion can be done with the help of these different UAVs.

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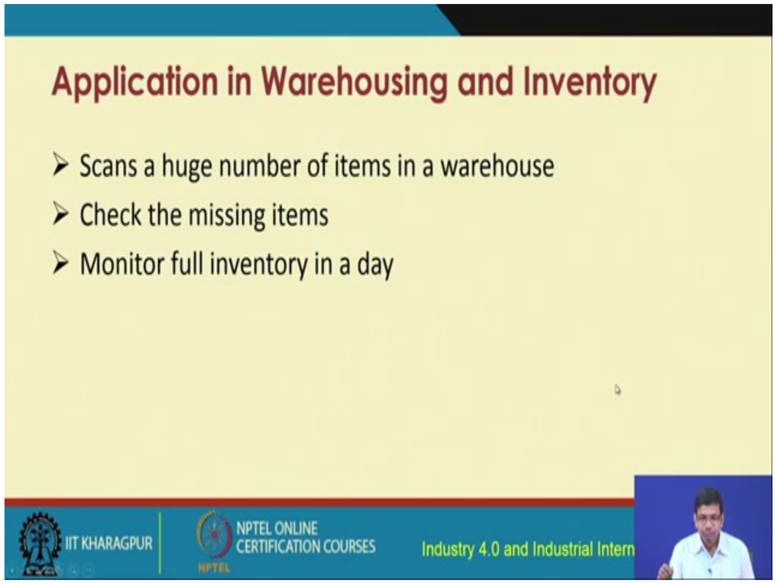


For warehousing and inventory control as well UAVs could be used. UAVs are used in different warehouses, the indoor UAVs particularly are used in the different warehouses to monitor the different shelves, in those warehouses. So, the inventories that are existing in those warehouses. So, all of these things can be done in with the help of indoor UAVs.

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For forestry applications also forestry survey, precision forestry, canopy mapping, wildfire detection tracking, monitoring of speed of wildfire; if a wildfire has already taken place, protecting endangered species saving the time manpower and resources, forest resources, forest rangers for example, with the help of UAVs they can monitor the condition of these forests, the species the wildlife that is there. And also the different plants that their growth of these plants all of these things can be monitored with the help of UAVs in a much more efficient manner.

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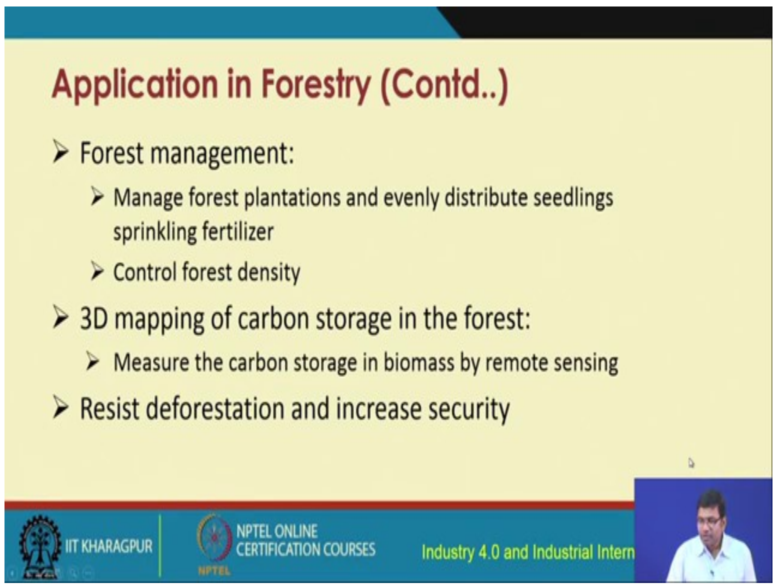

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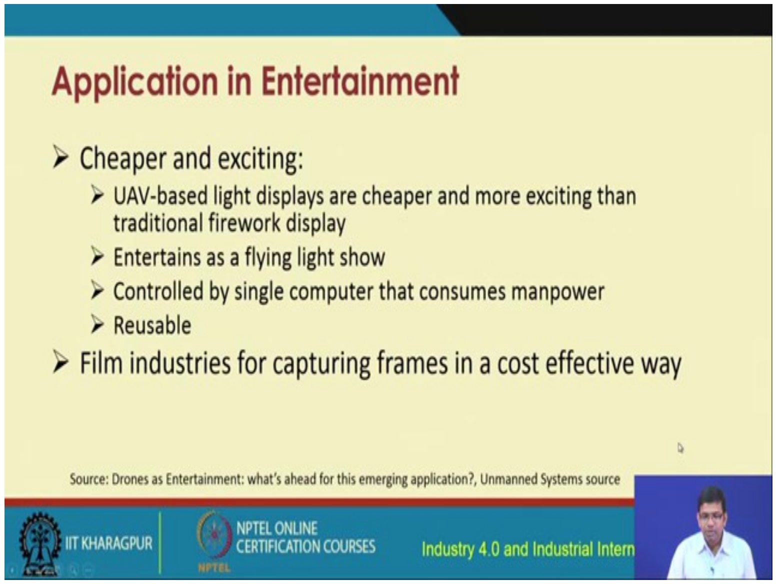


So, likewise there are different other applications in the forestry environment, forestry and environment as well, environmental monitoring by equipping these different these UAVs with different types of sensors temperature sensor or pressure sensor or different other air quality monitoring sensors could also be equipped with these different UAVs. And also capturing different images, image frames etc. so, together understanding the environment and the pollution etc. all these things can also be done with the help of these UAVs.

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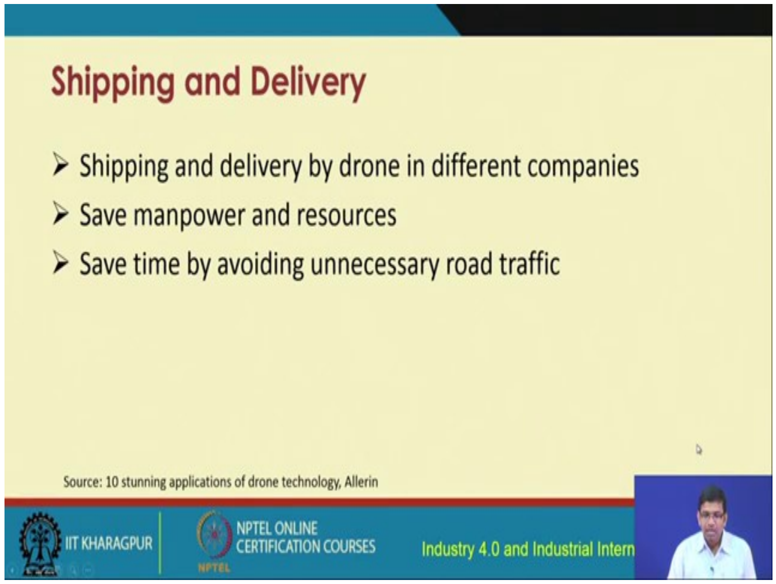


Shipping and delivery this is quite common lot of different applications, courier companies in certain parts of the world, they are using the UAVs to basically deliver different packages from one point to another.

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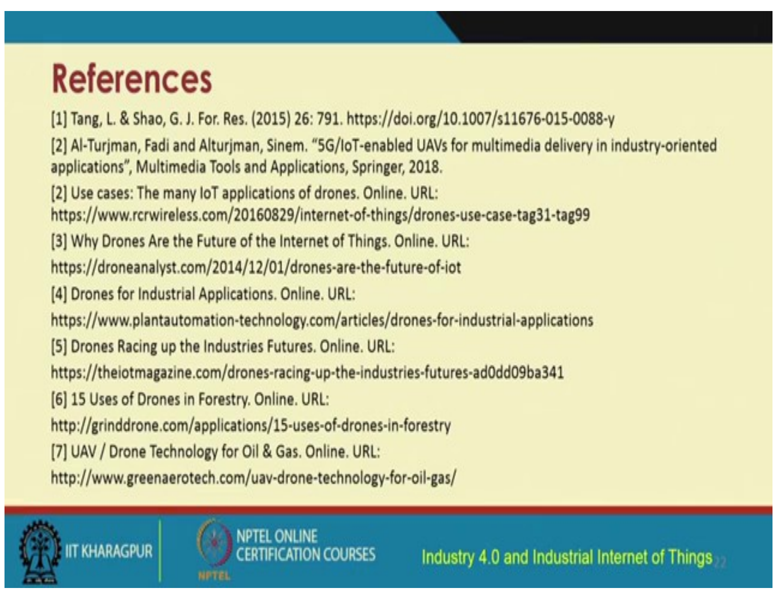


So, courier companies are also using UAVs. So, shipping and delivering UAVs are of attraction and they could be used for doing all of these different activities. These are these different types of applications that I have shown you, like this there are a lot of different applications of UAVs. These differences will help you to gain better understanding more information about these UAVs, use of UAVs flights of UAVs you can find lot of different videos in YouTube to excite you more beyond what I have shown you. But if you are interested to know more there are lots of online tutorials that you would be able to find in order to get you started on UAV projects.

So, what is important is in the context of this particular course, think about good industrial use cases where UAVs can be of benefit. And then try to execute projects and try to see whether you can address any of the industrial problems. Maybe if you are coming from an industry, you might yourself be involved in certain processes, maybe if you are coming from a manufacturing plant, there might be certain requirements that might be already there in your particular industry in which you are serving. And try to identify one such challenge one such problem and see whether you can have you can come up with a UAV solution to basically address that particular problem that you are experiencing.

So, single UAVs as I told you is an issue, having multiple UAVs which basically collaborate cooperate with each other in order to accomplish a particular task a mission that is a farther challenge. And also I what I told you is indoor and outdoor UAVs. I have mostly talked about outdoor UAVs the UAVs that I have shown you are basically outdoor UAVs, indoor UAVs and their design operations etc. that is a completely different ballgame. And so depending on your requirements you might want to focus on indoor UAVs or outdoor UAVs, working with outdoor UAVs is bit easier than working with indoor UAVs.

So, with this we come to an end. So, this last lecture on UAVs is something that I wanted to have in order to excite you more beyond the terrestrial IoT. Extend you from terrestrial to the aerial IoT domain and see how UAVs can help accomplish different activities, different tasks, execute different tasks, in a much more efficient manner. Monitor control different tasks different machines etc., in a much more efficient manner with this we come to an end these are all these other different references.

Thank you.

**Introduction to Industry 4.0 and Industrial Internet of Things**
**Prof. Sudip Misra**
**Department of Computer Science and Engineering**
**Indian Institute of Technology, Kharagpur**

**Lecture – 58**
**Case Studies for Industry 4.0 & IIoT**

So, in the next few lectures I am going to cover a few Case Studies on the topics of Industry 4.0 and industrial IoT. So, so far what we have done is we have looked into some of the fundamental issues of IoT and particularly concerning the networking aspects, the sensing networking actuation and so on. Thereafter we looked into the business aspects of it and also some of the very important technological aspects particularly concerning the networking issues in IIoT.

So, it is now very important to understand how these technologies can be adopted by the industries that are advancing themselves towards efficiency. So, what is a case study first of all? Let us try to understand that.

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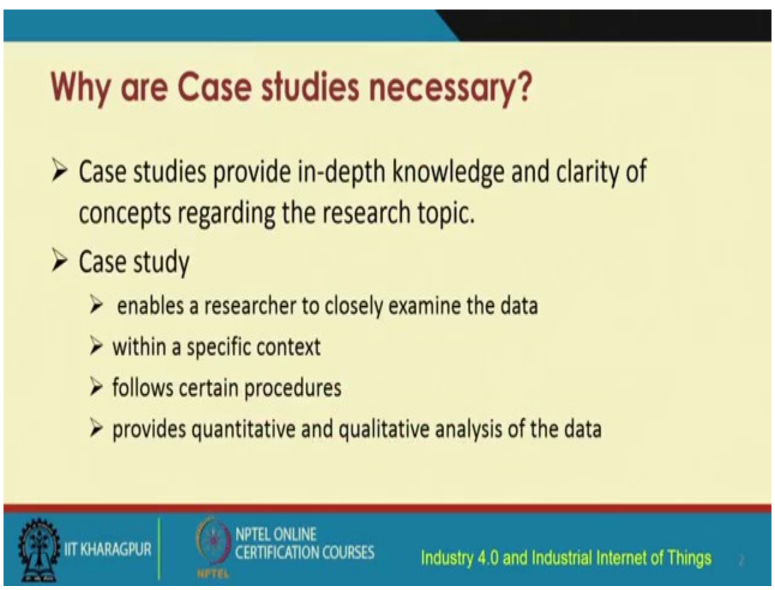


So, case studies are very important because they provide in-depth knowledge and clarity of concepts on a particular topic and in our case we are talking about the industry 4.0 and industrial

IoT as the topic. So, we need to understand in-depth whatever concepts the fundamental knowledge that we have acquired in the previous lectures.

How they can be really used to address a real life problem; that means, whatever the industries are using how the industry 4.0 and IIoT concepts can be adopted to transform themselves towards improved industry, industrial processes and products. How they can lead to if you are improving the industrial process, then automatically the quality of the product, the efficiency with which these products are made everything is going to improve.

So, we are going to look at some of the existing cases and we are going to follow from that point on and try to really ponder upon how things can be improved in our existing industries through the adoption of industry 4.0. So, basically a case study would enable one to closely examine the data within a particular context. So, it is context specific which certain procedures will have to be followed in order to understand the case and a case study would also provide qualitative and quantitative analysis of the data.

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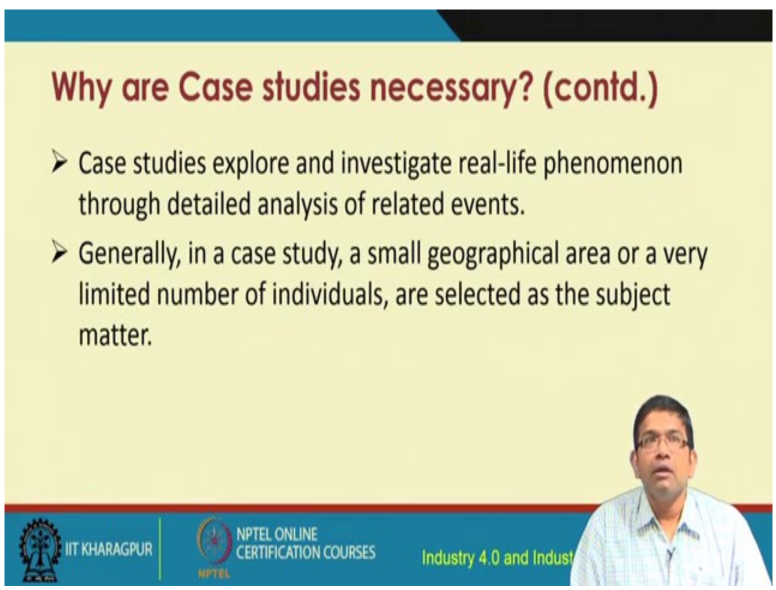


So, case studies would explore and investigate a real life phenomenon through the detailed analysis of related events and as I said that in our context we are talking about real-life industry, real industries, real functioning industries, that we have visited we have collected different information about real life industries which are doing very well, but then how they can improve their business processes, how they can improve their efficiency, how they can improve their technological processes towards improved efficiency of the business through the adoption of industry 4.0.

So, in a case study basically what happens is you pick up a particular case which could be a geographical area or maybe it may concern a particular industry, it may consider a few individuals or whatever be the subject. So, you need to first define which subject we are talking about.

So, once we have fix the subject, we need to really understand how understand in detail how the things are already taken place and then through the technological intervention how the existing processes can be improved. This is the whole purpose of the use of case studies in this particular context in our context of industry 4.0 and industrial IIoT.

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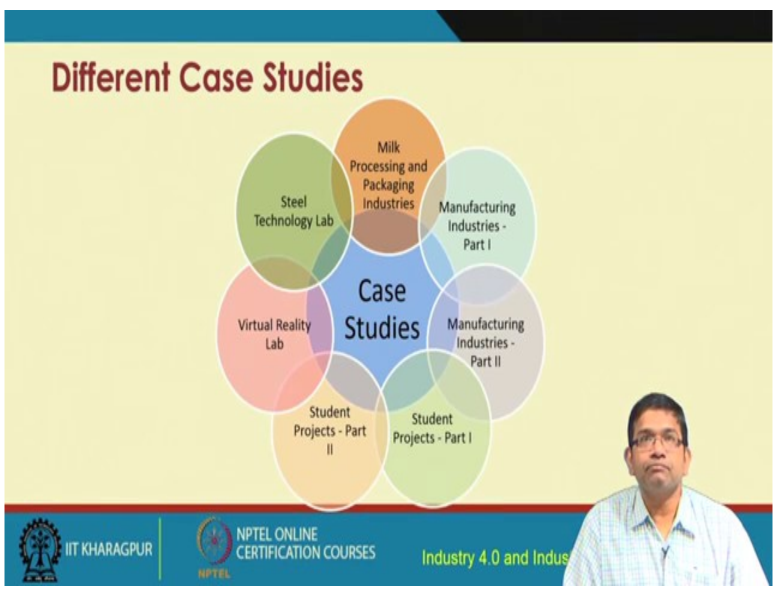


So, there are different case studies that we have prepared for you. In this particular course we have gone out to the real industries we have connected with real industries and these industries are in different parts of our country, particularly focusing on the western part of our country; that means, India and we have collected, we have gone to the different industries, we have reached out, we have understood their existing processes, we have recorded what they have what they do in practice and we have tried to bring these up for you.

So, that you can also try to analyze and try to understand how whatever you have learnt in terms of the technology, the business in the several lectures in this course how you can use the knowledge in order to improve their business processes. So, you would be analyzing those things. So, it is not necessary and in most cases it is not the case that the existing industries that we have contacted, that we have collected the data from which we have recorded it is in most cases you will find that they do not already have the high standards towards industry 4.0 and industrial IoT solutions.

But, they really understand that they need to improve their existing processes. So, they are very keen on that option part, but they at the same time they do not have good understanding about what needs to be done. So, we will take up these raw businesses, their raw data that we have collected and we will analyze ourselves that how we can improve their processes, how we can what we can suggest to improve their processes and then those suggestions can be adopted by them or not that is up to them, but we can analyze these things and we can give a prescription for them about what they could do in terms of that option of industry 4.0 and industrial IoT technological and business solutions.

So, some of these industries that we have visited are the milk processing and packaging industry, we have visited some manufacturing industries different case studies I am going to show you in the next few lectures about all these industries, what they are doing we have video recorded, we have collected these data for you so that you can see live what is going on. And, we have beyond this milk processing and different types of manufacturing industries and so on and so forth.

We have also given you some of the cases about some state of the art laboratories in our institute. The steel technology lab; so what they are doing. So, they have very advanced facility particularly in terms of the welding, the welding machinery. So, how they are using, how they are transforming themselves gradually towards the adoption of industrial IoT solutions you are going to see that.

You are also going to look at some of the student projects some of the students mini projects that they have done in the course that I teach over here, the semester course that I have that I teach over there some of these mini project can give you some idea about how you can gradually build up through the use of these small-small building blocks how you can gradually build up and transform some given industry as a prescription how you can transform them towards industry 4.0 adoption.

And, the last thing that I would like to mention is there is a very state of the art virtual reality lab in our institute that that I am also a part of and we have built it together. And, in this lab the virtual reality machinery that is there, how that can be used towards the transformation process for industry 4.0 we are going to have a look a virtual tour through this virtual reality lab.

So, so many rich content that we have prepared for you just so that you can understand better what goes on in the real industries and the different labs and how we could transform their processes to improve their existing processes towards betterment.

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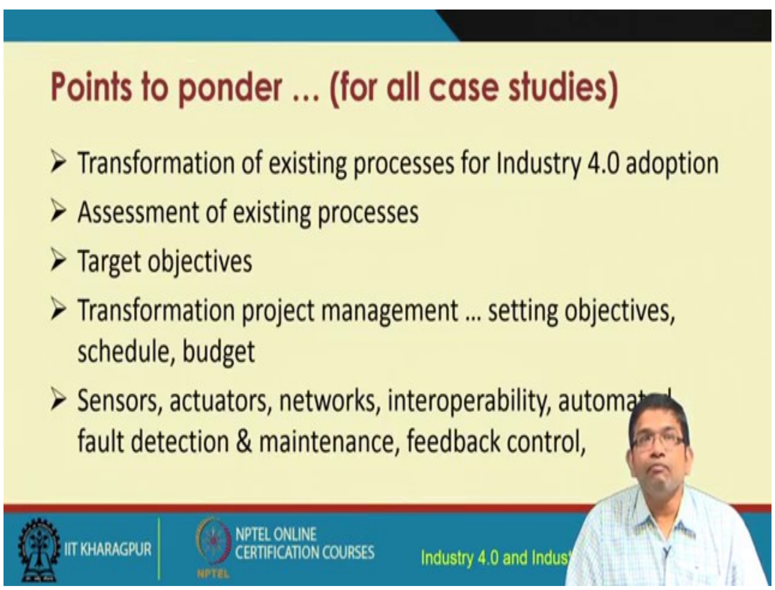


So, while you go through each of these case studies in the next few lectures, please try to think about what transformation you would prescribe for their existing processes towards the adoption of industry 4.0 and industrial IoT based on whatever you have learnt in the previous lectures the fundamentals the applications the technologies, the technological solutions, the business solutions and so on, the business architecture and so on. How you could use those existing knowledge that we have covered, we have taught you in the previous lectures how you could use them in order to improve their processes better.

So, remember one thing that none of not none, but in most of the cases these industries are not there yet they are trying to; they are striving towards improvement and they do not really always understand what they will have to do. So, this is an opportunity for us to analyze what is existing and preparing a prescription for them. So, take it in that particular way. Do not think that the case studies the recorded content that we will show you in the next few lectures will already have their advance technologies towards industry 4.0 and industrial IoT. They do not already have that, they are not there yet, but what could be done analyze the content in that perspective.

So, we need to what we need to do we need to really first understand what is going on through those videos that we are going to show you next. You first understand you need to understand and assess their existing processes, then set up some target objectives towards this adoption, set up these target objectives and then transformation activities will have to take place. So, the transformation itself is a project.

So, what all project management objectives, what all aspects of project management will have to be taken care of in terms of number one setting the objectives clear constraint by the facts of budget schedule and so on. So, how you can set the objectives for them? Then the last thing is think about whatever you have learnt in terms of the sensors, the actuators, the networks that is the beauty about industry 4.0. Connectivity – connecting the different machinery, connecting the different objects, one industry with another industry within a particular industry connecting different machines, tools, technologies, people processes and so on full connectivity how you can improve the connectivity. So, this is something very important.

So, what we need to do is to understand those things and also interoperability. Something is already existing, there is no point in completely removing the existing processes and building things from scratch that is not good. So, how you can come up with a solution that can serve as an interoperability solution between the existing technologies and the suggested technologies which are going to improve their processes.

So, automation, full automation we need to have we need to strive towards fully connected fully autonomous systems with reduced or ideally no human intervention. So, how we are going to do that while taking care of issues of automated fault detection, automated maintenance. Feedback control; feedback control is very elementary. So, basically what happens is let us say that there is some machine which is doing a job there is some machine which is doing a job. Then what needs to be done is that you collect the data you with the help of some sensors which are relevant.

Then, based on the sensors sensor data that is collected you need to send the data through a network, analyze the data analytics is very important consequently analyze the data and based on the results of the analysis you send a feedback message back to the machine for example, and based on the feedback signal that is received by the machine, the machine is going to improve upon what it is already doing in a to improve upon their existing job that is being done by it.

So, it is a very tied up kind of loop with everything put together sensing, actuation, connectivity then analytics and feedback control everything put together and everything remember one thing that everything is connected and consequently, there has to be reduced human intervention or no human intervention as I said before.

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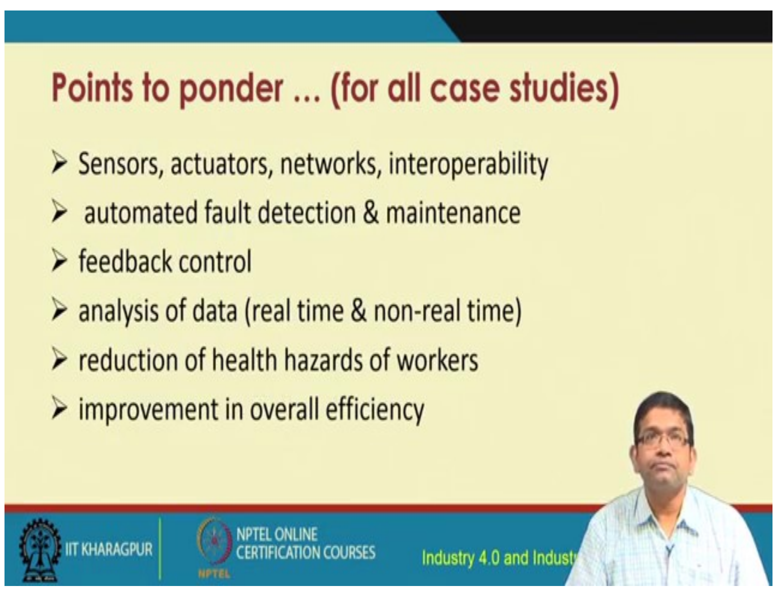

So, for every case study my suggestion to you would be think about whatever you have learnt in the previous lectures; think about for every case that we present which sensors are going to be required in order to address the problem that they face which sensors are going to be required because the sensors are going to be the connectors of the raw data about what is going on with these machines these pre-processes the business and so on which sensors are required, which actuators are required, which networks would need to be deployed in order to send the sensed data and also the signals to the actuators and so on.

So, which network many cases you will find that it is not a single network that we are talking about, it is a collection of different networks in the different parts of the system. So, how these different networks following different standards, following different protocols and so on how they are going to work hand in hand. So, interoperability consequently becomes important.

Interoperability in terms of the devices, device level interoperability, standard level interoperability, protocol level interoperability and also application level interoperability different diverse varied applications how they can hand shake and talk to each other. And, also think about automated fault detection, automated maintenance, automated anything that you can think about that is going to improve their existing processes and consequently monetarily they are going to be improved and that is why they are going to strive towards the adoption of industry 4.0 and IIoT solutions.

So, keeping that in mind it is not going to be that you introduce you suggest the introduction of any technology it is not like that. Think about what is their problem, think about what you already know about industry 4.0 and IIoT and think whether and how these existing concepts can improve their processes, and what prescription could to be meet to them and then we leave it to them to think about whether they would like to adopt whatever suggestions that we give for them.

So, that part we will leave out it is going to be out of the scope of this particular course. We will only do the analysis ourselves and we want to restrict to that only and I know so, that way so, we know that what has to be done, but we really do not go and reach out to them and try to convince them to adopt these solutions.

So, feedback control is also very important as I said before. So, you need to have a proper control machinery in place because without the feedback control you are not going to improve the existing processes in an autonomous fashion. So, so proper feedback control in place has to be there. Analysis of data both real time non real time data; the analytics itself is core to industrial IoT. So, analytics is very much integral to it. Reduction of the health hazards of the workers and improvement in overall efficiency.

These are some of the different issues that you should think about how you can look at these existing these cases that we are going to present and analyze in respect of these different issues, these different attributes.

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So, these are some of these different references and with this we come to an end. Keep in mind whatever I have said that take up each of these different cases and think about the items that I have listed in the points to point out in this particular lecture.

Thank you.

**Introduction to Industry 4.0 and Industrial Internet of Things**
**Prof. Sudip Misra**
**Department of Computer Science and Engineering**
**Indian Institute of Technology, Kharagpur**

**Lecture – 59**
**Milk Processing and Packaging Industries**

So, right now we are in the quality checking lab of this particular dairy. So, here I have with me one of the staffs of this dairy, who is going to explain how the quality checking is done. So, basically after the milk sample is brought to this lab, the quality of the milk that is received is checked. So, how it is checked, what are the parameters that are checked is going to be explained. So, ma'am could be please explain what you do over here in this lab?

Hello everyone myself Priyanka Rao and I am working here as training junior executive. So, basically this lab is known as raw milk receiving dock lab, where we are checking the various samples which are received by the bulk milk tankers. So, we are collecting the milk from the society people and they are bringing some samples over here. There are different parameters like fat, SNF and we are also checking the adulteration like water addition or some salt or sugar or sucrose or there are various other parameters. And then since we are directly dealing with the society members, we have to be very careful in regarding checking those parameters. So, let us show you the various parameters in our machine.

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So, once we receive these samples, we are checking these samples over here. This is our FD 1 machine and this machine shows some parameters like fat, SNF, protein, lactose, TS, acidity, salt and these are adulteration. When we move further, there are adulteration parameters.

So, right now we are in the processing and process control plant of this particular diary. So, I have with me two of their executives; on my right is Mr. Patel who is the Chief Plant Engineer in this particular lab and on my left I have the Chief Executive Engineer of this diary. So, I am going to request them to speak about this particular lab and the facility that they have, what is the processing that is done, how it is being done; all the details. So, could I request you sir to speak a few words about how it is being done.

Yeah, this is milk processing unit; we have a centralised milk processing unit. Here we have a nine plants and which we are pasteurising milk. Pasteurising means removing all bacteria or pathogens from milk and make it safe to safe for human consumption. (Refer Time: 03:36) Here we are processing; in processing we are having different sections like hot water section resolution section.

Hence in the heating section, we are heating the milk 278 degree centigrade. It will makes all bacteria removed and immediately we are cooling that milk below 4 degree which limits the growth of bacteria.

Ok

Subsequently.

Ok.

So, how is it working over here? You have number of instruments that are there.

Yeah we have nine plants.

9 plants.

Are there. So, we are you are going to explain.

Yes

In site how it is being done.

Yes.

So, I now have with me Mr. PC Patel who is the instrumentation engineer of this particular plant. So, sir could you please explain about the instrumentation facility that you have in this plant?

Hi myself PC Patel, I am looking after all the instrumentation related activity for whole the dairy plants. If we talking about this particular plants instrumentations, basically the individual temperature controls loops are installed on each and every pasteurisers the temperature loops includes the Hartley sensors I to P convertors. Then some microprocessors based controllers and finally, for controlling the temperatures, it is pneumatic controls valves. Apart from individuals set controls loops, there are certain level sensors are installs on each and every milk silo to see the actuals levels of milk in each silos the levels. Sensors are installs a basically hydrostatic types and working on this strain gauge principles.

Ok. So, how what are different other sensors that are there only level sensors?

No for each and every each and every level sensors are of hydrostatic types.

Hydrostatics types.

Earlier we were installed infrared type.

Ok.

But there we are facing some level sensing problems due to foaming of a foaming of a foaming happen in the milk.

So these level sensors the sensor data are all available through some console somewhere?

No basically individuals' controls levels are installed with the indicators.

So, through these indicators basically you are able to see.

Yeah

The scatters of the different instruments.

Yeah.

Ok, thank you so, much.

Thank you.

Now, we are at Alco rooms of a process sections, where we can see the how the hydrostatic level sensors and temperatures sensors are installed on milk silo to see the level of milk and temperatures of milk silos.

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We can first see the see the temperatures sensors called RTD sensors and this one is a hydrostatic level sensors. From where we take the outputs to some indicators to see the actuals level of milk in a milk silo.

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How we install the milk silo indicators and temperature indicators, where we can see the in top of the first row three level indicator indicators are installed. In first one we can see 12 where the multiplication factors is thousands. So, in the silo number ones are there is a 12000 litres milk are there and in second row some respectively temperatures indications are there.

And now we are at milk pasteurisation plants, where we can see here too much crowdy area is there. So, I can speak too much loudly so that you can hear so, that here correctly.

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Now this is the temperature microprocessor base level temperature controllers, and this is a temperature scanner.

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Here we can see the numbers of different type of temperatures of particular milk pasteurisers we can see and from here we can take the data to our computers by ethernet connections.

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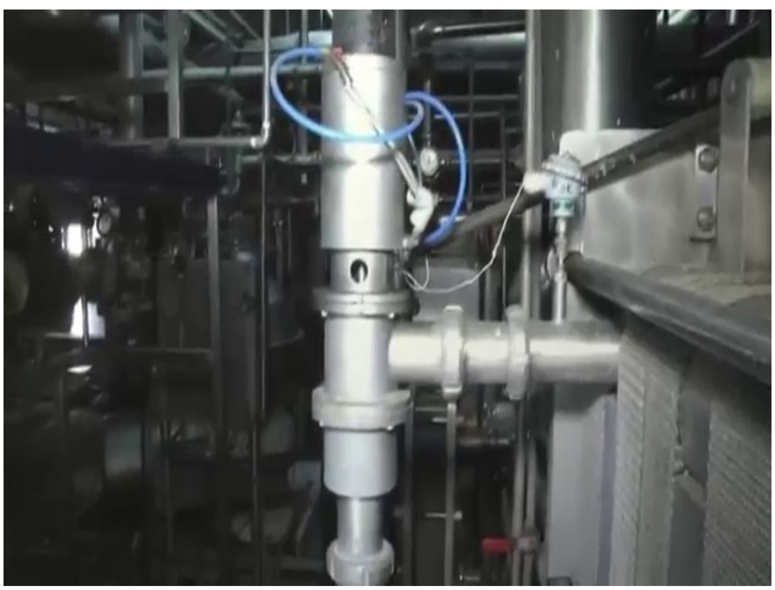

Now, here this is a diverter valve. The diverter valve is activated when the particular heating temperatures, goes below the set points ah. So, that it can be it comes into recycle area.

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Now, this is a pneumatic valves by means of pneumatic valves, we can control the temperatures according to set point at controller.

So, right now we are in the powder processing plant. So, from milk to milk powder how things are done that we are going to see in a how it is being done and here it is a very sophisticated plant, that this particular dairy has for this particular powder processing. So, I have with me the manager of this plant Mr. Parik, Mr. Parik could you please explain how the processing is done from milk to milk powder.

Basically milk is a perishable product. If we want to preserve the milk for a longer time, we should convert the milk into the milk powders.

You are right.

(Refer Time: 10:20) is a producing four different kinds of products.

That is skimmed powder. That does not have any fat.

Ok

That is a less fat. Another one is whole milk powder which directly if we the constituted that powder, it will give the directly the milk which we are taking in day to day life.

Ok.

The another one is infant milk food and the fourth one is Dairy whitener. (Refer Time: 10:47).

Correct.

The process of milk powder manufacturing is like the way. If we are.

We have to do eliminate the water from the milk.

Right

If we heat continuously and in an open air, then the products different protein and other things are denatured.

correct.

So, to preserve the milk as such in such form.

Correct

We are evaporating water from the milk under the evaporation plant.

Right.

That is under the vacuum.

Correct.

With the help of steam we heat the milk at the lower boiling temperature.

Ok

Then.

And how much is the temperature.

Temperature of a milk is maximum is 72 degree centigrade.

Ok.

And the minimum is 48 we have a different effects in an evaporation plant.

Ok.

So, the basically 1 kg steam is used for 1 kg water evaporation.

Ok.

But we have different effects in a plant, we have a six different plant in which.

We are using only 150 gram steam.

Ok.

To evaporate 1 kg water evaporation.

Ok.

So, in evaporation plant we evaporated water and concentrate milk.

Right.

And concentrated milk into the spray into the spray cart.

Ok.

In spray cart we are spray spraying through a centrifugal atomizer disc. Milk is spraying through the centrifugal atomizer disc.

Ok.

And hot with the help of hot air.

Ok.

Which temperature is around 175 to 200 degree centigrade.

Right.

With help of the hot air we dry them milk.

Ok.

Concentrated milk.

Ok.

Into the powder.

Ok.

Subsequently, we cool it and then we pack into the different types of packets.

Ok.

This is the basic.

All right. So, for this entire process the process control is done from this particular room right.

Yeah.

Ok.

It is the basic console.

Right

We have an APV Invensys DCS based system.

Hm.

So, we are in a one screen we summarize the all whatever the required process parameters.

Right.

And we control from there.

Correct ok.

Thank you.

Thank you.

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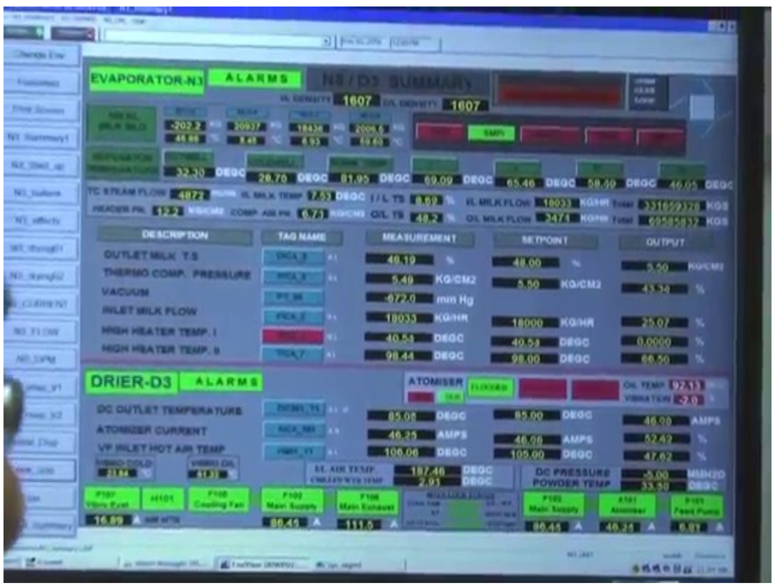


So, this is basically the distributed control system the DCS marshalling rack and here I would request Mr. Patel to speak about it what are the different components. So, some of these important components such as the processor, the field bus, the node bus these things you have studied when we are talking about the industrial communications systems. So, in that lecture you have already learnt about what is field bus, what is node bus and so, on. So, these things are going to be explained over here. So, how this is controlling this entire plant this is what Mr. Patel is going to be explain to us. So, Mr. Patel could you please explain how it works.

Yeah. So, we are at marshalling cabinet (Refer Time: 13:38) of whole DCA systems, where we can identify the different type of instruments involved a with a DCA systems.

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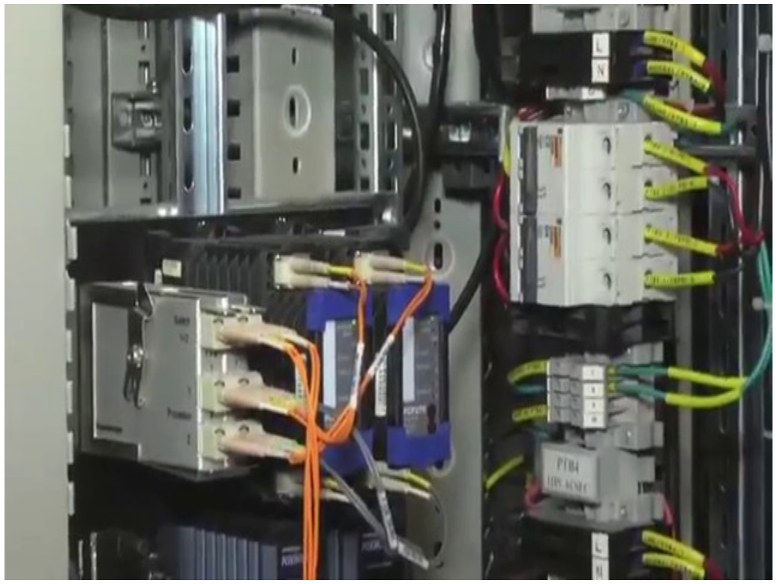

Here we can see the two control processors are there say, one question is there, why two control processors are installed hers. So, in case of one control processor fails the another one take the whole controls automatically.

So, this is basically the fault tolerance basically.

Yeah.

You know if.

Yeah yeah.

If one of these fails the other processor will take over it.

Automatically.

The transition.

The transfer the controls.

The transition is going to be happen automatically.

Yeah yeah

Ok.

And this is the node bus.

Right.

And this is the, a node bus why means the control processors communicate with the fielding instruments.

Ok.

And these are different type of APMs a the APMs there are two different types of field instruments from which inputs come comes to the DCA systems.

Ok.

One is the analog input and one is the digital inputs.

Ok.

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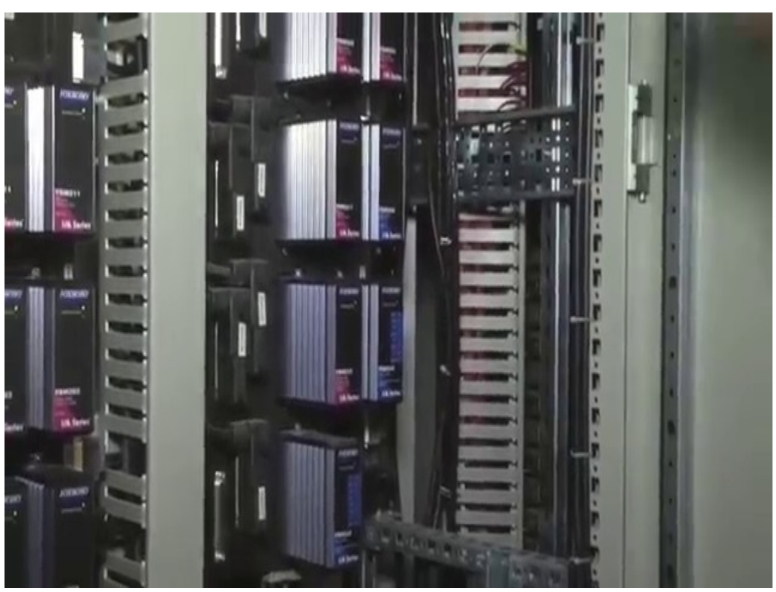

That blue colours APMs indicates the digital input.

Ok.

Come from the field and magenta colours indicates the analogue inputs

Ok

These are the architectures of the DCA systems.

Correct.

So, both the analog as well as the digital inputs are handled in this particular system.

yes.

Wonderful thank you.

Manufacturing of milk powder is divided in two process; one is evaporation, second one is spray drying. In evaporation plant milk is heating under a vacuum in a different effects and concentration of milk is increased up to the 50 percent in evaporation plant. In a spray drier concentrated 50 percent concentrated milk is sprayed and water is coming in a contact with it is having a around 200 degree centigrade temperature both are coming in a contact and it comes under the drying chamber in a form of powder milk powder, then it is packed into the different type of packing.

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We are packing in a powder in a 1 kg pouch and 500 gram pouches. This one is our infant milk food and this one is our skim milk powder the brand name of infant milk food is Amul spray and skim milk powder is of Sagar SMB.

This is our butter section; we will take cream for process section. From cream we will make this is our butter section in this section we will take cream for process section, we will take cream in continuous butter making from this buttering production we will take production daily 100 metric ton and in these 25 ton pack in Amul butter and 75 ton production in white butter. White butter for reconstitution in reseason and Amul butter various size packing 25 gram 100 gram 500 gram or 1 kg packing per day.

We will collect milk from 1200 societies 25 percent milk in can morning and evening, 75 percent milk collect through BMC, today we will product Amul butter, Sagar ghee, sweetened condensed milk and mainly our product with powder. Amul spray, skim milk powder, whole milk powder or Amulya powder. From these or today we will display for 3,50,000 meter litre milk in various places in Mehsana district. Today we will display 5 lakhs litre milk Daryuda and Manasarovar plant. Now in first season we will lease plant 3 lease plant for powder manufacturing plant.

Done.

So, right now we are in the Amul Dudhsagar dairy, which is one of the largest dairies in this particular region of the country, this is basically Mehsana district in Gujarat and so, right from the morning we are witnessing lot of milk coming from the adjacent villages in the form of containers which are loaded in trucks.

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Also trucks loaded with lot of bulk milk is also coming. In the processing of this container based milk and also the bulk milk it is done separately. So, we have seen that how these containers are being brought from the neighbouring villages and then how the milk is basically tested initially and after the initial testing for quality quantity etc. then what happens is the milk is sent for further processing.

And this processing happens through a very sophisticated system and this system is to a large extent an automated system with high end machinery and instruments. So, basically what happens is lot of pasteurisation then processing of the milk packets and so, on packeting of the milk and so, on that is what happens. Also what happens is there are different other products this particular dairy has. So, products in the form of butter, then packeting of butter and also packeting of the different powder milk all these things are done. So, how it is done this is what we are going to show you now and as you will see that lot of sophisticated system is involved in this processing of the milk to different products.

So, initially what happens as I was telling you, the milk is brought in the form of containers then there is some processing that takes place. So, I am going to show you how this processing is done.

**Introduction to Industry 4.0 and Industrial Internet of Things**
**Prof. Sudip Misra**
**Department of Computer Science and Engineering**
**Indian Institute of Technology, Kharagpur**

**Lecture – 60**
**Manufacturing Industries – Part I**

So, right now, we are in a different type of company a plastic based company. The name of the company is Growhill Plastics which is in Unjha in Gujarat. And this particular company, it is a small scale company and what it does is that it takes the raw plastic material and prepares the mould the cast for the battery, basically the mould of the plastic container that holds the batteries, right. So, that plastic container is made over here by them and so, they use PLC based machine, it is a small scale machine, but we will come to know about what this particular machine does and we will also have a look at the PLC panel that is there in this particular machine. So, I have with me Mr. Santhosh Yadav, one of the executives of this company.

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So, Mr. Yadav could you please explain the process that is followed over here in order to prepare this frame that is made for the plastic batteries. This is the beads like material, we mix color with it or without color for natural white. That material is melted here and it comes out as a box. The door opens after the cooling time is completed.

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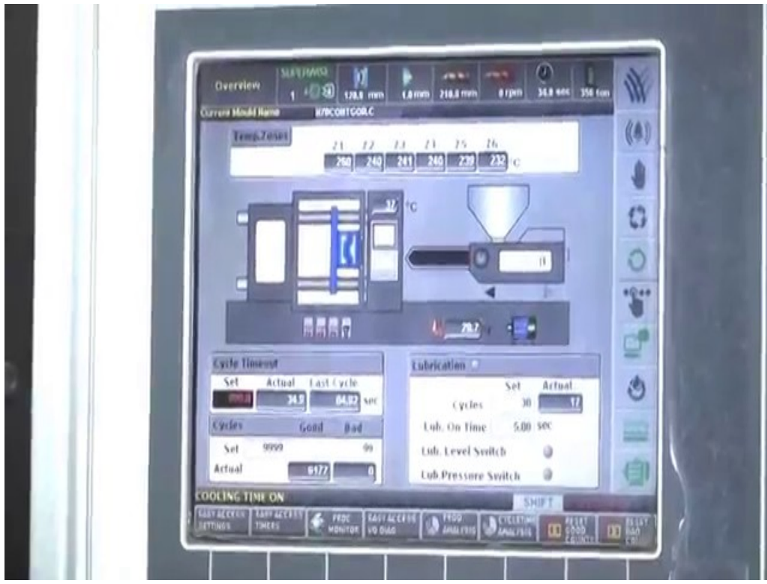


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The temperature here is 240. Now the cooling is complete and the mold is open.


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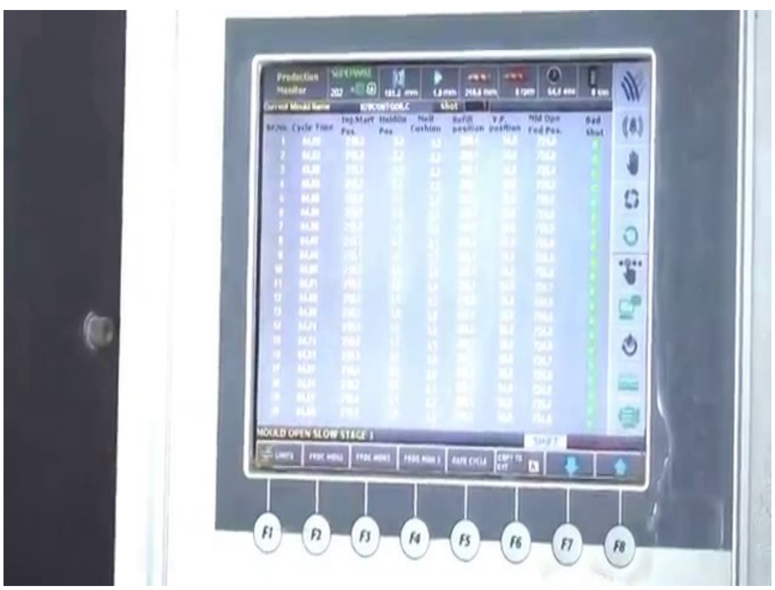
It will take 64.95seconds for manufacturing one piece.

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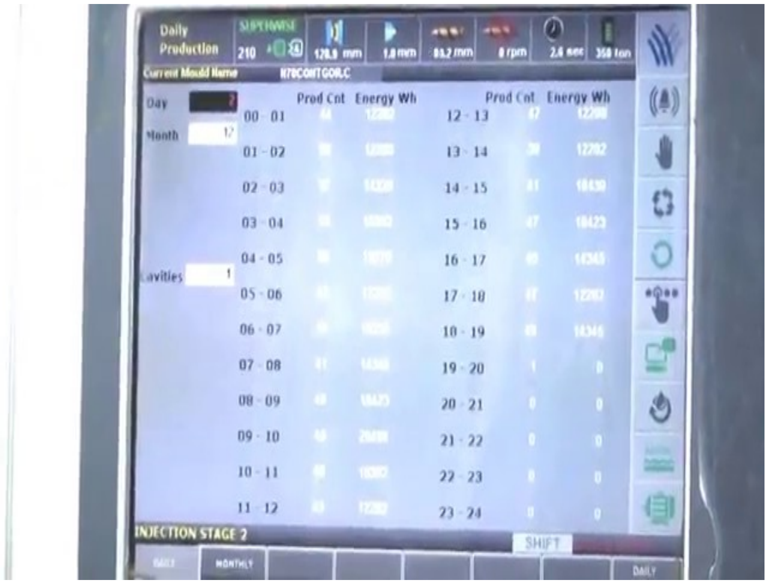


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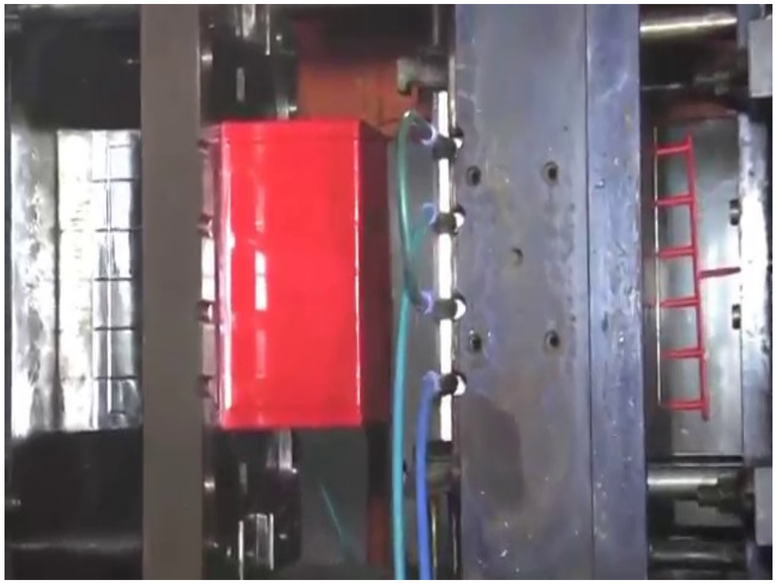

So, what you have just seen so far is basically a plastic container making machine which is an injection moulding machine. This machine is the sprint 358 model of the company Windsor which makes this machine. And so, in this machine what is happening is the raw materials are procured and they are put as input to this machine.

And this machine after you have set up all these different parameters through this PLC panel, based on the parameters that are set the machine basically takes those input raw materials and then based on the shape the cast and so on this machine basically prepares the final output the case that is required for the batteries. What is very important is to notice that it is a very precise job that has to be done. For precision there are number of sensors that are used in this machine and the similar ones. These sensors basically are very important in order to get the specific measurements that are required, because you know if you do not have accurate measurements that are done then what will happen is the final job is not going to be perfect as per the requirements.

So, essentially what we have is a cyber physical system which has number of different types of sensors these sensors basically capture the different measurements that are required. So, in this particular case one of the sensors basically senses the measurements in terms of how much length this particular you know this piston is going to move for. And based on that it is going to move for that much amount of distance and then what happens is this sensing based on the sensed data the actual operations are preformed and based on the actual operations the decisions are different.

You know different decisions that are made and then there is a feedback control that feeds the controller about you know what has to be done next. This is not a perfect example of an Industrial IoT or you know it is not really a machine which will get it to the requirements of Industry 4.0 and as you have seen for Industry 4.0. What is required are different components first of all inter information or data acquisition through the help of different sensors and so on which is already there , but after that the processing has to be done.

And based on the processing the different decisions has to be made and based on the decisions there is a feedback control that has to be sent back to the machine or elsewhere for further actions. So, this is one machine like this there are few other machines in this particular company and all of these machines could also be interconnected. So, interconnection as I told you earlier is a very important component of IIoT and Industry 4.0.

So, interconnection interconnectivity between these different machines and having all of them controlled through either centralized or a distributed mechanism or, or a combination of both is what is required. Additionally there are other important issues in Industry 4.0 issues of basically maintenance, right. So, if there is some defect that has happened then how do you take care of it? So, let us say that in the products production process there is some defect that comes in. So, one way is to manually go and you know correct, correct whatever it has gone wrong the other thing could be that if you already have this automated system built-in which will detect the error and then that will be detected the signals will be sent and the corrections are going to be made all autonomously then that is what is more desirable.

So, that will be a fully autonomous system. So, this is what is required. So, this is just to show how some of these industries are functioning and how an industry which is not yet there for Industry 4.0 compliance. How you can have different transformations, in these different machineries of these companies to make them more compliant with Industry 4.0 requirements.

So, Industry 4.0 requirements what is important is to have sensing actuation data processing decision making and feedback control. So, essentially these are some of these important components of a cyber physical system as well. So, what is also important the last component I would say what is important is the fault detection maintenance and automated detection and maintenance of faults is a very important component.

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So, let us see how these companies and others similar ones small or big ones how they transform themselves in the next few years towards industry 4.0 you know compliance. So, in the previous workshop floor what we have seen is basically how to make this which is essentially the casing for the battery. And this is a plastic based casing and through injection moulding process. As we have seen this particular case is made and so, this was done by a machine which is the Sprint H 350 machine and another machine the Sprint H 250 machine basically prepares the lid. So, this is the lid of the machine and there are other few similar kinds of machines that are here in this particular company which will make the other different plastic parts like the handle the screws that are there. So, this screw similar kinds of screws will also be made.

So, this screw basically gets in and so on. So, the entire plastic casing; that means, the bottom part as well as the top part the lid all of these are made in the different floor through the different workshop processes in this company. So, what I was talking about is the Industry 4.0. So, Industry 4.0, I have told you already that you need the interconnectivity between the different components of data acquisition through sensing processing then the feedback control and also the operator maintenance automation or of all of these things and so on but one of the very important things that I did not mentioned which is also very important is the interconnectivity. Interconnectivity within the machine and interconnectivity across the different machines..

So, for example, this part was made by one of the machines in another machine floor this is made by another machine in this particular machine floor and there are other parts that are made by other machines. So, would not it be very nice to have all of these different machines interconnected with one another.

So, essentially what happens is that when the bottom part is made after that the signals are sent to the next machine which will take the process over and automatically things are going to be started. So, all of these machines if they are all interconnected that is going to be the advantage you are going to reduce the down time and you are going to improve the overall productivity in the process and also consequently what is going to happen is the quality overall quality in terms of the product quality in terms of the processes the efficiency the productivity and the economic benefits all of these things are going to come through.

So, as you can see that in you know the when we will try to transition ourselves to Industry 4.0, you know then what is going to happen is we are going to gradually, gradually we are going to acquire all these different benefits into the processes. And hopefully these industry this one and many other similar industry who are maybe they are small in size now, but very progressive minded what is going happen probably is in the years to come maybe in another ten years or.

So, you know once they all are going to be Industry 4.0 compliant all of these automation that I told you the interconnectivity between the different machines the automation the collection of all these data, data from these individual different machines and putting them all together to have better inferencing and so on. So, all of these things are going to be come in come in place and there is going to be the improved productivity.

So, this is just a case study to show you how the machines which are not the industries which are not yet there how they can transform themselves into to make them industry 4.0 compliant.

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So, right now we are in another type of company which is basically a company which focuses on taking raw plastic materials and then converting them into plastic bottles. So, behind me is a machine a smart machine which is used for making these plastic bottles, it is known as the single state blow moulding machine. And this particular machine as you will see what it does is it takes the raw plastic materials and based on the program that is stored in this machine basically then that program the instructions are taken and the, the plastic bottles are made.

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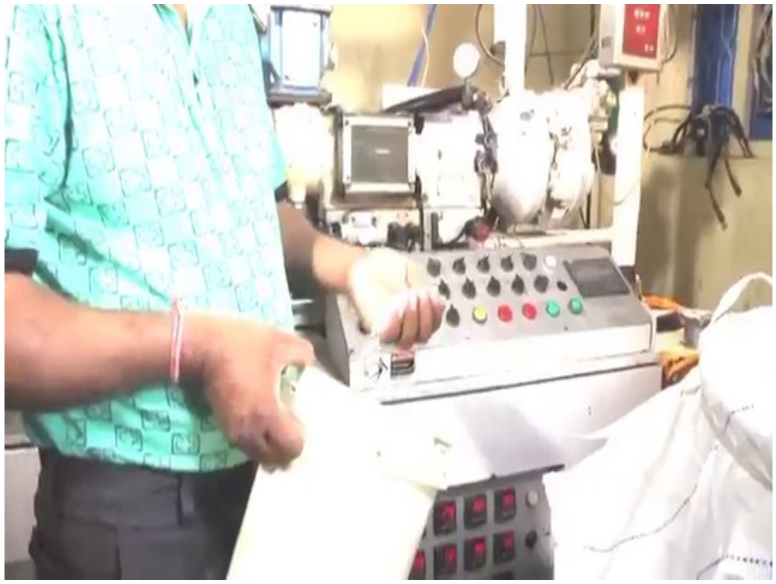

So, this is an intelligent machine where you can do the programming using the Man-Machine interface the MMI interface which is there and through the instructions that are basically programmed through the MMI. The, the instructions are taken through the PLC which is in this particular machine the programmable logic controller which is there. So, if it is which takes those instructions and those instructions are passed to the machine for taking the corresponding actions. So, this is one such machine which could be used to make the factory floors smart. So, you can have smart factories, but as you can understand that this is one machine like this there could be several, several other different types of machines.

So, if you are talking about a smart factory floor the interconnection between all these different machines is very important. So, that these machines you can do the monitoring of all the machines the health monitoring of all the different machines the type of the operational efficiency also could be monitored. So, like this different types of monitoring could be done the data that is coming from these machines these could also be stored and different predictive and operational efficiency could be the predictions can be made.

So, lot of different things could be done, but you know at this point what this machine does is intelligently. It takes the commands and then comes from the raw materials into plastic bottles. So, let us have a look at how this particular machine functions.

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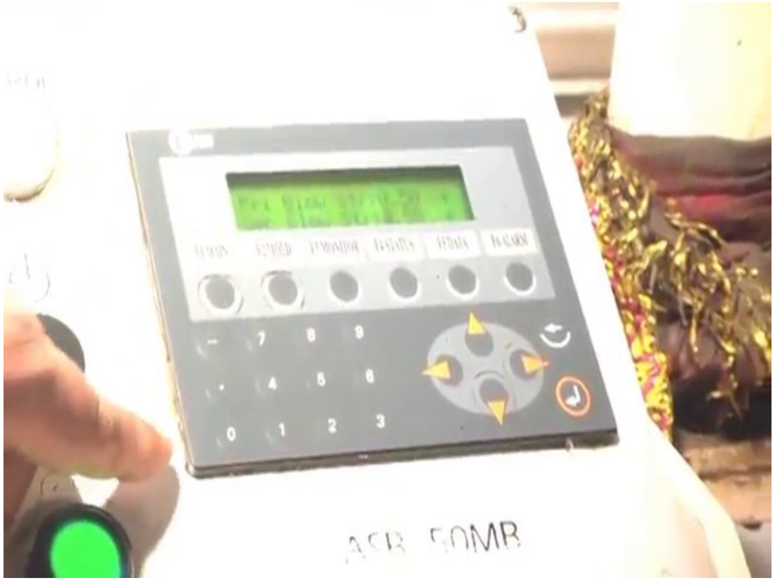

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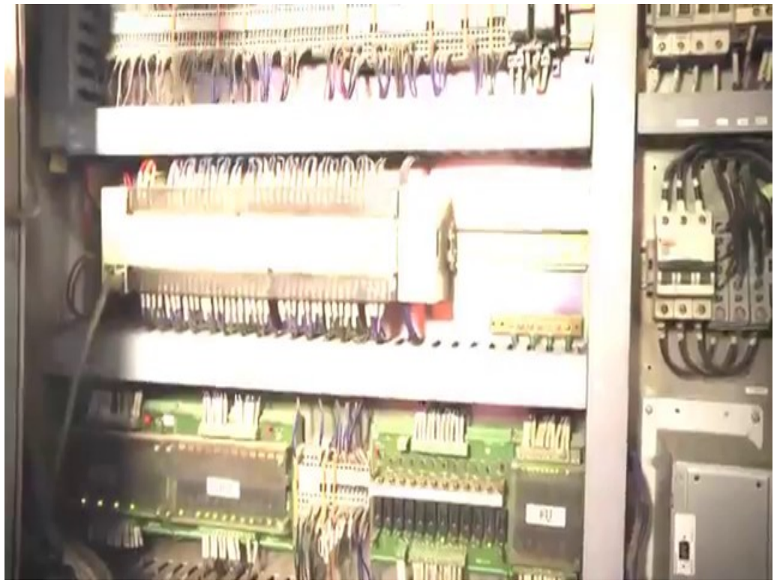

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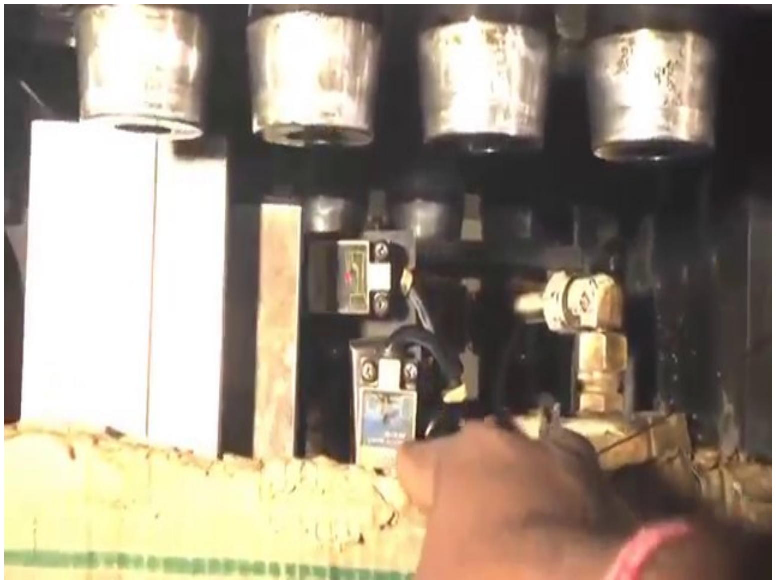

**Introduction to Industry 4.0 and Industrial Internet of Things**
**Prof. Sudip Misra**
**Department of Computer Science and Engineering**
**Indian Institute of Technology, Kharagpur**

**Lecture – 61**
**Manufacturing Industries – Part II**

So, right now we are in another company which is the Atomic India Private Limited. This particular company it is in the business of making the rims of wheels of motor cycles and bicycles. So, these are some of their products. So, this is one such rim of a motor cycle, and this is the rim of a bicycle.

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So, this is basically what they make. And so I have with me Mr. Sanjay Patel. He is the managing director of this company. So, we are going to ask him about what they exactly do, but before that I wanted to talk about the level of maturity of automation Industry 4.0, compliance and so on. So, this is a company that I chose not because they are matured enough for the adoption of Industry 4.0, in fact it is the other way round. So, this is a company which not so much yet, it is a small scale company, it is a small company which is not very much matured yet in terms of automation and Industry 4.0, but this particular company is one where if we take it up as a case, we can see that how we can adopt different, different technologies that we have studied in our course in order to confirm this company towards the adoption or transformation towards Industry 4.0 and compliance thereof.

So, there are lots of opportunities you will be able to find in this company of the technology that you have learned from the business aspects of it, all of these could be very well adopted over here. So, as you can see in front of you this is basically the actual, the raw sheet metal that comes, and then behind me is the roll forming process that basically what it does; is it does some preliminary processing and then preliminary processing basically includes stuff such as stamping the sheet metal with the company logo the name of the company and so on the brand name and so on. So, all of these things are done. And also there are two preliminary processes that are done. We will ask Mr. Patel about exactly how things are done.

So, we will talk about later on what is the current state of the practice, what is the current state of the art over here, and what all things can be done if they want to transform themselves towards Industry 4.0 adoption. So, automation is low in this company, the use of sensors is also very low, and definitely analytics particularly from an automated analytics point of view, predictive analytics and all of these things are pretty low in this company. But this is a company which has lot of potential for transforming themselves towards high-end automation and high-end adoption of industry 4.0 requirements.

So, Mr. Patel could you please explain what exactly you do in this company.

Hello, today our main products are a bicycle, motorcycle and moped wheel rims. Here we come to know about the manufacturing process of these wheel rims. Firstly, we start with raw materials. The basic is CRC strip which comes according to the thickness. This strip coil is hanged with coil holder from where strip goes to rolling machine. The initial requirement is the brand name of the company which is printed by the roll fouling machine. After that, shaping and folding of these CRC strips are done through the 16 rolls of roll fouling machine.

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So, I am now going to request Mr. Sanjay Patel, the managing director of this particular company to talk about the entire process, what things are done how it is done and the current state of the practice. So, Mr. Patel basically as I have told you that we are using this thing for educational content which will be made accessible to people who do not normally have high-end education in our country through online media. So, it is going to be made accessible through the NPTEL portal. So, could you please tell us that how this process is conducted what exactly happens over here?

Ok sir, thank you sir.

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I am Sanjay Patel from Gujrat. Our main objective here is to manufacture the rims of cycles, motorcycles, moped, bullet, etc. Today we will study and see the complete process of rim production. Here we take a look into the industrial manufacturing process. The process starts with the coil holder through which strip passes through the rolling machine. Rims are produced by CRC strip. Its thickness and width are important parameters as wheel rim carry the entire load of the vehicle. 2 sides of the rim strip are joined and folded by seam welding machine. Then in butt welding, both folded end of the rims are welded together. After that the grinding and polishing process has been completed. After that rim size is made of 190, 330, 400 and 600 grid size. To make the proper coating of nickel, polishing is required. After that, hole size (40, 32, 36) and diameter (19, 28 etc.) has been made according to the market requirement depending upon customer demand and applications. For nickel coating, sheet oil is removed, which is done by H2So4, HCl. In the Nickel tank, 8 to 9-micron thickness of Nickel layer is deposited on the rim. To add the property of anticorrosion and increase the life of rim, chrome process is being done. After this, the rim passes through chemicals for polishing to improve the shining and packed for selling in the market.

So where is the automation here? Automation as in using PLC or temperature sensors. I have seen sensors are used in the manufacturing process, please explain about them?

Sometimes when strip thickness (even > 1mm) or width increases, it causes the problem in the roller and the machine. So here is the automation used in stopping the machine when the strip parameter increases from pre-defined size. Secondly, in case the seam folding machine is getting improper power supply (less than what required) then it should be notified. PLCs are used to make the rim size (diameter) according to the market requirements. Thirdly, PLC is used in the polishing unit and same for the chrome unit (how much percentage required). So, there is a requirement of a single PLC unit (temperature/Nickel requirement), which can control the whole process as per requirement.

Which sensors are used for temperature monitoring?

The temperature is a very important parameter here. It must be within 65-70 degree. Also, the temperature is used to maintain the speed of Nickel atoms. In case when the temperature is lower than 50 degrees Celsius then adhesive capacity of the nickel lowers and hence loosely sticks to the rim. In chrome utilizer, if temperature goes beyond 40 degrees then it burns nickel and below 40-degree machine doesn't work. So automation is required to maintain this temperature. Also, the chrome layer is important parameter to maintain.

ok, yes, Thank you, so, Mr. Patel, thank you so much.

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So, what we have seen is that in this particular company there is some automation, they use PLC - Programmable Logic Controllers, which you have studied in this particular course. They also use different sensors. So, this is basically the first step, but there is a long way to go. So, what is required as you know already that the sensors are there but they are not interconnected?

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So, data is being acquired, but if you can have a system where the data can be exchanged, so the data from the different sources the different sensors they all can be made available. And if we can have a process by which centralized decisions can be made. So, after the sensing of the data, the data will have to be sent, so that communication the communication aspects, the protocols that are there which you have studied in this course, all of these are going to be required they have to be implemented.

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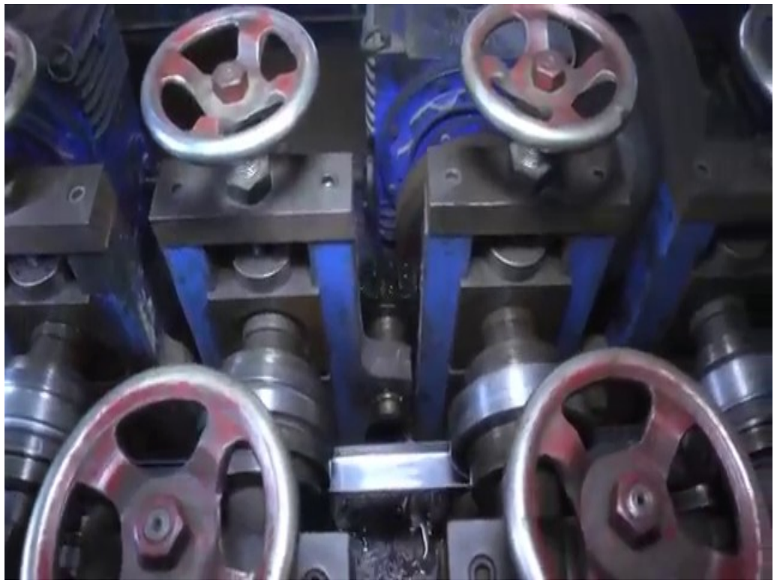

So, I was telling you that after all this data are made available in a centralized manner or some decentralized manner as well. So, they have to be processed. They have to be processed close to the age, that means, the source from where they are being collected or they have to be processed far away from it may be in a cloud or somewhere like that.

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So, all of these technologies the fog computing, the cloud computing all of these technologies could be very well adopted in this particular company to improve their processes.

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So, thereafter what happens is you can based on analytics, you can make decisions, decisions about the first of all we can monitor the operational efficiency. We can monitor the operational efficiency operational maintenance either anything is required or not based on the data that are being collected. Then there after predictive as well as prescriptive maintenance using machine learning techniques, those can also be adopted. And so what we can do is we can make the processes, the quality of the products in turn much more improve and of better quality.

One more thing that I forgot to mention earlier is what about safety, safety is very important in most of the industries. And I am sure they are also taking care of safety in a very serious manner, but automation in the safety domain is very important. So, can we adopt the IoT technologies in order to make the work place much more safe and also the processes much more improved, so that you can you can take care of the quality overall in a much more improved manner and in a much more integrated manner. Why I say integrated is all of these things will have to be interconnected, all these different components, all these different data that are coming, all these should contribute in a holistic manner in an integrated manner in order to improve the processes, the product quality as well as the work place safety.

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So, this is a company as I was telling you earlier which has taken the first steps, but there is a long way to go if they are willing to adopt Industry 4.0 in the future. So, adoption of IoT technologies will help them in order to achieve the goals, thank you.

So, right now we are in another company which is basically into the business of taking sheet metals and giving it some kind of a shape for its clients. So, the name of the company is Metal Texigency Private Limited in North Gujarat. So, I have with me Mr. Patel who is going to explain to you about the company. And so this particular company as you will see has lot of opportunities for adoption of the high technology industrial IoT and industry 4.0. We will talk about that later on. but let us first ask Mr. Patel about the company to speak about the company. My name is Bharath Patel; managing director from Metal Texigency Private Limited.

Ok.

We are manufacturing sheet metal component and fabrication.

Ok.

So, as I was telling you Mr. Patel. So, this particular course that we are doing this for the course. The name of the course is Introduction to Industry 4.0 and Industrial IoT. And this is an NPTEL course which is going to be made accessible to students from all over the country and even beyond. And so we are going to look at the different types of instruments that you have over here, and what is your current state of the art and how we can take it forward in order to adopt in the Industry 4.0.

So, we are going to talk about that later on, I am going to talk about it. My name is Keval Ganvir. My designation is production engineer in metal technology.

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First of all we get drawings from the customer party and accordingly we design them in AutoCAD, then convert the design with the help of machine software. This is to cut according to the shapes (hole, or square) in the design with the help of software.

So, this is the machine? CNC machine panel which we can see here? Do you program the design here?

We design it in our office and transfer the program to this CNC panel through the memory card.

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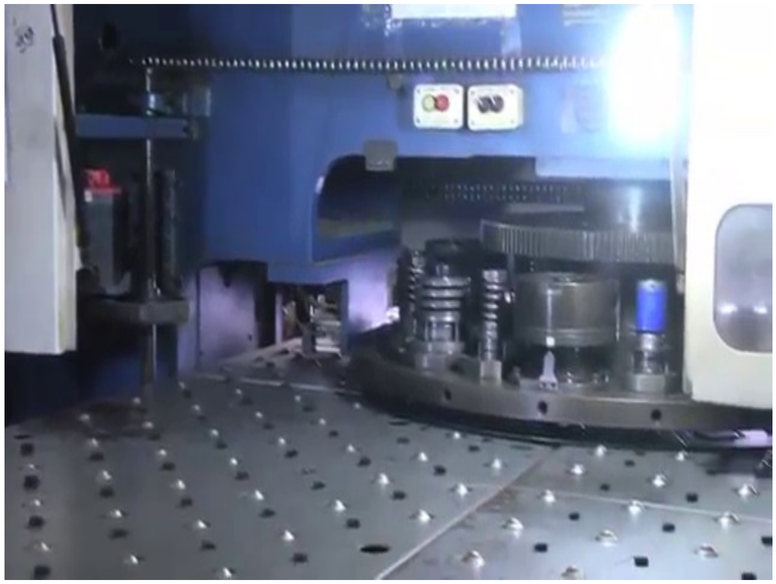

This machine has numbers from 1-28. The requirements are mentioned in the program; according to which the operator manually sets the tooling details. After that we connect the seeder and start the designing process.

So after that entire punching is done?

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Yes, after that punching process is completed. Following which we take it to the shearing machine. In shearing machine points are given. For example, points for a square are given in terms of left, up, down. Accordingly cutting is done and a single part comes out. Then we take it to the bending machine and bends the design according to the requirement – 45/90 degrees.

After that we go for powder coating – phosphating.

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By lifting it in a crane, it is done. This is called 7-tank process. Dipping is done there. Phosphating is required to clean the dirt in the component. After that we go for manual powder coating. Also we do this automatically using a conveyor belt. We hook the component and color paint it according to the requirements (one side or both, which color to apply).

After that the complete spare part is produced.

Then we made the model from different parts – base, top, side, etc. We fit these parts, screw them and make the model complete, box type component.

Ok, thank you so much for explaining the entire process.

So, as you have seen that this is yet another company which is basically let me just repeat the whole purpose of what they do. So, this particular company is into the business of taking sheet metals and making different spare parts for air conditioners including the body of the air conditioners, the outdoor unit of the air conditioners and so on. So, basically as we have seen that it starts with the sheet metal and which is taken into the CNC machines. CNC machine is the computerized numeric control machines which are bit different from the PLCs which are the programming programmable logic based machines. So, in this CNC machines basically what happens is the weight is different from the PLCs is that in the PLC it is the sequential operation and in the PLCs. And in the CNC machine, it is the conditional execution of the program, and so both of these the CNC as well as PLCs have lot of similarities.

But there are certain differences between the operations of the CNCs and the PLC machines. PLCs as well as CNC machines both are used in factories, the manufacturing plants and other similar plants a lot. And so these are some of the essential components for making the company smart, but for smart factories and so on for smart manufacturing what is required is the adoption of industrial IoT concepts that you have learned in the course. So, lot of different things are required in it. It starts with the sensors not just the sensors the sensors which are connected inter connected with one another.

So, the interconnected sensors, the sensor network which are fitted to the different machines not a single machine, but different, different machines, they are all fitted with these different sensors, and they can share the data between each other and also to a remote point where it has to be processed further. So, all these data are collected let me just repeat the process once again, and then undertake different, different analytics, may be some of these could be real time analytics, some of this could be non-real time analytics.

Some of this could give you idea about the quality and the processes that are being conducted the quality of it getting different, different data about those so the operational part of it. And some of this could be predictive about how this data can give you certain insights about what is going to happen in the future, and so that is the predictive one and also the prescriptive ones that also you have how it works. So, it goes beyond the predictive analytics and you can get a lot of different insights.

For all of these you see what we have is an ecosystem of cyber physical systems - CPS and with that you connect different, different sensors interconnected sensors, so that is what the industrial

IoT is all about. You collect the data you run different, different analytics into it. And also based on the analytics, you get different decisions which has to be feedback either to the machines or to the management in the company. So, all of these different things can be fascinating things can be done with the data that are collected, but this is we are still not there yet.

So, most of this companies are still in the primitive stages they are they still do not have adequate automation in them. And so basically the data that are collected you could even add SCADA to similar kind of systems for supervisory control and so on. So, analytics control communication and all of these things put together you can get a fascinating type of ecosystem that could that could be built out of these companies, and in fact what you could have is companies like this could be made smart they could be made smarter. So, you could have smart factories easily implemented by the adoption of all of this different ideas that I just talked about and also many different other things.

So, automation, analytics, communication and also the storage of the data through cloud or fog or whatever. So, all of these could be brought in together. So, we have lot of potential as we have seen in many of these companies. So, the question is that how you can take it forward what should be the next steps whether these companies are going to be interested in the adoption or not, but for that what is required is to make them sufficiently educated about what industry 4.0 is and what industrial IoT is all about.

One more thing let me repeat what we have covered in the course is basically the training part. The training part and particularly the training with respect to not only the systems the quality of them, the processes and the products and so on, but also the safety, safety, industrial safety is paramount. Many of these companies they take care of the industrial safety in their different, different ways, but not all of which is yet automated. So, if you have sufficient automation in place, you could basically have superior levels of safety ensured in the company.

So, quality, reliability, safety, all of these could be implemented and integrated in to the processes and the and the system and you could have a SCADA based or something similar supervisory control where everything would be monitored either in the plant itself or by the management, and the decisions could be taken either autonomously or semi autonomously, and feed back to the systems and the processes in these factories.

Thank you.

**Introduction to Industry 4.0 and Industrial Internet of Things**
**Prof. Sudip Misra**
**Department of Computer Science and Engineering**
**Indian Institute of Technology, Kharagpur**

**Lecture – 62**
**Student Projects – Part I**

Everyone I am Saketh Kumar from Computer Science and Engineering Department with my project partner Narayan Kunal from Computer Science and Engineering Department. Today we are going to demonstrate home automation system using NodeMCU, ESP8266. Basically our project aims at designing home automation system using NodeMCU ESP8266 and MQTT protocol. So, we have used NodeMCU which reads the data from MQTT client and decides the switching action of electrical appliances of home and we have used ThingSpeak cloud for data visualization and storage. We have used components which are NodeMCU ESP8266, four relay module, ultrasonic sensor that is HCSR04 and a power module.

We are using connectivity module which is Wi-Fi IEEE 802.11. We are using communication protocol MQTT and HTTP, we have used Arduino IDE for our coding purposes and the cloud platform is ThingSpeak and the language used is C and C ++; now, the pin connections ok.

Working of my project is as follows we have used MQTT broker. So, MQTT is based on publish subscribe models. So, as a broker we have used HiveMQ broker which we have installed on our laptop and for client we have used MQTT Dash which is installed on our smart phone and NodeMCU is also working as MQTT client. So, now, MQTT client is of two types; one is publisher, one is subscriber. So, here NodeMCU is working as a subscriber and MQTT Dash is working as a publisher.

So, through mobile we will control our electrical appliances, from mobile we will send the data, based on that data, NodeMCU will take the action. Means it will actuate the fan bulb whatever we it is connected through relay module. Now one more thing we have used ultrasonic sensor. So, ultrasonic sensor, we have used to simulate motion detection. So, whenever we go near the ultrasonic sensor, it will activate the bulb or it will deactivate the bulb.

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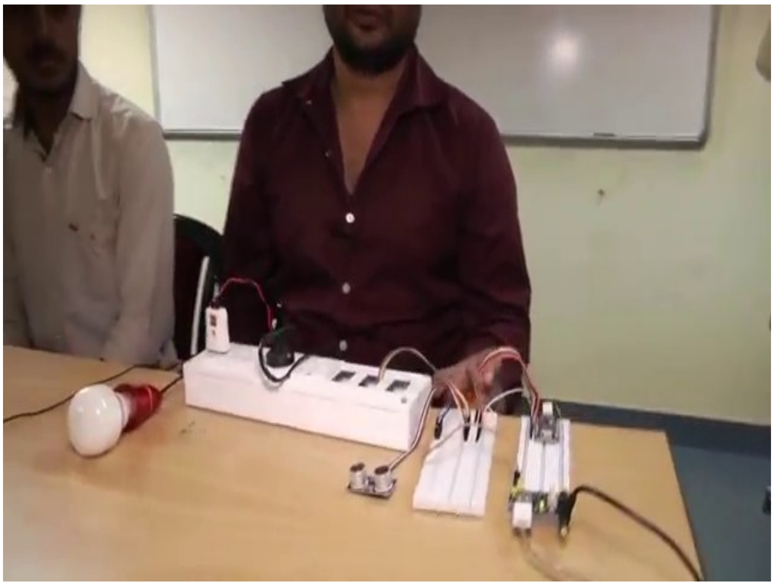

Now, I will give the demo about this project. So, this is our circuit diagram circuit of this project. So, this is NodeMCU and this is power module and this is ultrasonic sensor and here we have connected to relay module which is inside the board. Ok So, now, we will give the demo.

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So, and here we have MQTT Dash which is MQTT client working as a publisher. So, in this one we have four port; relay module, relay 1 port, relate 2, relay 3, relay 4. So, when we click on this  one, it will send the data to a NodeMCU server, then NodeMCU server will take the action based on this data.

Now we are clicking this button click. So, here the bulb is glowing on and when we turn it off, it is getting off. Similarly we have simulated all the four ports of the relay which is relay three that will control the fan and when we switch it off, it will turned off. Similarly we have simulated LED bulb that is on the board and we turn it off.

Now, we have ultrasonic sensor; through ultrasonic sensor we have simulated motion detection. So, when we go closer between 5 centimetre to 50 centimetre, it will automatically turn on the bulb. So, now, I am going see now distance. Now distance is below 50 centimetre that is why it turned on. Now once again if I go there it will be turned off, see now it is turned off; so, whatever action is being taken by NodeMCU server that is being sent to ThingSpeak  cloud. So, that data is here.

Hello everyone my name is Chandrani Ray Chaudhary PhD research scholar of IIT, Kharagpur and department of CSE. So, I am going to demonstrate a project, the project is road surface monitoring detections and notifications. So, for this purpose I am using the NodeMCU and MPU 6050 circuit.

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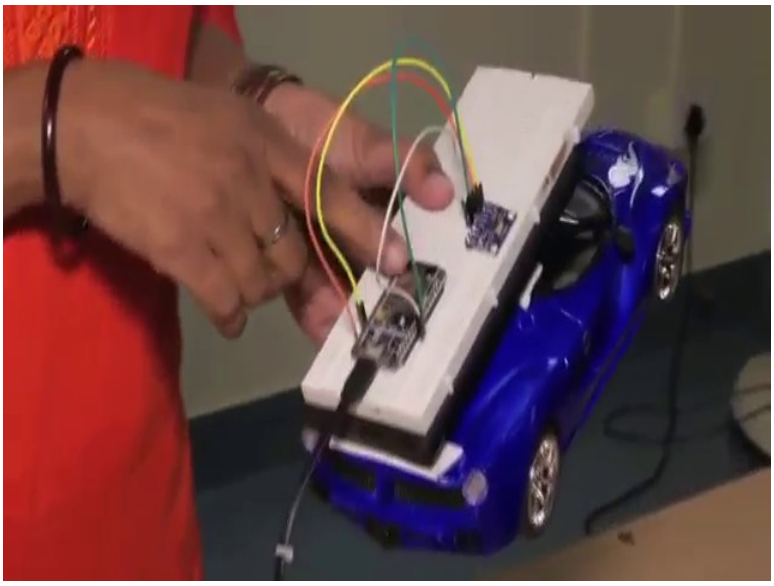

So, here the circuit consists of NodeMCU and this NodeMCU is connected with the MPU 6050 sensors. So, the basic things are that MPU 6050 sensor consists of accelerometer, gyroscope and temperature sensor. So, these sensor detects the accelerations about the road surface and it send this data from the NodeMCU, from the NodeMCU these data is going to send one server.

So, in this case, my laptop is going to act as a server. So, here one Python code is running over here, apart from this I am using the MQTT protocol. So, MQTT basically acts on publish subscribe mechanism. So, here for publishing purpose, I am using the HiveMQ broker and there is another client is required over here.

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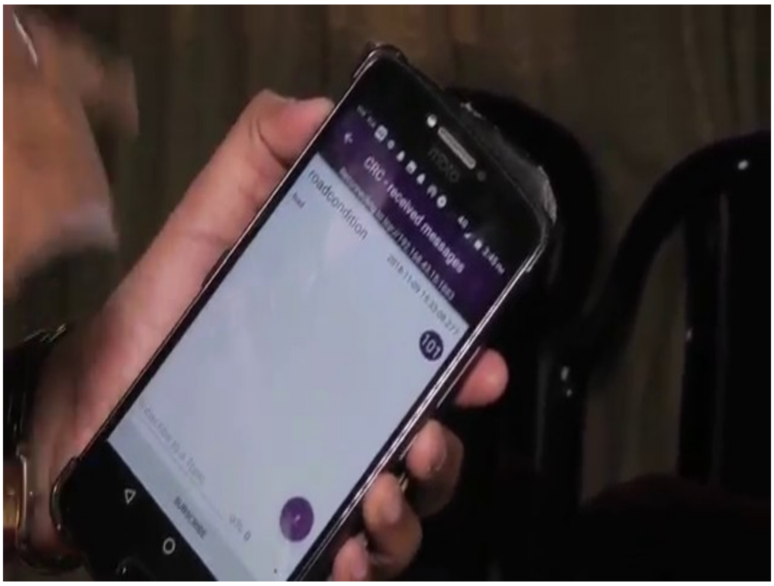


So, in my phone one client is here. So, that client is MQTT client. These client basically act and subscribe the informations about the road conditions. Say for examples, it is automatically displayed that is the road condition is bad, because it automatically subscribe about the topic road condition. So, it automatically gives the data.

So, this is the project about these things and the main purpose of this project is to aware about the road surfaces whether the road surface is bad or good and whether the road surface consists of potholes or bumps or not according to the notification is sent to the different address. So, that they can be also aware about the road service and accident also can be avoided in this way.

So, here I am going to demo of this project. So, basically thus the car which consists of this circuit; those car is moving and those car is simply acts gets the data about the road surfaces. So, in this case the road surface totally smooth, there is no anomaly over here. So, for this purpose, the output will be shown as a smooth. But whenever this goes to there so, there is some anomalies over  here. So, this will show the about the road service is bad and so on and the data will be transmitted into my server. So, for this purpose here, the server is simply whether the data road condition is smooth and bad.

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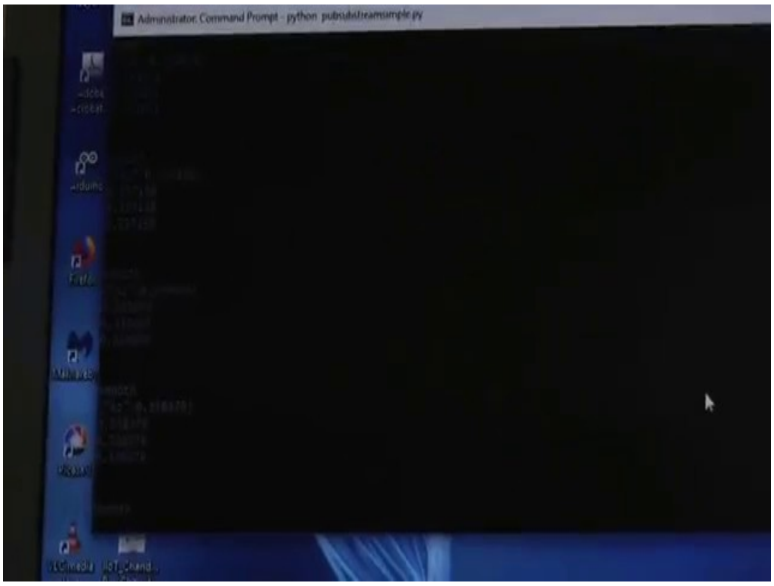

So, as there is no anomaly into the service. So, it simply shows road condition is smooth; that means, from these car the data is transmitted into the server here the HiveMQ broker is installed. And apart from the from these broker the data is given a data is going into this mobile phone because this mobile phone already subscribe the information and it is automatically shows that  the road conditions that was the smooth.

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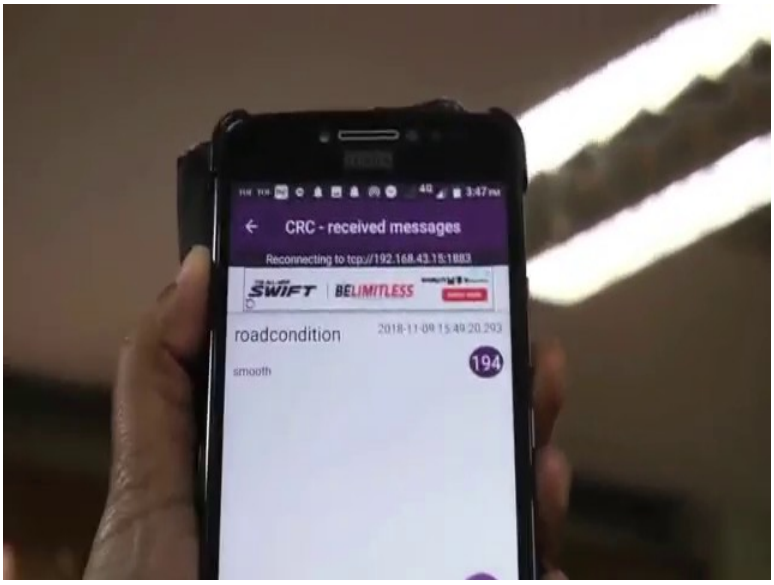


So, it shows and the number of messages which arrives over here that is 190 number of messages; that means, the data is automatically transmitted here.

Hello everyone I am Arun, this is Abbas. We both are from Department of Computer Science IIT, Kharagpur. Our project is a Smart Doorbell which is using the IoT technologies to improve the present day doorbells. The present day doorbells are sound notification system which will give a sound notification to the owner of the house if somebody is outside. And some advanced doorbell improve the functionality of a peephole which is already existing by showing the view of outside of the house by a CC TV camera or something.

So, we are using IoT technologies to improve this technologies by. There are mainly actually three features that we will we have included in this project. First one is if somebody clicks a doorbell even though the owner of the house is not present at house, our system can inform the owner on a smart phone through IoT technologies.

The second feature is even though if somebody is roaming around your house and not clicking the bell, we have a distance sensor to sense the presence of a person nearby. In that case also, we click an image and send to the owner whoever and I mean wherever he is in the world. And the third feature is if the owner wants to see what is going on near nearby his house, he can click an image from a remote place. Through IoT technologies, we can send that image from our doorbell to the owner's smart phone.

So, for this we are using mainly Wi-Fi, MQTT and the rest protocol the coding and software pattern done in the Python language.

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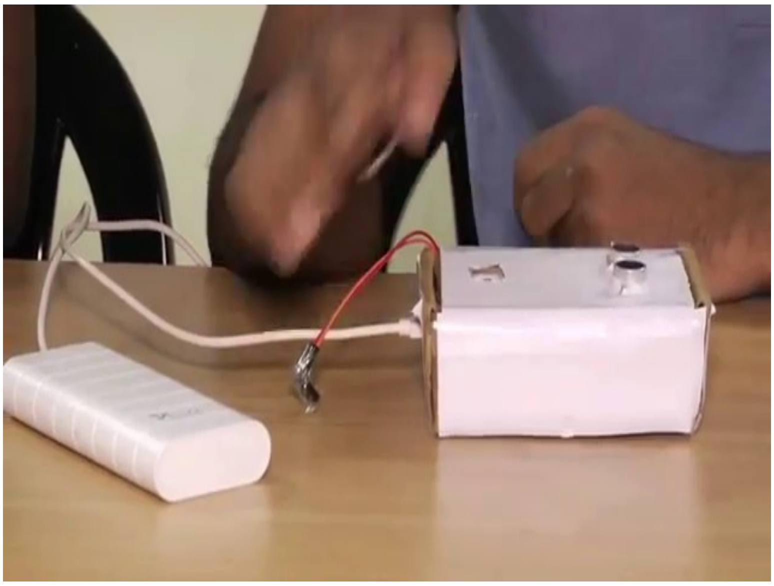

So, this is the product. It has a Raspberry Pi Zero, camera which is fit inside you can see this one and it has a distance sensor and the button. So, the button is put inside to simulate a bell, the distance sensor is for observing if someone is wandering around and there is a camera for clicking an image. The basic architecture of the project is that there is a Raspberry Pi inside, a camera is connected to it of 5 megapixel camera and using the GPIO pins, we have connected the distance sensor and a button. Also there is another server which is running up or which is running on a different machine which is a REST API server.

Now, what happens is there is (Refer Time: 10:17) is a MQTT broker on the Raspberry Pi. It is created using the Mosquito, it is a Linux package. So, using Mosquito, we have created a MQTT broker. Now whenever some event is happening like pressing a bell or distance sensor checking if someone is there or not. And even if someone is trying to check remotely if there is a presence of some person inside in front of the house. So, in that case a MQTT event is published on a topic, there is an android app MQTT Dash so, using that we can check. So, if you press the button, it publishes an MQTT message which reaches the broker on the Raspberry Pi. The Raspberry Pi instructs the camera to click an image, the clicked image is then sent to the REST API server which is on a different machine. There the image processing takes place. Now the image processing part is done using the openCV library and using the scikit-learn, we have created the HCM classifier for it. That deep it is a deep neural network torch in a framework named torch which is being used for the facial recognition.

We have a database of known faces. So, we can create different folders for different people like for example, you can use the family members faces, you can store them and learn the classifier; HCM classifier for those faces. After that what happens is the REST API server processes the faces and checks whether some known person is found from the database. If it is yes, then its fine; if some unknown face is found, then it has to trigger an event to the owner of the house that someone is trying to visit, someone either someone is visiting you or there is an intrusion. In both cases, it sends a notification on the android app where MQTT Dash which is installed on the phone.

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This is the android app from here you can monitor your doorbell using the remote click. So, if you click on this place, the pi will click an image. So, this is the camera (Refer Time: 12:21) and it will come in this part. So, if I zoom it so, you can see that it has been identified as Arun. Yeah So, it published the image, it published the image and sent it to the server. After the server recognized it, it send back to this client app. So, you can monitor whoever in front of your house. Similarly, this will work with the button and the distance sensor.

Thank you.

**Introduction to Industry 4.0 and Industrial Internet of Things**
**Prof. Sudip Misra**
**Department of Computer Science and Engineering**
**Indian Institute of Technology, Kharagpur**

**Lecture – 63**
**Student Projects – Part II**

Hello everyone, I am Gaurav Chaturvedi. And I am Deepak Kumar. Our project is about IoT Projection Meter and we are using NodeMCU DHT11 and MQ135. DHT11 is a temperature and humidity sensor and MQ135 is air quality measuring sensor. So, basically our project had two objectives. First one is we are sending the data from the NodeMCU to the Blynk server where the Blynk, Blynk server will represent the data in a mobile application.

And our second objective is we are sending the data from the NodeMCU to the central server where our Linux machine is acting as a central server. So, basically the centre server will act as a data storage purpose and the data will be stored in a CSV file and later on we will be divide KNN machine learning algorithm which will classify the data into as rainy and sunny and it will also tell us about the air quality whether it is good or bad.

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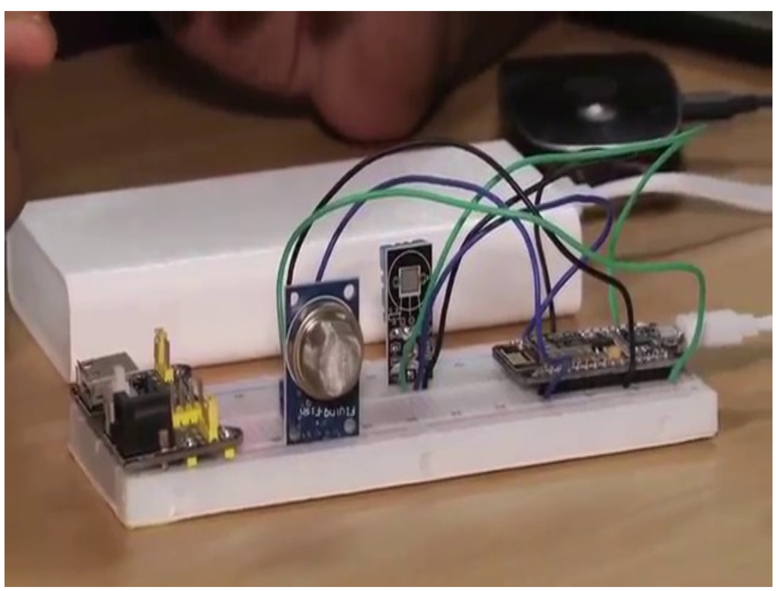

Now coming to the connections.

So, here it is a connection here we are powering in NodeMCU through the power bank and DHT11 output pin is connected to the D1 pin of NodeMCU and its ground connected to the ground of NodeMCU and VCC connected to the VCC of NodeMCU. And coming to the MQ13 sensor, here its output pin is connected to the A0 pin of NodeMCU and its ground to the ground of NodeMCU and its ground to the ground of NodeMCU and its VCC to the VCC of NodeMCU. Here DHT11 is sensing temperature and humidity and sending the data in digital format to NodeMCU and MQ135 sensing air quality and sending the data in analogue format to NodeMCU.

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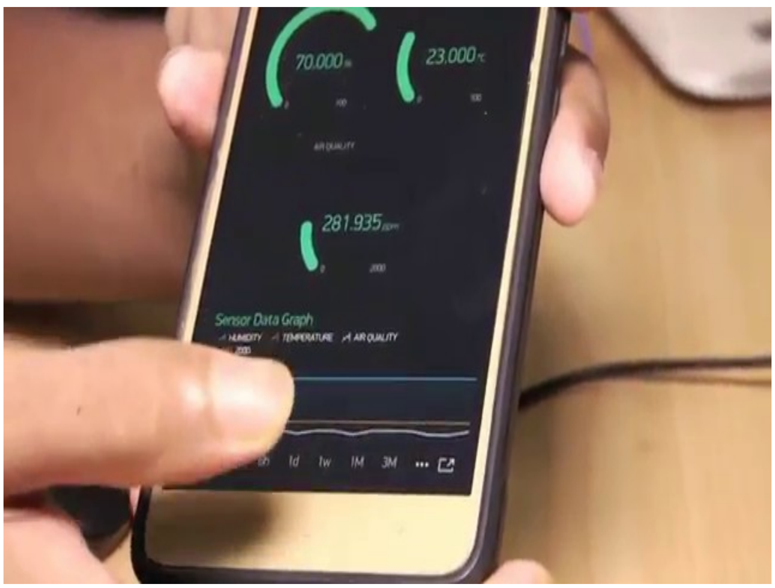


Now we will show the demo. Now so, in the application you can see it is showing humidity, temperature and air quality and also plotting the live graph as you can see here. So, here is a live graph.

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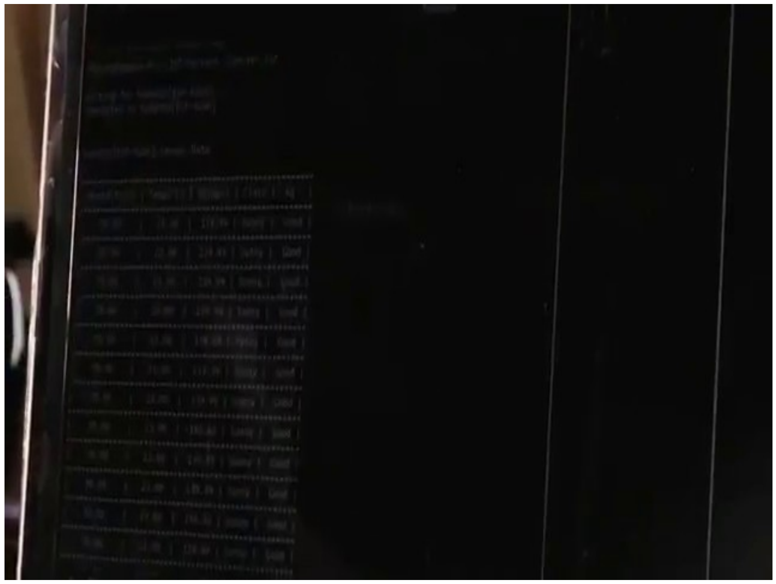

Now, coming to the central server as you can see here, it is show showing humidity, temperature.

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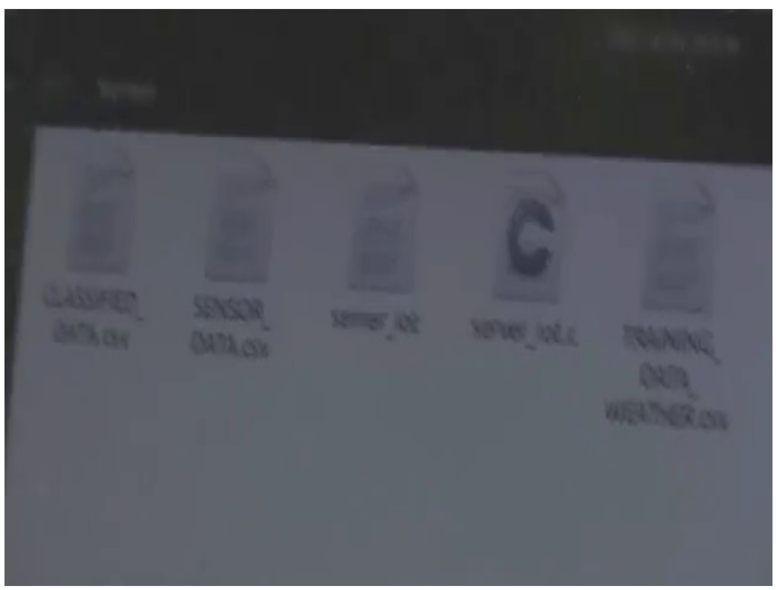

We are storing the data in CSV file. Here is the CSV file as you can see here and it is storing with timestamp.

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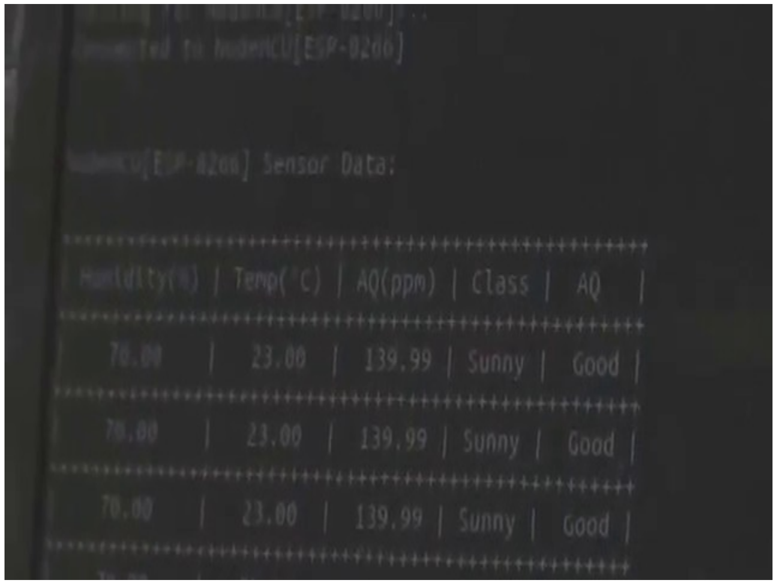


Now coming to the server, you can see here it is showing the data humidity, temperature, air quality and there is classes of the weather and air quality whether it is good or bad. So, for this we need training data. So for the training data, here we have given the training data to the program in CSV file you can see here. So, now this is the server, it is running and it is showing the data.

Hello everyone. We are here to present our class project which is Smart Bike Toolkit. I am Rajkumar M.Tech. first year. He is my teammate Ahwan Mishra, M.Tech. first year computer science. Now some basic information about our project is, this is basically a gadget which help in bike safety, security and also help to detect the bike accident.

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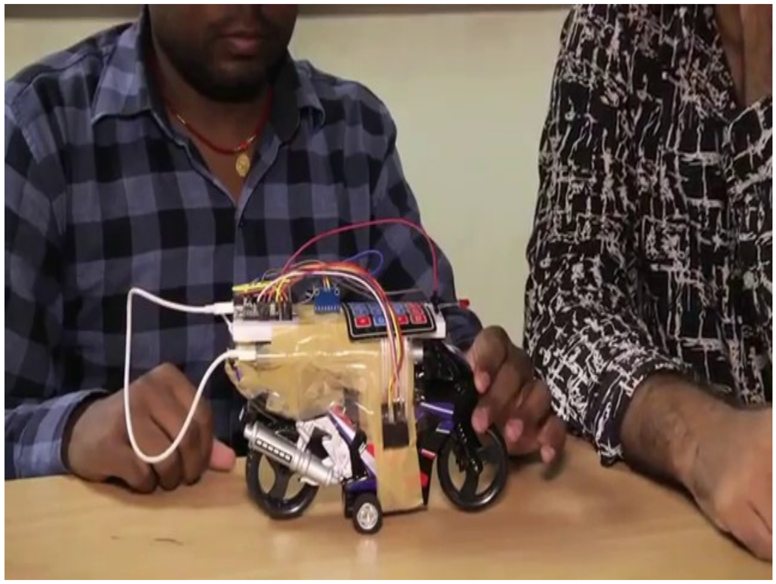

The basic component use in our product; project is NodeMCU 1.0. This is NodeMCU 1.0 and accelerometer sensor, gyroscope sensor, GPS sensor and matrix keypad. This is a one sensor MPU 6050 which contain three type of sensor; accelerometer sensor, gyroscope and temperature sensor. We are using only two sensor of; two sensor accelerometer sensor and gyro sensor of this sensor. Now for bike safety purpose and bike safety, and security purpose we using accelerometer sensor and a password protection. Now, for bike accident for checking the bike accident, we are using accelerometer sensor, gyroscope and sending the location of the accident happened; we are using GPS of our mobile.

Now, for communication purpose, we are using MQTT; for connectivity we are using Wi-Fi. We are using decision tree algorithm of machine learning for training our training around 500 data set.

Now, I will explain the working principle. Suppose the bike owner has kept the bike here and gone somewhere. Suppose someone else try to steal the bike, then there will be some change in motion and also if the bike has fallen away, then also there will be some change in motion. The motion sensor will detect it; sorry the accelerometer sensor would detect it and it will send, it will publish a MQTT message and the owner has an android mobile and he has a mobile client impunity client, he has subscribed to that topic. So, he will get the notification.

Next thing is whenever someone will try to; whenever someone will try to steal the bike using unlocking the password. First of all the owner has to unlock the bike using giving a right password. If someone will try to unlock the bike using wrong password; if he types wrong password three times, then also the theft message will go to the owners mobile. So, when the authorized user will call he will give the right password and he will ride the bike.

Suppose he meets a bike accident, then what will happen? The accelerometer sensor and gyroscope sensor both will capture the data and we are using that data analytics for that I will explain that. So, and they will send publish the message of the accident and it will the message will be sent to the mobile of the owners relatives. Now I will say about data analytics. Initially what we did, is we trained the bike about how the accident happens means if we move the bike like that and we trained it how the accident happens. We collected about 500 data sets and then we applied the Decision Tree algorithm to make the model, then we fit the model to the NodeMCU ok. This is how our model project is.

So, first of all if someone tries to steal the bike, then he will move the bike; move the bike.

First.

It got the so it will send the threat message, if the bike will fall off.

Without unlocking the password.

Without unlocking the password if the bike falls off, then also it will send the message to mobile I got a notification. Next thing is we got a.

Notification (Refer Time: 06:30).

screenshot, we will post a screenshot.

Someone try to

If someone gives the wrong password unlock [FL] unlock [FL] pause. If someone will give type wrong password for three times, then also it will send a message to the owner. Now restart it.

Now authorized user types the correct password. Now he is riding the bike when he will meet the accident, it will send the message. We will show a demo you can see, it will send the message.

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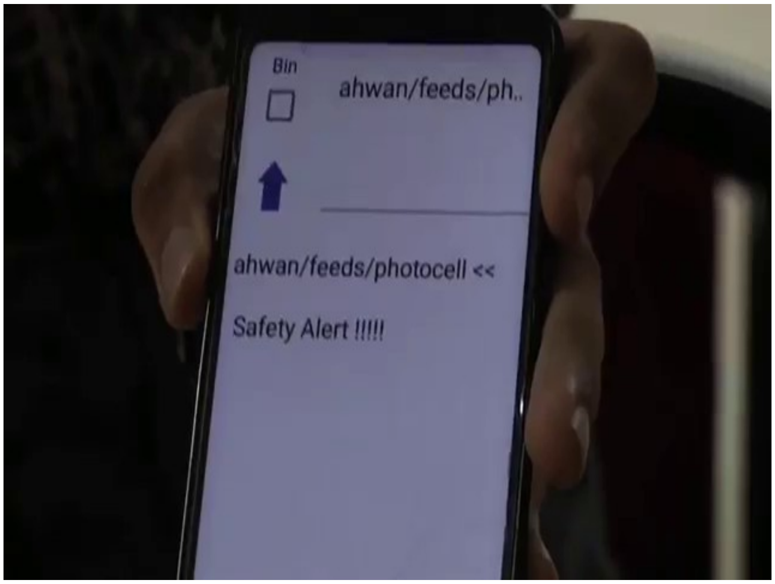


Now I will show this is the message I got, when I got the safety alert means either the bike is fallen or someone tries to steal it.

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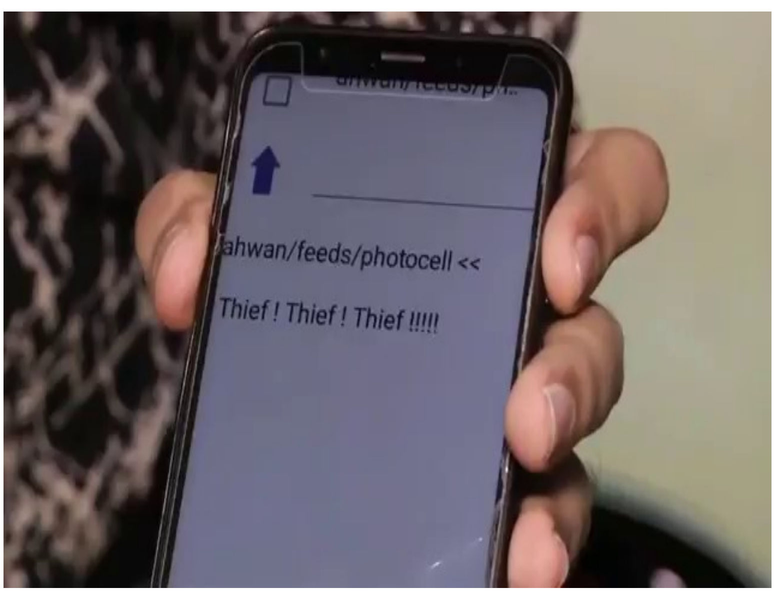
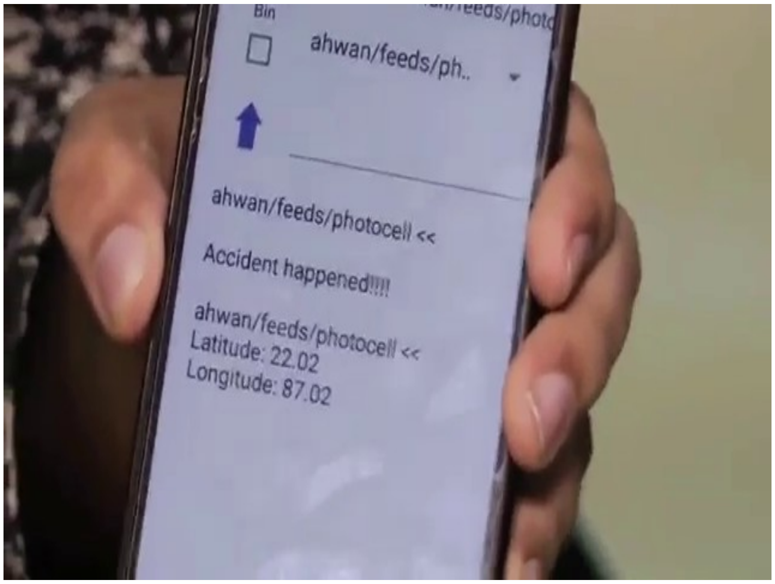


Next thing is, this is the message I got when someone gives the wrong password, then its send the Thief! Thief! Thief!!! message.

(Refer Side Time: 07:45)




This is the message I got when the accident happened and the GPS sensor sends the latitude and longitude to the owner's relatives.

Thank you.

Hello everyone. My name is Gaurav Gupta and he is Shagun Tudu. We are from Computer Science and Engineering department IIT, Kharagpur. Today we are going to present you an IoT project. The topic of our project is road accident detection using heartbeat sensor. So, basically whenever a person go through a bad road accidents, then his heart pulse gradually start slowing down. So, whenever his heart pulse beat come below to a certain threshold, then we will send its location and his heartbeat data to its; his relatives.

So, basically through this we can actually save his life by informing his relative as soon as possible. So, now we are going to show you what component we are going to use in our project.

Coming to the components parts in the software part, we are using Arduino for coding and we are using MQTT Dash and Blynk apps and other than software we are using hardware. The main components of the hardware are NodeMCU.

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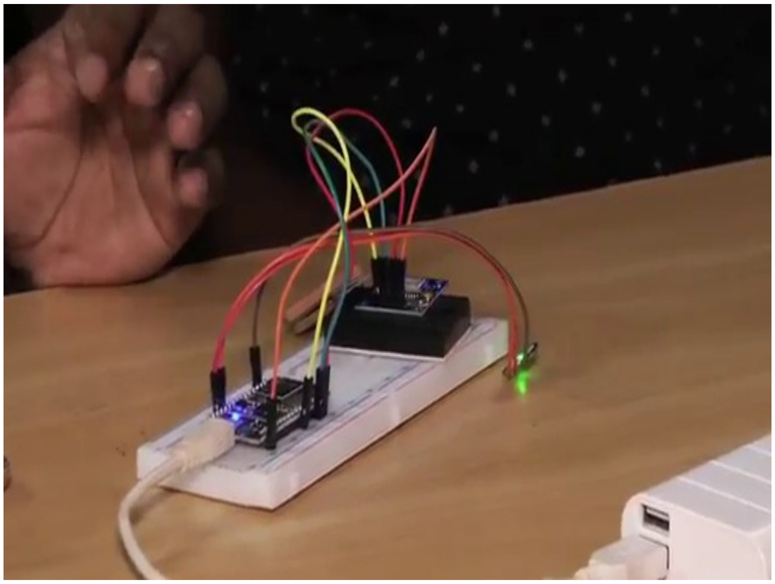

And there are two sensors; one sensor is GPS module and the one is heartbeat sensor. This is the heartbeat sensor and this is the GPS module.

Now, we are going to show you what, how we are going to connect it. So, we have the heartbeat sensors. So, we have connected it through one wire on the ground node and other in the voltage and one is the n an analogue node. And the other now we have the GPS module. We will show you the connection in the pdf we have provided. So, basically we are powering through our a power bank and to basically transfer or to build and for other purposes, we are using MQTT softwares and Blynk app. Now we are going to show you how the work flow, how this actually work.

Coming to the workflow; first of all from this device, we are sending the GPS location to the user's phone, directly to the phone using Blynk app. In the Blynk app we are sending that and the sensor I mean send the heartbeat sensor heartbeat data which we are sending from here, it is say it is directly sending to the MQTT server in the cloud and after that the MQTT server, it is coming to the user's phone in MQTT Dash.

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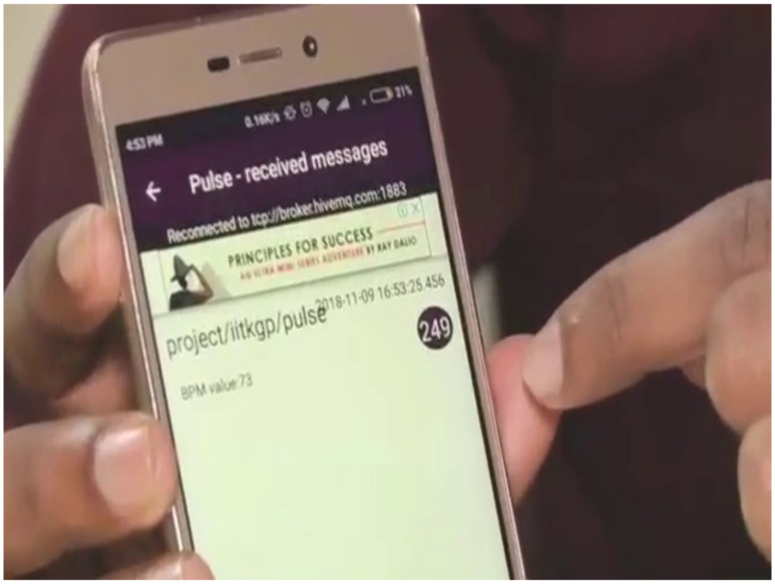


Now we are going to show you how it actually working. Here after touching the sensor, we are getting the reading here of the heart beat through the MQTT broker on our mobile. So, you can see the heartbeat pulse is rating 73 right now and now we will send the location of the person on the Blynk app. So, here we have the location of the person showing on our Blynk app. We have set the threshold less than or 75, you can actually set it to the even below than that. So, that whenever person go through an accident, its heart beats pulse is basically below from the normal. So, through this we can actually detect where the person is right now and what is his heart beat. So, as soon as we get this information, we will be able to rescue him.

Thank you.

Hello everyone. My name is Vishal Kumar from Computer Science and Engineering department. My demo project is fire alarm system, which are used to detect the fire and send an alert the message to owner and the nearest fire station.

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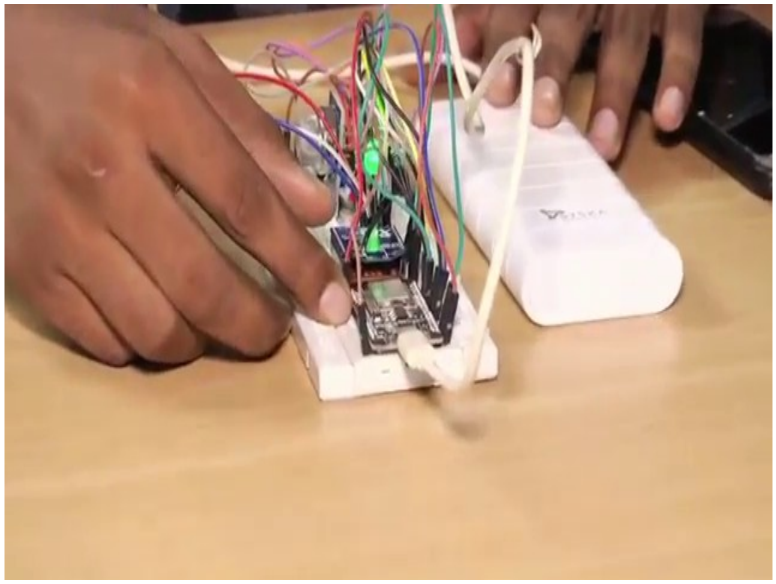

So, here we use our two nodes which are used one are used for the one; two node which are placed in different places which are used to detect the fire. In first node, here is first node which contained the NodeMCU which are used for processing of data a second and second; in second node we use the Arduino. And here between two nodes, we communicate through a Zigbee and from Zigbee, I this node send a data through this node through Zigbee device and this node send through Wi-Fi to a broker is MQTT broker which I installed in my local server. Here is a nearest fire station which can subscribe the topics through which are used in a my MQTT.

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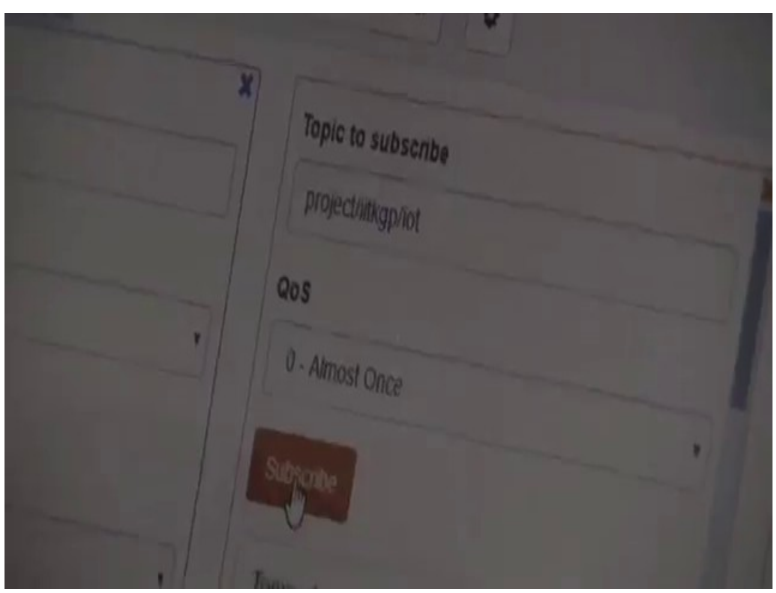

Here is a fire stations which are subscribed the topic project/iitkgp/iot.

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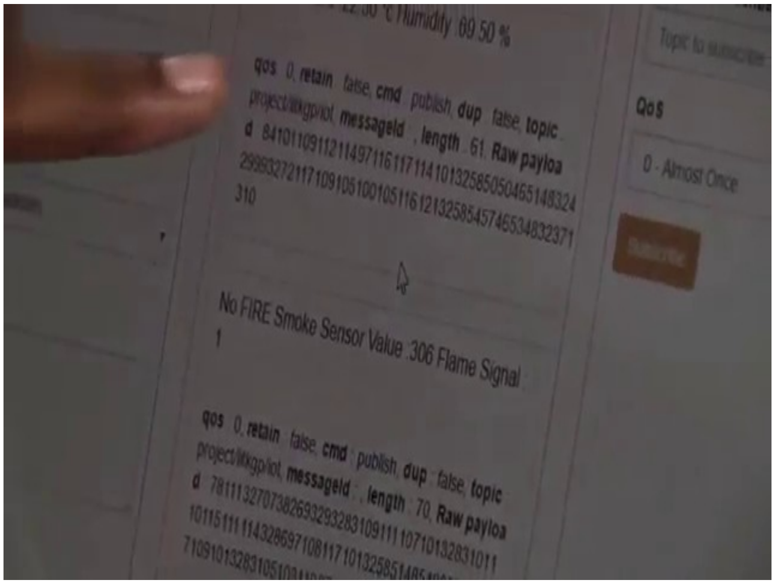


So, this see it automatically get message which can monitor the room conditions. Here is room condition is temperature, humidity and what is condition is there is smoke or not. So, this say that there is no fire. So, smoke values is what n is flame sensor. Here we use two sensor which are one is flame sensor and another is a smoke sensor which are used for detecting, flame sensors are used for detecting the fire and smoke sensor for use for false negative. And this alert also be sent to an owner, through MQTT client.

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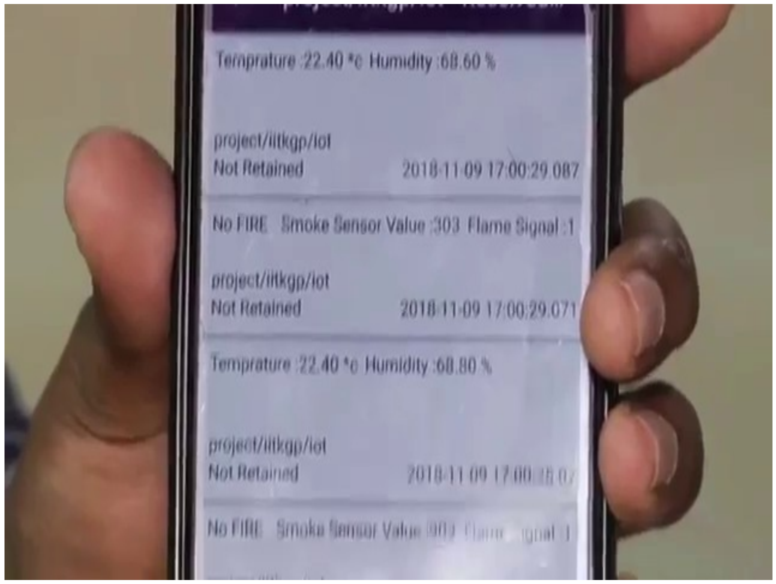


So, owner also subscribe the topic offer MQTT they also get a message that is a sent by the broker which I have installed locally. In this while they also get a no fire and current situation of the room where the node are installed. So now we are put off fire.

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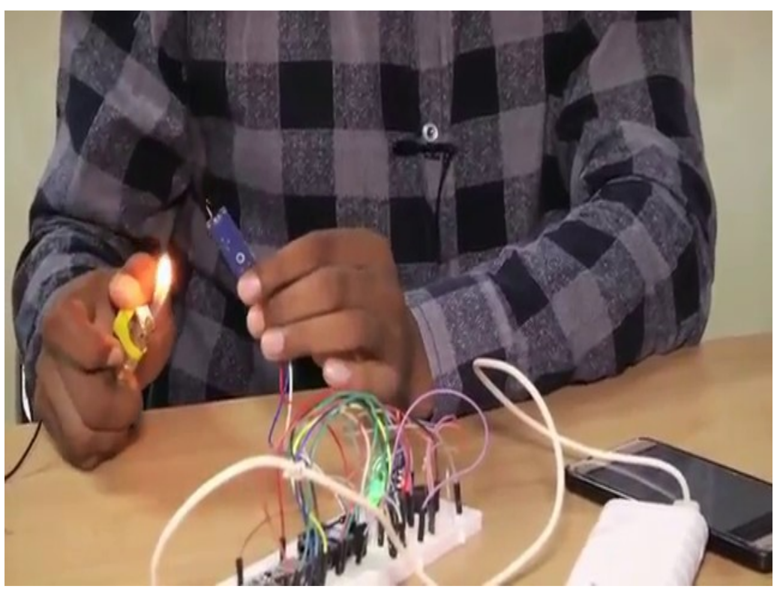

Now here is the flame sensor which are detect for the fire. Now we are test the depth if there it is a flame which detect by the flame sensor and automatically they buzzer the sound. So, nearby people also get an alert and also flee from the that place. On here also get a message, there is fire.

Here we if burn flame then automatically detect the fire, then also buzzer sounded and also get a alert message through a fire alarm system the here is a fire break out and what is the condition of the room and humidity what is temperature.

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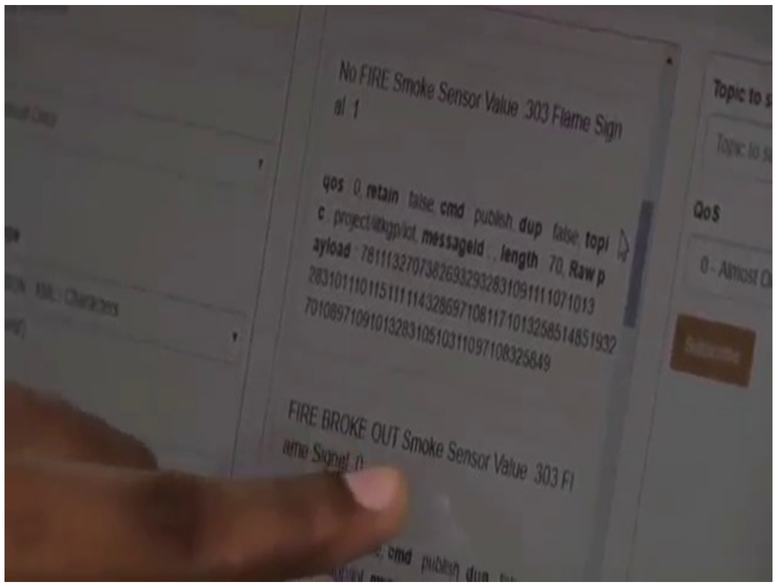


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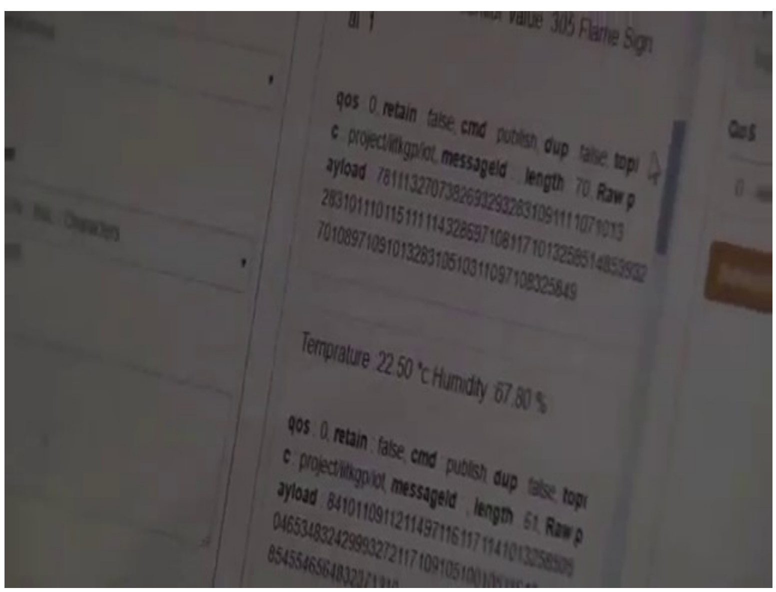


Here this show that fire broke out and what is the flame value and temperature value of that can that room and also get to also get a message in the mobile.

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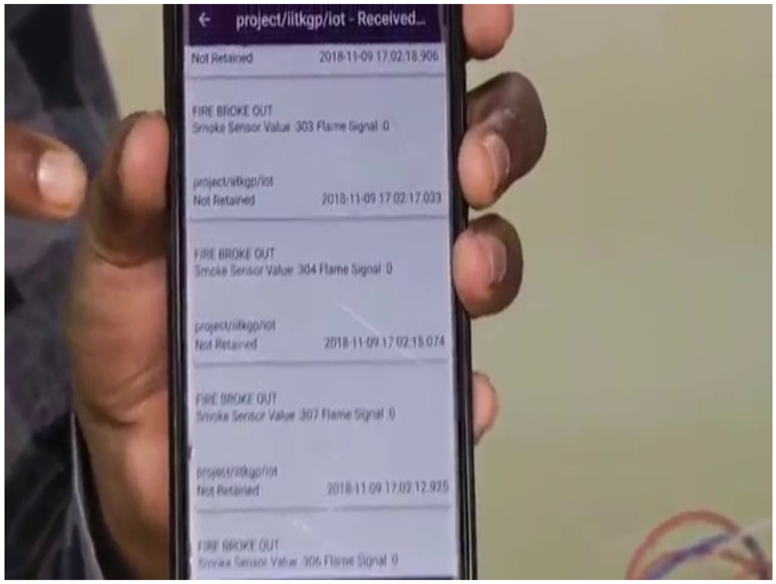


That is a; he also get a message that is a fire broke out what is the condition?

Keep it percent.

Here we show the fire broke out which alert the owner about the condition of room and what is the condition if there is also there is any smoke. So, smoke sensor show the value of the room condition. Thank you.

Hi, I am Akash; I am M. Tech. first year student from Department of Computer Science and Engineering IIT, Kharagpur.

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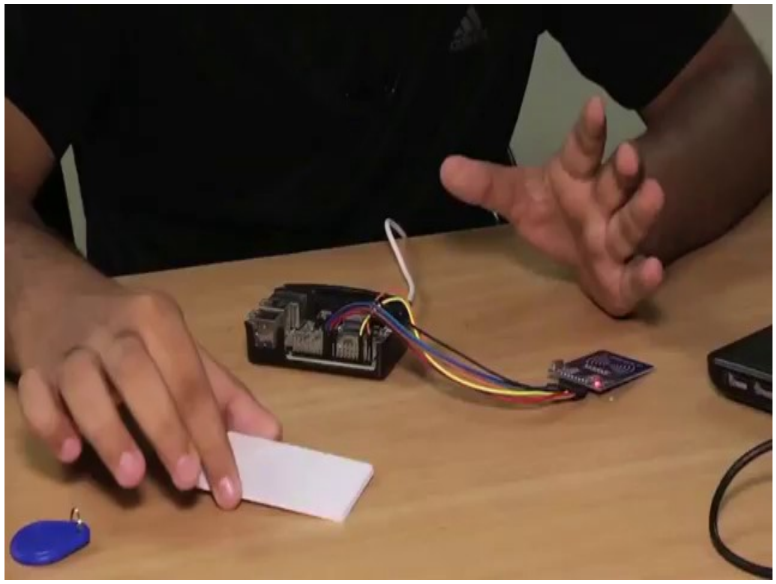

So, the demo that I am going to show is about RFID based attendance system. So, basically we are using RFID technology that is very short range communication technology and then building attendance system out of it. So, already RFID systems are widely used in all the companies and for authorization as well as attendance purposes, various institutes also use these for student authorization and attendance.

So, the hardware components involved are this is Raspberry Pi that is model 3B plus and this right here is RFID RC522 scanner that is basically a RFID scanner. So, these are RFID tags all these tags these are two different types of tags, but although the thing is same. So, these all have a unique ID associated with them. So, this scanner whenever we will place these in the close proximity of this scanner, the data their unique IDs will be read and accordingly we can process it by writing the code in whichever way we want. The way this is going to work is the students will be given these RFIDs. So, each RFID their unique ID will be associated to one student and using this they will mark attendance and this device will be placed in the class. And whenever they will place this card like this so, their UIDs will be read and their attendance will be marked.

So, how we are approaching on this is we are setting a timer for like that is on our convenience, but we are setting it for 10 minutes. So, in the middle of the class or in the beginning of the class basically, professor will turn on the system and then students will students can easily mark their attendance. And now their attendance will be stored in database that is set up in this Raspberry Pi and each attendance will separately be notified to professor on using MQTT protocol and also whenever the all the students have marked attendance or the timer that we have set is expired the complete list of students those who are present and those who are absent will be notified, will be published to the; published over MQTT and professor can receive it.

So, also there are some other things like some sort of data analytics is performed which will also be give sent to a professor. So, that they can judge students based on their attendance like which student is attending classes more frequently and so on ok. So now this system is running I have run the code.

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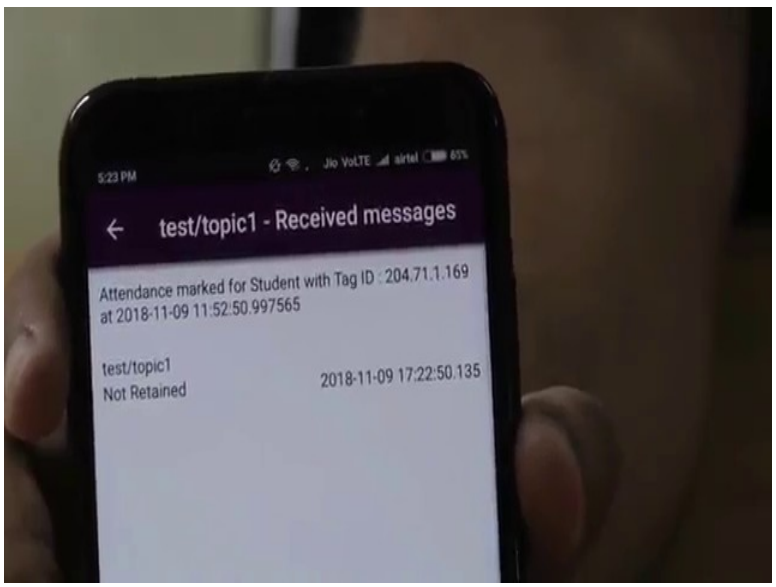


Now whenever I scan it, there will be a message and that will happen for every ID and if some unauthorized ID is placed, then there will be no message and even our code will not accept it and we will simply reject that entry.

Thank you.

**Introduction to Industry 4.0 and Industrial Internet of Things**
**Prof. Sudip Misra**
**Department of Computer Science and Engineering**
**Indian Institute of Technology, Kharagpur**

**Lecture – 64**
**Virtual Reality Lab**

I am now going to take you through one of the state of the art facilities in Virtual Reality in the country and there this particular lab the virtual reality lab was developed in the department of industrial and systems engineering at IIT Kharagpur, under the primary leadership of Director and Professor J Maiti of the industrial and systems engineering department and along with him there were different other faculty members including myself together we have developed this particular lab.

So, I now request Professor J Maiti who is currently the head of Industrial and Systems Engineering department and also the principal developer of this particular lab to say a few words describing this lab.

Thank you Professor Misra, this laboratory is a part of safety analytics and virtual reality laboratory it was established in the year 2016 under the mentorship of Professor Partho Prathim Chakraborty, our Director, it was conceived a primarily for accident research and virtual prototyping including simulation.

As accident cannot be created or experimented in industry, so our ultimate aim was that whether we should have some kind of facility where we can develop the industrial system and also create the different kind of accidents. And it is equipped with high-end computing, projection system, immersive system, tracking a navigation system apart from this laboratory is having other accessories or supporting equipment and it has lot of application in particularly in the area of industrial IoT and we can go through this particular facility thank you.

Thank you Professor Maiti. Let me first introduce to you Mr. Kranti who is currently the PhD student in the Department of Industrial and Systems Engineering at IIT Kharagpur under the supervision of Professor J Maiti. And let me just ask you Kranti could you please explain about the infrastructure of this particular lab, particularly the main components that we have over here.

Yes, sure so we are having different kinds of tracking and head mounted display kind of equipments which basically used for the virtual reality experiments.

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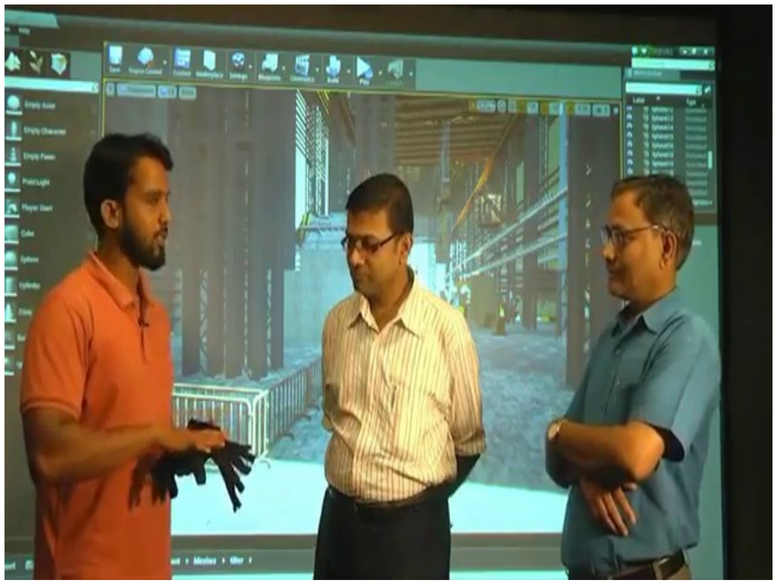

So, we are having different kinds of data gloves. So, these are the data gloves which are used to track all the, used to capture all the motions related to your finger. So, this particular data gloves is having 14 sensors, so it will capture all the finger motions and different wrist motions related to whatever user movement will do; similar.

What kind of sensors are there?

Sir piezoelectric sensors, these are piezoelectric sensors.

(Refer Side Time: 03:24)

Similarly we are having this hand tracker, so you just had to mount this hand; hand tracker on your wrist so that whenever you will move certain object or whenever you will capture and move certain object you it can capture what with what force you are capturing that object. Similarly what is your pitch roll this kind of motion also this will capture.

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Apart from that we are having a particular head tracker, so what it will do is I will show you how to use this head tracker having along with HMD.

So, while using the HMD in inside this HMD you can actually visualize means actually you can feel that how you are immersed inside that environment. So, whenever you are walking in that environment whenever you are moving your head in different directions. So, the head tracker will help you in tracking your head movement. So, these are the equipments basic equipments for the virtual reality.

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Then this is the main equipment with which you can feel the immersiveness of the virtual reality which is the most important part in the virtual reality. So, while wearing this particular HMD inside you can see that you know you do not have to see outside anything. So, everything every end developed environment you can see and feel inside it whenever you will be walking inside you can feel that you are immersed in that environment; environment and you are walking inside that environment.

Apart from this we are having an eye tracker, so these are basically used for the purpose of situational awareness now it is trending in the marketing research. So, it can capture your eye movements whenever you will wear this and it will be connected; connected to a particular computer. So, you can feel that whenever where is your gaze direction. So, particularly in a safety domain; safety domain if you are working, then one person if he is looking at one hazardous situation or different kinds of accident scenario, then you can automatically detect that what that person is looking at and which is the most severe accident that is going to occur. This is these are the equipments we are having inside our virtual reality lab.

Thank you Kranti. So, could you talk about some of the applications of virtual reality particularly in the industrial context and more specifically something that the lab is interested in.

So, virtual reality application is very wide it is mainly used in the industry mining industry, healthcare industry and manufacturing industry. In mining industry basically it is used to train the underground coal miners, whenever they are going to a very complex area. This should be aware of the things that they are going to face inside that underground coal mine.

Similarly, if a surgeon is going to operate on a particular patient. So, remote kind of surgery you can perform with the help of virtual reality and apart from that in manufacturing industry different assembly automation simulation and how to accident simulation kind of thing we can perform in the manufacturing industry. Apart from that we are nowadays fire workers are also; fire fighters are also trained with the help of virtual reality how to tackle with the emergency evacuation situations.

Wonderful yes, so could you please take us through one of the scenarios yes particularly something that you have, so we can see on the screen.

Yes, so we are currently working on an accident development scenario. So, we have developed a particular factory simulation fact workplace in scenario where we experience some of the accident situations.

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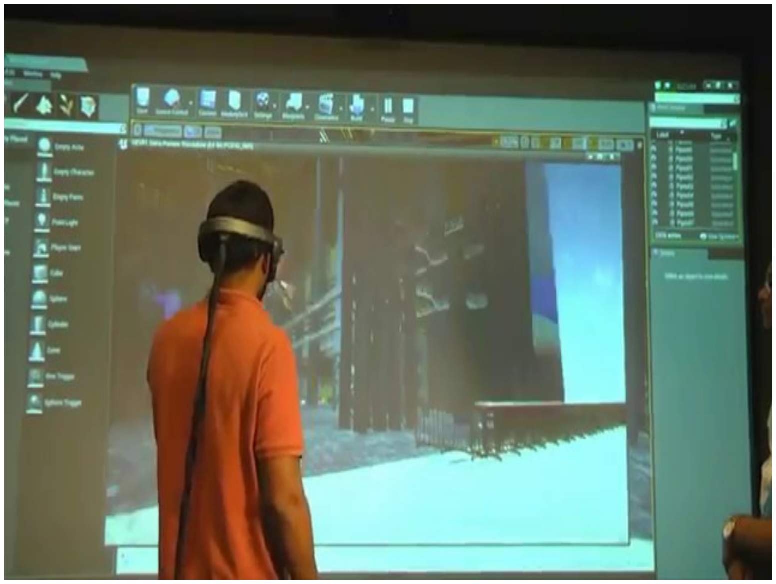

So, I am taking you through the accident workplace I am taking you into the workplace you can see visualize that, this is the complete workplace we have developed in a certain span of time. So, what we did is for this we have to collect some particular data how to develop these 3D models. So, in the first phase we developed the 3D models, you can see all the 3D models that is developed with the help of the software's like solidworks, then Google sketch up, then Maya this kind of software we used for the 3D modelling.

Then after the 3D modelling we focused on the texturing; why texturing because texturing gives you the real feeling of the 3D models that are present in the environment because real virtual reality in the virtual reality we have to mimic the real environment. So, we have to give the textures particular textures for the particular objects. Then we did all kinds of all kinds of simulations with the help of a game engine that is unreal engine we imported all the models to that.

Then according to our operation; according to our requirement we created different kinds of accident scenarios and different kind of simulation standard operating procedures those are followed inside this particular environment. So, this is the complete demonstration of the project we are working.

So, Kranti let me ask you that what is it that you are able to see inside this particular HMD.

So, if we will wear this particular HMD, so we have created the complete environment in the desktop. There are two kinds of VR that is one is your come display base VR, projection based VR and second is your computer VR, desktop VR.

So, what you can do is you can you will see this complete environment in a desktop parallelly you can see this complete environment in a VR, but in desktop VR you cannot feel that immersiveness in the projection VR that you will feel. So, whenever I am wearing this particular HMD, so I am feeling that I am particularly working I am feeling that I am working inside that environment. So, if I will move in different direction, I can see that this is the different equipments are present, this is the facility design in the particular workplace.

So, if given to the operator if operator will perform some operation I will be acting as an operator. So, I will be going to the particular operation designated work place and perform my operation. So, I can do by myself and I will act as a particular user inside that environment.

So, that is great ;so thank you Kranti and as we have seen that with the help of virtual reality instruments infrastructure and so on like the HMD, the different VR glasses and so on. One is able to emulate and get trained in different; different scenarios in even before the actual scenario is encountered. So, as Kranti was saying there are different; different scenarios where VR can find applications. For example, for training in the mining scenarios, healthcare where the doctors can perform some kind of doctors can practice even before actually performing the surgery and so on thank you Kranti.

So, let me now ask Professor Maiti is there anything else that we should know about the VR facility over here? Yes, this VR facility is a unique one and I also thank Kranti that he has given good explanation to this, to add to his explanation I want to tell you that there are different stages for ultimate VR that modelling and simulation and tracking. First one is the we have the high-end system, computing system basically for the image first image generation and which is basically projected through a projector or a set of projectors will be good one at present we have one projector.

So, first is image generation, second is image projection and then there is there comes the once the industry environment or the actual environment is created and it is component and every other things then working is simulated synchronized, then the ultimately how to interface with the user. So, we have so many equipment what Kranti already shown to you, primarily the hand gloves then head and hand tracker and then using all those things and the navigation system with the sensors you will be basically immersed in the environment.

And then whatever you want to do as per pre-planned program that you can do that particular kind of things. And from application point of view what I can tell you that it is enormous, particularly although we have started this lab from the accident causation modelling and simulation point of view and that this kind of work can be done in any kind of industries. But apart from this suppose the virtual prototyping in the area of product development and in medical healthcare system particularly from the operations point of view, the pilot who is basically running the plane aircraft that for his or her training point of view.

And hazardous systems like a violent gas, mining, chemical, steel manufacturing even in when working or developing something below the sea that mean under the water. So, it is huge and that is what I wanted to tell you.

Thank you Professor Maiti for adding to the information that we already have and so as we have seen that there is enormous potential of the use of virtual reality.  So, it can be used for varied application starting from training of pilots who are running the aircrafts for underground mining, coal mining or other types of mining.

Underwater works, high hazardous situation I think that situation in working at height, so many things can be done here.

And also from who trained the fire safety workers and so on.

And driving; driving particularly on road driving train drivers, so there are many different types of applications of virtual reality and so far depending on the type of industry the virtual reality environments can be created for the specific type of problem that is being addressed. And so it has lot of applications for industrial uses.

Particularly in the area of Industry 4.0.

For Industry 4.0 and Industrial IoT virtual reality has lot of applications. So, with this I would like to thank once again Professor Maiti and Mr. Kranti thank you so much.

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There is very another very exciting equipment which is the 3D laser scanner which is also used in VR facility. So, this is this one this instrument that you can see in front of you. So, I would like to ask Kranti as well as Avidev could you please explain about this particular instrument how it works?

This is a digitizing device, we can say 3D laser scanning. What it does? It captures the environment data, if we do not have any kind of 3D model or any 2D drawing of any workplace or any kind of environment. So, we capture the digitized form by the 3D laser scanning and we can get directly 3D models or any kind of category. So, it is a very handy thing we can go place it anywhere and we can get the 3D data. So, this is the plus point of it used for this regeneration of any kind of model for any kind of environment ok.

So, moreover I want to add that if you are having complex or intricate shapes in a particular your location which you want to model. So, if you are not getting proper data for that how to model it. So, what you can do is you simply take this equipment and place at that particular workplace, it will scale up to 500 or 600; 600 meter distance. So, it can capture all the more components present in that particular workplace in the form of a point clouds.

So, ultimately the point clouds will be connected through a software that will give you the output as a 3D model. So, instead of giving more time to 3D modelling software and developing the 3D models, we can directly use this and obtain the 3D models as a final product.

Great thank you; basically something like we in order to create the actual industrial environment the 3D modelling what is required in VR models. So, we can just use this equipment in order to get the 3D model get the three point clouds and then through the software or through program get the 3D environment and straight way using the that VR system.

You see right the virtual reality scenario.

That scenario.

Thank you.

**Introduction to Industry 4.0 and Industrial Internet of Things**
**Prof. Sudip Misra**
**Department of Computer Science and Engineering**
**Indian Institute of Technology, Kharagpur**

**Lecture - 65**
**Steel Technology Lab**

So, right now we are in the friction stir welding facility of the department of Mechanical Engineering at IIT Kharagpur. So, I have with me over here the lead of this particular lab Professor S.K. Pal. So, here actually what we intend to do is to show you the use of cyber physical systems, the concept of cyber physical systems and IIoT over here. So, these are as we have seen in the previous lectures that these are prime contributors to the development of Industry 4.0 concepts. So, I have with me Professor S.K. Pal who is going to explain how this kind of friction stir welding is cyber physical system what's impacted?

So, just you give you a recap of how a cyber physical system works. So, we have the physical system; that means, the machine which is actually performing the work and the cyber component so, working hand in hand. So, we have different sensors that are equipped with this particular machine that we are going to show you now and then these sensors they collect lot of data and based on that there is some actuation that is performed and also consequently some kind of control.

So, we have the sensing component, the computing component and the contour component all working hand in hand. So, this is what the cyber physical system is and this friction stir welding machine is a good example of this particular system the cyber physical system. So, these are actually prime contributors to the Industry 4.0 development.

So, Professor Pal would you please explain over here how this friction stir welding process works.

Yeah, thank you. Thank you Professor Misra. So, friction stir welding is a solid state joining process. So, it means it is the most advanced you know the joining technique and you know it is quite different from this the fusion welding process because in case of fusion welding we melt the material and then after that it gets you know  the after solidification you gets the joint and all. So, I quickly explain, what I mean what is the process about.

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So, if you would like to; let us take an example if these two plates have to be joined. So, they are placed side by side in an arc welding configuration and we make use of this the tool, tool has got a projected part which is called the pin and the flat part which is called the shoulder.

So, that the tool rotates and plunges into this the joining line until and unless this flat part touches on the top surface of the tool ok. So, this; there is a friction between the platform of the tool and the job surface that is why the term is the friction is there, friction is aiding the generation of the heat and there is a plastic deformation because of the movement of the pin so that material from one side gets moved to the other one so, that is the starting operation so, that is why the second name is there.

And since there is a relative movement so, that the joining is taken place. So, when the tool comes up it leaves a hole over there. So, the advantage of this process as I mentioned that there is no melting so, it is a solid joining process. So, a lot of industries have you know they come forward and they have already started using it you know for different applications if you could look at this board.

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So, there are applications like this apple, the computer they have welded the front part as well as the back part by the friction welding process. We have got the example of these high speed railway carriages, we have got also the example of the space shuttle ah, but all these examples what we see is that from the industries which are Abroad which are outside. There is no Indian industry so far that use this process, but there is a recent announcement by the chairman of the ISRO Dr. Sivan told in the last satellite launching, that they are going to use this process to a large extent so that there is increase in the payload.

What (Refer Time: 04:21).

Yeah. So, the most beautiful example of this process is that this automobile industry, because there we need to always think for this light weighting. So, light weighting means that the situation comes for the different dissimilar material welding.

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We have got several examples like aluminum and then steel we have got the material the one different composites in LAP and (Refer Time: 04:47), you have got the magnesium and then steel, we have also used this HDPE that high density polyethylene, copper and aluminum, and also different configurations including this the pipe holding.

So, we have exposed all this process, but each and every industry these days is looking for these the compliance of the missing towards the industry 4.0. So, for this compliance the main thing is that as you mentioned that the sensor, sensor we can engage different types of the sensor which collects the data and then we can work on that. But essentially based on these sensors information and your analysis analytics you have to control the process and so, the feedback loop is very much important over here.

So, we have come up with the module for this online control, online monitoring and then analysis and then control everything is done on the cloud based. So, in this particular machine we have engaged the two types of the sensor; one is inbuilt that is the node sensor so, node sensor senses the course information. Because if during welding if any defect comes up, so that will be reflection on the signature of this force.

And this force data is sent to the cloud similarly, we have also acquired the power sensor, power is a direct and the power it has got the direct indication about the defects. And also not only that the defects we basically mean the type of the defects and also the severity of the defects. So, depending on the different varieties of the defect the signature gets changed and also the severity of the defect the signature gets changed.

So, we collected all these information and then we have send it to the cloud, in the cloud we have got the decision the box is an engine. So,

So, basically the analytics is performed at the cloud.

Analytics is performed at the cloud, you are absolutely right and then based on the decision and then which is taken in the cloud out of the knowledge box is there. So, data is that information is information comes from the cloud to the machine, you change the parameter; parameter means the welding parameter, the rotational speed and also the linear speed so that the different case….

Basically, the accuracy of the job can be controlled with a help of this entire play back cycle.

Yeah, exactly because for any manufacturing the process or any if you like to study the performance of the product and the quality of the product, you always need to study the performance of the machine ok. Even though you are setting the optimum parameter, that you are not you are bound to get the true quality, but essentially you won’t get it. So, you always need to look at the weld quality or the product of any process and accordingly you have to change the parameter so, that in terms of essentially in the product.

So, that is the essence of this Industry 4.0. So, we have implemented that one to friction stir welding process which you have you know we are also working on that in a large extent. So, that different machines can be connected to the cloud so, the knowledge of one machines can also be thus shared with the other machine; just like the human being interacting with social media and in the society.

And that physically solves also the purpose of Industry 4.0.

Yeah.

We need to have connectivity between the different processes

Yeah, because when you say the Industry 4.0 you essentially means that the performance of the different types of these you know that the machines and also how do we interact with the other machine, and also the supply chain line; that means, how in this sequence the material's coming up and going out so with the entire change starting from the include the raw material supply to the finished product. You have to think when it is connected with the cyber system then that would connect me to cyber systems and the physical system, and that essentially is very good for Industry 4.0 compact to the process.

So, thank you so much can we have a look at the.

Yes I will request one of my doctor's scholars Mr. Devashish Mishra. So, Devashish Mishra works on this Industry 4.0 process analysis.

Yeah.

So, he is Mr. Devashish Mishra, he will quickly run this the machine and we demonstrate that the welding process, it will show the defects and then essentially over the period of the time how the defects get erradicated. Because when you see the joining process, it means the assembly of the different components and which might be a process to the other the manufacturing technique. So, the quality check on online basis is very very important otherwise can be the rejection of that entire thing.

So, I will. Devashish, could you please quickly switch on the machine and then demonstrate the process?

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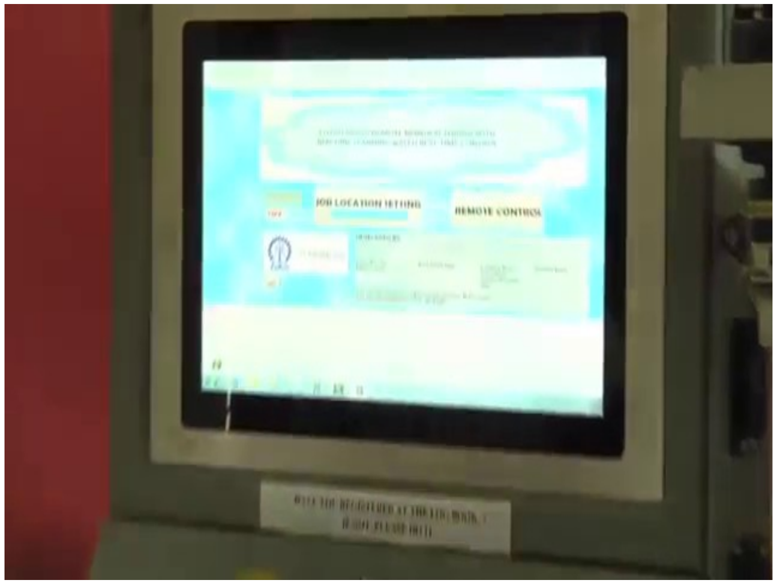


And would like to show it; please show the how bad qualities will getting changed and coming up with a good one.

(Refer Slide Time: 10:11)

So, behind me what you see over here is an indigenous friction stir welding machine which can do friction stir welding on two different materials. So, this particular machine is able to do linear jobs; that means, that two different materials it can weld together in a linear fashion. So, I have with me Mr. Devashish Mishra, who have been the scholar in this particular department and he is going to explain to you how this particular machine works. But before that let me just tell you that what is the whole purpose of showing this particular machine here.

So, we have studied about cyber physical systems and Industrial IoT. So, this is a good example of how cyber physical systems work. So, as I told you before that there is a cyber component and the physical component of these systems which work hand in hand. So, we have different sensors which basically sends different parameters as Mr. Mishra will be explaining shortly.

So, the sensor parameters will be taken and then some computation that is that is done and based on the computation getting some control that is also implemented on this particular system. So, the sensing component the computing and the control working together hand in hand, this is how this particular system works so, this is a good example of a cyber physical system in action. And these types of systems are very much important for industrial environments in the Industry 4.0 scenarios. So, Mr. Mishra could you please explain the functionality of this particular machine?

Yes sir. So, this is manufactured by (Refer Time: 11:46) private limited and it is a three axis friction stir welder. So, as you told it has the capability to join dissimilar materials with similar materials. It has got a maximum rotational speed of 200 rpm and the maximum (Refer Time: 11:59) 1000 (Refer Time: 12:03) per minute. And with this machine we have inbuilt load cells of 10 kilo newton 10 kilo newton capacity inch.

So, this gives us the force section to direction as well as (Refer Time: 12:12) utilization. And apart from that, we have the speed sensors which senses the rotational speed of the machine doing the welding (Refer Time: 12:18) and the covers (Refer Time: 12:19).

So, apart from this rotational speed and travel speed we have two different parameters as well. We till (Refer Time: 12:26)concept, however in this machine we cannot controlled the real time. Now, what .

So, where are these sensors?

Real time monitoring (Refer Time: 12:35) and controlled video of this path, so we have here two aluminum plates which are being placed very close to each other without maintaining any gap between them. And this is the tool which is going to weld these two materials.

So, we have two materials which are aluminum and this particular tool is a steel tool.

Yeah, this a H 1 tool.

Ok.

Which has a (Refer Time: 12:55).

Ok.

Which has been fabricated as per of the dimension of the workpiece

Ok.

So, the thickness of this material is 2.5 mm. So, we have a pin which is of length 2.2 mm and this is the pin diameter is 5 mm and we have this shoulder of 30 mm diameter

Ok. Can we see how it works?

Yes. Actually this is the GY (Refer Time: 13:27); so I am going to switch on the machine (Refer Time: 13:32).

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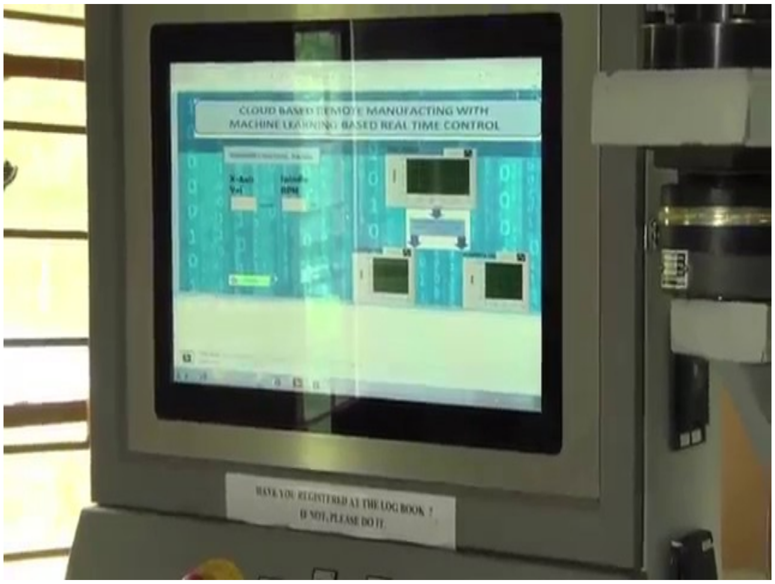


And this is the remote controlled panel I am going to turn up the security. Then (Refer Time: 13:52) this is a remote control

This is the (Refer Time: 13:57) you can remotely.

Access the machine (Refer Time: 13:59).

You can control the machine also remotely.

Yes sir. So, here initially we have set the rotational speed and power speed in such a way, that they are bound to get some (Refer Time: 14:57).

Here, what you see is a vertical milling machine the conventional, traditional, vertical, milling machine. Milling machine as you know are used for smoothing of some metal sheets. And this particular milling machine is something that has been transformed to a friction stir welding machine with the help of different technologies, which will be explained by Mr. Mahathva who is a PhD scholar in this particular lab. So, Mr. Mahathva could you please explain, how this particular machine works.

(Refer Slide Time: 15:46)

This is the vertical manual milling machine and this machine has got wide range of this spindle speed and this machine has got wide machine or table as well. And this table can carry the weight up to the 600 kg and the spindle rpm can be up to 31.5 rpm to 1800 rpm. And on the same time this table can move along x axis, y axis, z axis (Refer Time: 16:17) 16 (Refer Time: 16:19) per minute (Refer Time: 16:20) to 1600 minute (Refer Time: 16:22).

So, with the help of this (Refer Time: 16:26) spindle speed and the rate at which speed and its high weight carrying capacity. This machine can be used for the of friction stir welding of similar and dissimilar material and so far we have converted this machine as a manual FSW machine and we have performed FSW on aluminum sheet and also on aluminum sheet dissimilar (Refer Time: 16:55) aluminum sheet and for monitoring the welding process we have inter related this machine with the same sensor.

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Such as the piezoelectric dynamometer has been installed with this spindles by using this piezoelectric dynamometer during the welding the forces acting on the (Refer Time: 17:14) movement. We can one monitor and on the same time we have also integrated other sensors such as or thermo buffersto (Refer Time: 17.26) the wielding and the heat input. And by using the power sensor we can a measure the power the electric power consumed by this machine.

So, with the help of these data such as the single flow stir welding heat input and electric path and electric path (Refer Time: 17:48) this machine can monitor given a quality. However, since this is not a CNC controlled machine control machine. So, this whole data can be used after welding piezoelectric dynamometer has been connected with a charge amplifier and this inside the piezoelectric dynamometer few piezoelectric crystals are there.

So whenever the spindle is experiencing some sort of the force; electric volt is getting generated on those piezoelectric crystal and by using sensors we are that voltage we are recorded by using our computer.

Thank you.

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