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Key Enablers of Industrial IoT: Sensing-Part 1

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IIoT Features – Recap

- A network of billions of machines and devices, which are connected by communication technologies
- Smart machines and advanced analytics
- Detection of system/machine/product failure and downtime
- More concern about the improvement of efficiency, productivity, health, and safety of a system

Applications with Smart Sensors

Source: IIoT Application, Online: https://internetofthingsagenda.techtarget.com/definition/Industrial-Internet-of-Things-IIoT

IIoT Layer-wise Architecture

Idea Taken from: “Securing the Internet of Things: A Proposed Framework”, Cisco, Online: https://www.cisco.com/c/en/us/about/security-center/secure-iot-proposed-framework.html

Benefits of Sensor Usage in Industry

- Real-time monitoring
- Improving visibility
- Operational efficiency
- Increasing productivity
- Efficient quality management

Source: Online: https://www.newgenapps.com/blog/8-uses-applications-and-benefits-of-industrial-iot-in-manufacturing

Benefits of Sensor usage in Industry (Contd.)

- Improving Safety
- Minimizing downtime
- Improving the prediction and prevention of system failure
- Remote diagnosis

Sensing for Manufacturing Process in IIoT

Remote Control Unit

Central Processing, Controlling, and Storage Unit

Transporting Unit

Quality Testing Unit

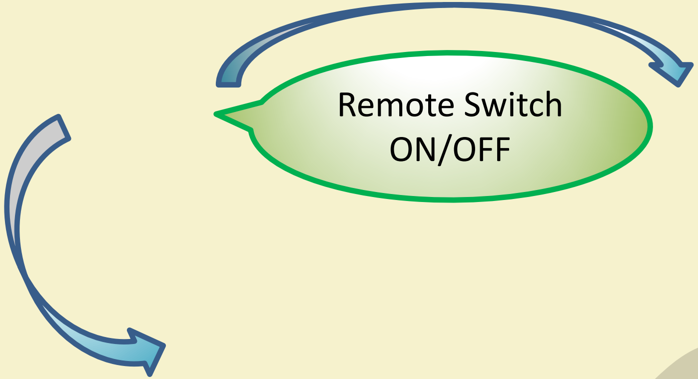
Production Unit

Product Counting Unit

Packaging Unit

Idea taken from: Microsoft and IoT presented by Marlon Luz, Online: https://www.slideshare.net/marlonluz/microsoft-internet-of-things

Sensing for Manufacturing Process in IIoT (Contd.)



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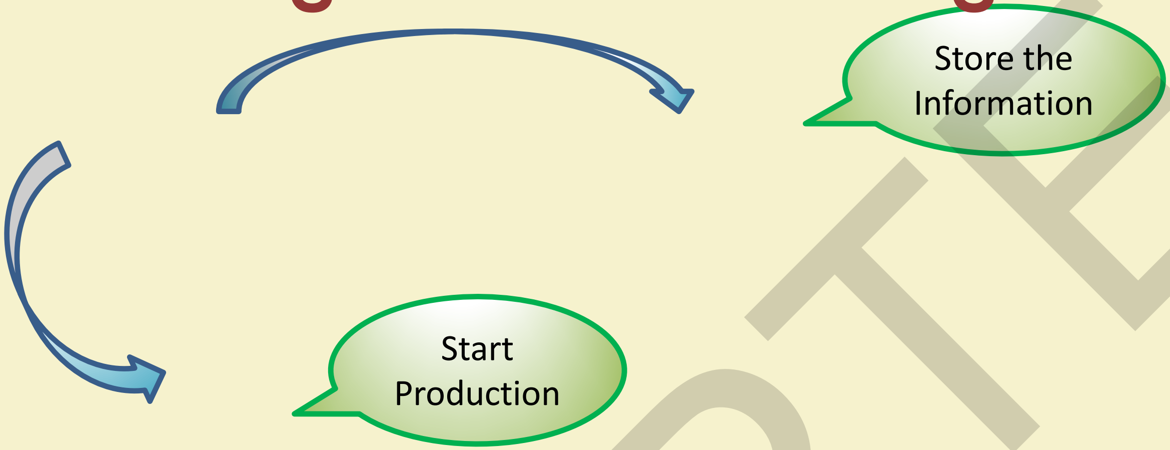

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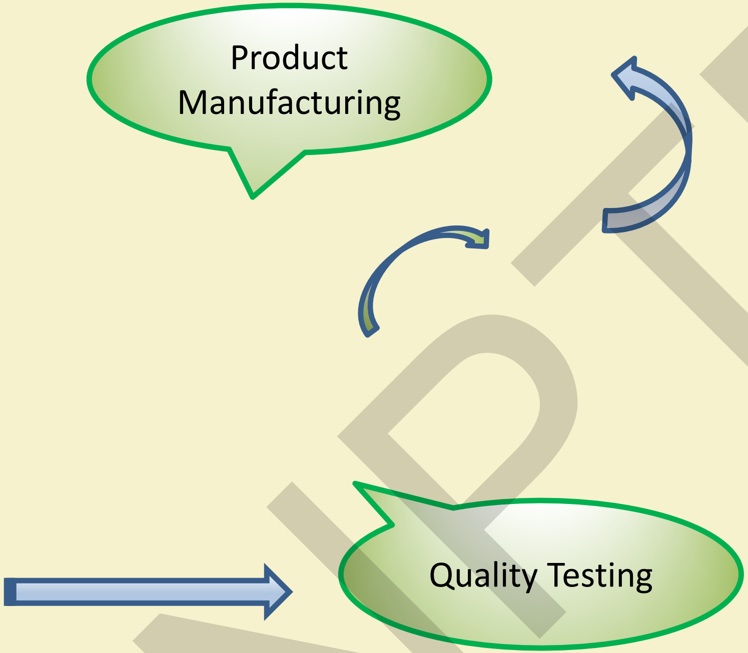

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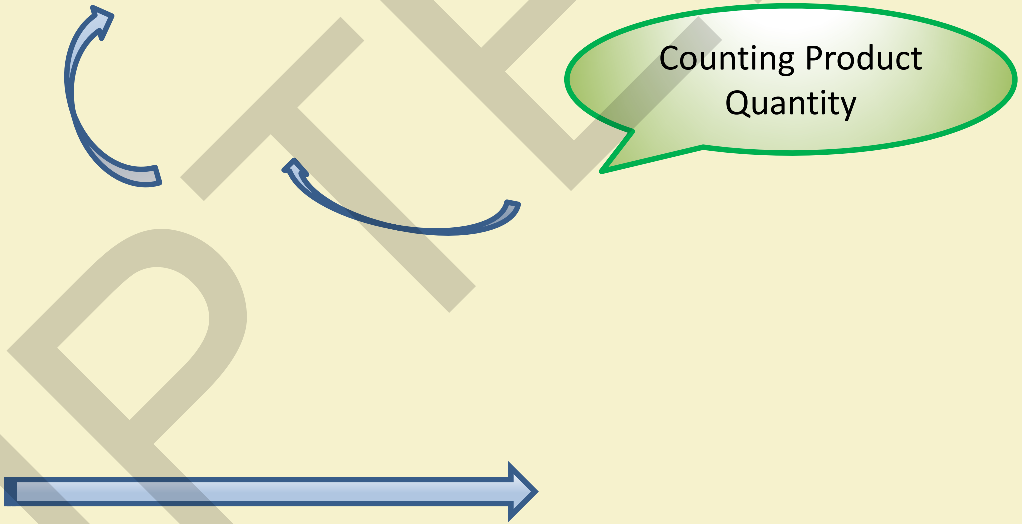

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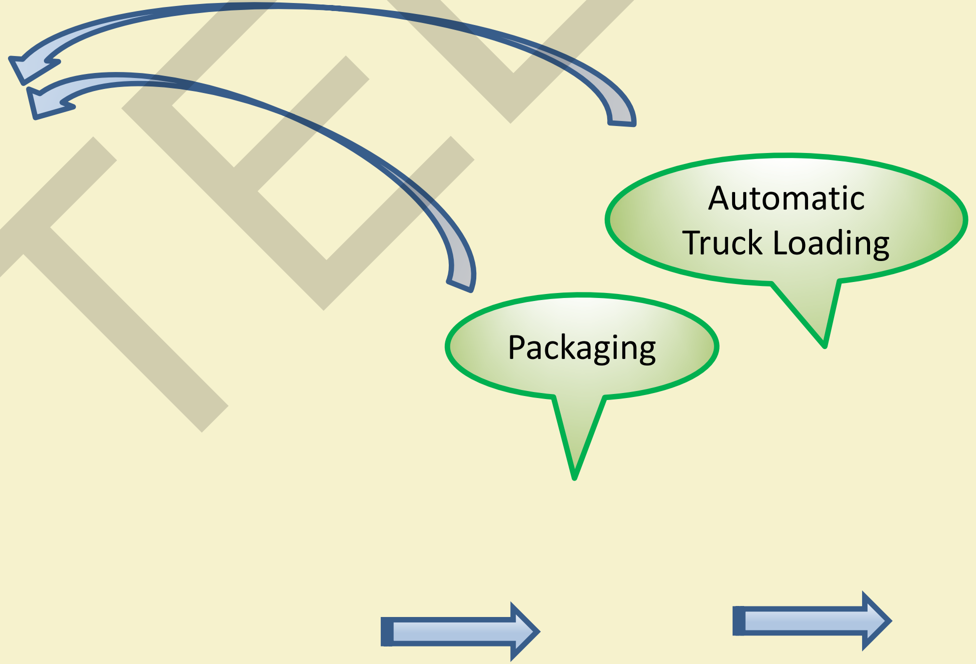

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Sensing for Manufacturing Process in IIoT (Contd.)

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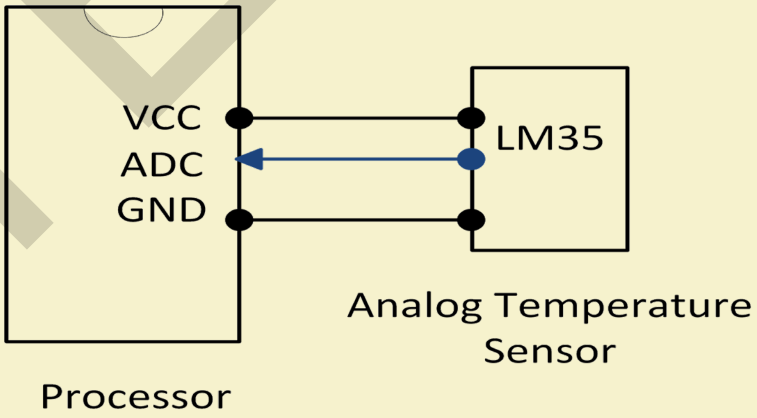
Block Diagram of a IoT Sensing Device

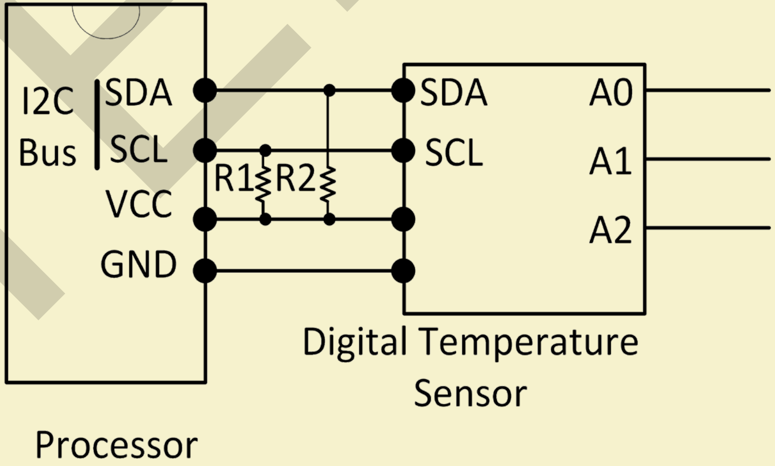
Temperature Sensor Interfacing Circuit

- Monitoring temperature of used devices in industrial applications
- LM 35 temperature sensor generates analog voltage
- The output voltage of LM 35 is linearly proportional to Celsius temperature



Temperature Sensor Interfacing Circuit (Contd.)

- Temperature sensor DS1621 is a <u>digital sensor</u>, which generates <u>9 bits temperature data</u>.
- Operating voltage from 2.7 to 5.5 Volt
- User can define thermostatic settings
- The value of resistors R1 and R2 is from 4.7 to 10 KOhm



Temperature Sensor Interfacing Circuit (Contd.)

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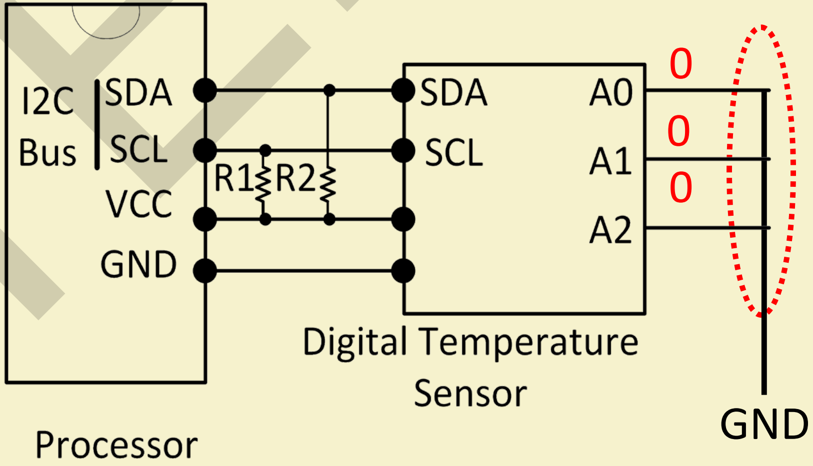

Temperature Sensor Interfacing Circuit (Contd.)

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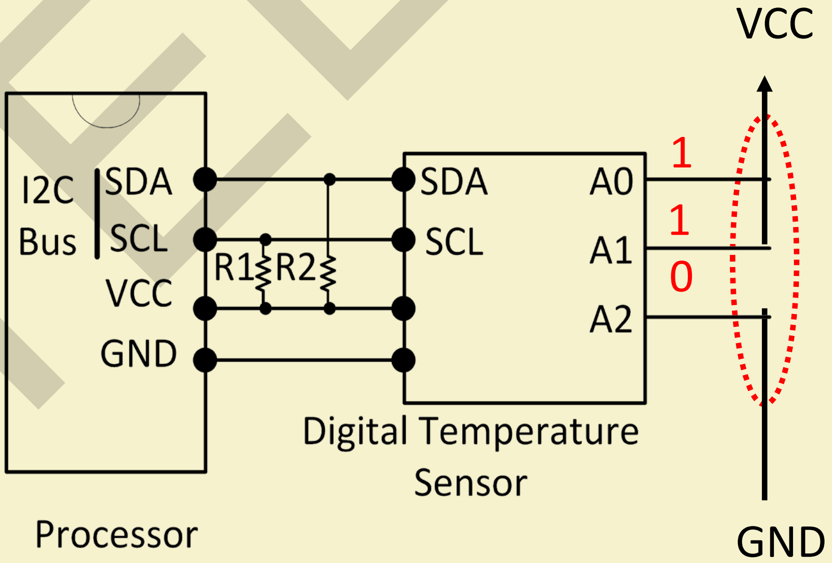
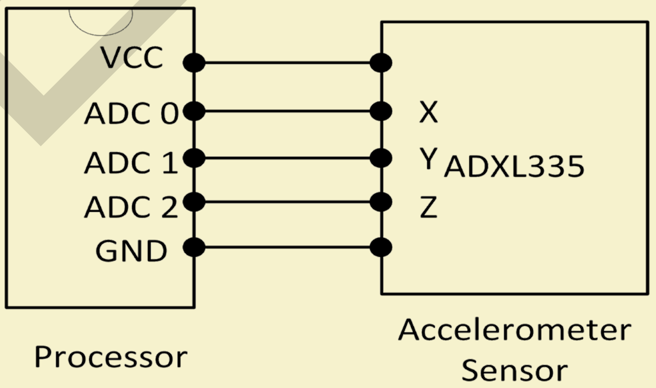


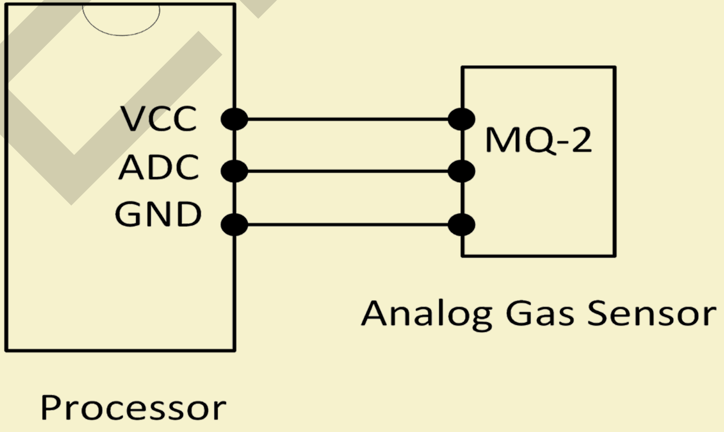
Accelerometer Sensor Interfacing Circuit

- Generates the magnitude and direction of the acceleration
- Accelerometer sensor ADXL335 provides 3 axes (X, Y, and Z) values in analog voltage



Gas Sensor Interfacing Circuit

- Measures and detects concentration of different gases
- Gas sensor MQ-2 provides the concentration of LPG, propane, and hydrogen in analog voltage



Sensors in IIoT Applications

- Temperature sensor
  - Monitoring temperature of used devices in industrial applications such as petrochemical, defense, aerospace, consumer electronics, and automotive
  - Used in some special types of application where a specific temperature is to be maintained, such as fabricate medical drugs and heat liquids.
- Magnetostrictive sensor
  - Measures and detects time-varying stresses or strains in ferromagnetic materials
  - Used for inspection of steel pipes, condition monitoring of machinery, and detection of vehicle safety

Sensors in IIoT Applications (Contd.)

- Torque sensor
  - Measures rotating torque
  - Used to measure the speed of rotation
- Pressure sensor
  - Used to measure pressure in Industrial and hydraulic systems
  - Measures different variables such as speed, water level, and gas/water flow

Sensors in IIoT Applications (Contd.)

- Vacuum sensor
  - Used to measure pressure below than atmospheric pressure
  - Used in different industrial applications such as chemical processing, detection, cathode ray tubes, gas turbine, and helium leak
- Acceleration sensor
  - Measures rate of change of velocity
  - Used to detect the magnitude and direction of the acceleration
  - Used in car electronics, ships, marine, and agricultural machines

Sensors in IIoT Applications (Contd.)

- Speed sensor
  - A measure of how fast
  - Basically measures speed which is determined by the travelling distance in a given time
  - Used in vehicle, diesel engine, engine-powered generator, anti-lock brake, printer, memory, engine-powered compressor
- PIR sensor
  - Detects infrared radiations coming from human body in its surrounding area
  - Used for automatic door open/close, human detection, lift lobby, common staircase, and shopping Mall

Sensors in IIoT Applications (Contd.)

- Image sensor
  - Used for distance measurement, pattern matching, color checking, structured lighting, and motion capture
  - Used in different applications such as 3D imaging, video/broadcast, space, security, automotive, biometrics, medical, and machine vision
- Ultrasonic sensor
  - Mainly uses for object detection, measuring distance, and dynamic body detection
  - Applications: Liquid level monitoring of tank, trash level monitoring, manufacturing process, automobile, and people detection for counting

Source: Camera Sensor’s Application, Online: http://www.cmosis.com/technology/applications/

Sensors in IIoT Applications (Contd.)

- Optical sensor
- Radiation sensor
- Level sensor
- Flow sensor
- Touch sensor
- Gas sensor

References

1. IIoT Application. Online: https://internetofthingsagenda.techtarget.com/definition/Industrial-Internet-of-Things-IIoT
2. Securing the Internet of Things: A Proposed Framework, Cisco, Online: https://www.cisco.com/c/en/us/about/security-center/secure-iot-proposed-framework.html
3. Microsoft and IoT, Presented by Marlon Luz, Online: https://www.slideshare.net/marlonluz/microsoft-internet-of-things
4. Camera Sensor's Application, Online: http://www.cmosis.com/technology/applications/

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Key Enablers of Industrial IoT: Sensing Part-2

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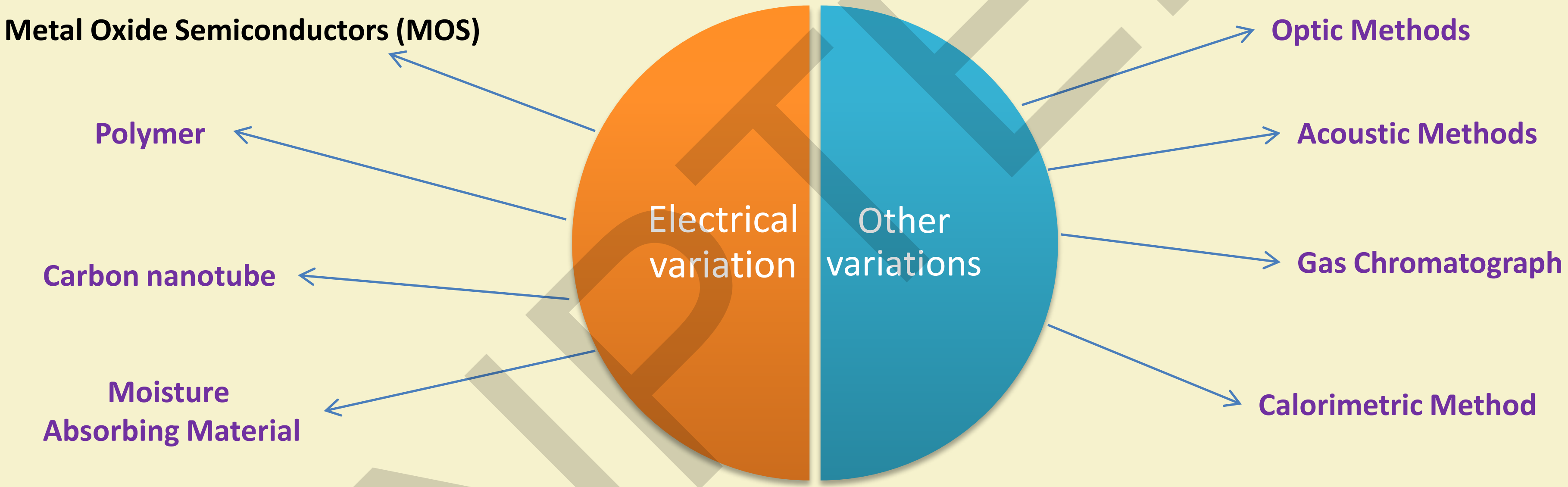
Introduction

- A <u>gas sensing system</u> plays a vital role for monitoring the concentration of flammable, combustible and toxic gases in the environment
- <u>Air quality monitoring and alert systems</u> with gas sensing units may be deployed to avoid risks of harmful exposure of gases in the environment

Gas Sensing Methods



Source: A Survey on Gas Sensing Technology, Sensors 2012

MOS Gas Sensor's Working Principle

- MOS Gas sensors are also called Chemi-Resistive Gas sensors
- Baseline Resistance: Resistance of the sensor material in **air** when not exposed to target gas
- Chemi-resistive gas sensors depend on the thermal energy for its operation which is supplied with an heater
- A particular temperature at which the sensor gives best response is called Optimum Temperature

Source: Electroceramics, Second Edition, A.J.Moulson,J.M.Herbert,Wiley

MOS Gas sensor working Principle(Contd.)

- Resistance changes when exposed to gas depending on the rise or fall in conductivity of the sensor material
- In n-type sensors, resistance decreases, and in p-type sensors, resistance increases with respect to the Baseline resistance when exposed to a reducing gas

Characterisics of Gas Sensor

- **Sensitivity**: It is the change in the output signal with respect to unit change in input (which is the target gas concentration).
- **Selectivity**: Ability to detect a particular gas in a mixture of different gases.
- **Stability**: This parameter determines the robustness in the gas sensing property of a gas sensor in a long time period when exposed to hostile ambience

Characteristics of Gas Sensor (Cond.)

- **Response time:** The time taken by the sensor to stabilize its response while sensing the target gas to reach some percent (80% or 90%) of the final value
- **Reversibility**: Whether the sensor resistance can return back to its base resistance value, if exposure to the target gas is stopped
- **Response Percent:** of a gas sensor is calculated by computing the percentage change in the resistance when exposed to target gas with respect to the resistance when not exposed.

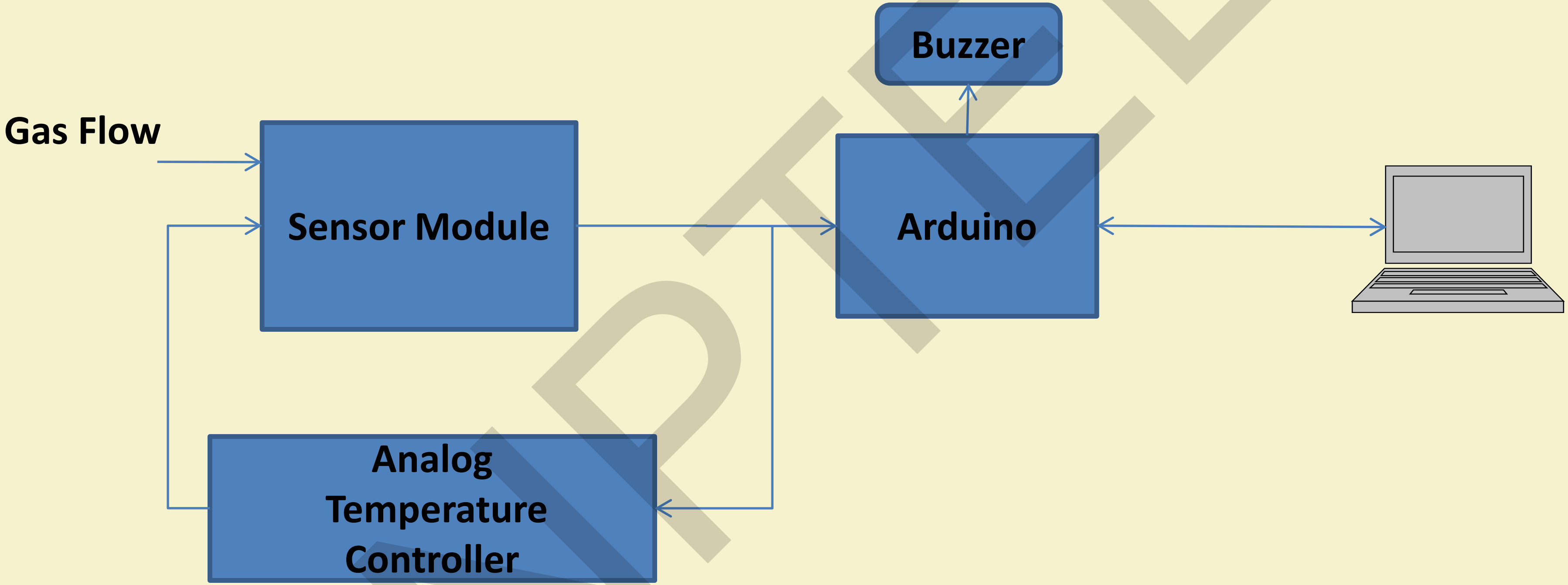
Applications of Gas sensors

- Air quality monitoring
- Leakage Detection of Toxic gases
- Manhole & Sewage Treatment
- Automotive Exhaust
- Alcohol Breath Test

A Demo on VOC Sensing

- **Introduction**
  - This gas sensing system is able to detect the presence of VOCs (Volatile Organic Compounds)
  - As soon as the gas sensors sense these gases, its resistance changes from its baseline resistance.
  - As the resistance changes, an alert is generated

Gas Sensing System



References

[1] A Survey on Gas Sensing Technology, Xiao Liu , Sitian Cheng , Hong Liu , Sha Hu , Daqiang Zhang and Huansheng Ning [1] , Sensors 2012. Online URL: www.mdpi.com/1424-8220/12/7/9635/pdf

[2] How Gas Sensors work.Online URL: https://www.thomasnet.com/articles/instruments-controls/How-Gas-Detectors-Work

[3] Semiconductor metal oxide gas sensors : A Reveiw.,Ananya Dey, Elsevier 2018 . Online URL: https://doi.org/10.1016/j.mseb.2017.12.036

[4] Gas Detection Applications.Online URL: http://www.pem-tech.com/gas-detection-applications.html

[5] Electroceramics, Second Edition, A.J.Moulson, J.M.Herbert,Wiley

[6] Metal oxide for solid state gas sensor : What determines our choice?, G. Korotcenkov ,Elsevier 2007.Online URL: https://doi.org/10.1016/j.mseb.2007.01.044

[7] Detection of hazardous volatile organic compounds (VOCs) by metal oxide nanostructures-based gas sensors: A review, A. Mirzaei, S.G. Leonardi, G. Neri, Elsevier 2017. Online URL: https://doi.org/10.1016/j.ceramint.2016.06.145

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Key Enablers of Industrial IoT: Connectivity-Part 1

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Industrial Communication

- Typical industrial communication requirements
  - Real-time
  - Very low duty-cycle
  - Very low latency
  - Very low jitter
- Industrial Communication majorly thrives on the following technologies:
  - Industrial Ethernet
    - Industrial Ethernet protocols for real-time control and automation.
    - Used in manufacturing processes dealing with clock synchronization and performance.
  - Fieldbus
    - A communication standard for Local Area Network (LAN) of field devices for industrial automation.
    - Used in manufacturing processes dealing with periodic I/O data transfer.

Industrial Communication (contd.)

- Industrial Ethernet
    - ModBus-TCP
    - EtherCat
    - EtherNet/IP
    - Profinet
    - TSN
- Fieldbus
    - Modbus-RTU
    - Profibus
    - Interbus
    - CC-Link
    - DeviceNet

Reference: Industrial Ethernet & Fieldbus solutions from KUNBUS.

ModBus-TCP

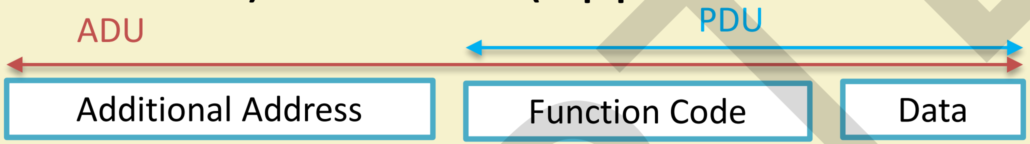
Introduction to ModBus-TCP

- A standard communication protocol used in industry, developed by Modicon Inc (Schneider Electric).
- It uses TCP/IP & Ethernet for data transmission between two compatible devices.
- The communicating system includes several devices:
  - Client-Server devices linked to a TCP/IP network
  - Interlinked devices – bridge or router or gateway
  - Serial line sub-network to grant links between client-server

Source: Modbus messaging on TCP/IP implementation guide.

Features of ModBus-TCP

- A standard date frame is embedded into a TCP frame.
- The protocol defines 2 units in the data frame: PDU (Protocol Data Unit) and ADU (Application Data Unit)



- ADU is identified by a header called MBAP.

Transaction Identifier (2 bytes)	Protocol Identifier (2 bytes)	Length (2 bytes)	Unit Identifier (1 byte)

(MODBUS Application Protocol header – 7 bytes)

Source: Swales, A. Open ModBus/TCP specification.

Features of ModBus-TCP (contd.)

- It is a connection-oriented protocol following the Client-Server architecture.
- Masters are the clients, whereas slaves are denoted as servers.
- The protocol supports up to 10 active connections/sockets at one time.

Source: Introduction to MODBUS TCP/IP.

EtherCat

Introduction to EtherCat

- EthernetCAT (Control Automation Technology) was developed by the ETG (EtherCAT Technology Group).
- It is based on IEC 61158 & IEC 61784 (international standards).
- It follows a master-slave architecture utilizing the standard IEEE 802.3.
- Application areas: time-sensitive scenario (due to high-speed of the system)

Source: Communication solutions for EtherCAT networks from KUNBUS.

Features of EtherCat

- Master and slave exchange data as PDO (process data objects)/telegram.
- Slaves follow multicast or broadcast communication initiated by the master.
- Every PDO contains a distinct address denoting several slaves.
- EtherCAT telegram = Process data + Header.
- Processing incurs a few nanoseconds delay for the telegrams.
- Each telegram utilizes memory up to 4 GB in size.

Source: Communication solutions for EtherCAT networks from KUNBUS.

Features of EtherCat (contd.)

- Data exchange provide low duty cycle time of <~100 µs and low jitter for better synchronization.
- Range of data transmission rate is ~200 Mbps
- Allow transmission range up to 100 m between the individual participants. (Using optical waveguides: up to 20 km).
- Utilizes CRC checksum for fault recognition (bit errors).
- Network topology – tree, star, line, ring, or hybrid.

Source: Communication solutions for EtherCAT networks from KUNBUS.

EtherNet/IP

Introduction to EtherNet/IP

- It is based on the standard Internet Protocol suite and IEEE 802.3.
- EtherNet/IP: CIP (Common Industrial Protocol) Over Ethernet.
- CIP: Unified communication architecture for industrial applications.
  - CIP is a media independent, connection-based, object oriented procedure intended for automation applications.
- It is constructed from layers used in DeviceNet and ControlNet.
- IIoT requires improved throughput and extensive approachability via CIP, which is offered by Ethernet.

Source: EtherNet/IP Quick Start for Vendors Handbook.

Communication Type

- EtherNet/IP defines two primary types of communications:
  - Explicit
    - Provide generic, multi-purpose transmission path between devices.
    - Message transfer is asynchronous.
    - Handles non time-critical information.
  - Implicit
    - Provide distinct and special-purpose transmission paths between a master and several clients.
    - Message transfer is continuous.
    - Handles real-time I/O data.

Source: Brooks, P. EtherNet/IP: Industrial Protocol White Paper.

Features of EtherNet/IP

- Based on active star topology.
- Easy set-up, operation, maintenance, and expansion.
- Handles large amount of information at speed of 10/100 Mbps.
- Maximum data rate up to 1500 bytes per packet.
- Mainly used with PCs, robots, I/O devices, and PLCs (Programmable Logic Controllers).

Source: EtherNet/IP Quick Start for Vendors Handbook.

Profinet

Introduction to Profinet

- Profinet (PROcess FIeld NETwork) is the standard for industrial Ethernet developed by Profibus & Profinet Int.
- The technology is based upon Ethernet/IP.
- Defines the communication channel between controller and distributed devices in the field.
- Basically used for process control and process measurement.

Source: PROFINET Unplugged – An introduction to PROFINET IO.

Communication Channel

- Uses three different communication channels:
  - Non-Real Time (NRT) – Used for non time-critical processes (acyclic read/write operations). Uses standard TCP/IP and UDP/IP to transmit data packets.
  - Real Time (RT) – Used for time-sensitive processes (cyclic data transfer and event-driven procedures). Utilized for optimized and high speed data exchange.
  - Isochronous Real Time (IRT) - Used for clock-synchronized communication. Suitable for motion control applications. Allows short cycle time (~250 μs).

Source: PROFINET. Siemens.

Time-Sensitive Networking (TSN)

Introduction to TSN

- It is an extension of Ethernet based on set of IEEE 802.1Q (virtual LAN) and 802.3 technology.
- It was developed to enable deterministic communication (predictive) for industries on standard Ethernet.
- This protocol is time-aware and distributes data over the bandwidth according to a schedule.
- It is centralized and minimizes jitter using time scheduling for real-time applications.

Source: Time-Sensitive Networking: A Technical Introduction. Cisco Public.

Features of TSN

- It supports cyclic data transfer.
- Provides pre-emption for packets with high priority.
- Network topologies: ring, chain, star, and hybrid topologies.
- Data rate is 100Mbit and 1Gbit for industrial applications.
- TSN offers IT/OT network convergence.
- The network and operation cost is minimized due to the convergence.

Source: TSN: Converging Networks for a Better Industrial IoT.

Modbus-RTU (Remote Terminal Unit)

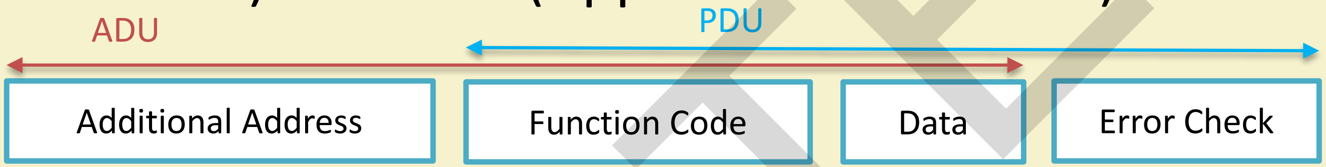
Introduction to Modbus-RTU

- It is a serial protocol (RS-232/485) that follows the Master and Slave architecture.
- It follows a request/response model.
- It is used for transmission of data signal from control/ instrumentation devices to the control unit.
- It is a messaging protocol intended for application layer.

Source: Modbus RTU Unplugged – An introduction to Modbus RTU Addressing, Function Codes and Modbus RTU Networking.

Features of Modbus-RTU

- The protocol defines 2 units in the data frame - PDU (Protocol Data Unit) and ADU (Application Data Unit)



- The client initiates the MODBUS transaction with a request.
- The format of a message request contains the address of the slave, the command (read/write register), the data, and error check.

Source: Modbus RTU Unplugged – An introduction to Modbus RTU Addressing, Function Codes and Modbus RTU Networking.

References

1. Industrial Ethernet & Fieldbus solutions from KUNBUS. Online. URL: https://www.kunbus.com/industrial-communication.html
2. Swales, A. (1999). Open modbus/tcp specification. Schneider Electric, *29*.
3. (2005). Introduction to MODBUS TCP/IP. Acromag, Inc. Online. URL: https://www.prosoft-technology.com/kb/assets/intro_modbustcp.pdf
4. (2014). Modbus TCP/IP Option. Walchem, Iwaki America Inc. Online. URL: https://www.walchem.com/literature/.../180413_WIND%20Modbus%20Manual.pdf
5. (2002). Modbus messaging on tcp/ip implementation guide. Online. URL: https://www.honeywellprocess.com/library/support/Public/Documents/51-52-25-121.pdf
6. Communication solutions for EtherCAT networks. Online. URL: https://www.kunbus.com/ethercat.html
7. (2008). EtherNet/IP Quick Start for Vendors Handbook. ODVA Inc. Online. URL: https://www.odva.org/Portals/0/Library/Publications_Numbered/PUB00213R0_EtherNetIP_Developers_Guide.pdf
8. Brooks, P. (2001). EtherNet/IP: Industrial Protocol White Paper. Logix/NetLinx Technology Adoption Rockwell Automation.

References (contd.)

9. PROFINET Unplugged – An introduction to PROFINET IO. RTA Automation. Online. URL: https://www.rtaautomation.com/technologies/profinet-io/
10. PROFINET. Siemens. Online. URL: https://w3.siemens.com/mcms/water-industry/en/Documents/PROFINET.pdf
11. (2017). Time-Sensitive Networking: A Technical Introduction. Cisco Public. Online. URL: https://www.cisco.com/c/dam/en/us/solutions/collateral/industry-solutions/white-paper-c11-738950.pdf
12. Taylor, A. and Zapke, M. (2017). TSN: Converging Networks for a Better Industrial IoT. Online. URL: https://www.electronicdesign.com/industrial-automation/tsn-converging-networks-better-industrial-iot
13. (2010). Modbus RTU Unplugged – An introduction to Modbus RTU Addressing, Function Codes and Modbus RTU Networking. RTA Automation. Online. URL: https://www.rtaautomation.com/technologies/modbus-rtu/

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Key Enablers of Industrial IoT: Connectivity-Part 2

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Profibus (Process field bus)

Introduction to Profibus

- It is based on the standard IEC 61158.
- It was first started in Germany in late 1980s and then used by Siemens.
- It is a field-bus technology that supports several protocols.
- It supports cyclic as well as acyclic data transmission, isochronous messaging, and alarm-handling.

Source: PROFIBUS Protocol. Smar.

Variants of Profibus

- There are 3 variants:
  - Profibus FMS (Fieldbus Message Specification)
    - Handles communication between PCs and Programmable Logic Controllers.
  - Profibus DP (Decentralized Peripherals)
    - The speed varies from 9.6Kbps to 12Mbps.
    - It uses RS485 balanced transmission.
    - It supports 32 devices at a time (up to 1900 m, up to 10 Km with 4 repeaters).
  - Profibus PA (Process Automation)
    - The speed is fixed at 31.2Kbps.
    - Uses Manchester Bus Power (MBP) for transmission (suits hazardous environment).

Source: PROFIBUS Protocol. Smar.

Features of Profibus

- It defines 2 layers:
  - Data link - accomplished over a FDL (Field bus Data Link).
  - Physical
- It uses bus topology where, the bus or central line is underwired all through the system.
- Buses using MBP supports transmission range up to 1900 meters and can support branches.
- MBP supports data as well as power transmission.

Source: PROFIBUS, PLC Manual; PROFIBUS Protocol. Smar.

Interbus

Introduction to Interbus

- It was developed by Phoenix Contact in 1987.
- It is based upon European Standard, EN 50254 as well as IEC 61158.
- It supports serial communication among control systems (PCs, PLCs) and spatially arranged I/O modules which connects to several sensors & actuators.
- Application areas: sensing-actuating application, machine & system production, and process engineering.

Source: Interbus Basics.

Features of Interbus

- Network topology: Active ring (Supports maximum 512 subscribers, and the last subscriber closes the ring.)
- Total bus length is 13 km. Length between two remote bus devices is 400m.
- Supports master/slave architecture, fixed telegram length, deterministic communication.
- Master & Slave forms a large and distributed shift register ring with master the starting-ending point, while slave as a part of it.
- Transmission rate: 500 kbps

Source: Interbus Basics

CC-Link (Control and Communication)

Introduction to CC-Link

- It is an open industrial network established by Mitsubishi Electric Corporation in 1997.
- It is based upon the standards EN 954 as well as IEC 61508 in the safety area (compatible to ISO 15693 & 14443).
- It enables devices from several manufacturers to communicate.
- Application areas: facilities management, manufacturing & production industries, process control & automation.

Source: CC-Link Protocol. Kunbus.

Variants of CC-Link

Standard CC-Link	CC-Link/LT	CC-Link Safety	CC-Link IE (Industrial Ethernet)
Facilitates transmission of information & control data.	Convenient for implementing sensors and actuators.	Based on CC-Link.	Enables operation, device monitoring & data transmission.
Transmission rate: 10 Mbps	Transmission rate: 2.5 Mbps	Transmission rate: 10 Mbps	Transmission rate: 1 Gbps
Transmission range: up to 1.2 km (RS485), expansible to 13.2 km using repeaters.	Transmission range: up to 500m	-	-
64 stations for every network.	64 stations for every network.	-	Available as fieldbus (254 stations per network) as well as a control network (120 stations per network)

Source: CC-Link Industrial Networks, Wikipedia

Features of CC-Link

- Allows variable communication speed of 2.5Mbps - 1Gbps.
- Maximum transmission distance up to 100 meters (Fieldbus) while 550 meters (Control).
- Operating frequency: 13.56 MHz (licenses global usage).
- Data transmission utilizes both duplex & single lines.
- Facilitates a deterministic communication.

Source: CC-Link Industrial Networks, Wikipedia

DeviceNet

Introduction to DeviceNet

- It is based up on the standard CAN (Controller Area Network) protocol.
- CAN standard is a serial protocol defining the communication of data link layer.
- It links industrial sensors & actuators with high-end devices (Programmable Logic Controllers).
- Application areas: safety devices, data exchange, and large I/O networks.

Source: DeviceNet Communication Manual.

Features of DeviceNet

- Data in CAN is conveyed via data frame: Identifier field (11 bit) and Data field (8 data bytes).
- Also has a remote frame (RTR) that only contains the identifier.
- CAN uses the CSMA/NBA channel access scheme (physical layer).
- It defines different sorts of telegrams (frames), error detecting scheme, and data validation.
- It uses linear network topology that permits the signal (shielded cable) and the power wiring (twisted-pair) in the same cable.

Source: DeviceNet Communication Manual.

Communication Infrastructure

- In IIoT and Industry 4.0 IoT deployments, the connectivity infrastructure can be classified as follows:

  - Wired Connectivity
    - DSL
    - Modem
    - PSTN
  - Wireless Connectivity
    - IEC-PAS 62601/WIA-PA
    - Satellite Connectivity
    - ISA 100
    - LPWAN

Note: ISA 100 is discussed in IoT Communication-Part II of this course.

DSL

Introduction to DSL

- DSL stands for "Digital Subscriber Line".
- Aims at bringing high data rate to households and industries using the common telecommunication line.
- A DSL line can carry both data and voice signals.
- DSL may be categorized as Asymmetric DSL(ADSL) and Symmetric DSL(SDSL).
- ADSL supports a higher download speed compared to the upload speed.
- SDSL supports equal speed for both upload and download.

Features of DSL

- Supports simultaneous connection for voice and data communication.
- Basic DSL supports data rate between 1.544 Mbps and 8.448 Mbps for download service.
- Data is transmitted in its digital format, without any conversion to analog format.
- This digital transmission allows wide range of bandwidth for communication.
- The speed of the service decreases with the increasing distance of the user from the central office of the service provider.

MODEM

Introduction to MODEM

- MODEM is a short form of Modulator-Demodulator.
- A network hardware device to perform the modulation and demodulation of carrier signals with encoded data.
- Data is modulated into analog form at the transmitting side MODEM.
- The received analog data by the MODEM is transformed into digital form, called demodulation.

Types of MODEM

- On the basis of directional capacity:
  - Simplex: It offers data transmission in only one direction, from digital device to network or vice-versa.
  - Half duplex: It offers bi-directional data transmission but one at a time.
  - Duplex: Data transmission can take place in both directions, simultaneously
- On the basis of transmission mode:
  - Synchronous Mode: In this mode a continuous stream of bits of data can be handled but requires an external clock pulse.
  - Asynchronous Mode: In this mode data bytes with start and stop bits can be handled without any external clock signal.

PSTN

Introduction to PSTN

- PSTN stands for "Public Switched Telephone Network".
- It is considered as an aggregation of all the circuit switched networks across the world, used for public telecommunication.
- PSTN networks are also called POTS, Plain Old Telephone Systems.
- These network run on a regional, local, national and international scale using fiber optic cables, telephone connection lines, cellular communications or microwave transmission links.

Source: TSSN - Telephone Networks, Tutorialspoint.

IEC/PAS 62601: WIA-PA

Introduction to IEC/PAS 62601: WIA-PA

- WIA-PA stands for "Wireless Networks for Industrial Automation-Process Automation", is a wireless communication technology, primarily focused on Industrial IoT.
- It is a variation of IEEE 802.15 and IEC.
- Advantages:
  - It supports Adaptive Frequency Hopping (AFH).
  - Aggregation of data packets is done.
  - Variable routing methodologies and modes of application are available.

Source: Yu Chen. IEC 62601: Wireless Networks for Industrial Automation- Process Automation(WIA-PA).

Satellite Communication Technology

Introduction to Satellite Communication

- Satellite communication handles large number of devices providing long range data transmission with global coverage.
- Advantages:
  - <u>Long range communication</u> with <u>global coverage</u>.
  - Cost of transmission is independent of the geographical coverage region.
- Limitations:
  - Launching of satellite in space comes at a <u>higher cost</u>.
  - <u>Propagation delay</u> is more compared to other terrestrial methods.
  - <u>Difficulty in repairs</u> in case of any damage.

Source: Satellite Communication – Introduction, Tutorialspoint

References

1. PROFIBUS. RTA Automation. Online. URL: https://www.rtaautomation.com/technologies/profibus/
2. (2018) PROFIBUS. PLC Manual. Online. URL: http://www.plcmanual.com/profibus
3. PROFIBUS Protocol. Smar. Online. URL: http://www.smar.com/en/profibus
4. Interbus Basics. Online. URL: http://www.interbus.de/dl/Dok_interbus_basics_en.pdf
5. Interbus - The Network For Enterprises. Kunbus. Online. URL: https://www.kunbus.com/interbus.html
6. Speed, C. (2005). INTERBUS Means Speed, Connectivity, Safety.
7. CC-Link Protocol. Kunbus. Online. URL: https://www.kunbus.com/cc-link.html
8. CC-Link Industrial Networks. Wikipedia. Online. URL: https://en.wikipedia.org/wiki/CC-Link_Industrial_Networks
9. (2008). DeviceNet Communication Manual. Online. URL: http://ecatalog.weg.net/files/wegnet/WEG-ssw07-devicenet-communication-manual-10000046963-manual-english.pdf
10. DeviceNet® Communications. Online. URL: https://www.eurotherm.com/devicenet-communications
11. Margaret Rouse. Fast Guide to DSL (Digital Subscriber Line). Online. URL: https://whatis.techtarget.com/reference/Fast-Guide-to-DSL-Digital-Subscriber-Line.
12. Bradley Mitchell. July 05, 2018. DSL: Digital Subscriber Line. Online. URL: https://www.lifewire.com/digital-subscriber-line-817527

References (contd.)

13. Dinesh Thakur. Modem: What is a Modem? Types of Modems. Online. URL: http://ecomputernotes.com/computernetworkingnotes/computer-network/explain-about-modem
14. TutorialsPoint. Network Devices. Online. URL: https://www.tutorialspoint.com/communication_technologies/communication_technologies_network_devices.htm.
15. Yu Chen. IEC 62601: Wireless Networks for Industrial Automation- Process Automation(WIA-PA). URL: https://pdfs.semanticscholar.org/presentation/c5da/da2c05aeff9065ed22b1967b97bdc059dda1.pdf
16. May/June 2016. Satellite and the industrial IoT market in EMEA: an opportunity for Ku-band service. Online. URL: http://www.satelliteevolutiongroup.com/articles/IoT.pdf
17. TutorialsPoint. Satellite Communication – Introduction. Online. URL: https://www.tutorialspoint.com/satellite_communication/satellite_communication_introduction.htm.

Thank You!!

Key Enablers of Industrial IoT: Connectivity-Part 3

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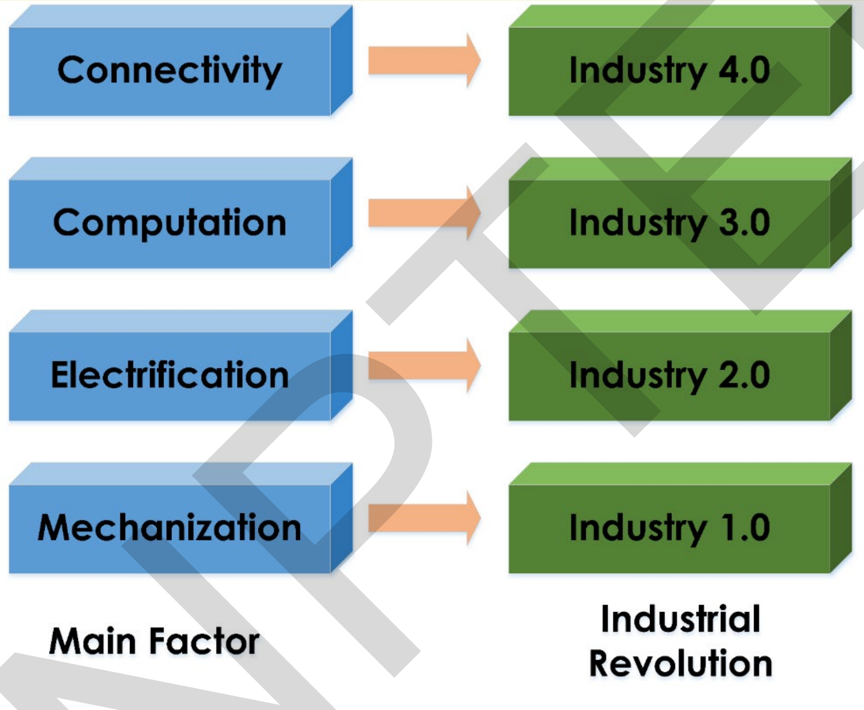
Introduction



Key Requirements

- Supports heterogeneity
  - Devices: Industrial robots, machineries, security cameras
  - Device-specific QoS parameters: delay, availability, reliability, throughput
- Unified connectivity
- Optimized service
- Dedicated network
- Low-latency communication
- Ultra-reliable communication

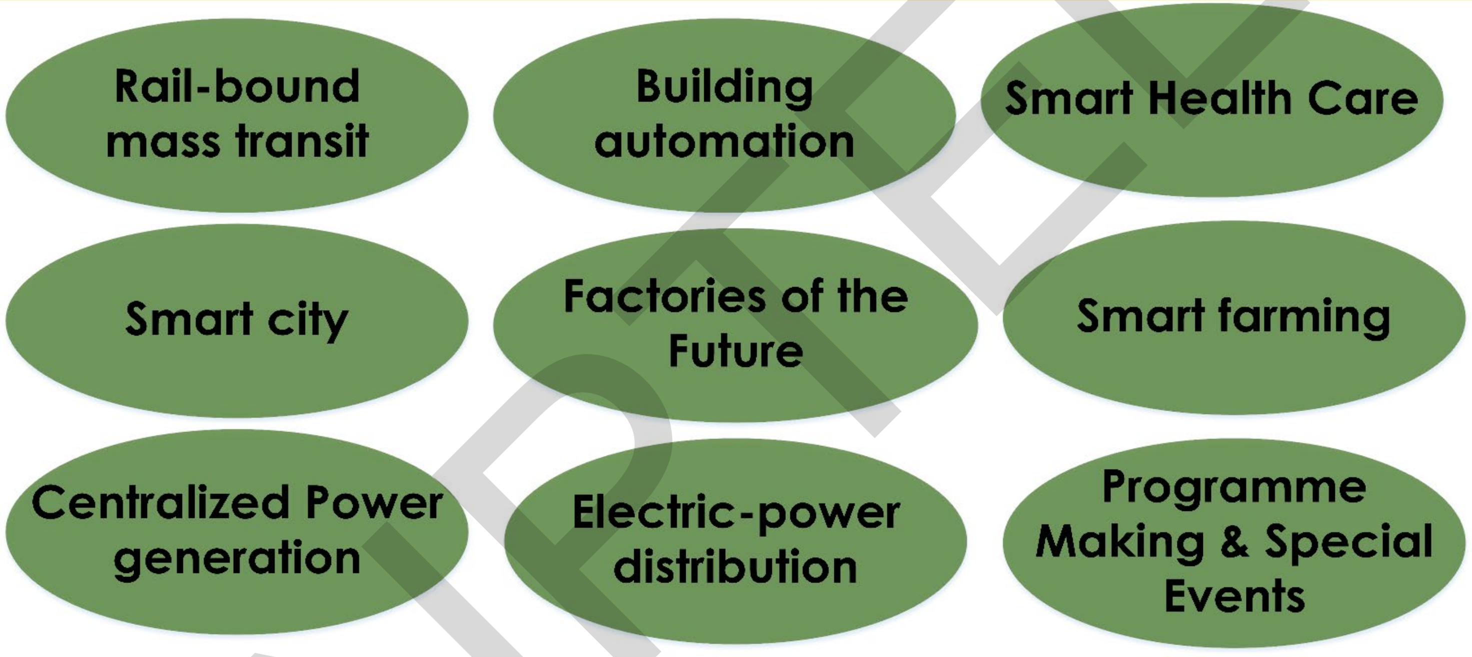
Source: G. Brown and M. Yavuz, "What Does 5G NR Bring to the Industrial IoT & the Factory of the Future? " Qualcomm (Producer), June 2018

Community Initiatives

- 3GPP
  - Study communication requirements specific to industries (Release 15)
  - “*Factories of the Future*” 5G usecase in (Release 16)
- 5G-ACIA
  - Unite OT industries, ICT industries and academia for enabling 5G for industries
- IEEE
  - Enabling Ethernet for Time Sensitive Network (TSN) - 802.1Q Ethernet

Source: G. Brownl and M. Yavuz, "What Does 5G NR Bring to the Industrial IoT & the Factory of the Future? " Qualcomm (Producer), June 2018

3GPP Release16 Usecases



Source: 3GPP Technical Report 22.804, “Study on Communication for Automation in Vertical domains”, 2018

Factories of the future

- Realization of heavy industries
  - Oil refineries
  - Mining
  - Manufacturing
  - Warehouses
- Systems in Interest
  - Motion Control
  - Robotics
  - Massive wireless sensor networks

Source: 3GPP Technical Report 22.804, "Study on Communication for Automation in Vertical domains", 2018

5G support for Private Network

- 5G new radio (NR)
  - Low band (<1 GHz)
  - Middle band (1-6 GHz)
  - High band (>24 GHz) millimeter wave
- Smallcell deployments
  - Femtocell
  - Picocell
  - Integrated WiFi
- Device-to-Device communication

Source: G. Brownl and M. Yavuz, "What Does 5G NR Bring to the Industrial IoT & the Factory of the Future? " Qualcomm (Producer), June 2018

5G -NR

5G-NR

- New air-interface proposed by 3GPP
- Aligned with ITU service categories
  - Enhanced mobile broadband (eMBB)
  - Massive machine-type communication (mMTC)
  - Ultra reliable low latency communication (uRLLC)
- Design objectives
  - Backward compatibility
  - Enabling versatile connections

Source: H. Ji et al., "Ultra-Reliable and Low-Latency Communications in 5G Downlink: Physical Layer Aspects," IEEE Wireless Communications, vol. 25, no. 3, pp. 124-130, JUNE 2018.

Smallcell Deployment

Smallcell Deployment

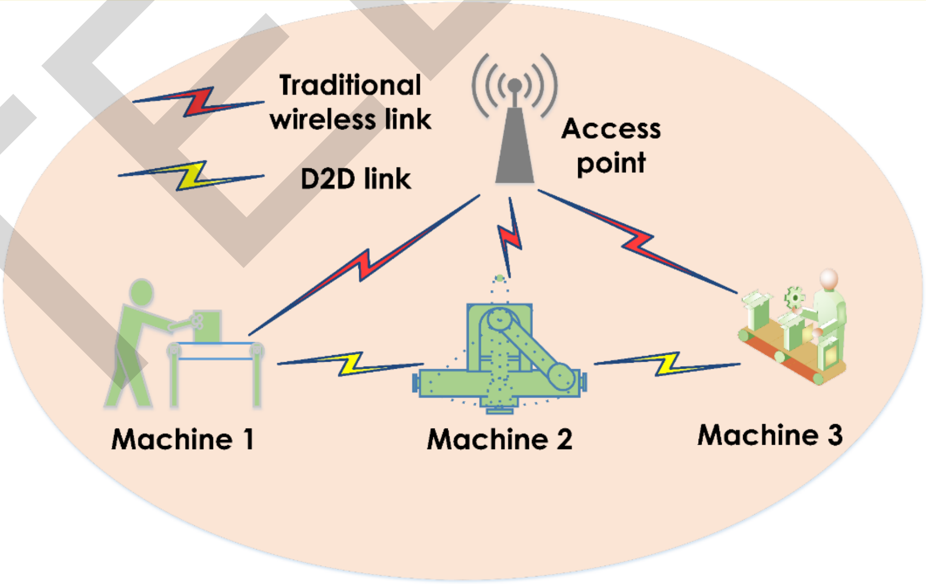
- Objectives
  - Alleviating burden on backhaul
  - Improving energy efficiency
  - Decreasing dead zones
- Operating frequency
  - Licensed spectrum
  - License-exempted spectrum

Source: A. Damnjanovic et al., "A survey on 3GPP heterogeneous networks," IEEE Wireless Communications, vol. 18, no. 3, pp. 10-21, 2011

Device-to-Device Communication

Device-to-Device Communication

- Objectives
  - Achieving low latency
  - Increasing throughput
  - Eliminating load core network
- Operating frequency
  - Inband deployment
    - Overlay, Underlay
  - Outband deployment
    - Controlled, Autonomous



Source: A. Asadi et al., "A Survey on Device-to-Device Communication in Cellular Networks," IEEE Communications Surveys & Tutorials, vol. 16, no. 4, pp. 1801-1819, Fourthquarter 2014.

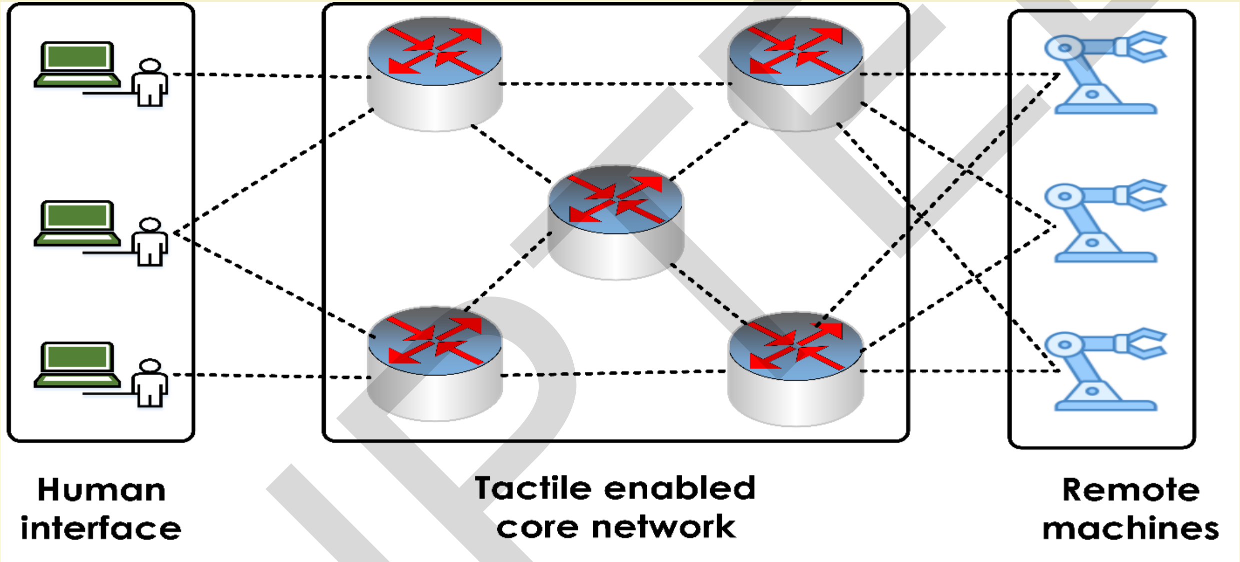
Tactile Internet

Introduction

- Real-time transmission of touch/sense and actuation
- Provides new facet to human-machine interaction
- Enables haptic communication
- Supports low end-to-end latency
  - < 1 ms round trip latency

Source: G. P. Fettweis, "The Tactile Internet: Applications and Challenges," in IEEE Vehicular Technology Magazine, vol. 9, no. 1, pp. 64-70, 2014.

Haptic communication architecture



Source: K. Antonakoglou, et al., "Towards Haptic Communications over the 5G Tactile Internet," in IEEE Communications Surveys & Tutorials. doi: 10.1109/COMST.2018.2851452

Requirements

- Ultra-responsive connectivity
  - Latency in the order of 1 ms
- Ultra-reliable connectivity
  - Ubiquitous connectivity and wide range coverage
- Security and privacy
- Tactile data
- Edge intelligence

Source: M. Simsek, et. al., "5G-Enabled Tactile Internet," in IEEE Journal on Selected Areas in Communications, vol. 34, no. 3, pp. 460-473, 2016.

Way to realizing tactile internet

- Software Defined Networking (SDN)
- Massive Multiple-Input and Multiple-Output (MIMO)
- Dual connectivity
- Mobile Edge Computing (MEC)
- Network Function Virtualization (NFV)

Source: K. Antonakoglou, et. al., "Towards Haptic Communications over the 5G Tactile Internet," in IEEE Communications Surveys & Tutorials. doi: 10.1109/COMST.2018.2851452

Applications

- Industry automation
- Autonomous driving
- Robotics
- Healthcare
- Virtual and augmented reality
- Gaming
- Unmanned autonomous system

Source: M. Simsek, et. al., "5G-Enabled Tactile Internet," in IEEE Journal on Selected Areas in Communications, vol. 34, no. 3, pp. 460-473, 2016.

uRLLC

Introduction

- Ultra-reliable Low Latency Communication
- Requirements:
  - Availability: 6-Nines (99.9999%)
  - End-to-End Latency : 1ms
  - Reliability: < 10^{-5} outage probability
  - Packet size: 32-200 B
  - Smaller transmission duration

Source: G. Pocovi et. al., "Achieving Ultra-Reliable Low-Latency Communications: Challenges and Envisioned System Enhancements," in IEEE Network, vol. 32, no. 2, pp. 8-15, 2018

Design Challenges

- Lacuna in traditional communication systems:
  - Primary objective: High throughput
  - Large latency (10 – 100 ms)
  - Large transmission time interval (TTI)
  - Large processing delay
  - Aggressive retransmission scheme
- Shorter TTI
  - Larger signal overhead
- Error prone channel
  - Decreases reliablity

Source: G. Pocovi et. al., "Achieving Ultra-Reliable Low-Latency Communications: Challenges and Envisioned System Enhancements," in IEEE Network, vol. 32, no. 2, pp. 8-15, 2018

Enabling Methods

- Shorter TTLs
  - Smaller slot length (micro scale)
  - Flexible transmission frame structure
  - Reducing Orthogonal Frequency Division Multiplexing **symbols** in TTL
  - Reducing symbol duration
  - Application: Mission-critical services

Source: G. Pocovi et. al., "Achieving Ultra-Reliable Low-Latency Communications: Challenges and Envisioned System Enhancements," in IEEE Network, vol. 32, no. 2, pp. 8-15, 2018

Enabling Methods (Contd..)

- Fast HARQ Retransmission scheme
  - Procedure: Predicting correctness of received symbol before decoding
  - Advantage: Reduces processing time
  - Disadvantage: False positive error
- Control channel enhancement methods:
  - CQI based Link adaptation
  - Compact downlink control information (DCI)

Source: G. Pocovi et. al., "Achieving Ultra-Reliable Low-Latency Communications: Challenges and Envisioned System Enhancements," in IEEE Network, vol. 32, no. 2, pp. 8-15, 2018

mmWave Communication

Introduction

- Frequency Spectrum : 30 – 300 GHz
  - mmWave for cellular communication: 30 – 100 GHz
  - Indoor communication : 57 – 64 GHz (Unlicensed band)
- Wave length : 1 - 10 mm
- Reduced element size
- MIMO based narrow beam formation

Source: G. Pocovi et. al., "Achieving Ultra-Reliable Low-Latency Communications: Challenges and Envisioned System Enhancements," in IEEE Network, vol. 32, no. 2, pp. 8-15, 2018

Enabling Methods

- Heterogeneous structure
  - Single macrocell with multiple smallcell
- Separate control and data channel
  - Control channel : microwave frequency (3G, 4G)
  - Data channel : mmWave frequency
- Dual mode smallcell

Source: G. Pocovi et. al., "Achieving Ultra-Reliable Low-Latency Communications: Challenges and Envisioned System Enhancements," in IEEE Network, vol. 32, no. 2, pp. 8-15, 2018

Disadvantages

- Need high-gain and high-directional antennas
- Signal blocking
- Suffer high penetration loss and shadowing
- Focused beam has very less chance to avoid blocking
- Low transmitting power due to maintain power amplifier efficiency

Source: J. G. Andrews, et. al. , "Modeling and Analyzing Millimeter Wave Cellular Systems," in IEEE Transactions on Communications, vol. 65, no. 1, pp. 403-430, 2017.

References

1. G. Brown and M. Yavuz, webinar on "What Does 5G NR Bring to the Industrial IoT & the Factory of the Future? ", *Qualcomm*, June 2018.
2. 3GPP Technical Report 22.804, "Study on Communication for Automation in Vertical domains", 2018.
3. A. Damnjanovic et al., "A survey on 3GPP heterogeneous networks," *IEEE Wireless Communications*, vol. 18, no. 3, pp. 10-21, 2011.
4. H. Ji et al., "Ultra-Reliable and Low-Latency Communications in 5G Downlink: Physical Layer Aspects," *IEEE Wireless Communications*, vol. 25, no. 3, pp. 124-130, JUNE 2018.
5. A. Asadi et al., "A Survey on Device-to-Device Communication in Cellular Networks," *IEEE Communications Surveys & Tutorials*, vol. 16, no. 4, pp. 1801-1819, Fourthquarter 2014.
6. G. P. Fettweis, "The Tactile Internet: Applications and Challenges," *IEEE Vehicular Technology Magazine*, vol. 9, no. 1, pp. 64-70, 2014.
7. K. Antonakoglou, et. al., "Towards Haptic Communications over the 5G Tactile Internet," *IEEE Communications Surveys & Tutorials*. doi: 10.1109/COMST.2018.2851452.

References

7. M. Simsek, et. al., "5G-Enabled Tactile Internet," *IEEE Journal on Selected Areas in Communications*, vol. 34, no. 3, pp. 460-473, 2016.
8. G. Pocovi et. al., "Achieving Ultra-Reliable Low-Latency Communications: Challenges and Envisioned System Enhancements," *IEEE Network*, vol. 32, no. 2, pp. 8-15, March-April 2018
9. J. G. Andrews, et. al. , "Modeling and Analyzing Millimeter Wave Cellular Systems," *IEEE Transactions on Communications*, vol. 65, no. 1, pp. 403-430, Jan. 2017

Thank You!!