GCR Code: 4te5zrg

EIE228 – IoT for Automation

For V Semester Minors in ROBOTICS & AUTOMATION

UNIT 1- Fundamentals of Industry 4.0 & IIOT

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SASTRA

ENGINEERING · MANAGEMENT · LAW · SCIENCES · HUMANITIES · EDUCATION

DEEMED TO BE UNIVERSITY

(U/S 3 of the UGC Act,1956)

THINK MERIT | THINK TRANSPARENCY | THINK SASTRA

THANJAVUR | KUMBAKONAM | CHENNAI

Learning Outcomes:

- *The subject aims to ensure that the students will be able to*
  - *Describe the enabling factors and technologies of I-IoT and Comprehend Industry automation and CIM pyramid*
  - *Acquire knowledge on open-source microcontroller platform and describe protocols for industry automation*
  - *Comprehend the significance of edge and fog computing and distinguish IoT and M2M Applications*

UNIT – I **11Periods**

Industrial IoT:

IoT Enabling Factors and Key Technologies - IoT vs Industrial IoT (I-IoT) - Industry Environment and Scenarios covered by I-IoT - Automation and Types in the Industrial Process – Computer-integrated manufacturing (CIM) Pyramid - IoT Levels and Deployments

UNIT – II **10 periods**

Prototyping Devices and Protocols:

Physical and Logical Design of I-IoT - Communication Models and APIs - I-IoT Design Methodology - Device & Component Integration - Message Queuing Telemetry Transport (MQTT) Protocol - Industrial Protocols - Automation Networks & Fieldbus - Cloud I-IoT Solution.

UNIT – III **11 Periods**

Enablement Platform for IoT:

Application Enablement Platforms - Data Analytics Platforms - Data Virtualization Platforms - Data Visualization Platform - Cloud inspired IoT environments - Emergence of Edge and Fog Clouds - Edge Data Analytics - I-IoT Data Flow in Factory and Cloud.

UNIT – IV **12 Periods**

Industrial Applications & Technologies:

M2M - Communication and 5G Technologies for supporting IoT in Industry Automation - Software Defined Networks and Network Function Virtualization - Mobile Application Development Platforms - Case studies: Industrial Automation - Autonomous Robots.

Textbooks:

1. Veneri, Giacomo, and Antonio Capasso. Hands-on Industrial Internet of Things: Create a powerful industrial IoT infrastructure using industry 4.0. Packt Publishing Ltd, 2018.

2. Pethuru Raj, Anupama C.Raman.The Internet of Things: Enabling Technologies, Platforms, and use cases, CRC Press, 1st Edition, 2017.

Reference Books:

1. Alice James, Avishkar Seth , Subhas Chandra Mukhopadhyay. IoT System Design: Project Based Approach, Volume 41, Springer, 2021.

2. Arshdeep Bahga, Vijay Madisetti. Internet of Things: A Hands of Approach, 1st Edition, 2014.

Online Materials

1. https://nptel.ac.in/courses/108105063/

Assignments – Mini Project (batch of 3).

1. Select a simple application, such as smart automation, automated irrigation, smart parking, smart lighting, smart appliances, intrusion detection, air quality monitoring, or machine diagnosis. Identify the cutting-edge technologies required to make it Industry 4.0 ready. Determine the suitable components and cloud platforms to enable IoT functionality.
2. Develop a solution for the selected application. Integrate relevant sensors, a microcontroller, and a cloud platform. Ensure that the sensor data is logged in the cloud for historical analysis.
3. Choose an appropriate actuator for the selected application and interface it with the controller. Log all relevant parametric and status data of the system, including historical data, in the cloud.
4. Successfully demonstrate the system for the selected application, ensuring it meets all the specified objectives

Assessment Model

Components	Weightage
CIA-1, 2 and 3	30% (best of two)
Assignment:	
Problem Identification (1)	3%
Design of Solution (2)	5%
Integration (3)	5%
Demonstration (4)	7%
ESE	50%
Total	100%

Course Model

- 3 hours of lectures and discussion per week
- Assignments – Mini Project – Group of 3 preferrable

Automation

- **Automation** is the use of machines and technology to make processes run on their own without manpower

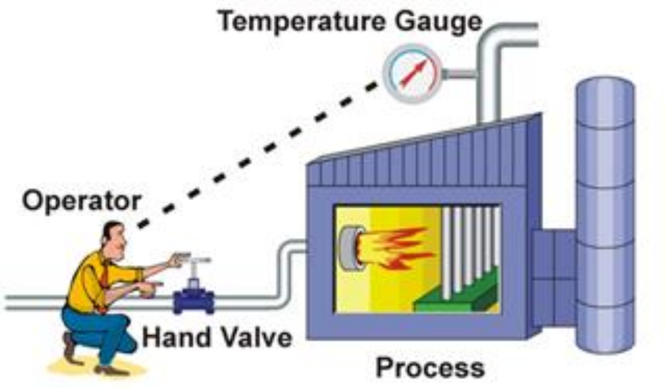
- Technique, method, or system of operating or controlling a process by electronic devices, reducing human intervention to a minimum

- Appropriate use of machines, electronic devices and computer software for the Task

✓ Increase the productivity and Quality

✓ Reduces the duration and laborious work

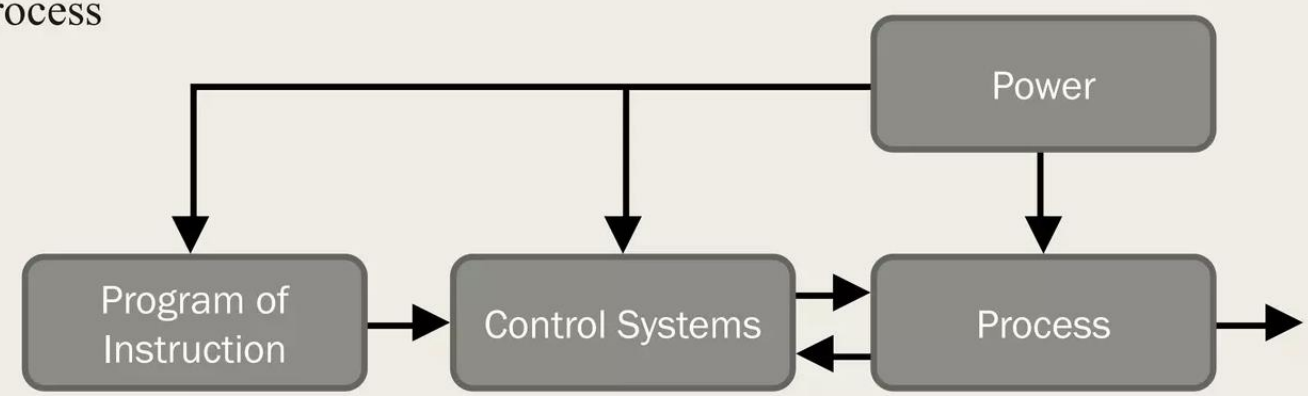
✓ Increases the safety and flexibility



Elements of Automation

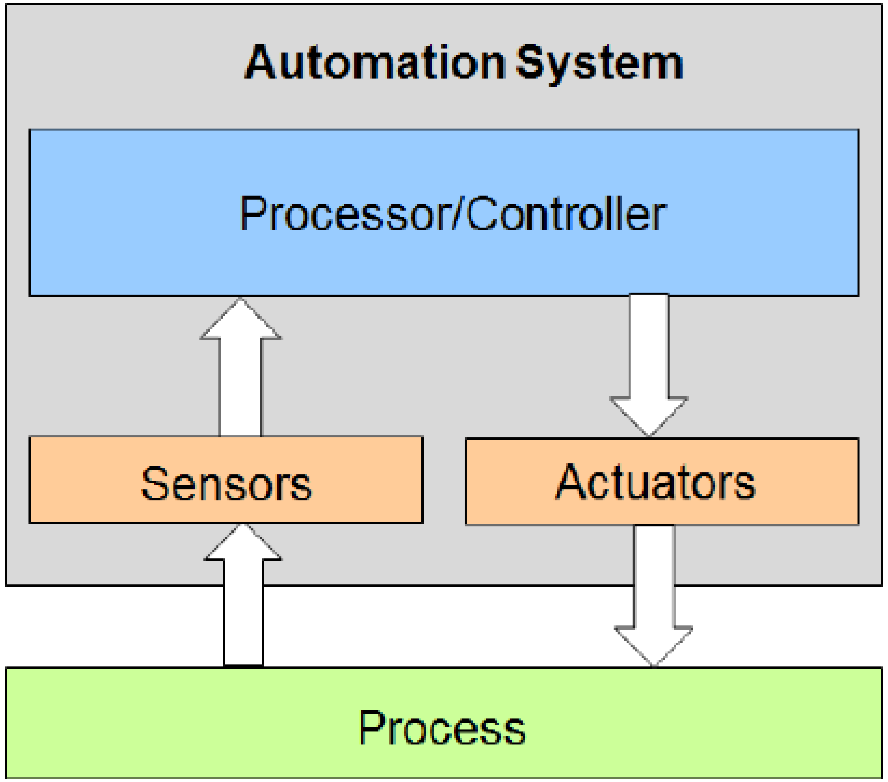
1. Power
2. Program of instructions
3. Control systems
4. Process

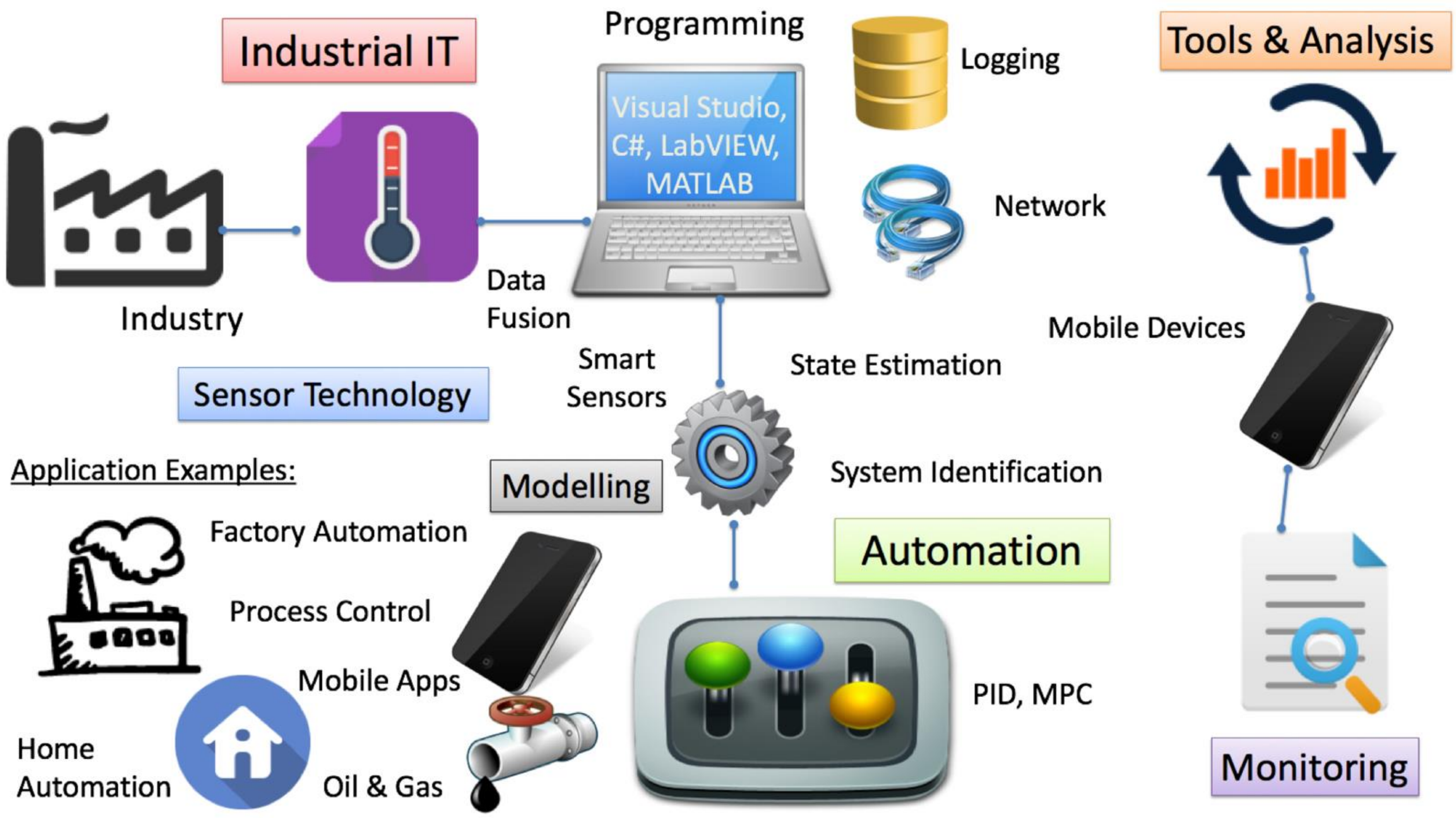
- Energy conversion
- requirements of complete systems
- Mainly electrical



Set of instruction
- Work cycles
- Decision making in programmed cycle

- Open loop control system
- Closed loop control system

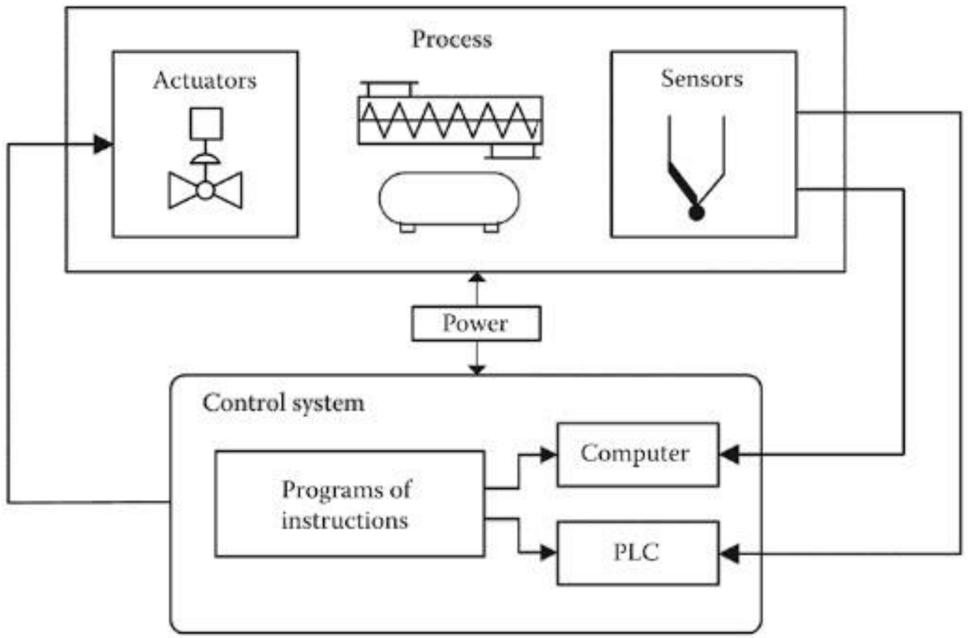


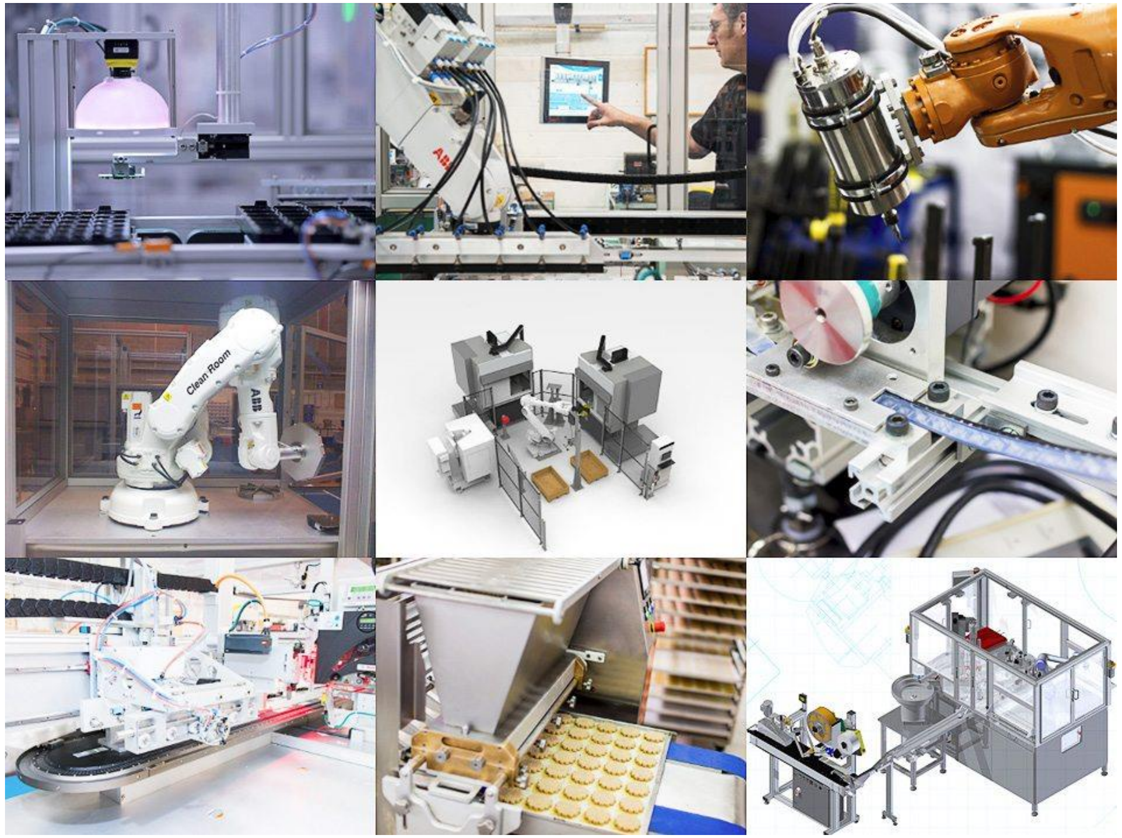

Industrial IT
Programming
Logging
Tools & Analysis
Visual Studio, C#, LabVIEW, MATLAB
Network
Industry
Data Fusion
Smart Sensors
State Estimation
Mobile Devices
Sensor Technology
System Identification
Application Examples:
Modelling
Factory Automation
Automation
Process Control
Mobile Apps
PID, MPC
Home Automation
Oil & Gas
Monitoring

0

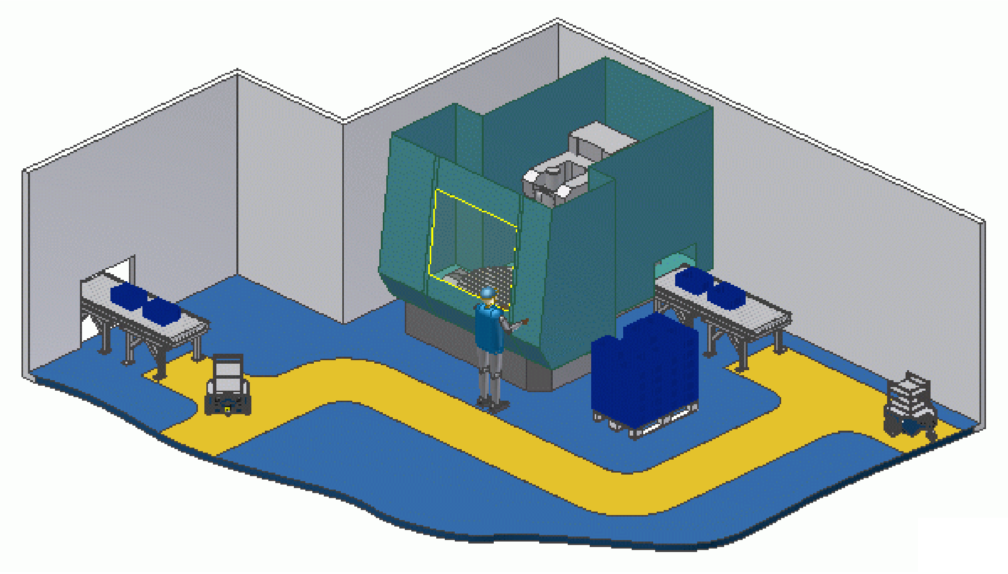
Industrial Automation

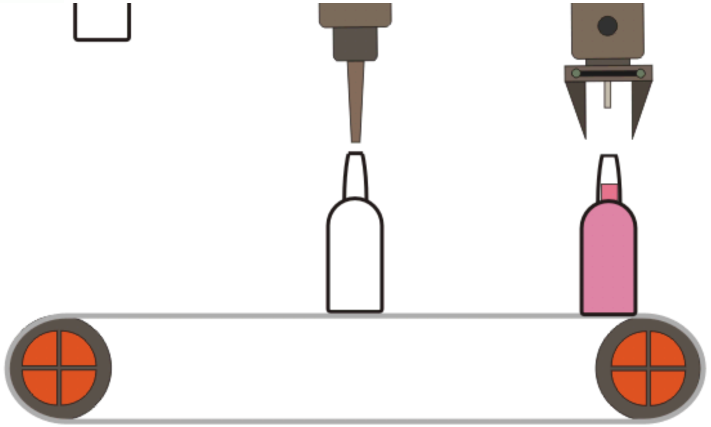
Process of operating machines and other industrial equipment with the help of digital logical programming and reducing human intervention in decision making and manual command process with the help of mechanized equipment.

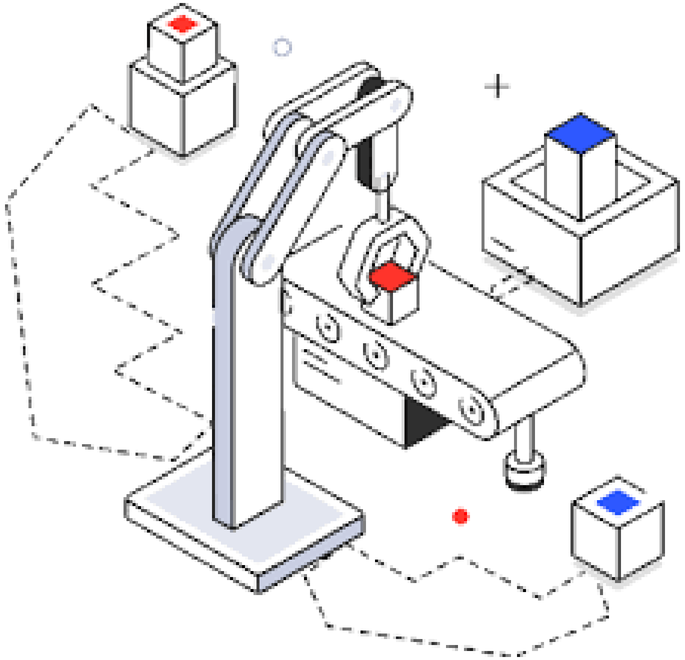




computer software, machines or other technology to carry out a task which would otherwise be done by a human worker







Advantages of Industrial Automation

New level of data support and production traceability

Improved flexibility

Increased added value and human capacity

Real-time monitoring and predictive maintenance

Greater safety

Reduced cost

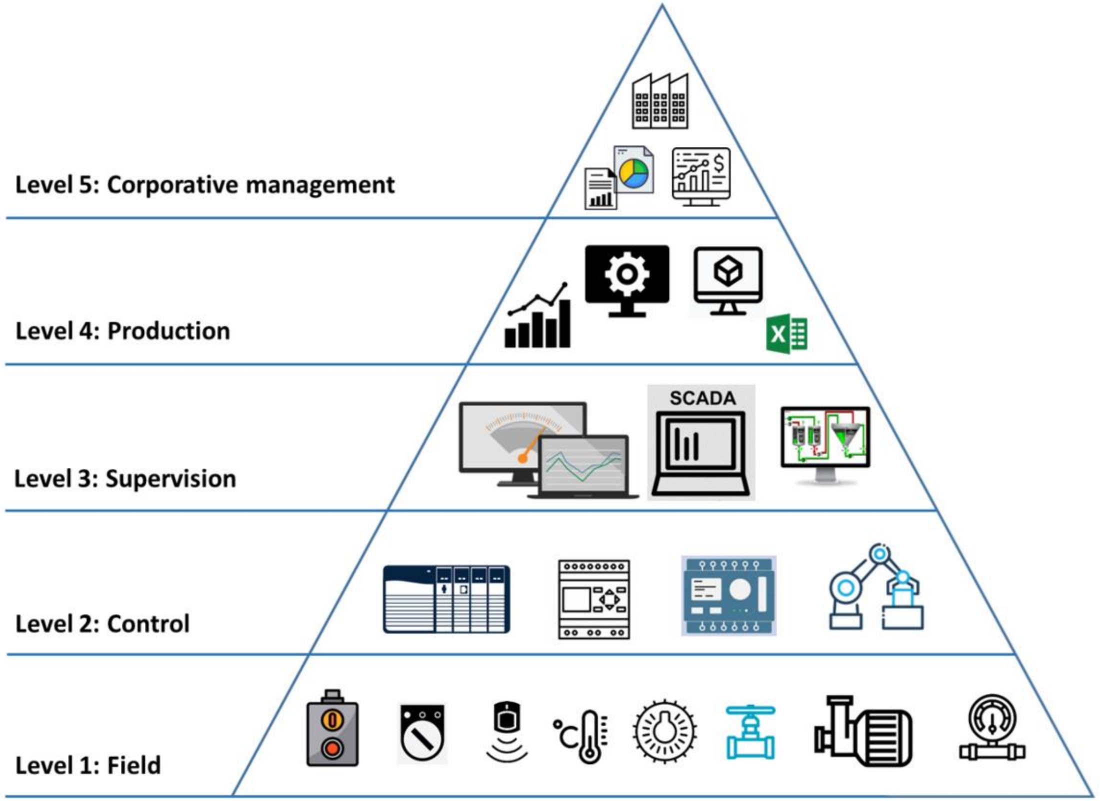
High productivity

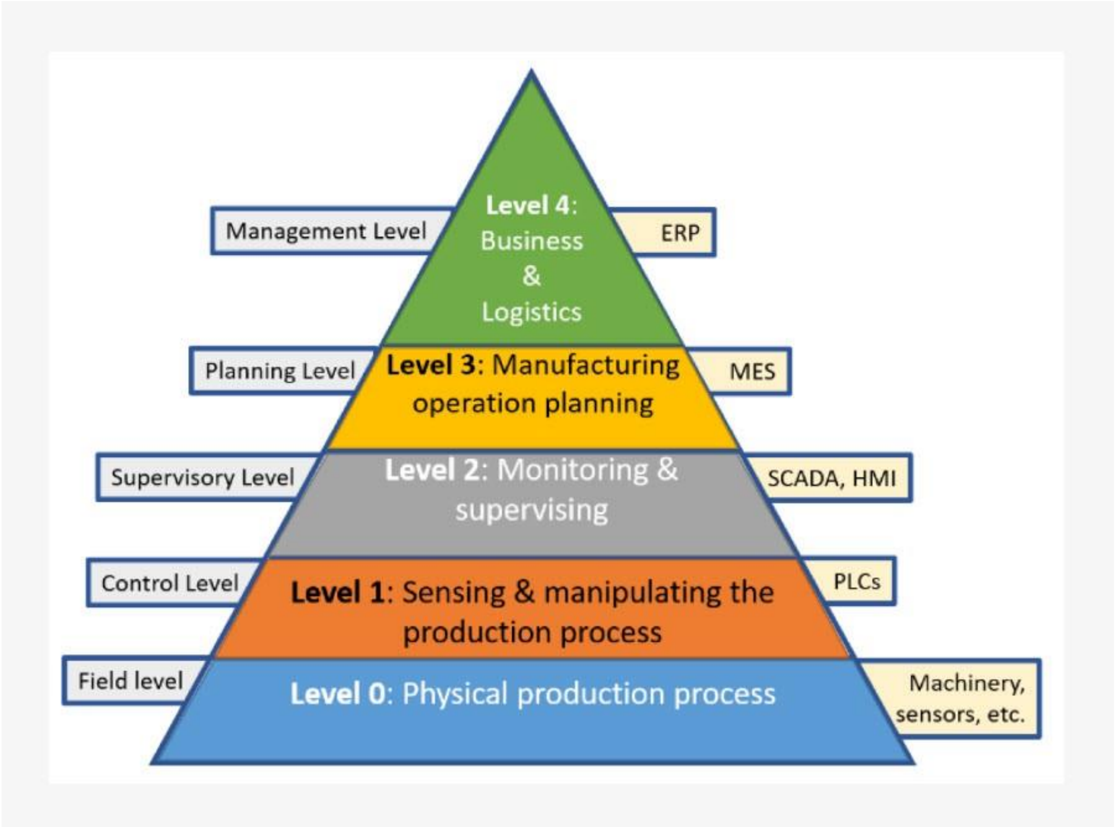
Better quality and consistency

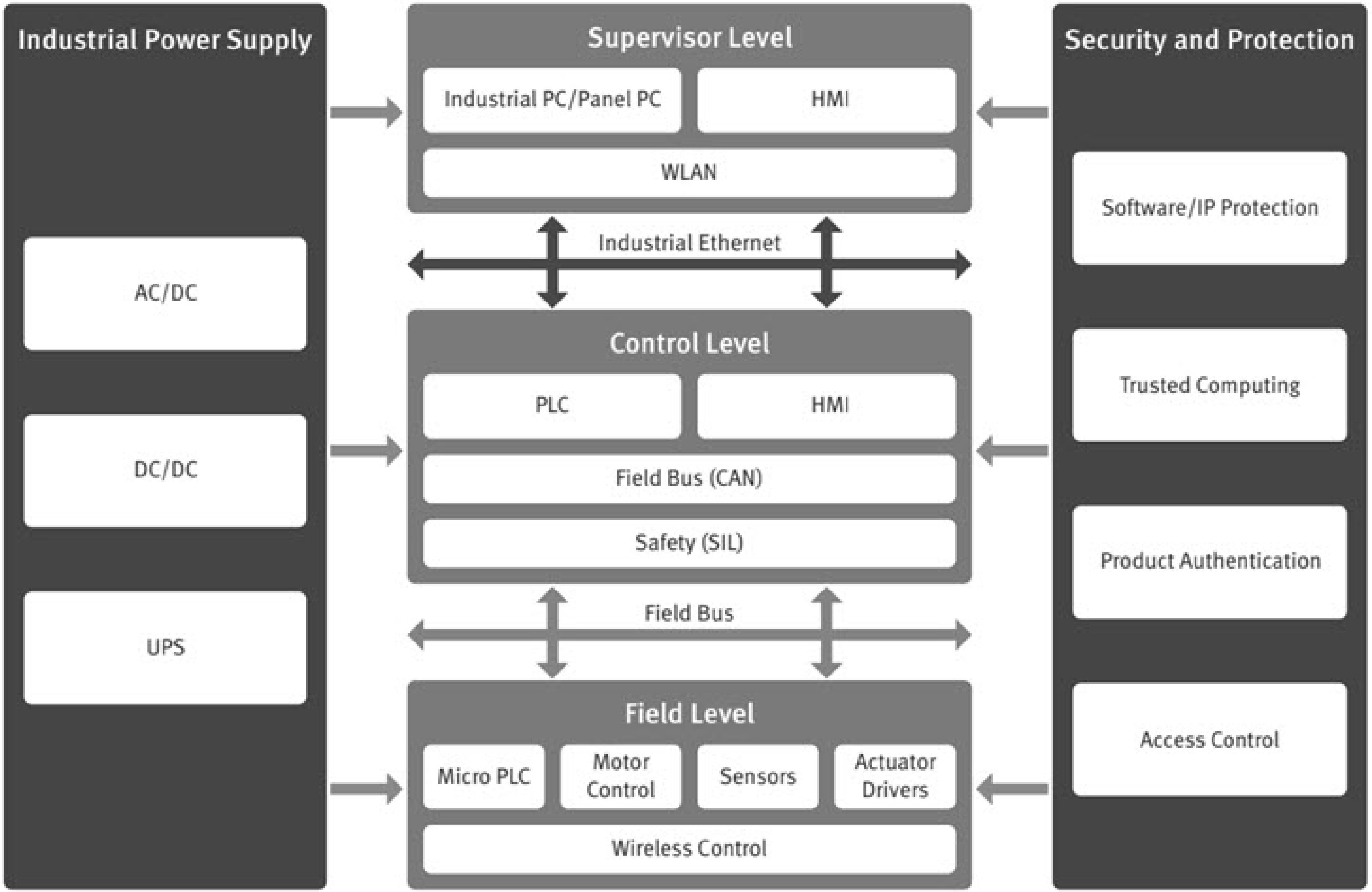
Figure 1: Automation Pyramid

- Productivity and maintenance tools provide performance targets to the self-aware motion control elements to modulate factory performance through the APIs

- Self-aware motion control system continuously drives real-time performance optimization at the control and field levels based on the working environment conditions

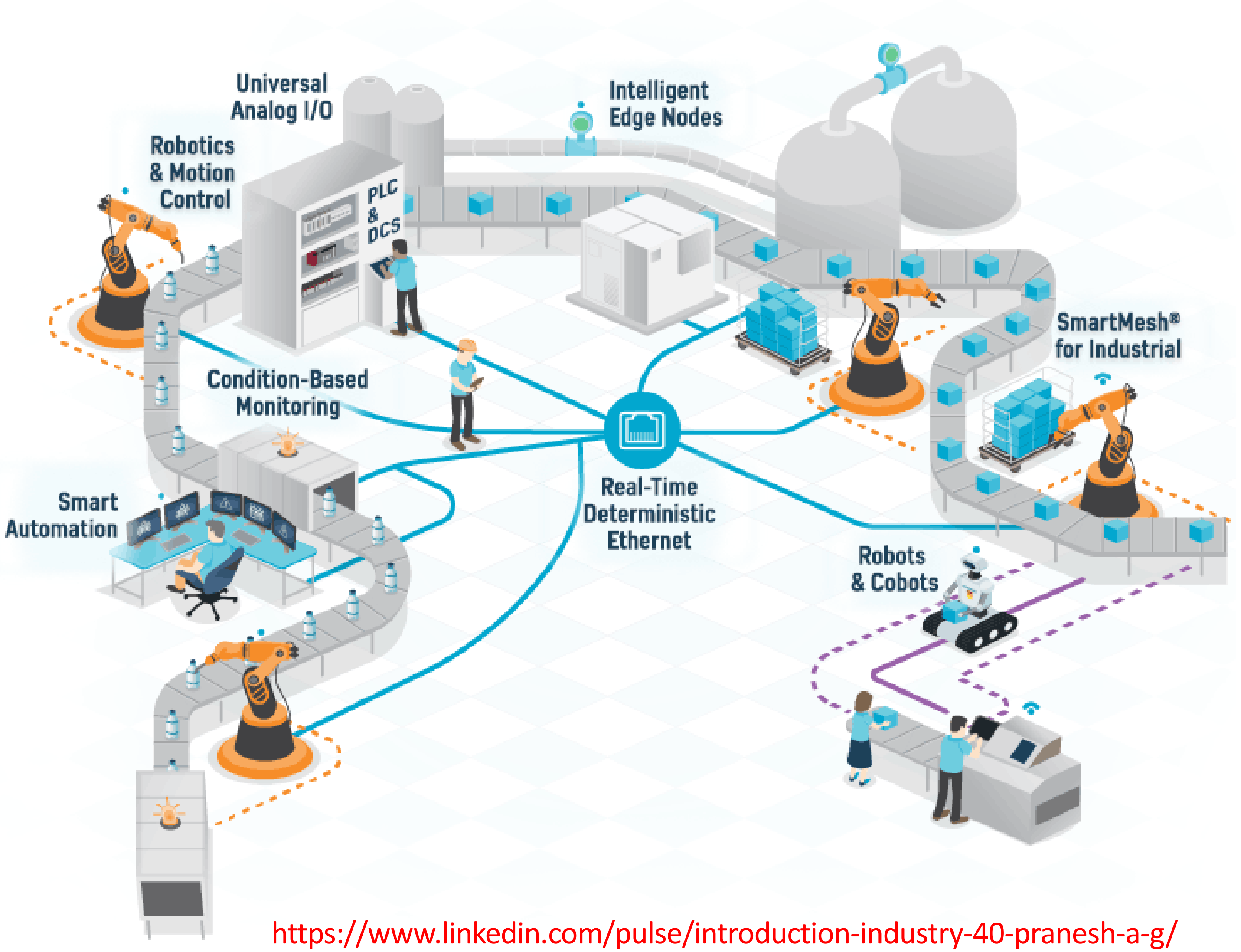

Level 5: Corporative management
Level 4: Production
Level 3: Supervision
SCADA
Level 2: Control
Level 1: Field


Management Level
Level 4: Business & Logistics
ERP
Planning Level
Level 3: Manufacturing operation planning
MES
Supervisory Level
Level 2: Monitoring & supervising
SCADA, HMI
Control Level
Level 1: Sensing & manipulating the production process
PLCs
Field level
Level 0: Physical production process
Machinery, sensors, etc.


Industrial Power Supply
AC/DC
DC/DC
UPS
Supervisor Level
Industrial PC/Panel PC
HMI
WLAN
Industrial Ethernet
Control Level
PLC
HMI
Field Bus (CAN)
Safety (SIL)
Field Bus
Field Level
Micro PLC
Motor Control
Sensors
Actuator Drivers
Wireless Control
Security and Protection
Software/IP Protection
Trusted Computing
Product Authentication
Access Control

What is Industry 4.0?

- It conceptualizes rapid change to technology, industries, and societal patterns and processes in the 21st century.
- Enabled by increasing *interconnectivity* and *smart automation.*
- Merging of technologies such as *Artificial Intelligence* and *Advanced Robotics.*
- **Industry 4.0** can be defined as the *integration of intelligent digital technologies* such as cyber physical systems, cloud computing and Internet of things (IoT) into manufacturing and industrial processes.

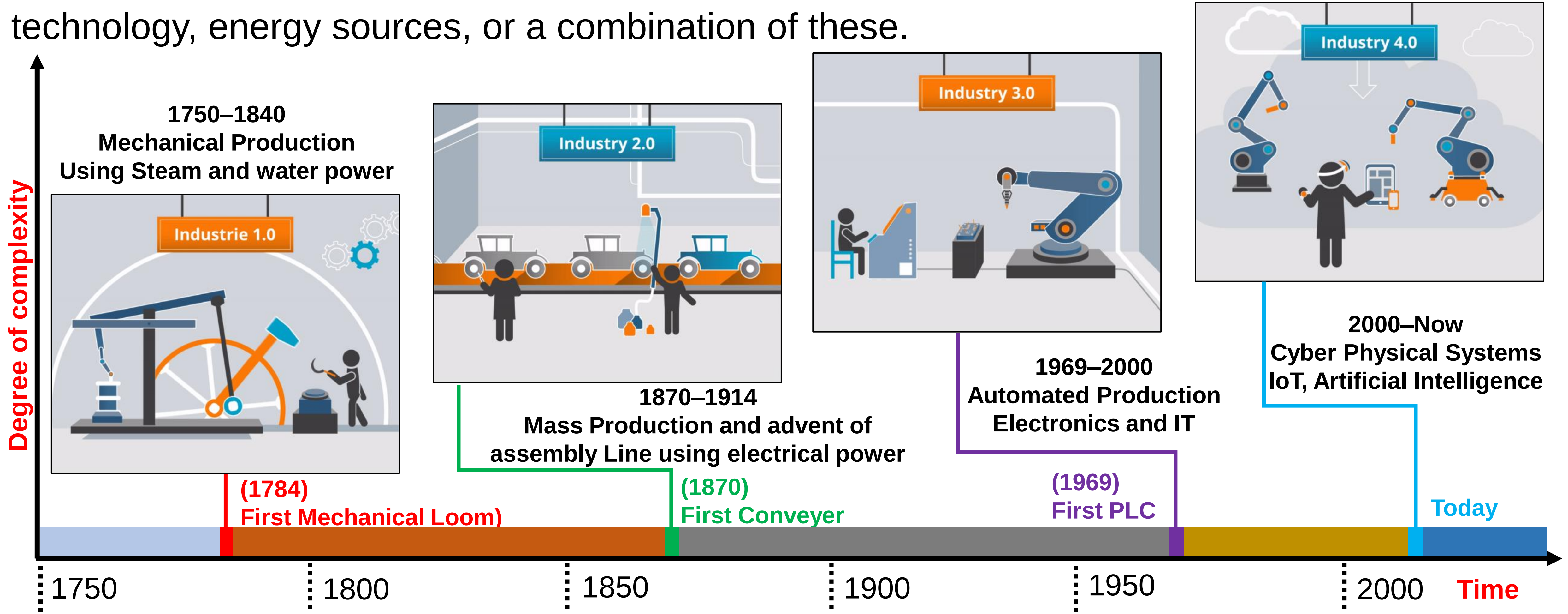


https://www.linkedin.com/pulse/introduction-industry-40-pranesh-a-g/

Industrial Revolution: Phase of development

Transforming Industries and Innovation

Industrial revolutions are defined as the increase in productions as a result of new machinery, technology, energy sources, or a combination of these.



https://digitalcontrols.org/blog/blog-1/post/fourth-industrial-revolution-21

Industrial Revolution: Phase of development…

Transforming Industries and Innovation

First Industrial Revolution:

❖ *Steam and water-powered machines* replaced hand production

Second Industrial Revolution:

❖ Creation of *assembly line for production*, enabled by electrification, railroad networks (faster movement) and telegraph networks (faster communication)

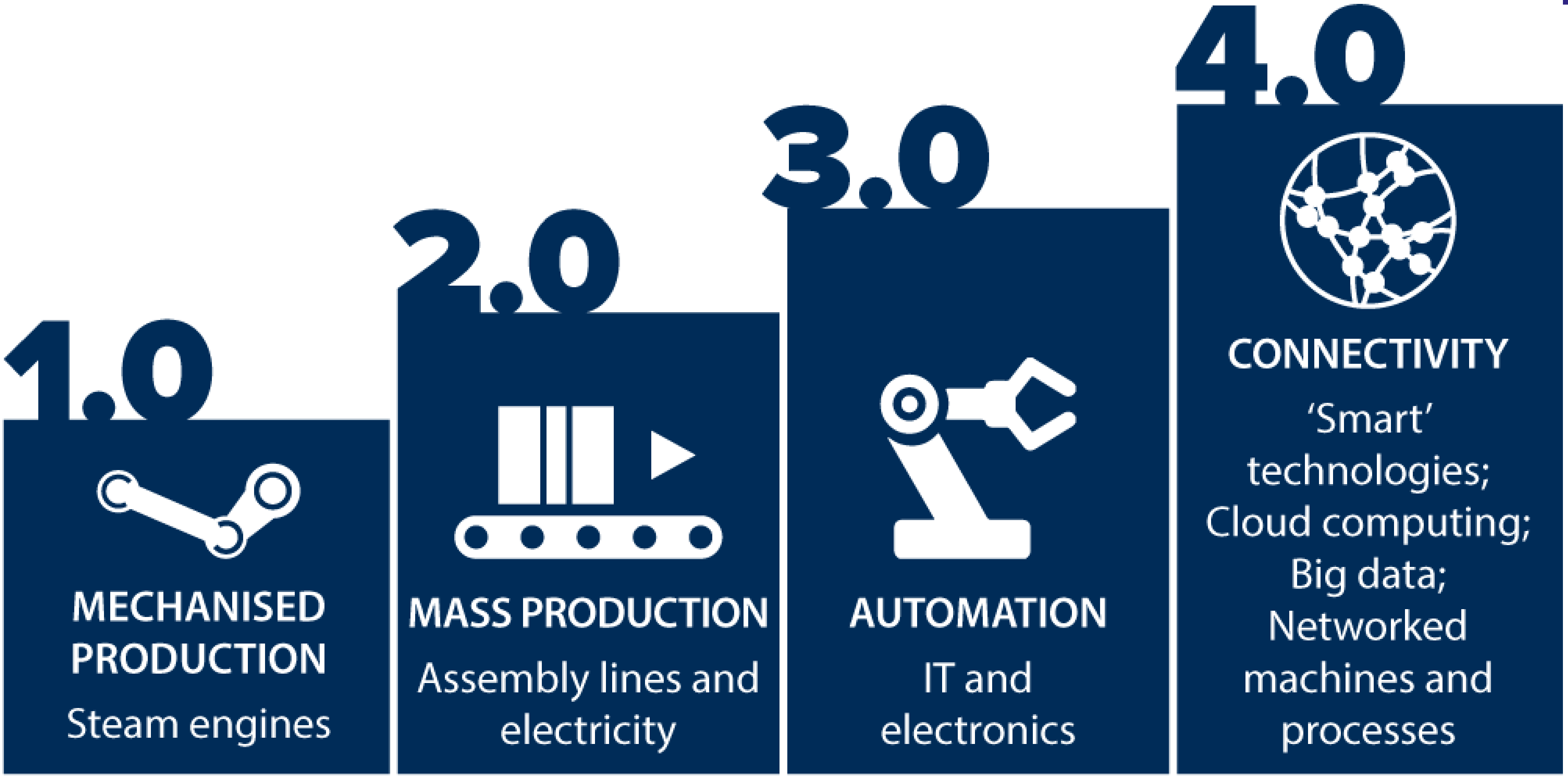
Third Industrial Revolution:

❖ Introduction of computers, digital components, electronics, Robots to *automate production*

Fourth Industrial Revolution:

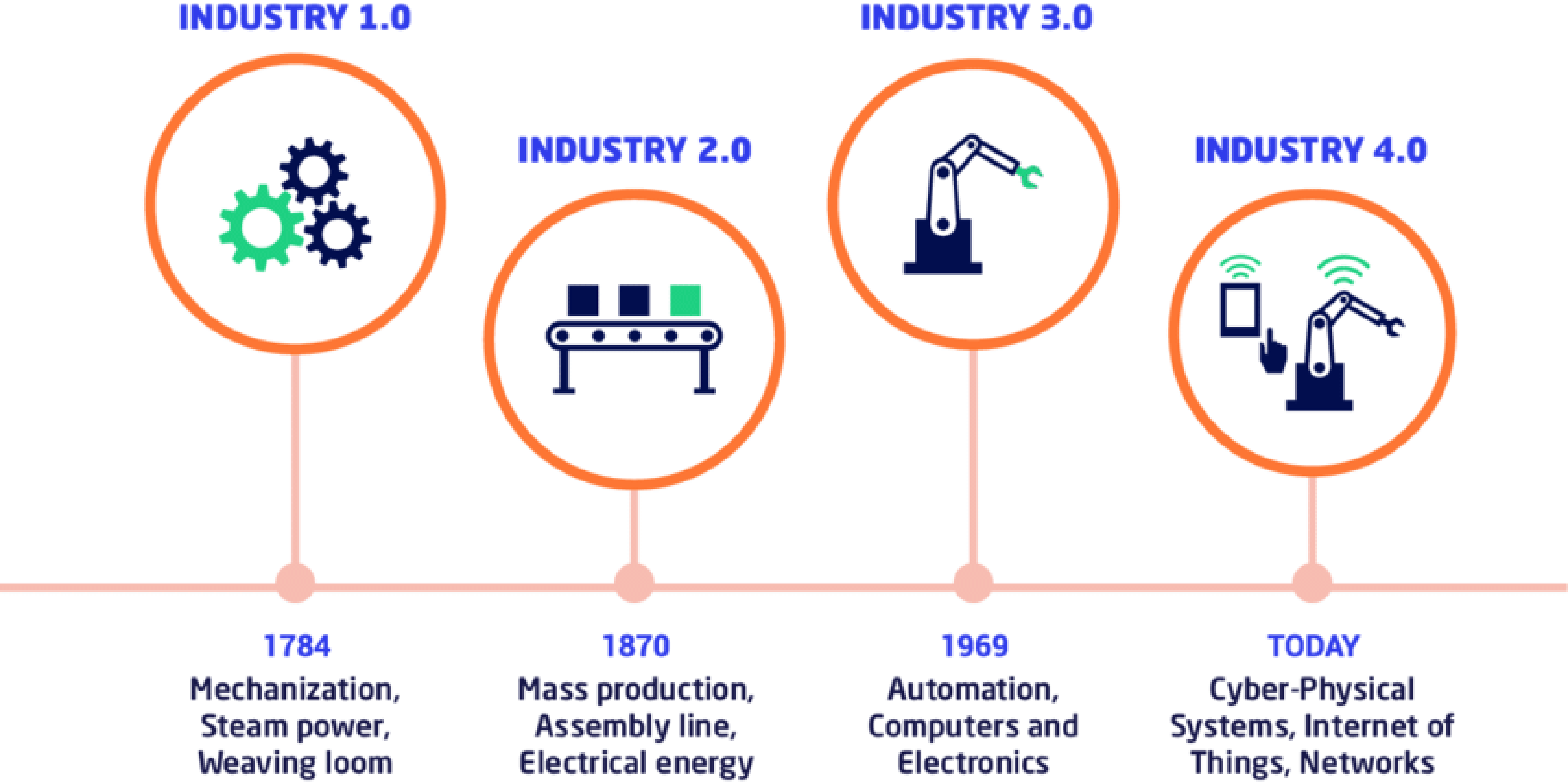
❖ Focused on *automation of manufacturing technologies and processes*, data exchange, cyber-physical systems, IoT, IIoT, cloud computing, Artificial Intelligence (AI).

Industrial Revolution

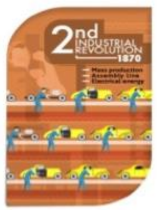


The stages of industrial development

Source: Oxford Analytica


INDUSTRY 1.0
INDUSTRY 2.0
INDUSTRY 3.0
INDUSTRY 4.0
1784
Mechanization, Steam power, Weaving loom
1870
Mass production, Assembly line, Electrical energy
1969
Automation, Computers and Electronics
TODAY
Cyber-Physical Systems, Internet of Things, Networks

Key Initiatives



	Industry 1.0	Industry 2.0	Industry 3.0	Industry 4.0
Timeline	18th Century (1784)	19th Century (1870)	20th Century (1969)	21st Century (Today)
Production System	First Mechanical Loom	First Production Line Cincinnati Slaughter House Car assembly	First Programmable Logic Controller (PLC) Modicon 084	Cyber Physical System (CPS)
Technology	Introduction of water and steam powered mechanical manufacturing system	Introduction of electrically powered mass production based on the division of labour	Uses electronics, IT and OT to achieve further automation of manufacturing	Convergence IT and OT, autonomous machine based on Cyber-Physical Systems (CPS)
Competitive Priorities Evolution	Quality, Cost	Quality, Cost, Time	Quality, Cost, Time, Flexibility	Quality, Cost, Time, Flexibility, Innovation, Adaptability
Manufacturing Concept	Mass Manufacturing	Moving Assembly Line	Mass Customisation	Mass Personalisation

Industry 1.0: Goods became more affordable and more accessible. The rapid evolution of labour-saving inventions.

Industry 2.0: The creation of new jobs. Technological advancements led to better standards of housing, food, education.

Industry 3.0: Increased efficiency and productivity through automation. Improved working conditions through reduced manual labor.

Industry 4.0: Increased customization through flexible manufacturing systems. Improved supply chain management through real-time data analysis.

What is Internet of Things (IoT)?

What is a thing?

- *A thing,* in the context of the internet of things (IoT), refers to *any entity* such as *a device* (sensors, processing ability, software, and technologies) that *forms a network* and can *transfer data* with other devices over the network.

What is Internet?

- Internet simply implies a network of such entities where the objects can be individually addressed.
- It is not the usual internet connection.

Definition of IoT

- The Internet of Things, or IoT, is a network of physical devices.
- In other words, IoT comprises things that have unique identities and are connected to the Internet.
- These devices can transfer data to one another without human intervention.

What is Internet of Things (IoT)?...

- Eg.: Smart homes
  - Things present on this IoT can be
    - ➢ Lighting
    - ➢ Heating/cooling
    - ➢ security systems, camera systems
    - ➢ Media
- Eg.: Agriculture
  - ➢ IoT may include sensors for measuring temperature, rainfall, humidity, wind speed, soil moisture and so on.
  - ➢ Farm automation can be achieved which can reduce wastage of water, improve quality and quantity of produce.
- Since there are multiple “things” or objects with sensing capabilities, a lot of data is generated.
- This becomes a starting point for *Big data, analytics, AI technologies, Cloud*.

What is Industrial Internet of Things?

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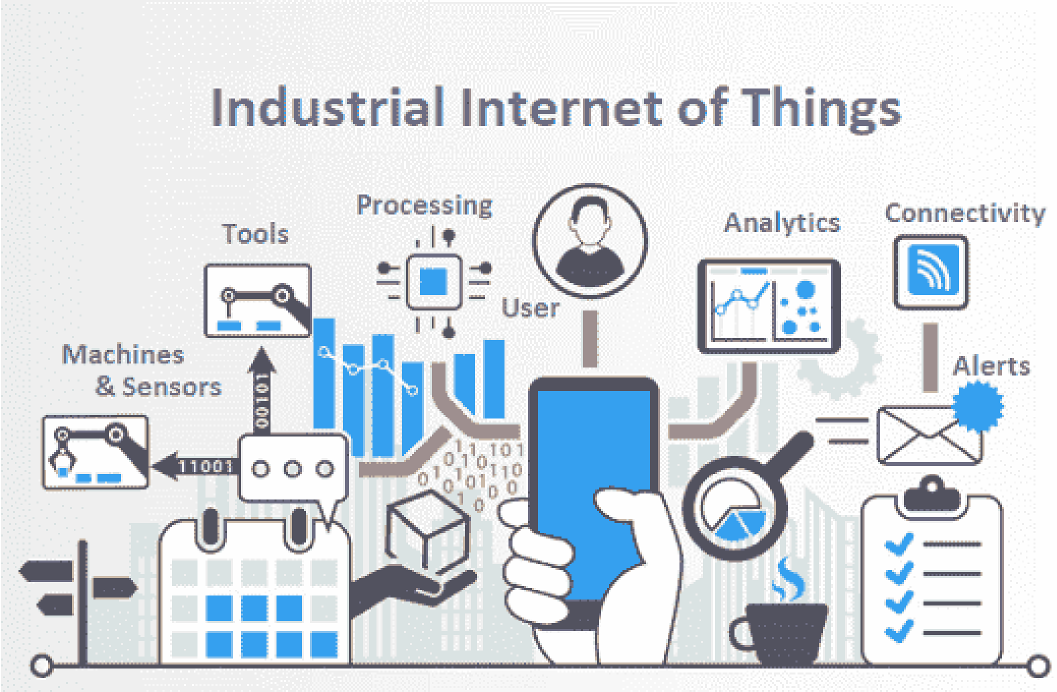
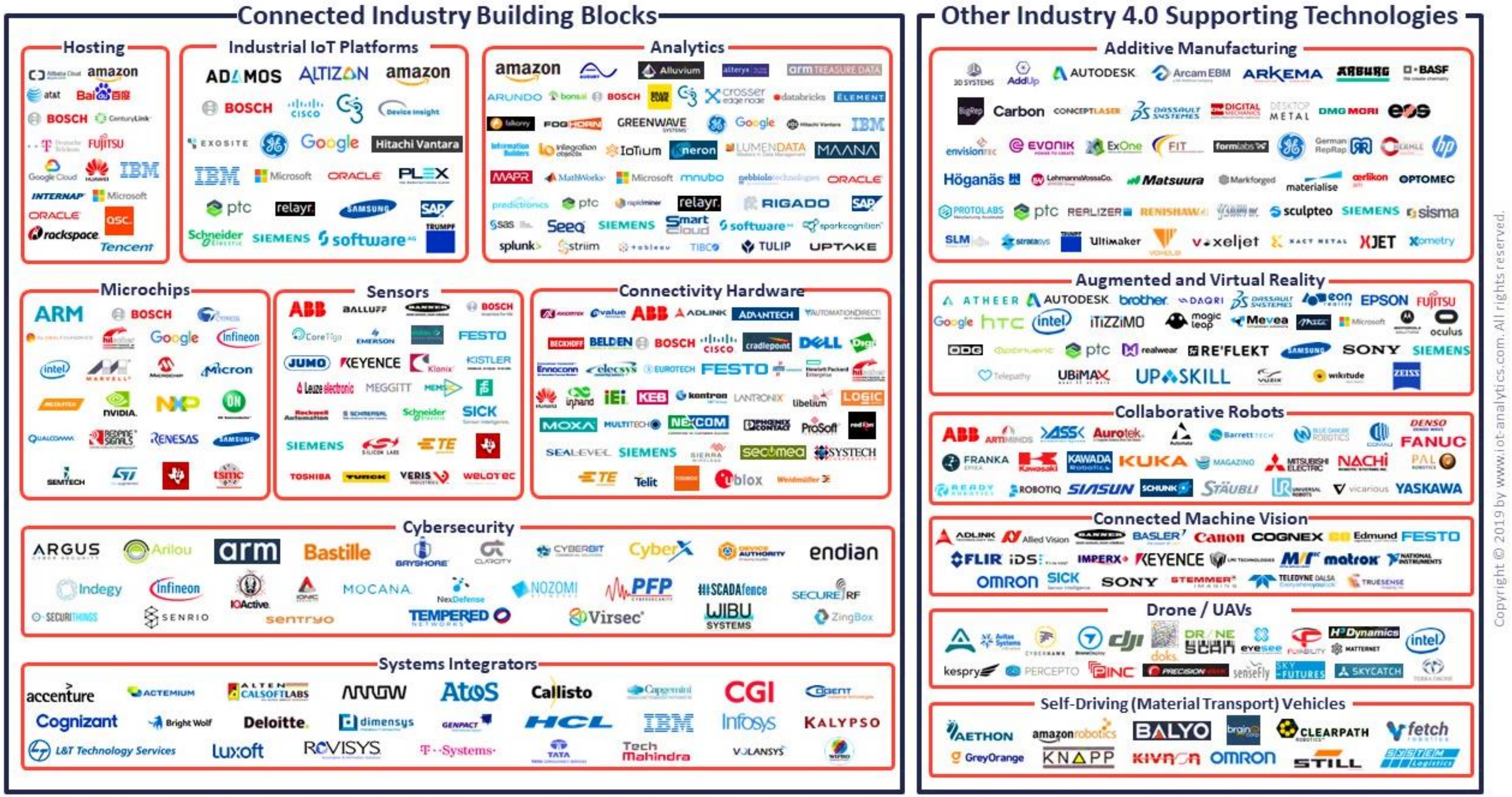
- ❖ Industrial Internet of Things (IIoT) can be considered as a branch of Internet of Things (IoT).
- ❖ If IoT includes industrial devices and equipment, it is called IIoT
- ❖ In other words, Industrial IoT is an *ecosystem of devices, sensors, applications, and associated networking equipment* that work together to *collect, monitor, and analyze data* from industrial operations.
- ❖ Analysis of such data helps increase visibility and enhances troubleshooting and maintenance capabilities.
- ❖ It can also *increase efficiencies*, reduce costs, and improve safety and security.
- ❖ IIoT is the application of IoT in manufacturing and other industrial processes with the aim to enhance the working condition, increase machine life and optimize operational efficiency.



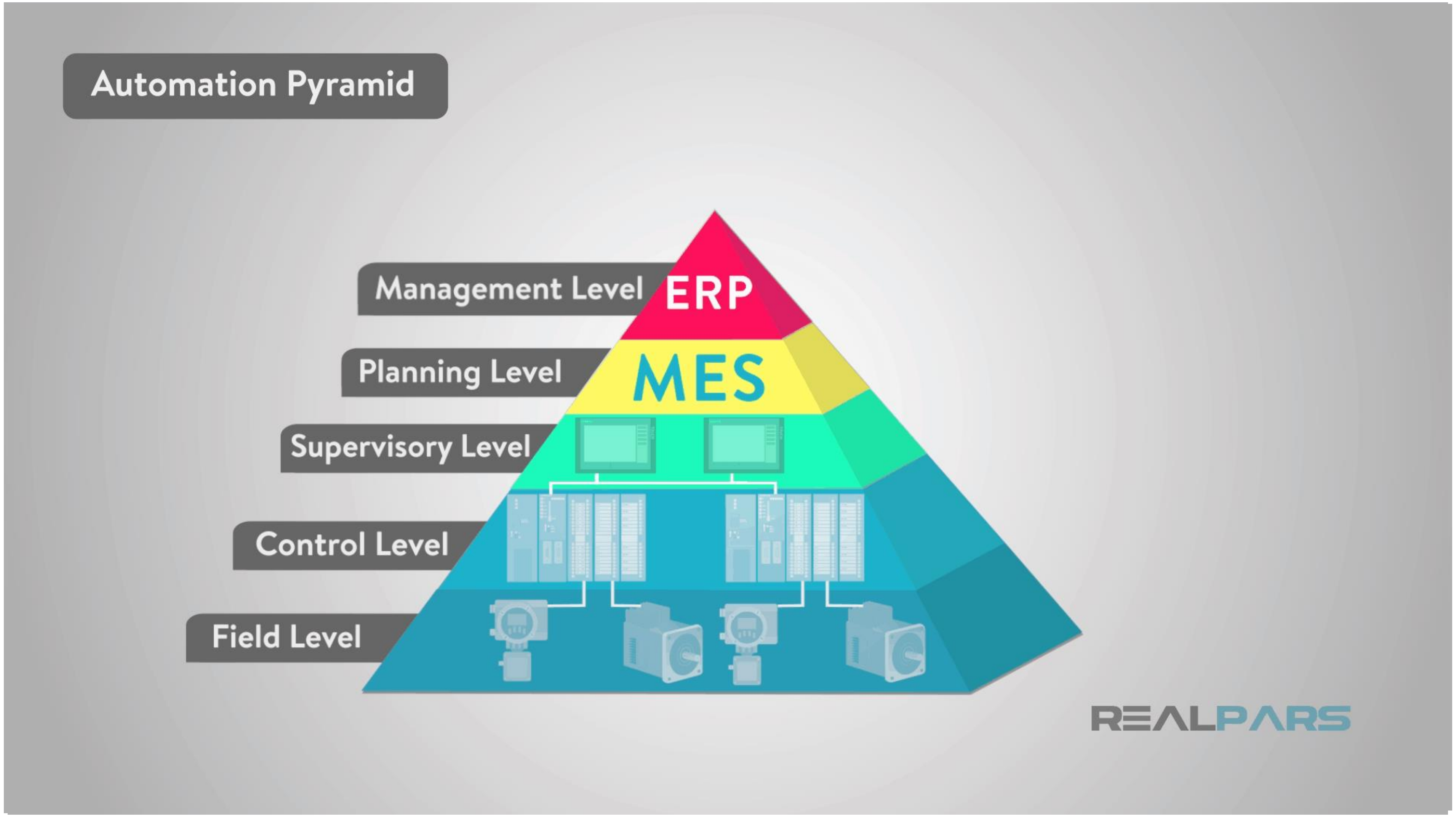
Source: https://optiware.com/blog/what-is-industrial-internet-of-things-iiot-and-why-is-it-important-in-manufacturing/

Leading Industry 4.0 Vendors



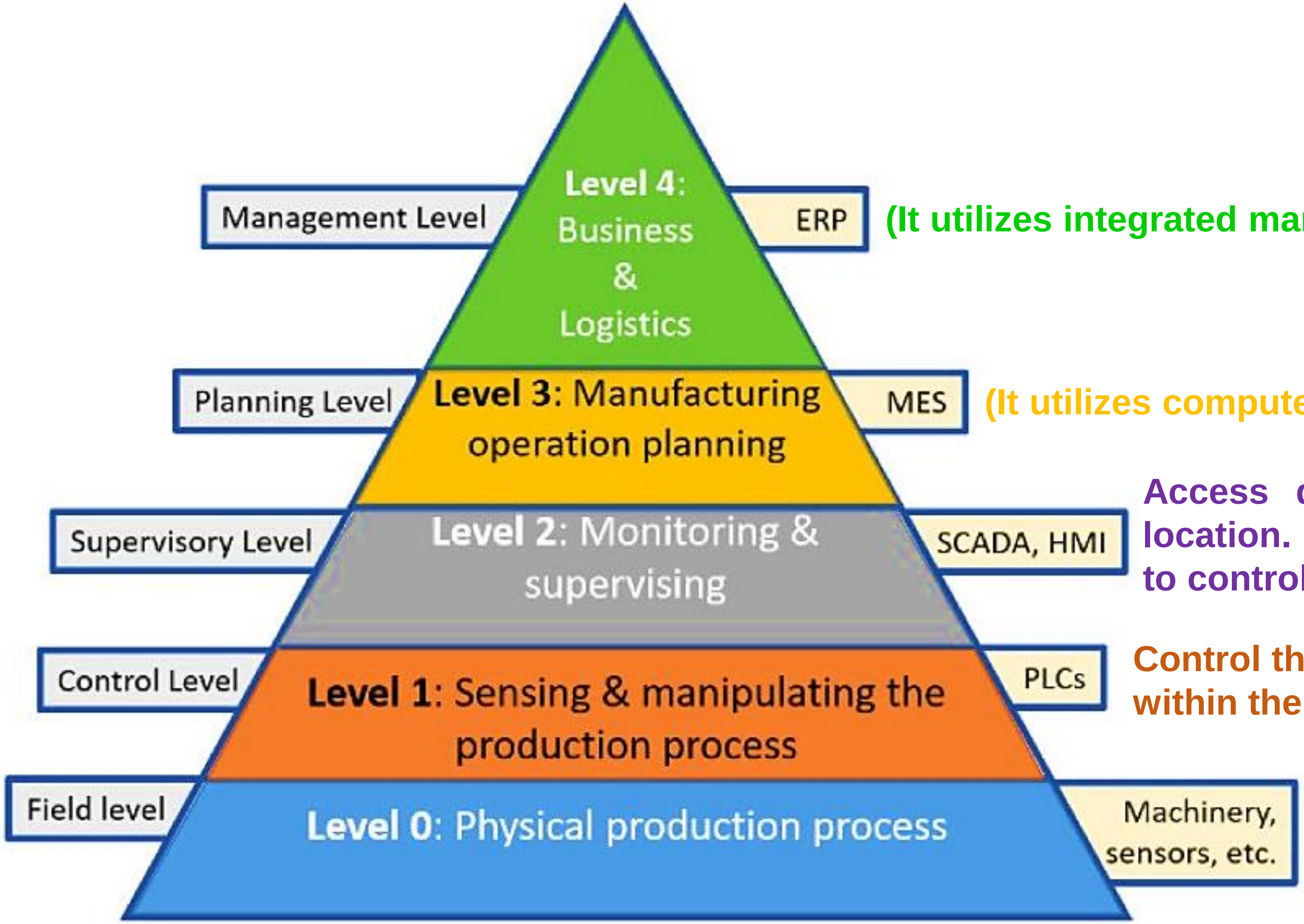
Source: IoT Analytics, January 2019. Vendor map does not include suppliers of vertical or use case specific solutions (i.e. end-to-end vibration monitoring solutions, etc.). Leading companies were selected based on a number of factors including sophistication of relevant product offerings, number of compelling case studies, and size of Industry 4.0 business. It is possible that some vendors have been missed. To submit a company for consideration in the 2020 vendor map, please contact research@iot-analytics.com with the company information.

Automation Pyramid



Source: https://www.realpars.com/blog/automation-pyramid

Automation Pyramid…



(It utilizes integrated management system)

(It utilizes computer management system)

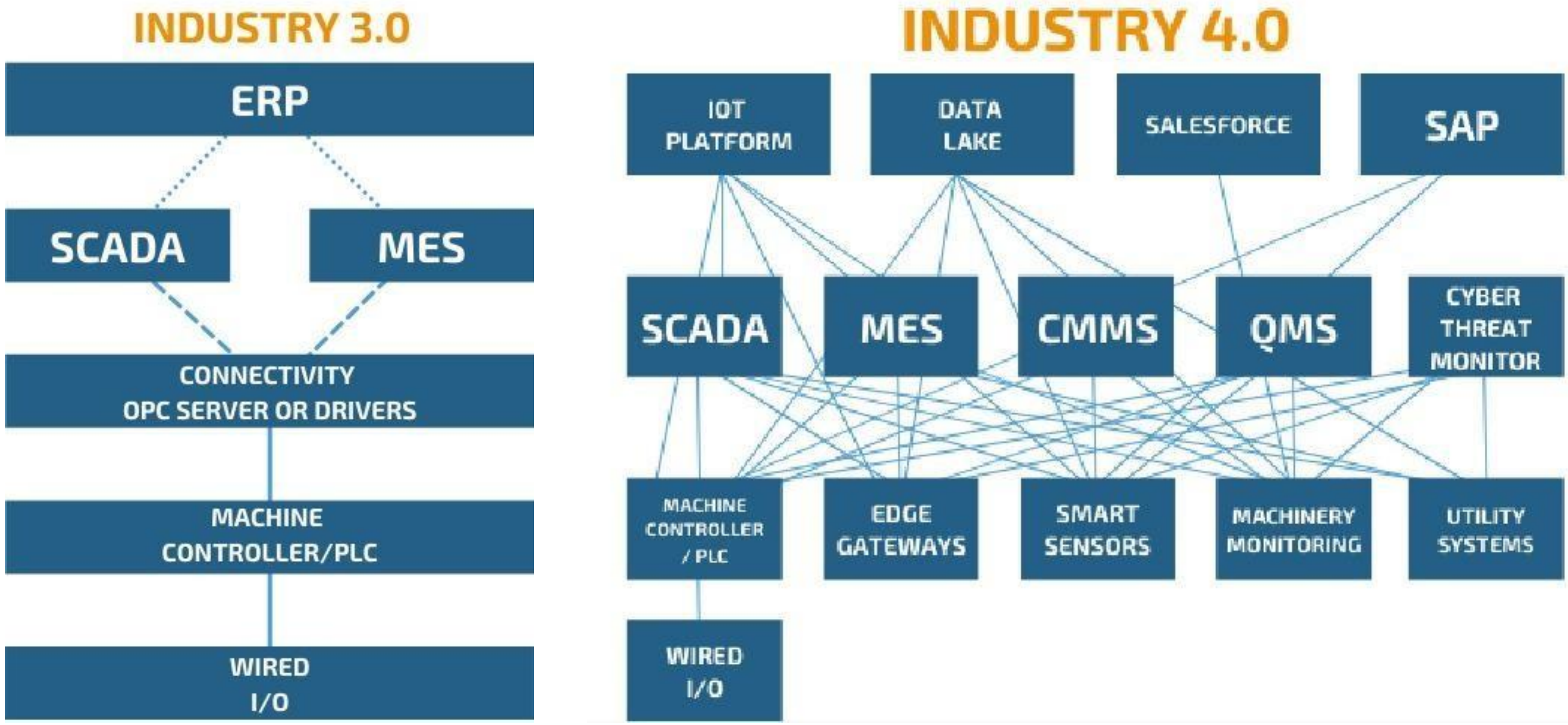
Access data and control systems from a single location. It adds a graphical user interface, or an HMI, to control functions remotely

Control the system with controller (PD, PID, etc.) block within the PLC

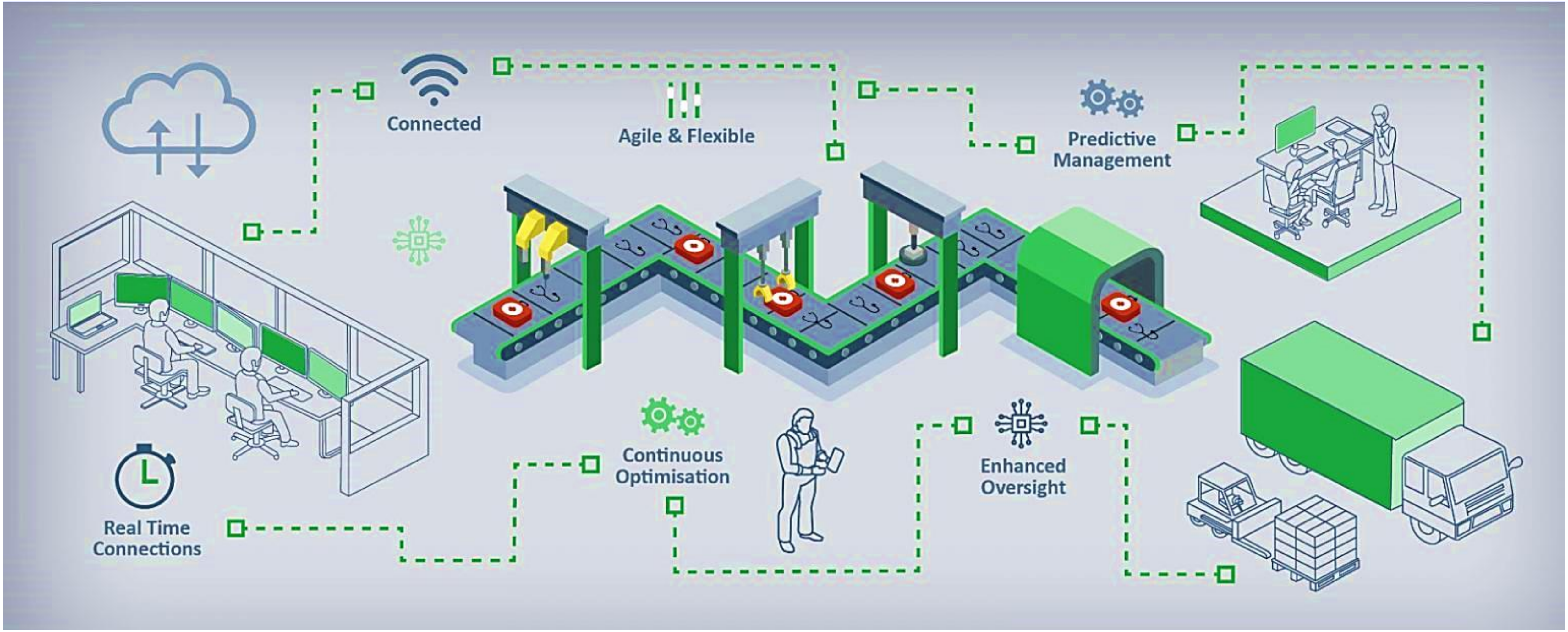
It is the production floor that does the physical work and monitoring

Source: https://www.mdpi.com/

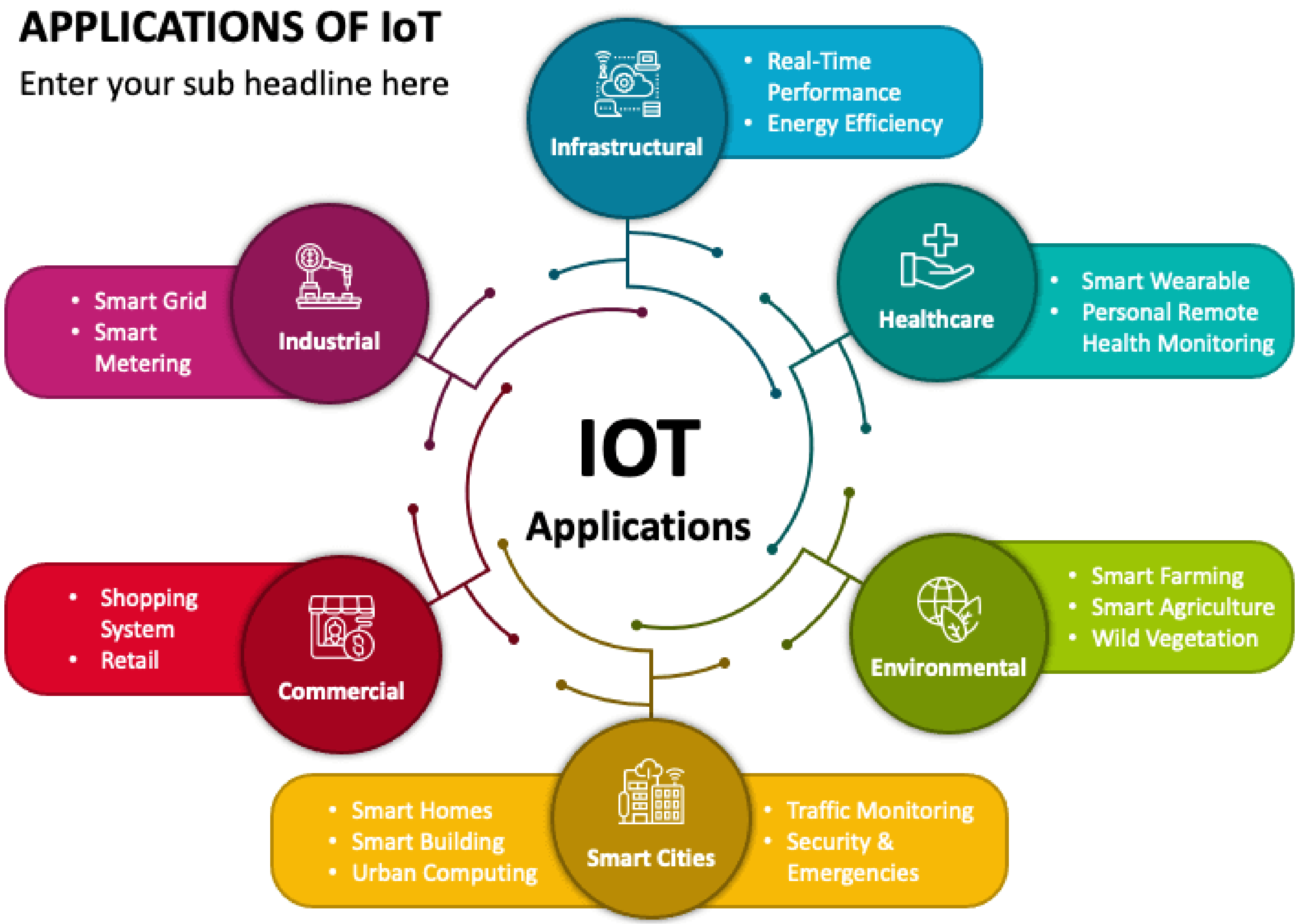
Industry 3.0 vs 4.0



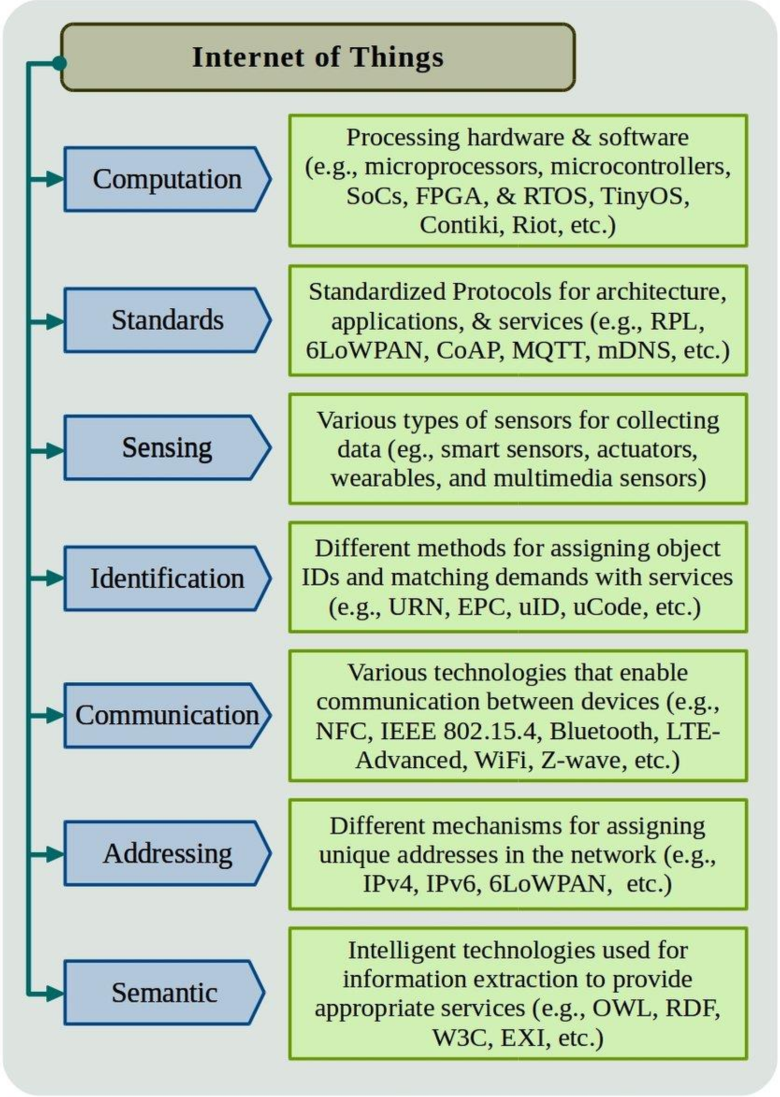
Industry 4.0



https://slcontrols.com/the-essential-steps-in-your-smart-factory-evolution/



APPLICATIONS OF IoT
Enter your sub headline here
IOT
Applications
Infrastructural
• Real-Time Performance
• Energy Efficiency
Healthcare
• Smart Wearable
• Personal Remote Health Monitoring
Environmental
• Smart Farming
• Smart Agriculture
• Wild Vegetation
Smart Cities
• Smart Homes
• Smart Building
• Urban Computing
• Traffic Monitoring
• Security & Emergencies
Commercial
• Shopping System
• Retail
Industrial
• Smart Grid
• Smart Metering



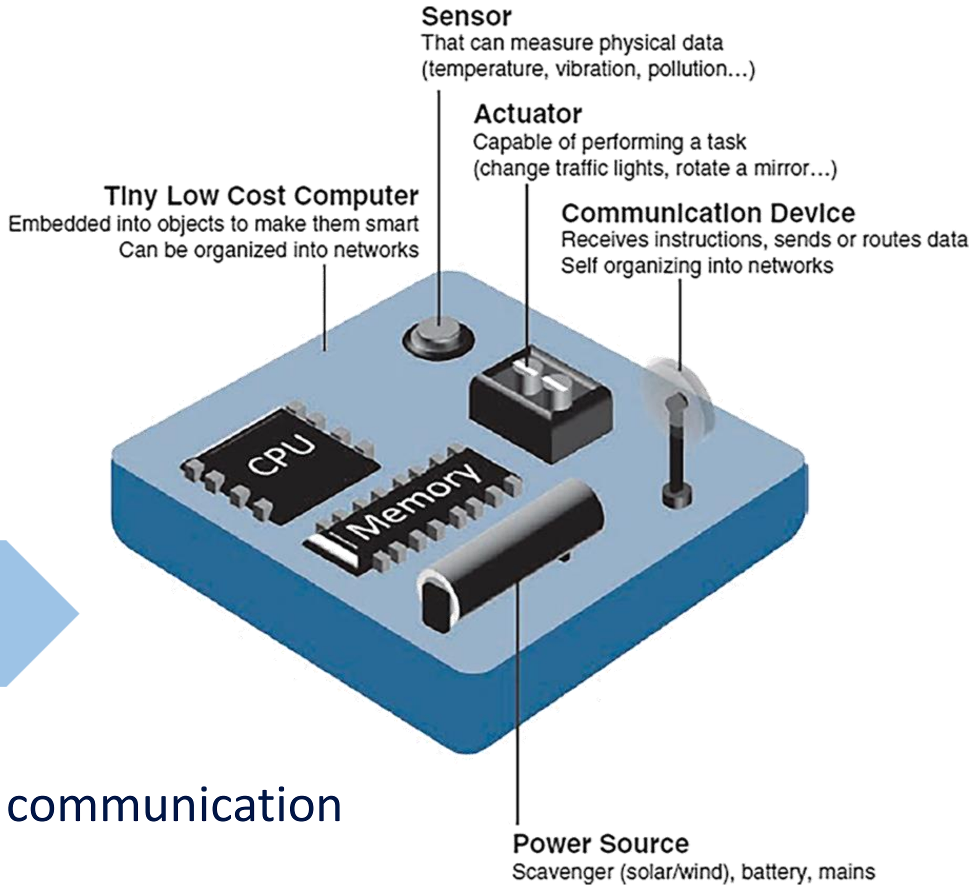
Internet of Things
Computation
Processing hardware & software (e.g., microprocessors, microcontrollers, SoCs, FPGA, & RTOS, TinyOS, Contiki, Riot, etc.)
Standards
Standardized Protocols for architecture, applications, & services (e.g., RPL, 6LoWPAN, CoAP, MQTT, mDNS, etc.)
Sensing
Various types of sensors for collecting data (eg., smart sensors, actuators, wearables, and multimedia sensors)
Identification
Different methods for assigning object IDs and matching demands with services (e.g., URN, EPC, uID, uCode, etc.)
Communication
Various technologies that enable communication between devices (e.g., NFC, IEEE 802.15.4, Bluetooth, LTE-Advanced, WiFi, Z-wave, etc.)
Addressing
Different mechanisms for assigning unique addresses in the network (e.g., IPv4, IPv6, 6LoWPAN, etc.)
Semantic
Intelligent technologies used for information extraction to provide appropriate services (e.g., OWL, RDF, W3C, EXI, etc.)

IoT Use Cases and applications

Four increasing levels classifying smartness of the object / product

- **Autonomy**: Product with autonomous control having coordination, self-diagnosis or service capabilities
- **Optimization**: Enhancement in product performance, predictive diagnostics, service and repair through algorithms
- **Control**: Control through software embedded in the product or cloud
- **Monitoring**: Monitoring of Product Conditions, External Operation, Usage
  Enables alerts and notifications of changes

Smart Object:

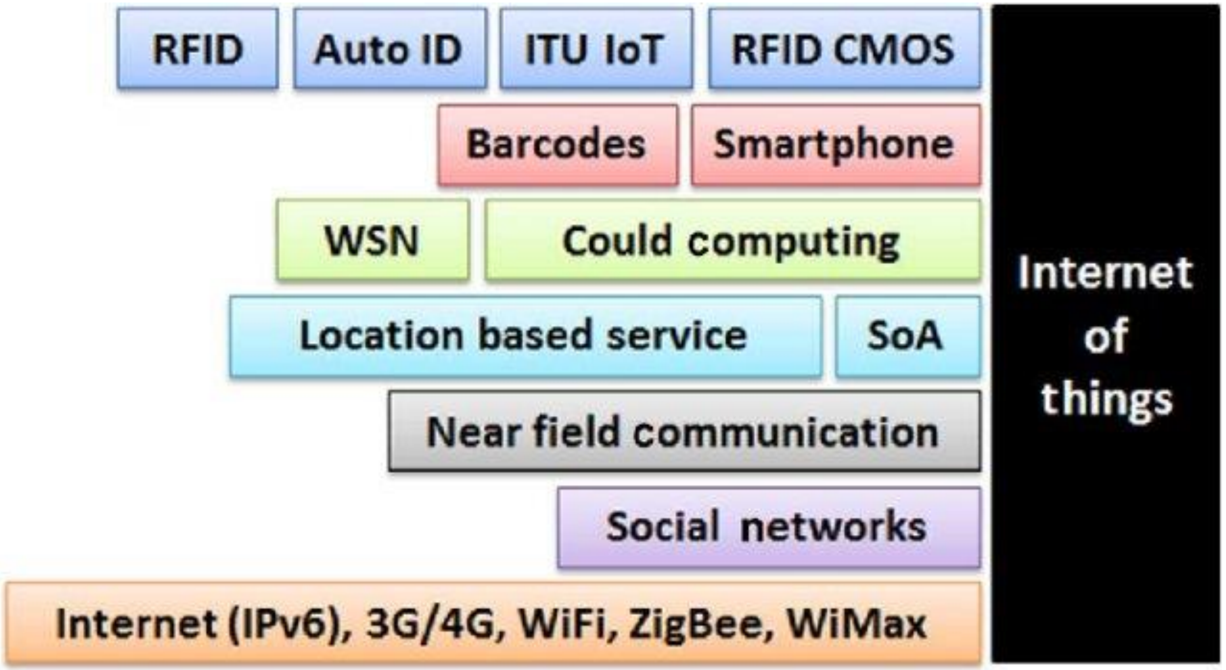


Memory, processor and wireless communication is added to the sensor

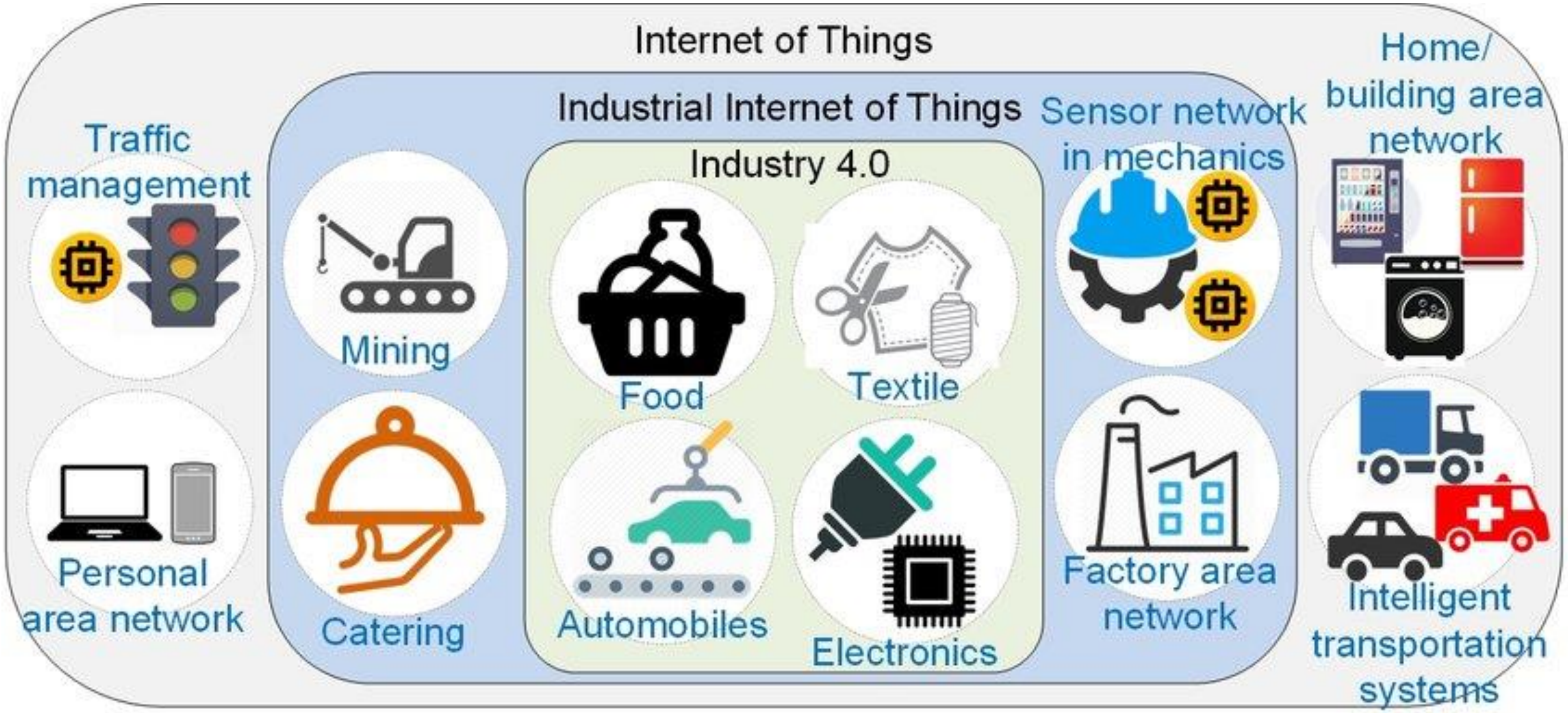
Also has an embedded operating system

IoT Key Technologies

- Wireless Sensor Network
- Cloud Computing
- Big Data Analytics
- Communication Protocols
- Embedded Systems
- AI/ML
  - Diagnostic
  - Maintenance
  - Efficiency
  - Prognostic
  - Optimization
  - Logistic and Supply Chain



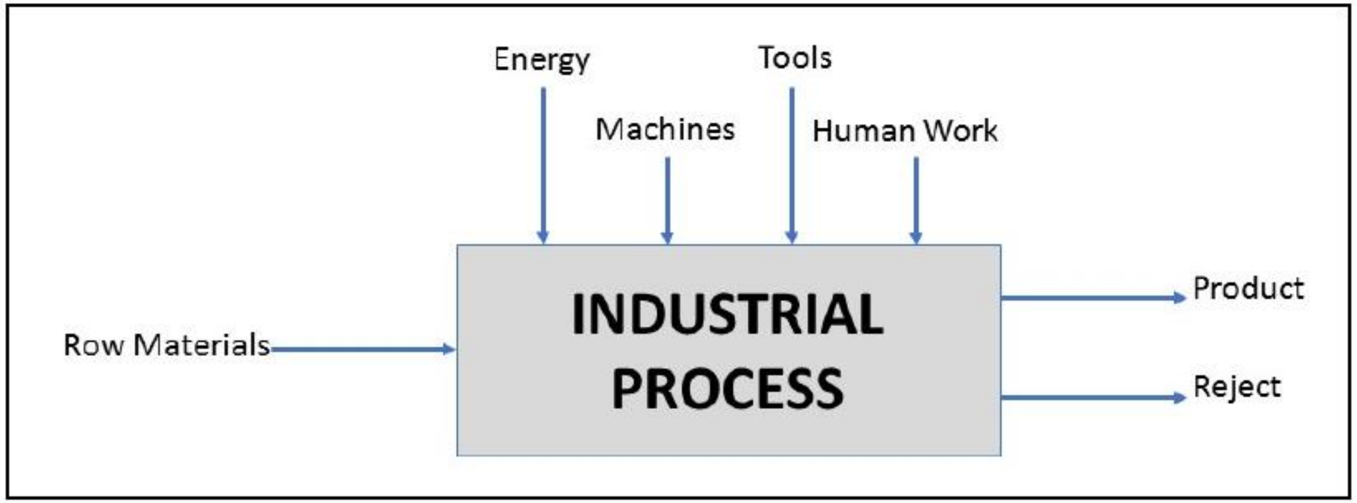
Industry Environments and Scenarios by I-IoT

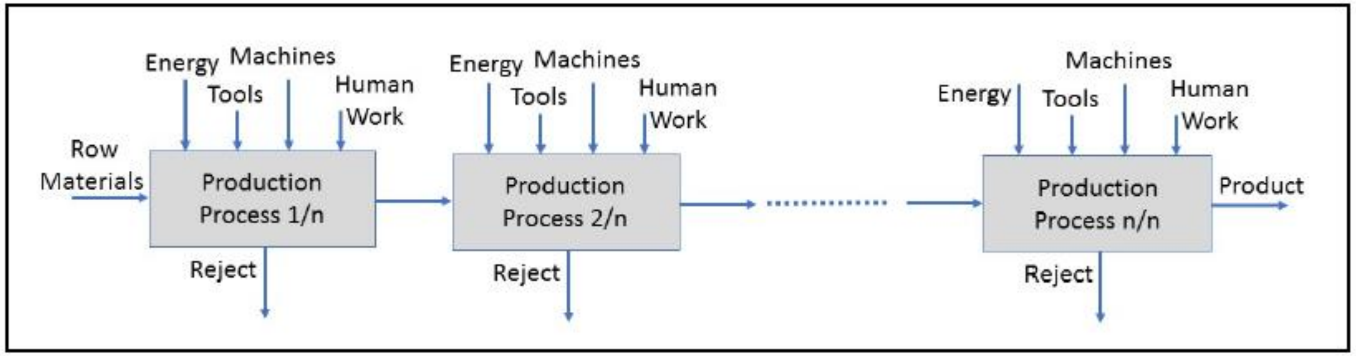


- Manufacturing
  - Chemicals
  - Food and drink
  - Automotive
  - Mining
  - Pharmaceuticals
- Power and energy
- Renewable energy
- Healthcare
- Logistics and supply chain

Industrial Process

- Transformation from raw materials to a product requires
  - Energy, Machines, Tools, Human work
- Mostly industrial processes are Sequential process
- Each production process is made of
  - Making
  - Assembly
  - Transport and Storage
  - Testing
  - Coordination and Control



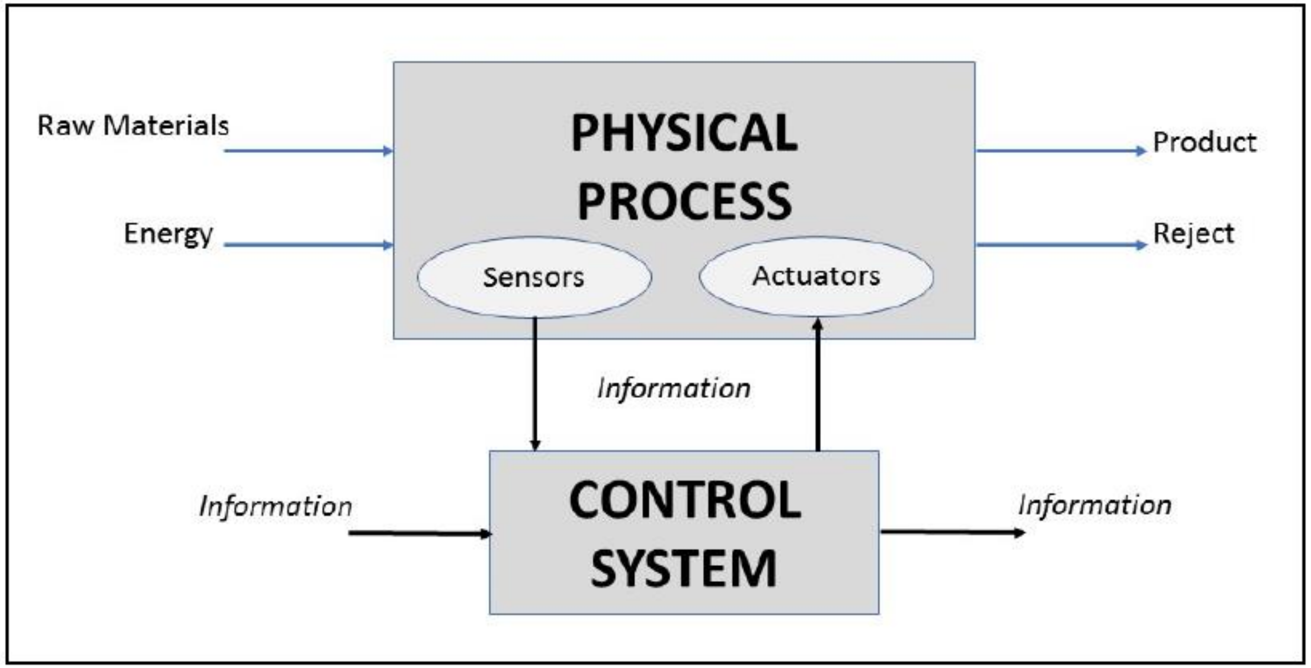


Industrial process and its steps

Automation & Types in Industrial Process

Automation in the Industrial Process

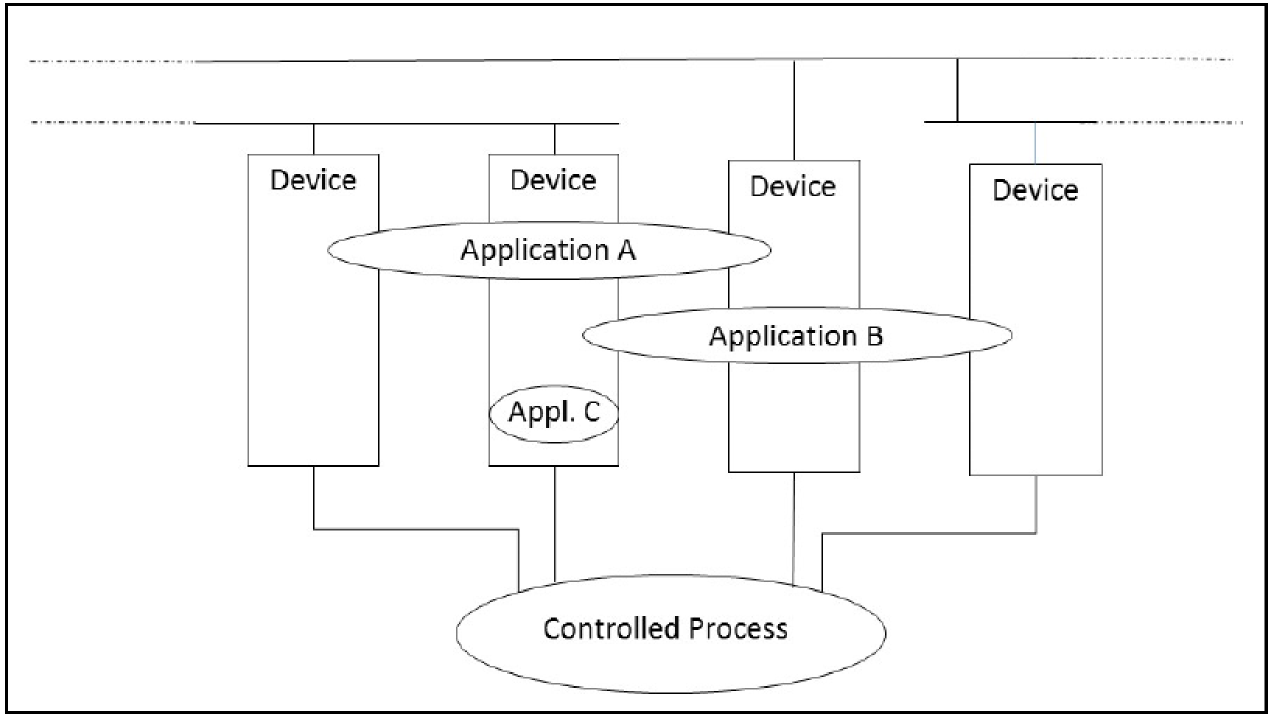
- Improvement of Quality of product
- Flexibility of the plant
- Shorter Production times
- Reduction in Processing waste
- Lowering cost of production
- Reduce environmental impact
- Energy saving etc.



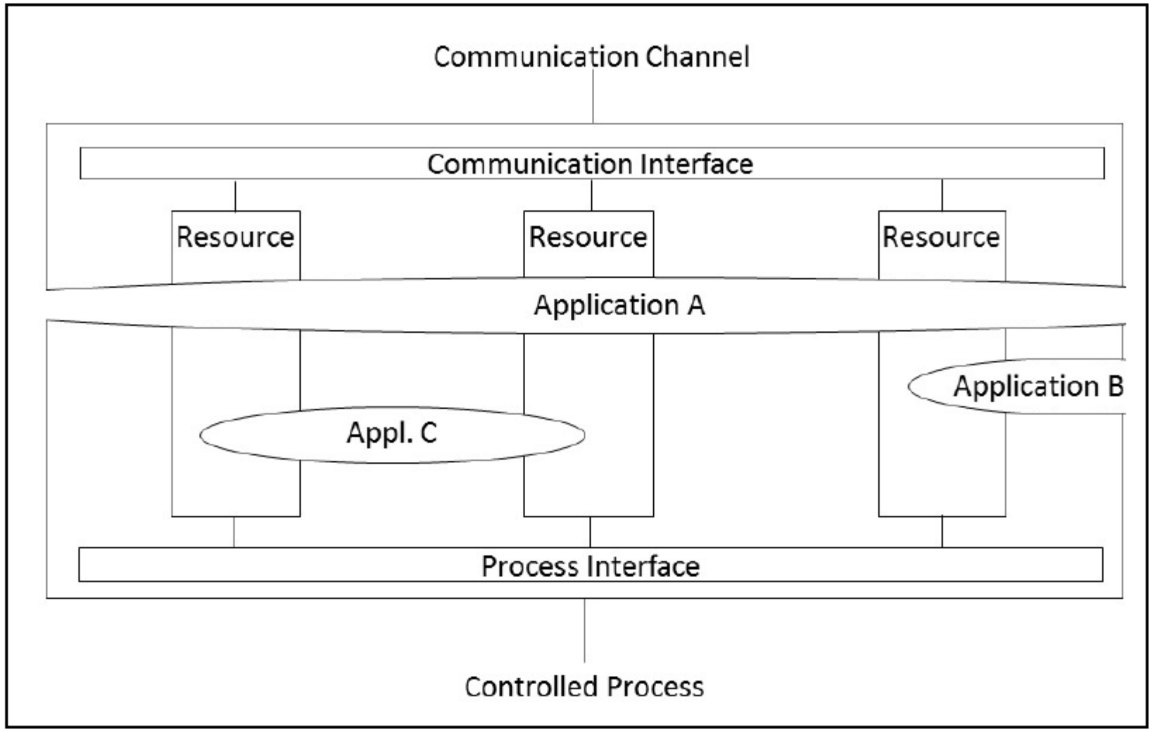
Elements of an Automation Industrial System

- Consist of
  - Physical Process
    - Sensors and Actuators along with energy and raw material flow
  - Control System

Control and Measurement Systems



The control and measurement model



The device model

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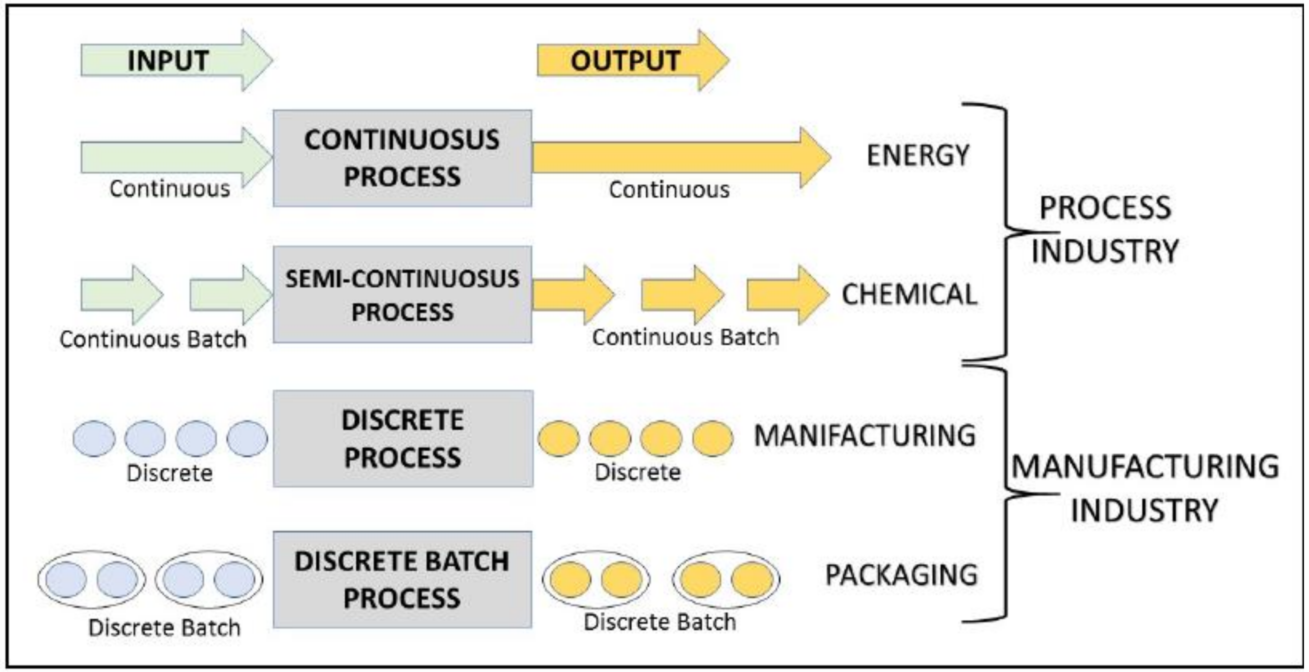
Types of Industrial Process



Continuous Process — **Goal is to obtain a product of uniform quality over a time, regardless of time**

- Energy Production
- Distribution of energy, water and gas
- Crude oil and gas extraction
- Rolling plants, cement, glass, paper and so on.

Batch Process — **Finite quantities of a final product, from a finite quantity of raw material over the ordered set of activities**

- Consumer products

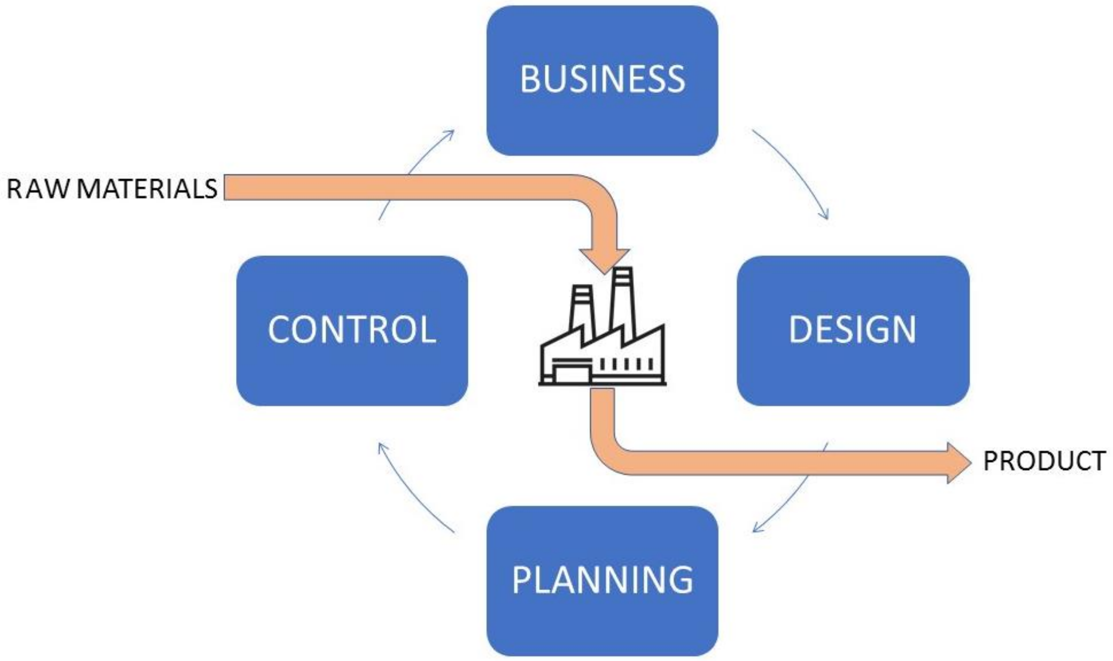
Semi Continuous Process — **Some characteristics in common with both continuous and batch process**

- Water treatment
- Filtering and cleaning of gasses and liquids etc.

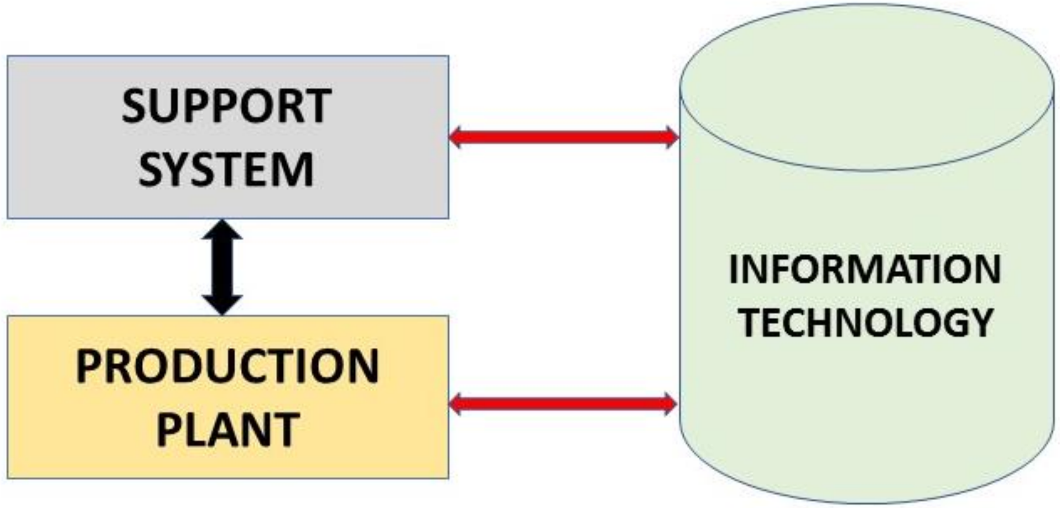
Discrete Process — **Both raw materials and product are countable**

- Machining operations
- Transport of products, AGV's etc.
- Buffers

CIM Model & Pyramid



Production Support Systems

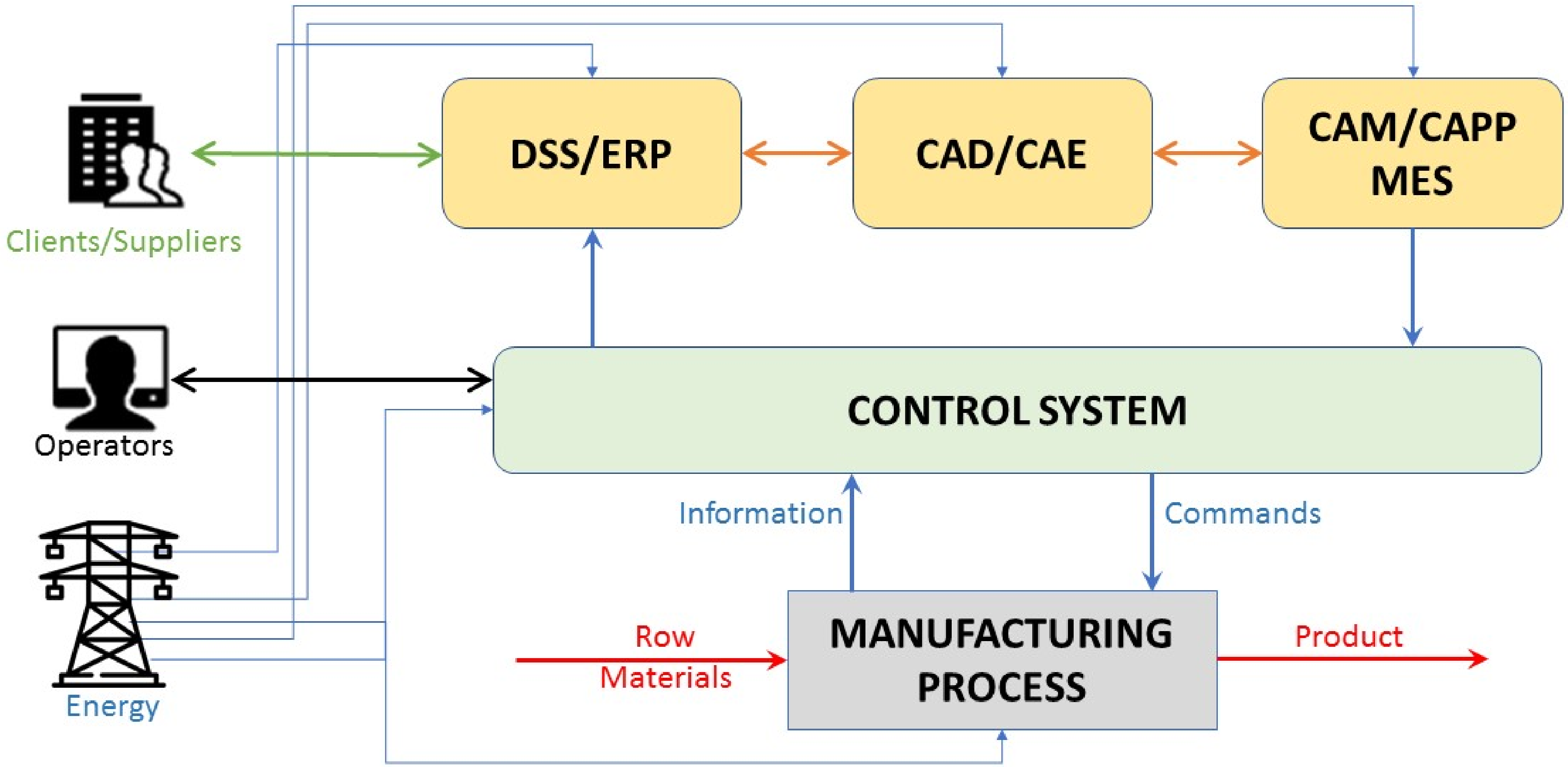


CIM Logical Schema

ERP; CAD and CAE, CAPP and MES

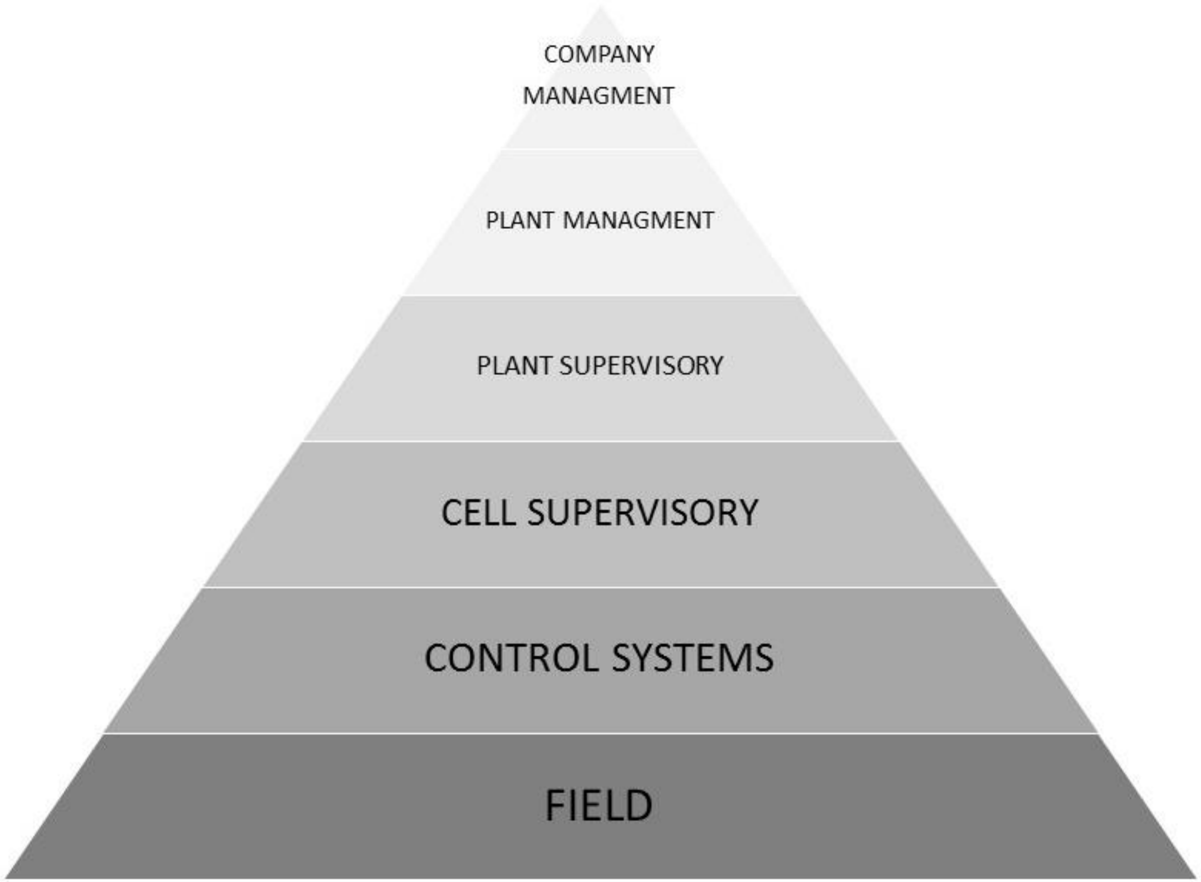
Automation & Types in Industrial Process

CIM Model



Automation & Types in Industrial Process

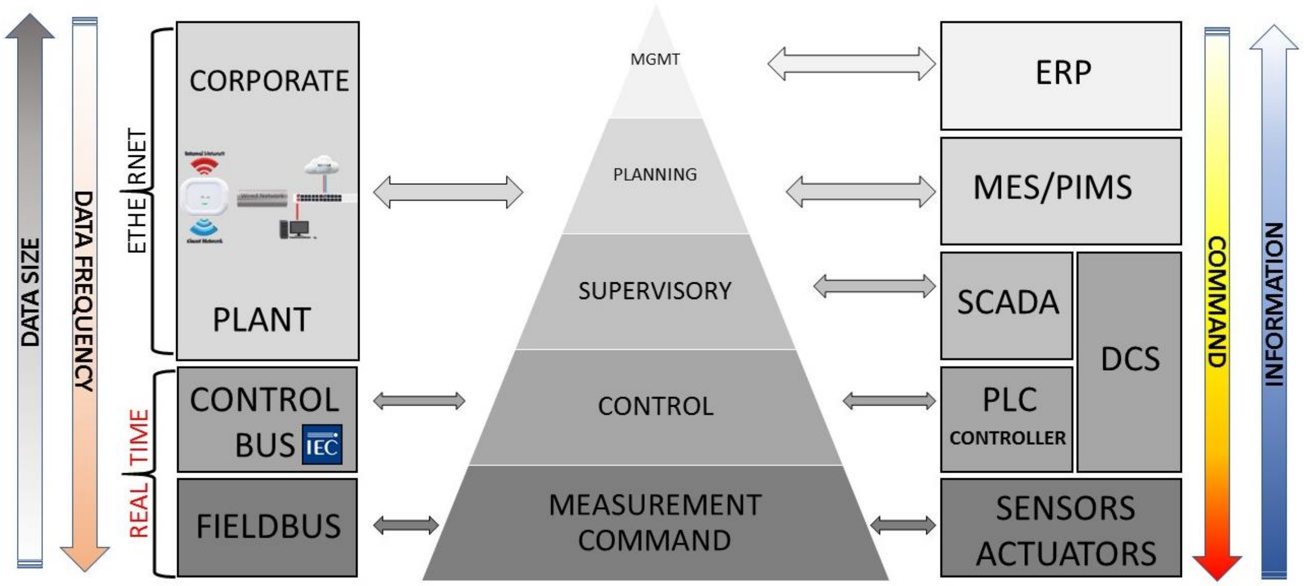
CIM Pyramid

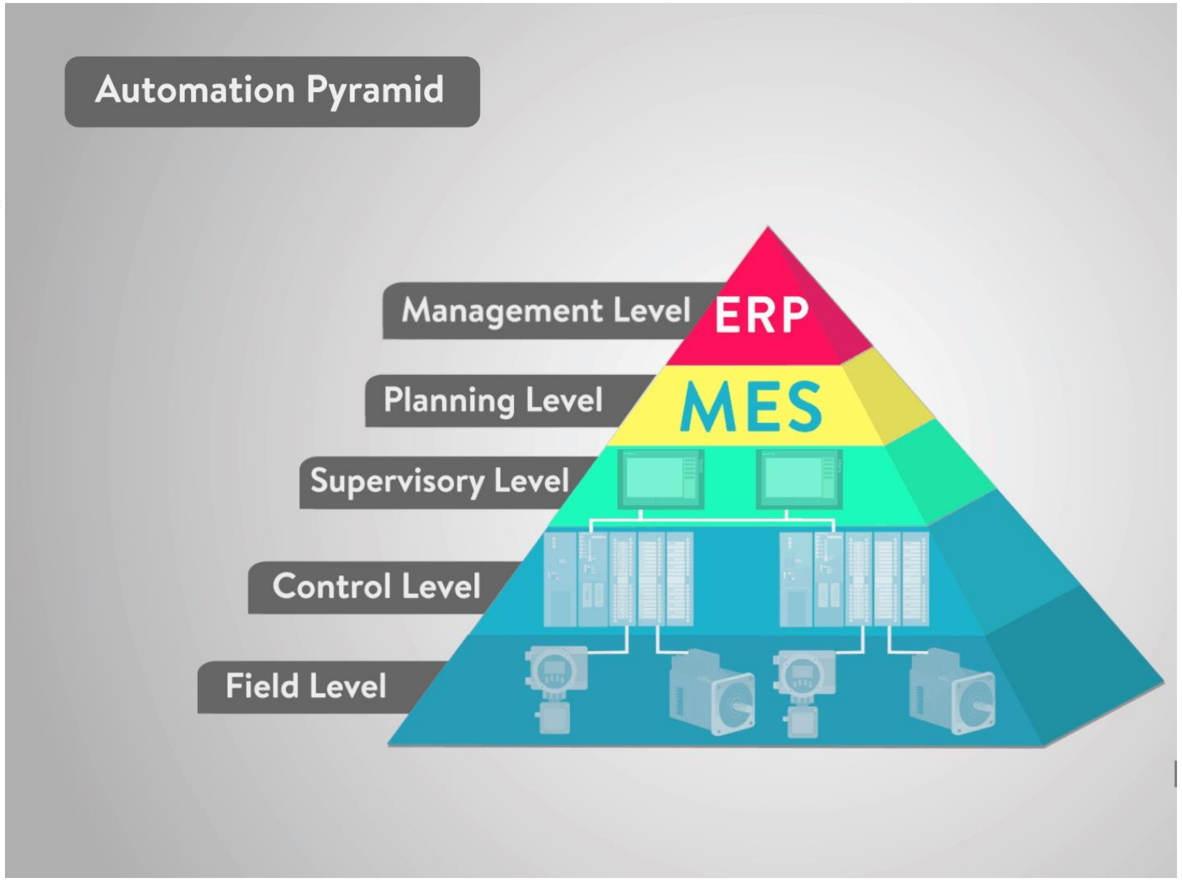


- Level 1 – field: Sensors, Actuators, Hardware
- Level 2 – Command and Control – Control Systems – PLC, DCS
- Level 3 – Cell Supervisory – SCADA, Alarm Management etc.
- Level 4 – Plant Supervisory – SCADA
- Level 5 – Plant Management Level: MES, Asset Management
- Level 6 – Company Management – ERP Systems

Automation & Types in Industrial Process

CIM Pyramid





Sensors and Transducers

- **Sensors are also expected to be part of a network**
- **Wireless sensor networks are being used for this purpose**

- **WSNs are becoming increasingly heterogeneous with mix of many types of sensors**
- **WSNs can use specific sensor types for multiple different applications**

Example -a temperature sensor that can be flexibly used for environmental applications, weather applications, and smart farming applications.

Components of automation in Industry 4.0

- **Sensor** : provides IIoT data, Big data, analog/digital
- **Intelligence** in IoT is built on top of sensor data acquired
- **Actuator:** implement the result of intelligent processing of sensor data

Why is sensing required?

- Sensing is required in the industry for:
  - Increasing degree of automation
  - Increase productivity
  - Improve quality
  - Improve safety
  - Reduce downtime

Industrial Sensing & Actuation contd.,

Features of industrial sensing & actuation

- ➢ Industrial standard requirement differs from regular usage of sensors and actuators
- ➢ Sensors need to be **very highly reliable**
- ➢ Sensing and actuation need to be available at **low cost**
- ➢ Sensors and actuators need to be **perpetually connected** to the network

Video examples:

- Sensor and switch solutions for Aerospace & Defense | Honeywell Sensing & Internet of Things: https://www.youtube.com/watch?v=JxRNaMPsaFM
- How gas sensing gets intelligent with BME688 and BME AI-Studio: https://www.youtube.com/watch?v=xcZKKNrBt2g
- Bosch MEMS sensors: Working principle of an accelerometer https://www.youtube.com/watch?v=RLQGZl0lpjQ

Industrial Sensing

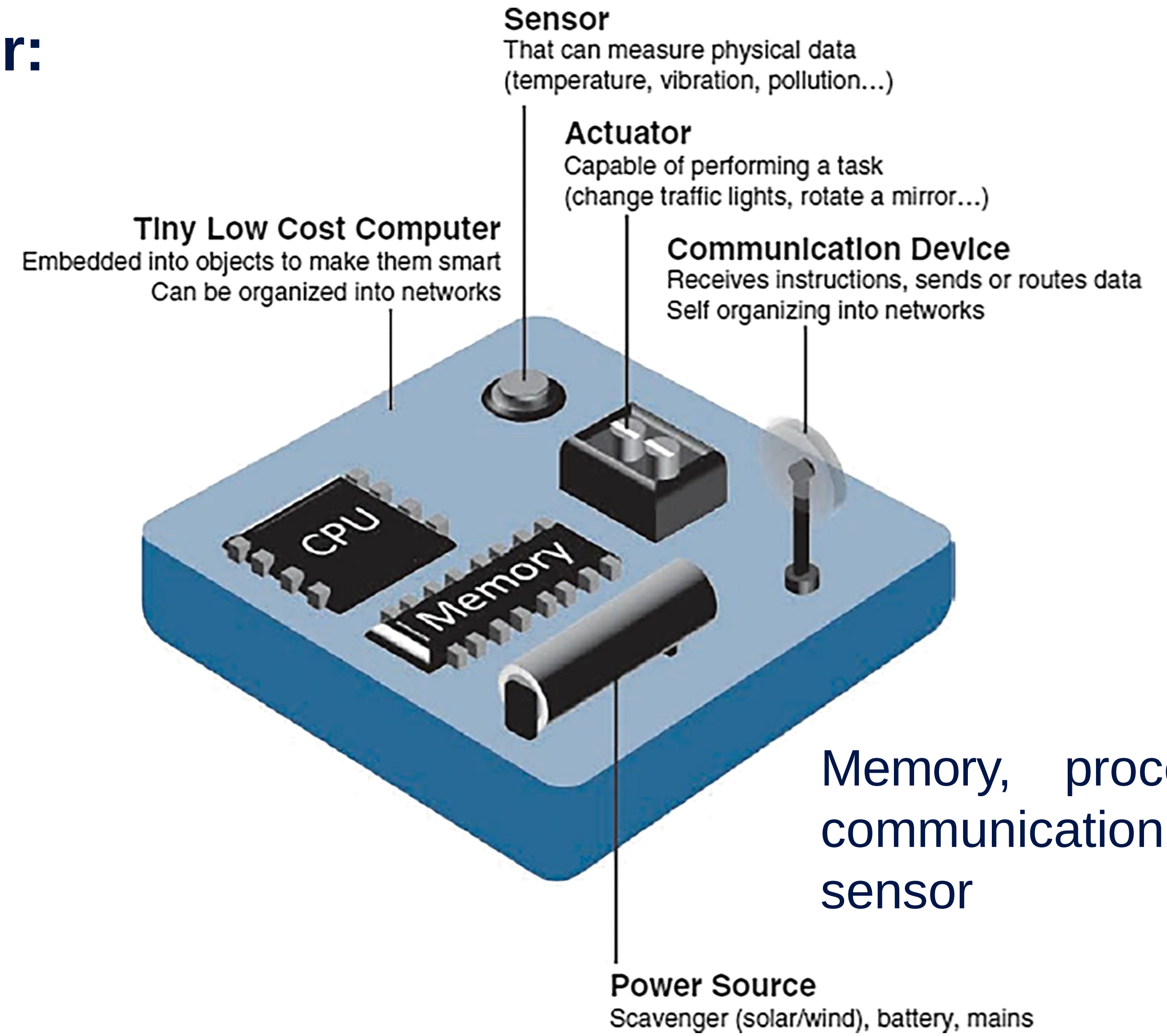
Industrial sensing: Conventional v/s Contemporary sensing

- **Conventional sensing** requires sensors deployed in a feedback loop of a process in an industrial control system
- Actuation is based on the sensed values
- **Contemporary (sensing)** requirement on sensors is very different
  - Sensors are required to connect to the Internet
  - They may be required to sense
    - Product lifetime
    - Safety
    - Reliability
    - Multiple parameters

- **Smart Sensor:** Definition of IEEE 1451 standard – *“Sensor with small memory and standardized physical connection to enable communication with the processor and data network”*

Industrial Sensing

Smart Sensor:



Memory, processor and wireless communication is added to the sensor

Karn, A. L., Manickam, P. S., Saravanan, R., Alroobaea, R., Almotiri, J., & Sengan, S. (2022). IoT Based Smart Framework Monitoring System for Power Station. Computers, Materials & Continua Tech Science Press.

Industrial Sensing: Wireless sensor networks

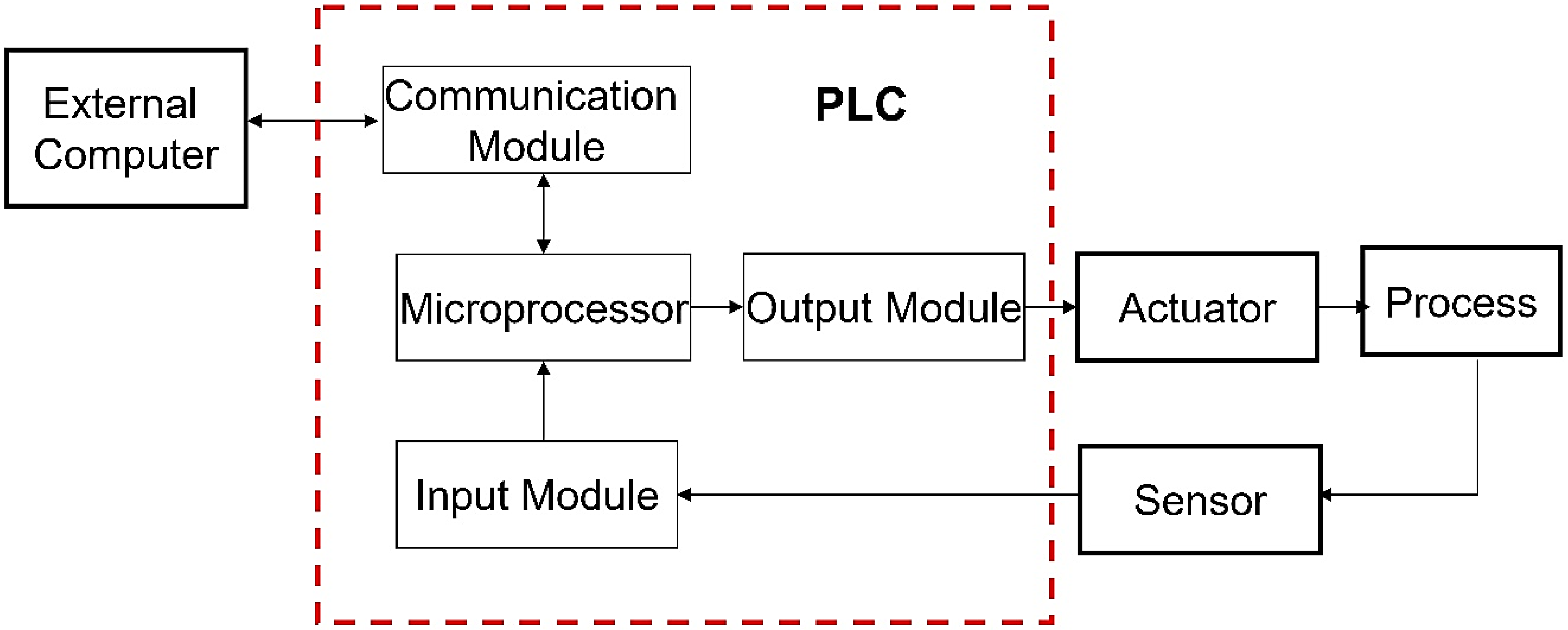
- ➢ Sensors are also expected to be part of a network
- ➢ Wireless sensor networks are being used for this purpose
- ❑ **WSNs are becoming increasingly heterogeneous with mix of many types of sensors**
- ❑ **WSNs can use specific sensor types for multiple different applications**

• Example -a temperature sensor that can be flexibly used for environmental applications, weather applications, and smart farming applications.

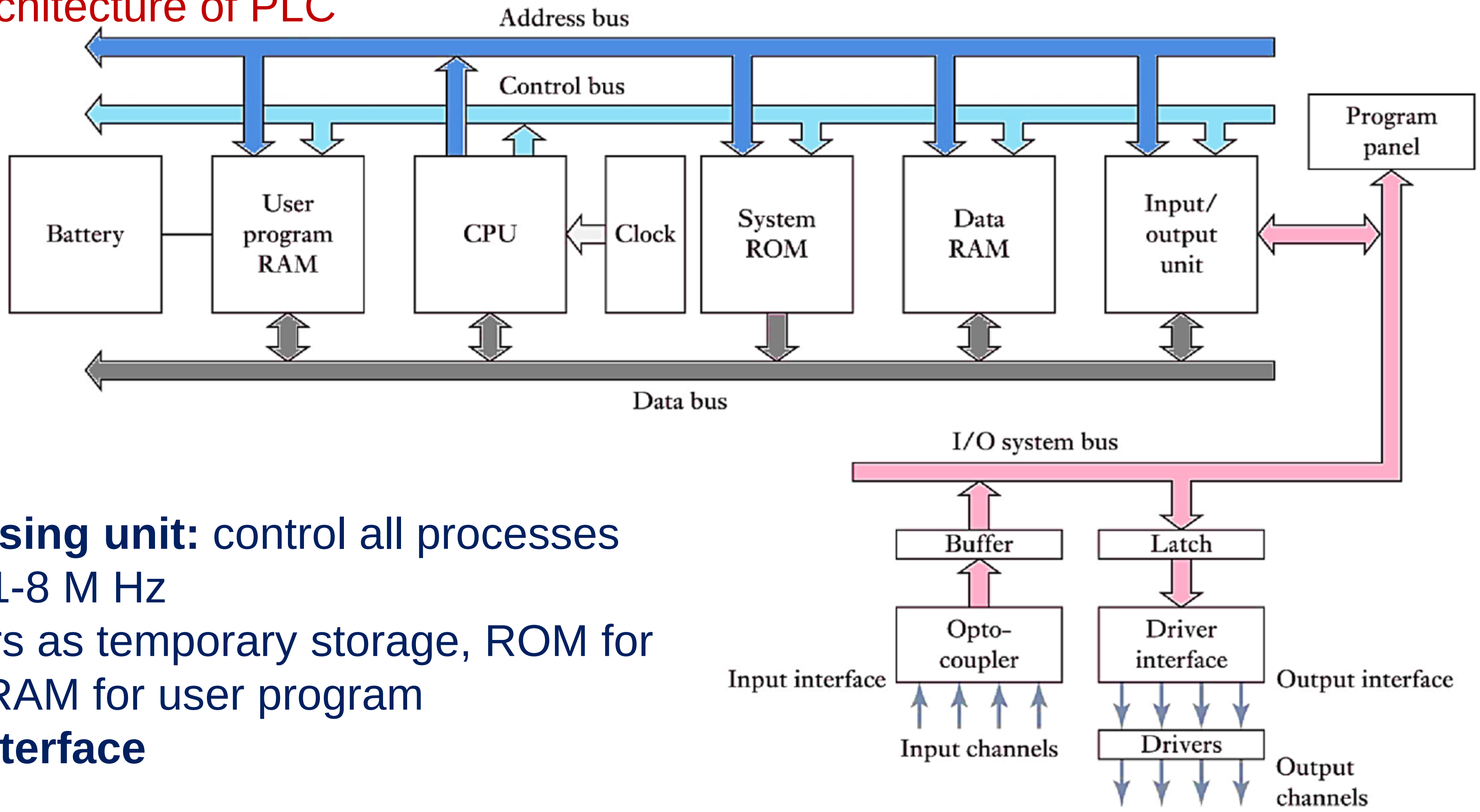
Industrial Sensing

- Smart sensors need to perform multiple functions
  - ✓ **Multisensing:** sensor can sense multiple parameters such as temperature, pressure, light, humidity at a single node
  - ✓ **Communicate data:** sensors need to communicate vital information such as measured data, calibration and compensation data to a central control unit
  - ✓ **A/D or D/A Conversion:** sensor data may need to be converted from analog to digital and vice-versa
  - ✓ **Self-Decision making:** the sensor needs to be able to self-monitor its operation and changes in the environment by compensating readings appropriately by itself, or by alerting humans for manual action

PLC in Control Circuits



Basic Structure\ Architecture of PLC



It consist of:

1. **Central processing unit:** control all processes with frequency 1-8 M Hz
2. **Memory:** Buffers as temporary storage, ROM for system data & RAM for user program
3. **Input/output interface**
4. **System buses**

Industrial Actuation

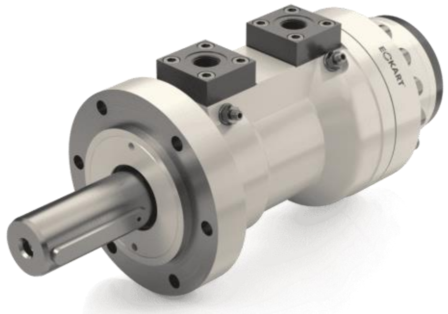
- Industrial monitoring is made easier through technologies such as **SCADA** (Supervisory Control and Data Acquisition) and **networks** such as Wireless Sensing & Actuation Network or **WSAN**

What is an Actuator?

- An **actuator** is a machine part that *receives feedback from a control signal* and then begins *movement*.
- The actuator makes *distinct motions* depending on the *machine's purpose* once it receives electricity.
- **Industrial actuators** can be electrical, hydraulic, pneumatic, electro-hydrostatic or electro-pneumatic.

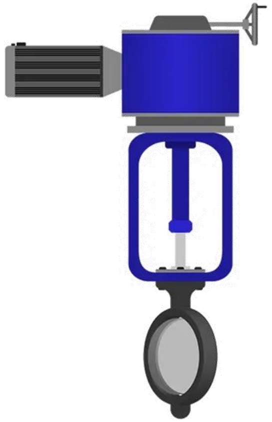
Industrial Actuation

Linear Actuators

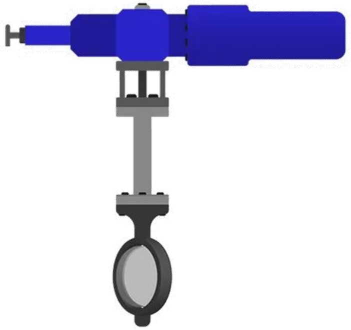


Rotary Actuators

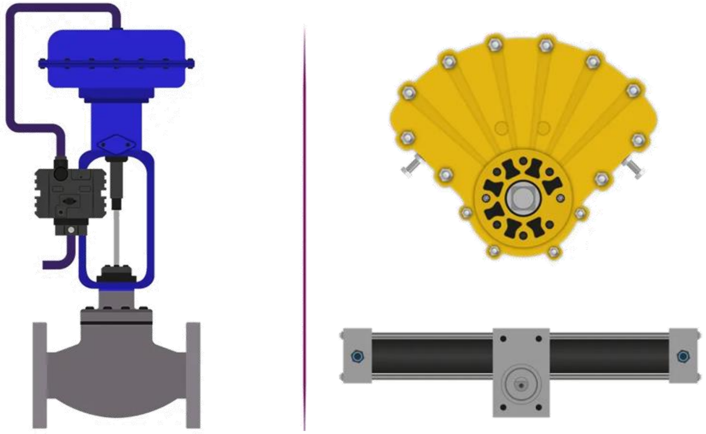
Thermal Actuator



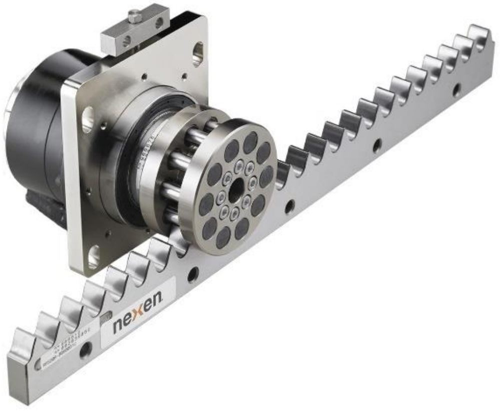
Electric Actuator



Hydraulic Actuator



Pneumatic Actuators

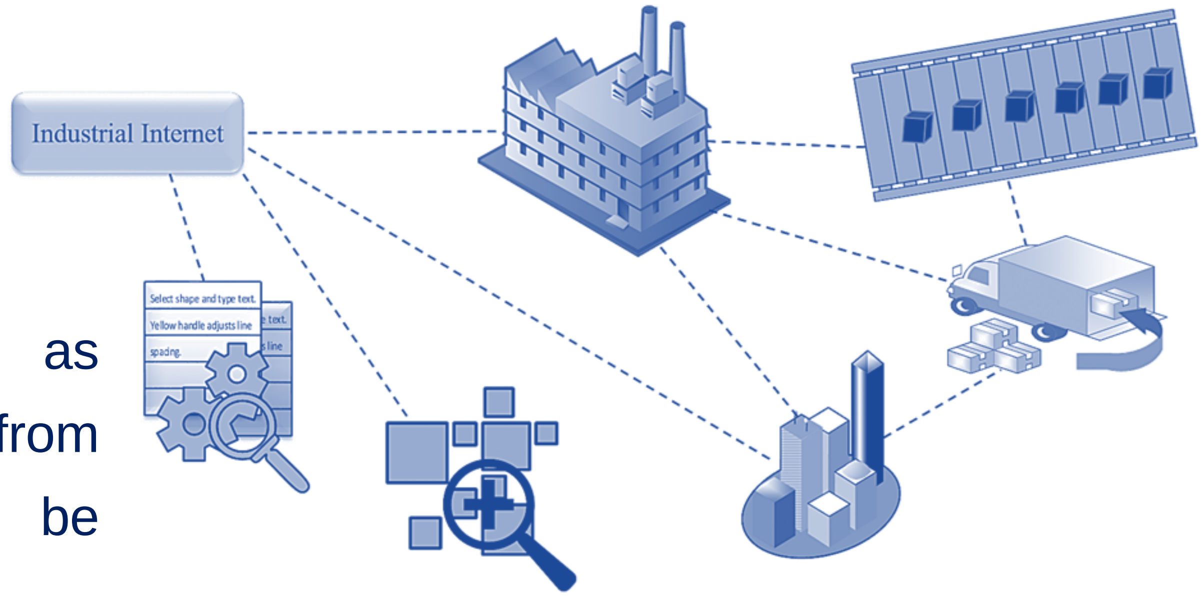


Mechanical Actuator

https://www.linquip.com/blog/types-of-actuators/

Industrial Internet

- The term *Industrial Internet* was coined by the *U.S. corporation, GE*.
- Industrial Internet resulted from the *combination of physical and digital worlds*.
- As defined by GE, Industrial Internet is “the *convergence* of the global industrial systems with the *power of advanced computing, analytics, low-cost sensing*, and new levels of connectivity permitted by the Internet.”
- The Industrial Internet-enabled organizations use *sensor nodes, software, and Machine-to-Machine (M2M) communication* to *collect data* from material things or devices.
- The interconnected devices in industries, such as automated assembly line, real-time data collected from sensor nodes, and their analysis together can be referred to as the *Industrial Internet*.

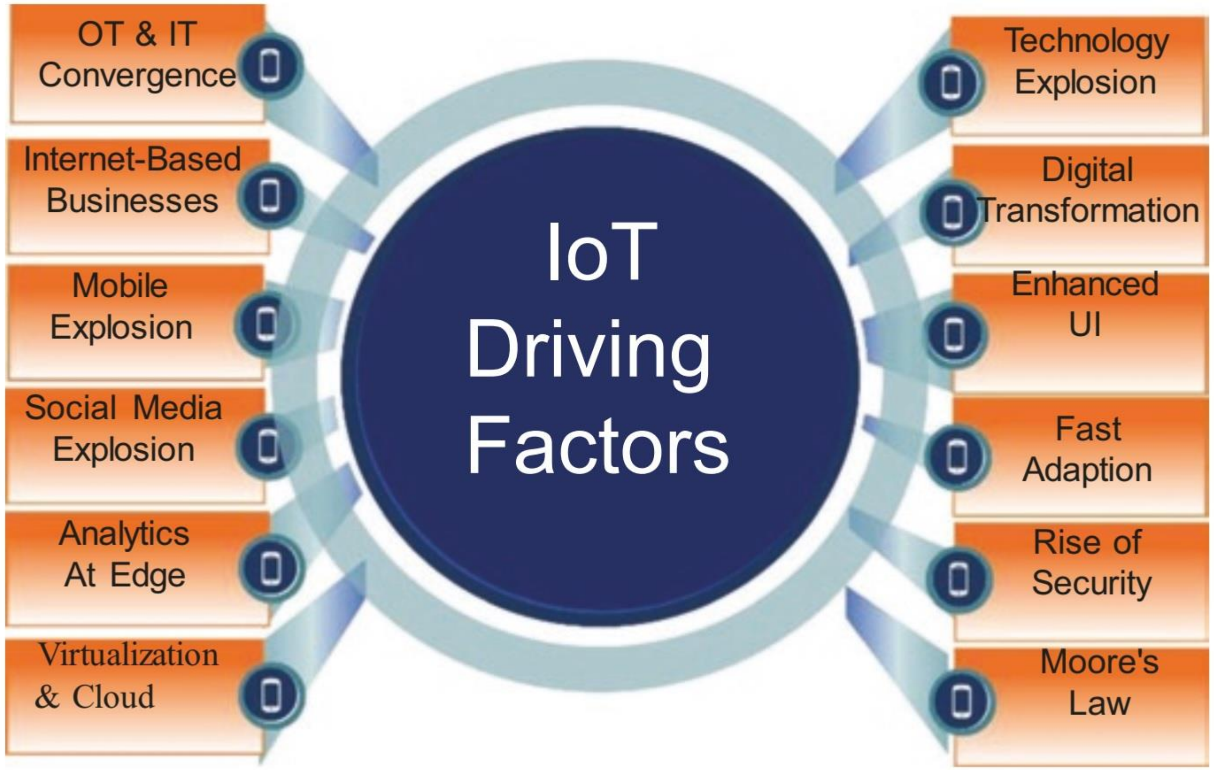


Industrial Internet.

Industrial Internet

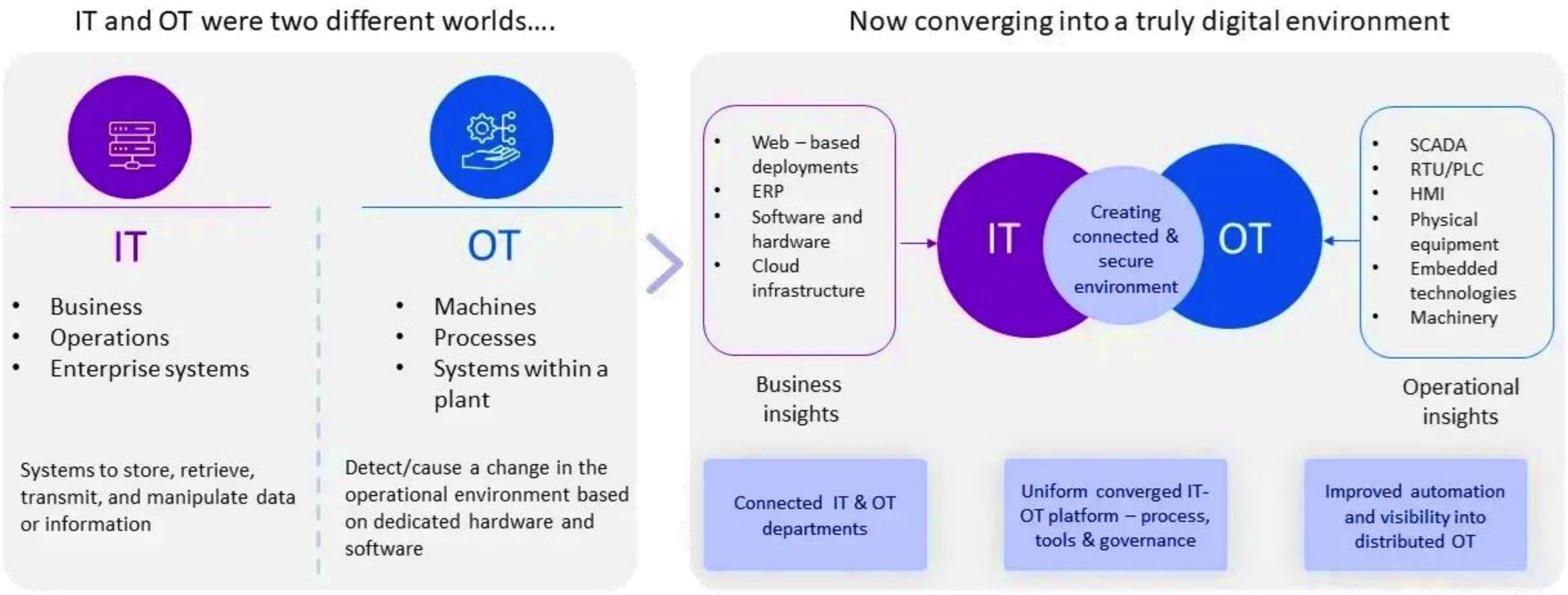
- Industrial Internet will lead to an *increase in the speed and efficiency* in a wide range of industries such as aviation, railways, mining, power generation, and healthcare systems.
- It will result in *improved job facilities, accelerate the productivity* of the manufacturing system, and promote all-round economic growth.
- According to GE, there exist *three phases* in the development of the Industrial Internet
  - ✓ **Industrial Revolution:** During the *first and second industrial revolution*, the productivity and mechanization of factories were initiated.
  - ✓ **Internet Revolution:** The *third industrial revolution* led to the development of *automation in the manufacturing system*, computers, and the emergence of the internet (World Wide Web).
  - ✓ **Industrial Internet:** The amalgamation of *CPS* and the *evolution of Internet-based technologie*s led to the development of the Industrial Internet.

Operations Technology/Information Technology convergence

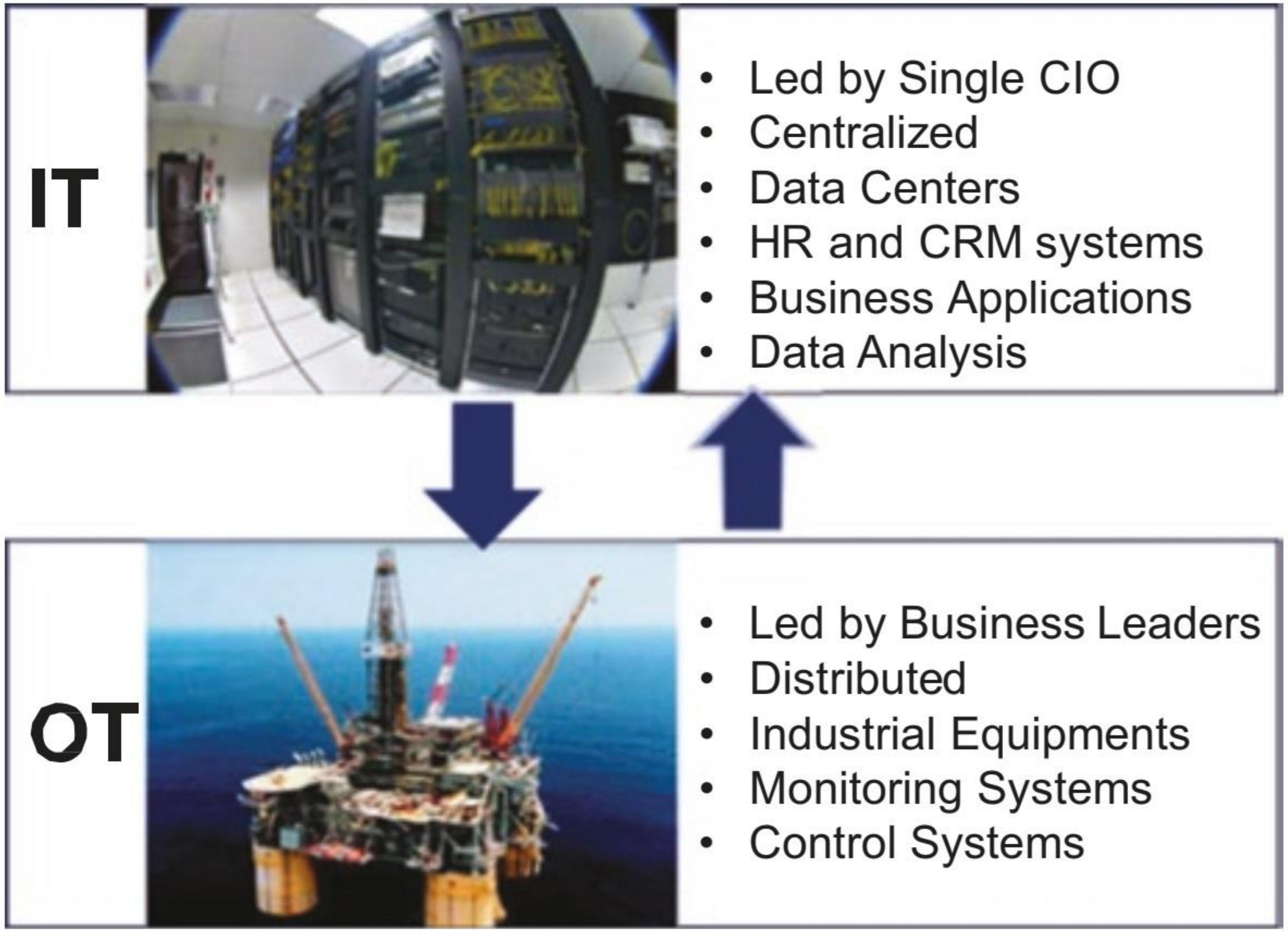


- OT relies on real-time data that drives safety, security, and control.
- Traditional IT departments simply lack the required resources to introduce IoT solutions in a timely fashion, effectively operate and monitor
- With the pressure of IoT technology adoption by cutting-edge businesses, OT is forced to accept a greater level of integration.

OT/IT convergence



OT/IT convergence



CRM- Customer Relationship Management

Industrial internet

- When accessing data from PLCs or industrial PCs, engineers usually have to deal with
  - ✓ vendor-specific industrial fieldbuses or
  - ✓ implement Ethernet-based data exchange mechanisms (e.g., over TCP/IP or UDP).
- There are two mechanisms for exchanging this data:
  1. **a client-server model** in which clients use the dedicated services of the server; TCP and HTTPS
  2. **a publisher-subscriber model** in which a server makes configurable subsets of information available to any number of recipients. AMQP or MQTT

Industrial Internet- Benefits to Industrial economy

Heavy Industries

- Within the industrial sector, the heaviest energy consumers are the *steel and metals industries and the petrochemical industry*.
- Heavy industries represent about 50 percent of the industrial energy consumed.
- Recent studies indicated that if best practice technologies are deployed, *heavy industry energy consumption could be reduced by 15 to 20 percent*.
- The continued and expanded Industrial Internet deployment can support this effort through process integration, life-cycle optimization, and more efficient utilization and maintenance of equipment

IoT Levels & Deployment Templates

An IoT system comprises of the following components:

- **Device**: An IoT device allows identification, remote sensing, actuating and remote monitoring capabilities. You learned about various examples of IoT devices in section
- **Resource**: Resources are software components on the IoT device for accessing, processing, and storing sensor information, or controlling actuators connected to the device. Resources also include the software components that enable network access for the device.
- **Controller Service**: Controller service is a native service that runs on the device and interacts with the web services. Controller service sends data from the device to the web service and receives commands from the application (via web services) for controlling the device.

IoT Levels & Deployment Templates

Database: Database can be either local or in the cloud and stores the data generated by the IoT device.

Web Service: Web services serve as a link between the IoT device, application, database and analysis components. Web service can be either implemented using HTTP and REST principles (REST service) or using WebSocket protocol (WebSocket service).

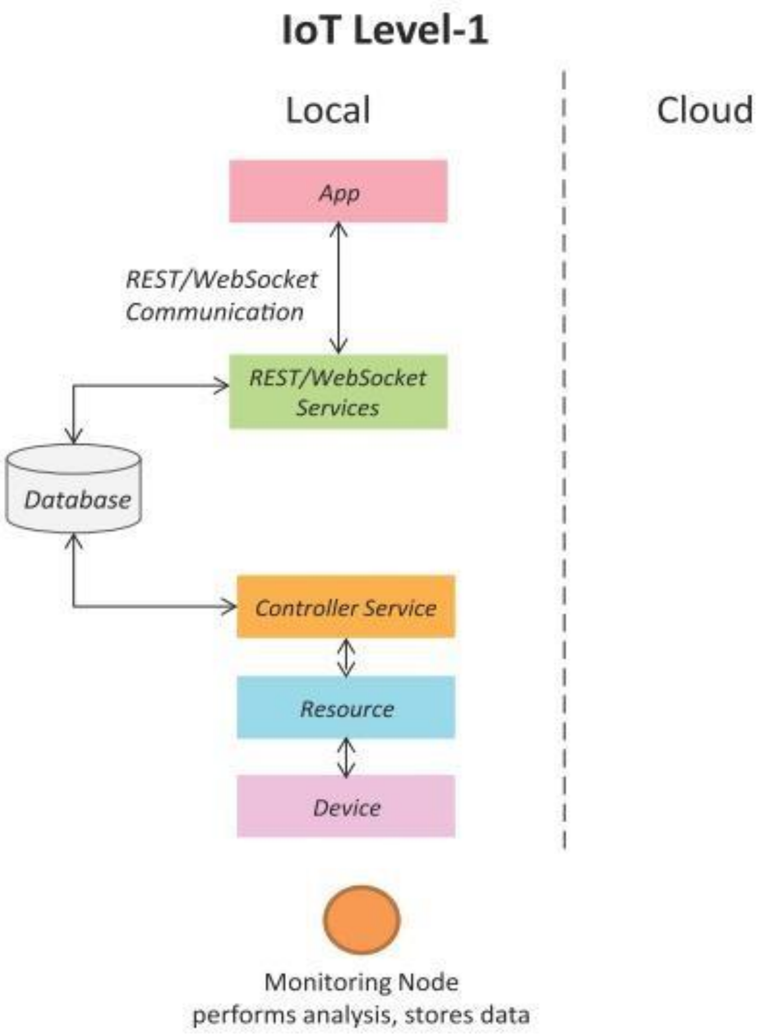
Analysis Component: The Analysis Component is responsible for analyzing the IoT data and generate results in a form which are easy for the user to understand.

Application: IoT applications provide an interface that the users can use to control and monitor various aspects of the IoT system. Applications also allow users to view the system status and view the processed data.

IoT Level-1

- A level-1 IoT system has a single node/device that performs sensing and/or actuation, stores data, performs analysis and hosts the application

- Level-1 IoT systems are suitable for modeling low- cost and low-complexity solutions where the data involved is not big and the analysis requirements are not computationally intensive.

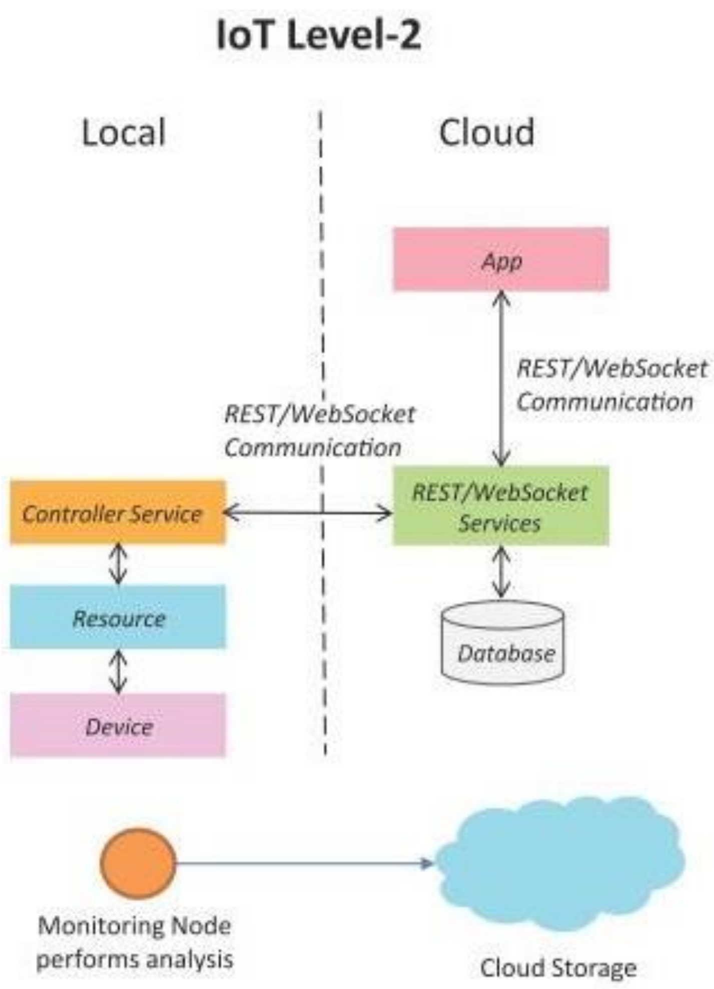


IoT Level-2

- A level-2 IoT system has a single node that performs sensing and/or actuation and local analysis.

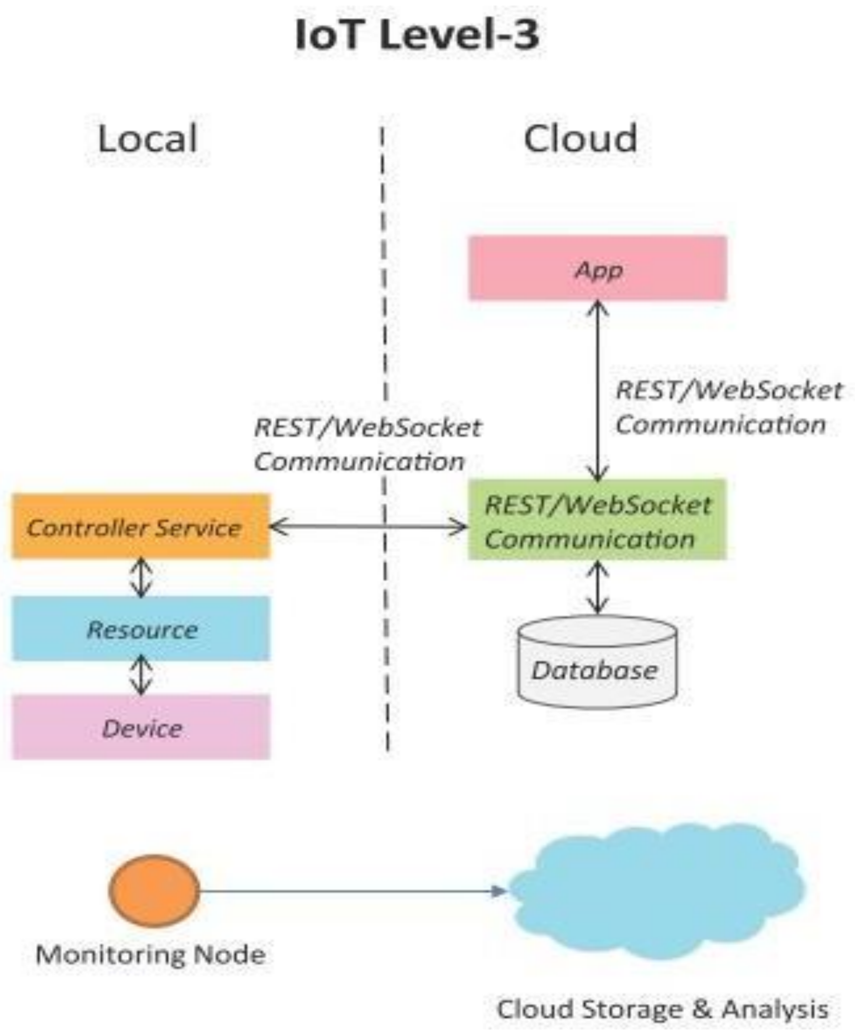
- Data is stored in the cloud and application is usually cloud- based.

- Level-2 IoT systems are suitable for solutions where the data involved is big, however, the primary analysis requirement is not computationally intensive and can be done locally itself.



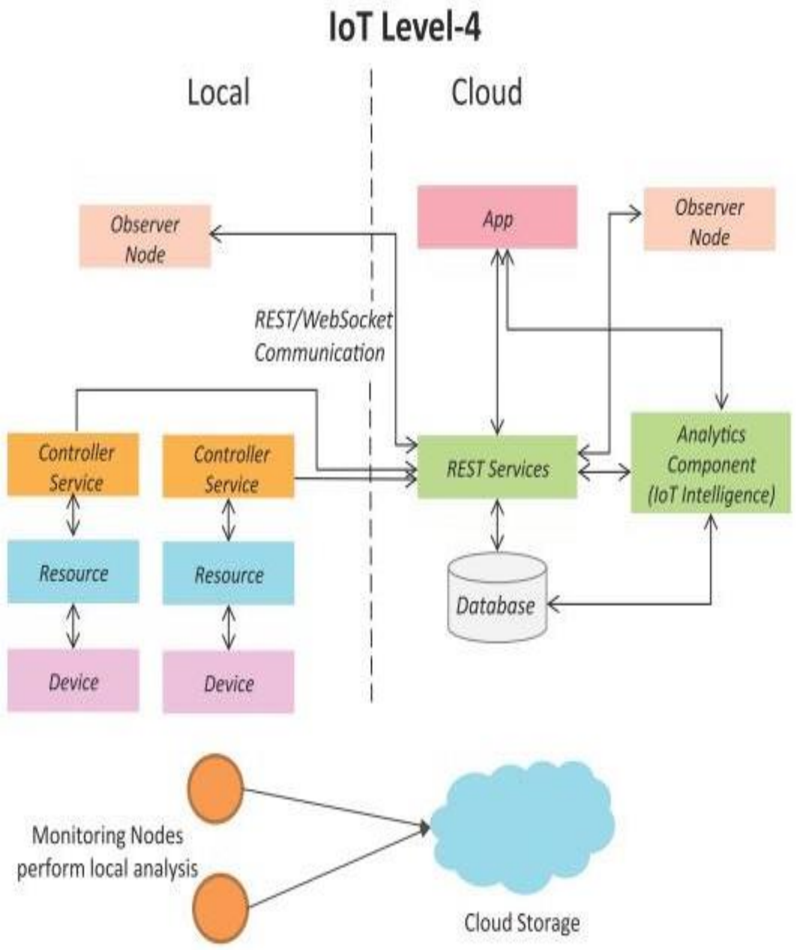
IoT Level-3

- A level-3 IoT system has a single node. Data is stored and analyzed in the cloud and application is cloud- based.
- Level-3 IoT systems are suitable for solutions where the data involved is big and the analysis requirements are computationally intensive.



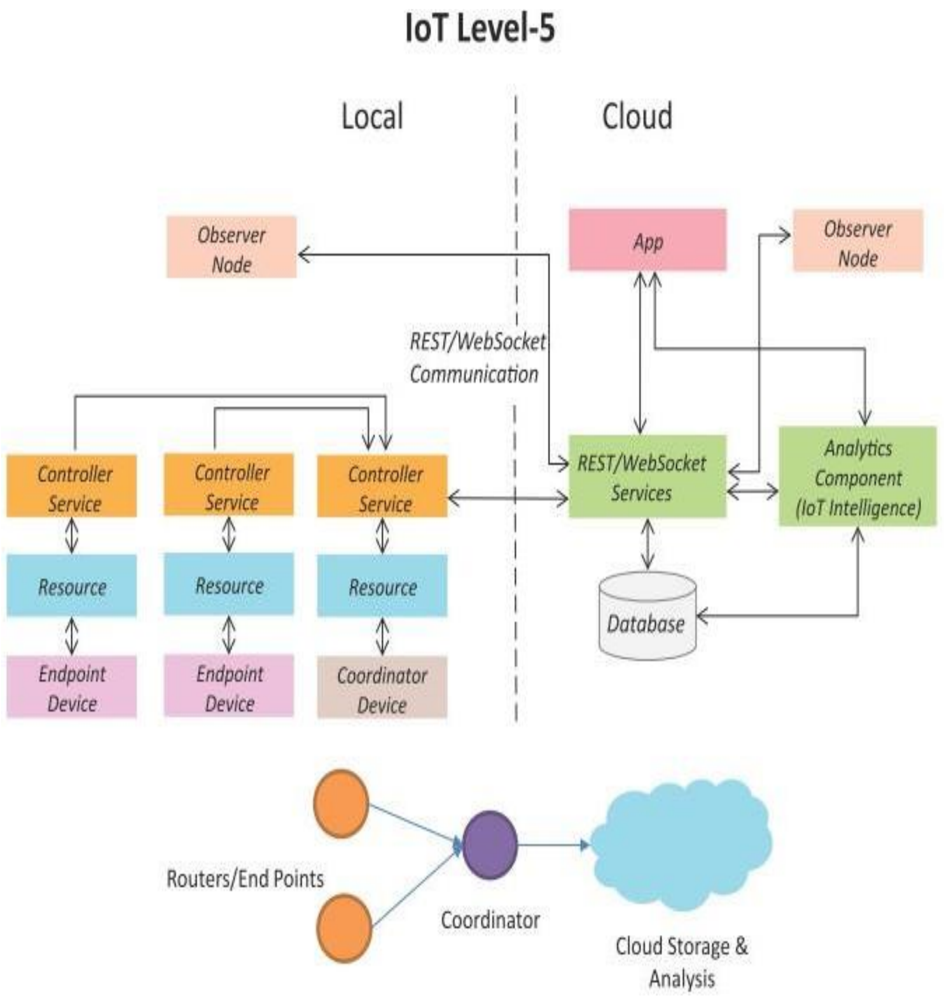
IoT Level-4

- A level-4 IoT system has multiple nodes that perform local analysis. Data is stored in the cloud and application is cloud-based.
- Level-4 contains local and cloud- based observer nodes which can subscribe to and receive information collected in the cloud from IoT devices.
- Level-4 IoT systems are suitable for solutions where multiple nodes are required, the data involved is big and the analysis requirements are computationally intensive.



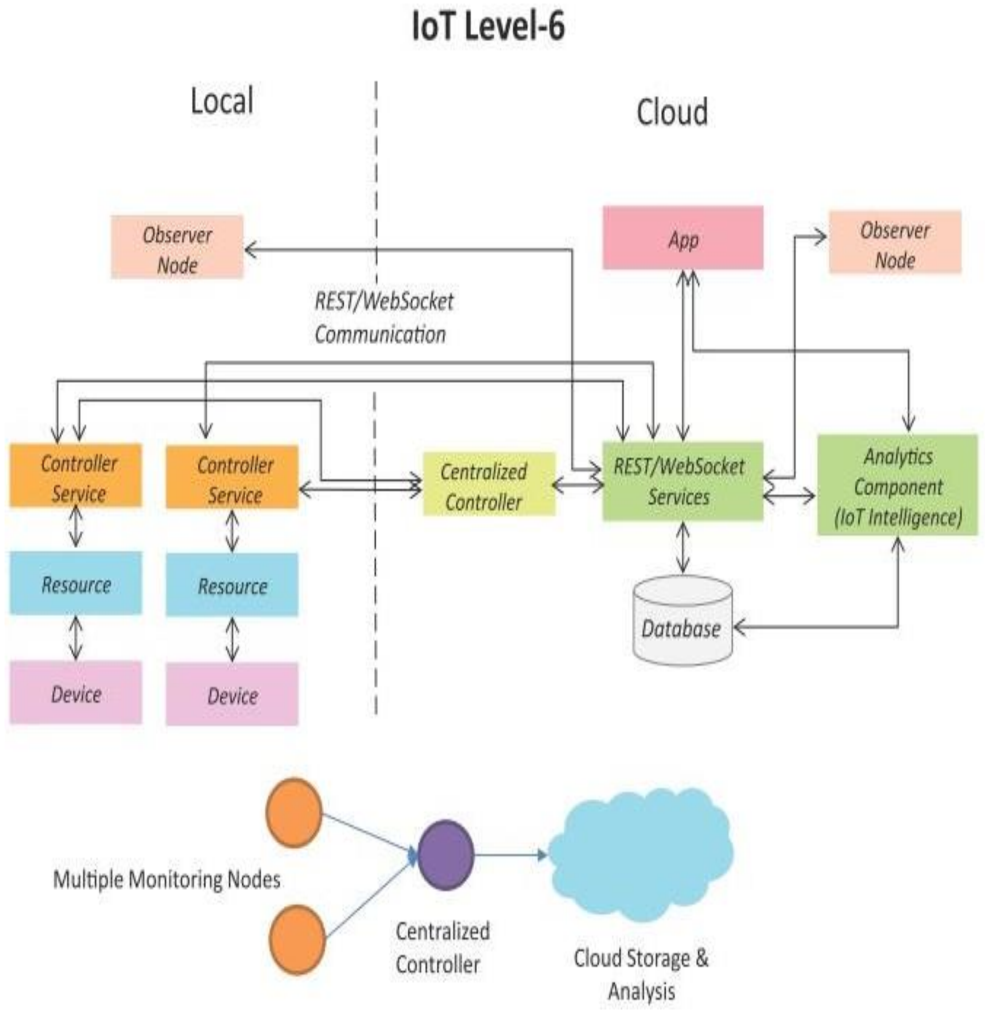
IoT Level-5

- A level-5 IoT system has multiple end nodes and one coordinator node.
- The end nodes that perform sensing and/or actuation.
- Coordinator node collects data from the end nodes and sends to the cloud.
- Data is stored and analyzed in the cloud and application is cloud-based.
- Level-5 IoT systems are suitable for solutions based on wireless sensor networks, in which the data involved is big and the analysis requirements are computationally intensive.



IoT Level-6

- A level-6 IoT system has multiple independent end nodes that perform sensing and/or actuation and send data to the cloud.
- Data is stored in the cloud and application is cloud-based.
- The analytics component analyzes the data and stores the results in the cloud database.
- The results are visualized with the cloud-based application.
- The centralized controller is aware of the status of all the end nodes and sends control commands to the nodes.



Cyber-Physical Systems (CPS)

- *“Cyber-Physical Systems or Smart systems are co-engineered interacting networks of physical and computational components. These systems will provide the foundation of our critical infrastructure, form the basis of emerging and future smart services, and improve our quality of life in many areas”* – **NIST, Engineering Laboratory**
- Systems where there are strong components of the *cyber world* & the *physical world* and interaction between them.
- Cyber-physical systems enable the virtual digital world to interact with the physical world.
- Example: Intelligent manufacturing line, where the *machine can communicate with the other assets* such as Robots or Tool magazines and sometimes even the products they are in the process of making. In simple words, A cyber-physical system consists of a collection of computing devices communicating with one another and interacting with the physical world via sensors and actuators in a feedback loop.

Cyber-Physical Systems contd.,

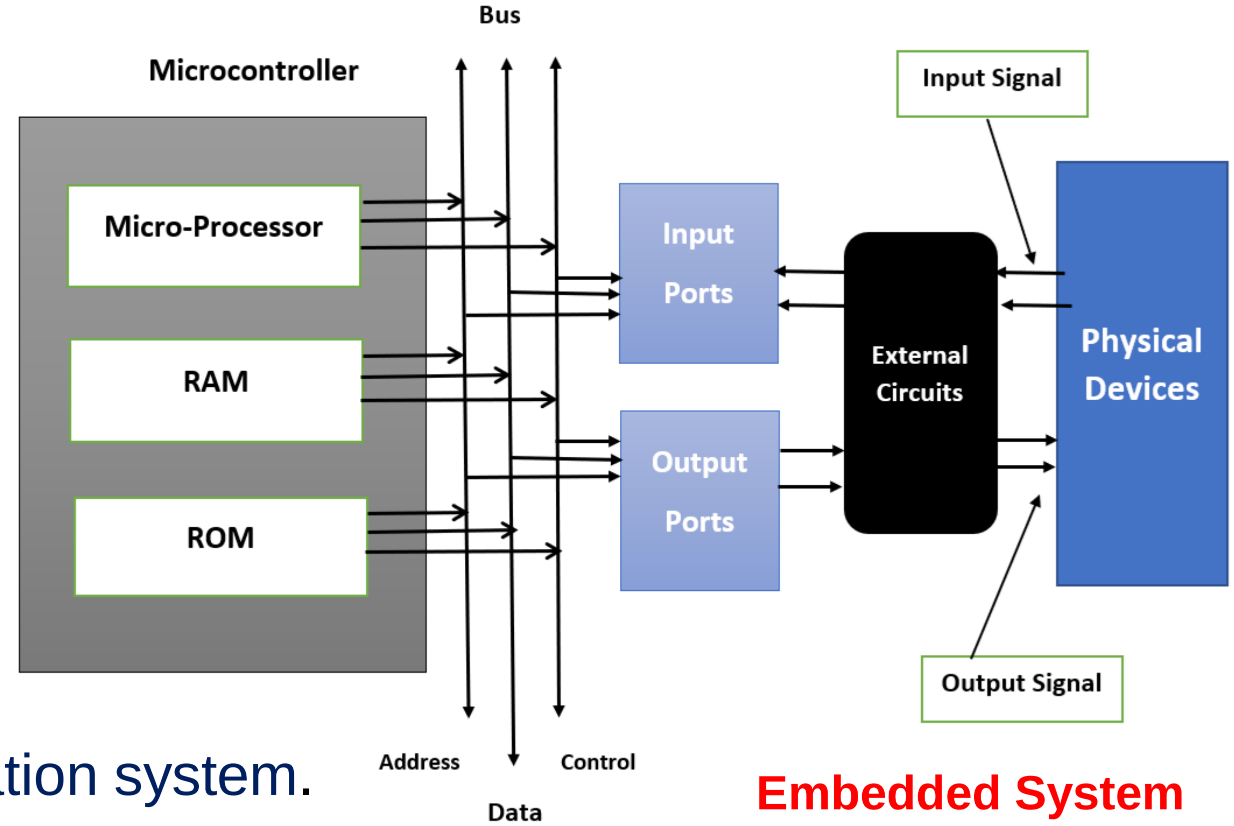
Am I CPS?

Embedded System

Cyber-Physical Systems contd.,

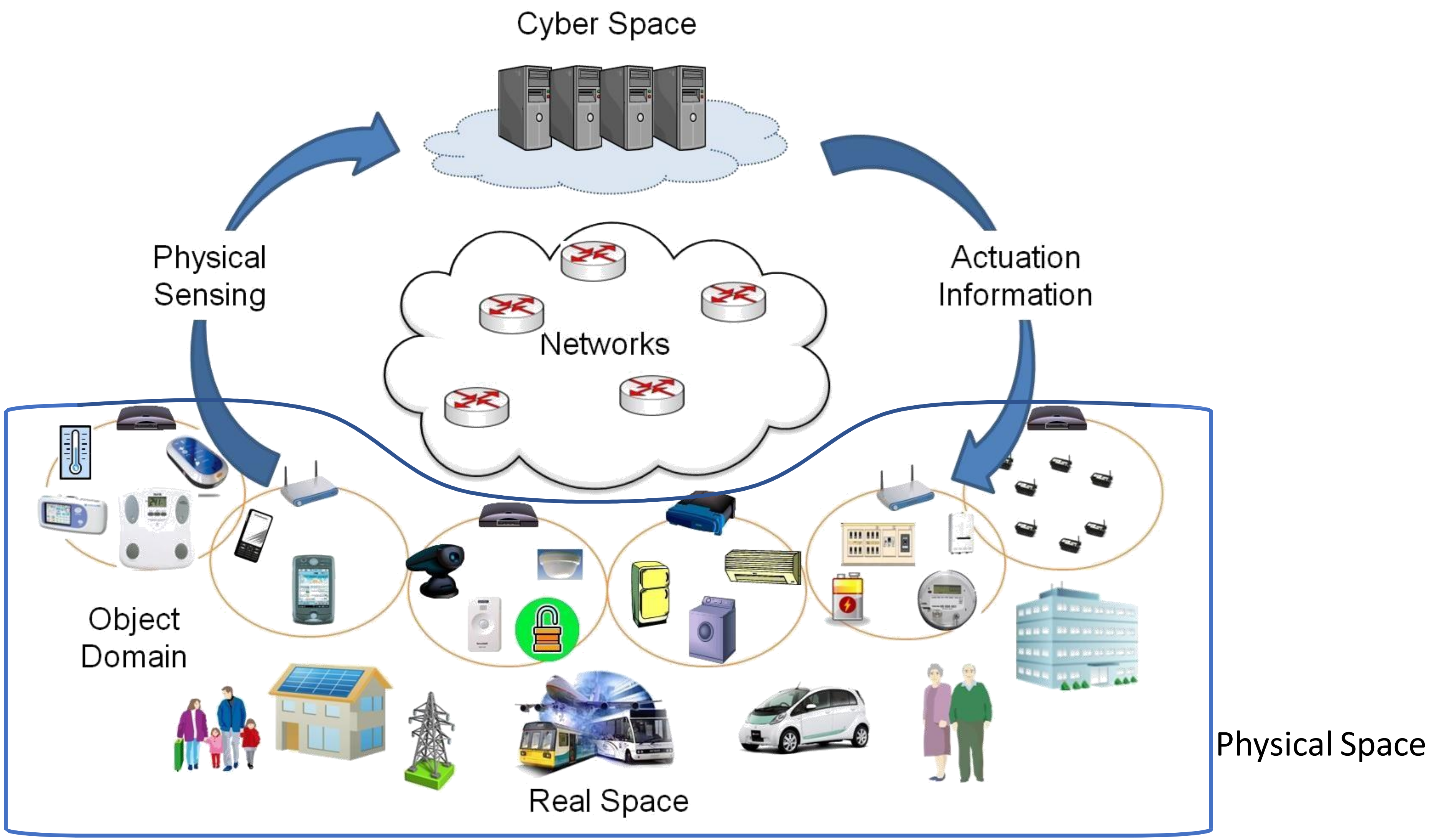
- To understand Cyber-Physical Systems, one should understand *Embedded Systems*
- Cyber-Physical System is a combination of *Embedded Systems* and *Physical systems*
- If embedded systems are generalized to have the following capabilities-
  - ✓ Compute, communicate and control
  - ✓ Interact with the physical world using sensors & actuators

  Then it becomes a cyber-physical system
- Examples-
  - ✓ Medical Instruments
  - ✓ Transportation Vehicles
  - ✓ Defense systems
  - ✓ Robotic Systems
  - ✓ Process monitoring and Factory Automation system.



Embedded System

Cyber-Physical Systems contd.,



Source: https://devicesmart.wordpress.com/tag/cyber-physical-systems/

Cyber-Physical Systems

- Embedded Systems vs Cyber Physical Systems

Embedded Systems	CPS
Devices having information processing systems embedded into them	Complete system having physical components and software
Typically confined to a single device	Networked set of embedded systems
Limited resources for performing limited number of tasks	Not resource constrained
Main issues are real-time response and reliability	Main issues are timing and concurrency

Cyber-Physical Systems- Key Features

- **Reactive Computation**
  - Classical computation model: output produced when input is supplied – a typical computer program
  - *Reactive system interacts* with its environment in an ongoing manner via inputs and outputs
  - Eg. Cruise control in a car
    - Inputs: Turn cruise controller ON or OFF
    - Change desired cruising speed
    - Program responds to such inputs by changing its output – output can be force applied to engine throttle
  - Interaction of the system with the environment in a continuous fashion
  - Behavior of the system is naturally described by a sequence of observed inputs & outputs
  - CPS are reactive systems

Cyber-Physical Systems- Key Features

- **Concurrency**
  - Traditional model of computation is sequential – instructions are executed one at a time
  - *Concurrent computation* has multiple threads of computation executing concurrently, exchanging information to achieve desired goal
  - Eg: Team of autonomous mobile robots executing their code concurrently
    - Each robot has different tasks (building map of environment, motion planning) which itself could be running in parallel
  - Can operate in synchronous or asynchronous mode
  - *Synchronous mode*: processes are executed in lock-step
  - *Asynchronous mode*: different processes execute at independent speeds
  - Eg. System of robots can be viewed as an asynchronous system with individual robots exchanging messages
  - An individual robot may be running multiple processes in a synchronous manner

Video Links

- **Multi-robot Coordination with Agent-Server Architecture for Autonomous Navigation - IROS 2020**
- https://www.youtube.com/watch?v=BlFbiuV-d10
- **IkeaBot: An Autonomous Multi-Robot Coordinated Furniture Assembly System**
- https://www.youtube.com/watch?v=6IX2nTgUQqE
- **GLAS (Global-to-Local Autonomy Synthesis) for Multi-Robot Motion Planning with End-to-End Learning**
- https://www.youtube.com/watch?v=z9LjSfLfG6c
- **Decentralised Multi-Robot Warehouse Commissioning**
- https://www.youtube.com/watch?v=WjEodQRq_Ro

Cyber-Physical Systems- Features

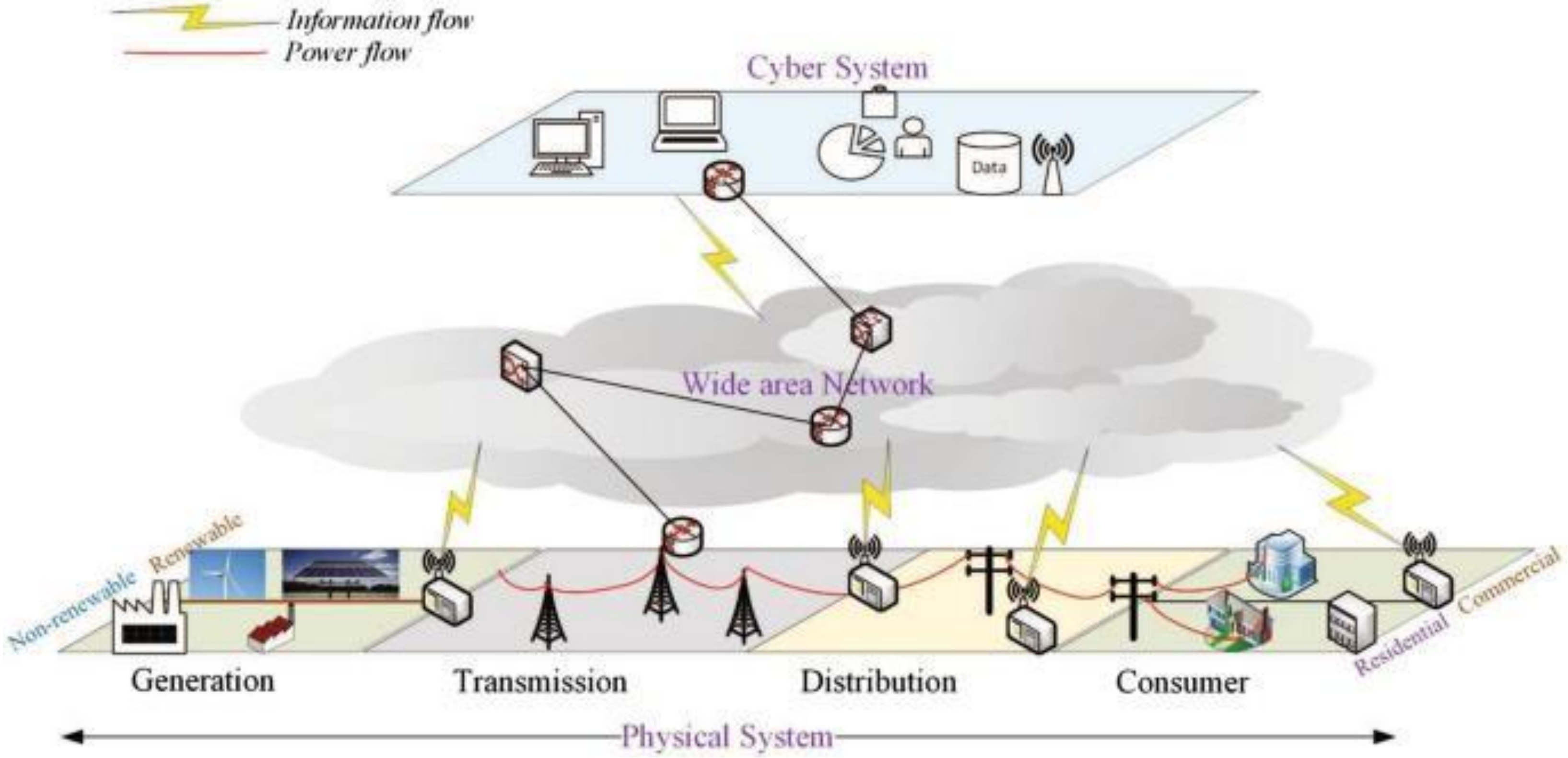
- **Feedback control of the Physical world**
  - A control system interacts with the physical world in a feedback loop by measuring the environment via sensors and influencing it via actuators
  - Cruise controller is constantly monitoring the speed of the car
  - Adjusts the throttle force so that the speed stays close to the desired cruising speed
  - Design of controllers requires modeling of the dynamics of physical quantities
  - Eg. Need a model of how the speed of the car changes with time as a function of the throttle force
  - Traditional control theory focuses on continuous-time systems
  - In CPS, controllers consists of discrete software operations producing discrete outputs which makes the system interact with the continuously evolving physical environment
  - Mix of discrete and continuous systems is called a hybrid system

Cyber-Physical Systems- Features

- **Real-Time computation**
  - Real time performance is critical for cyber-physical systems unlike typical programs
  - Eg. For a cruise controller to control the speed of car properly, time taken for subprocesses to execute necessary computation and communicate the results
- **Safety-critical application**
  - When designing and implementing a cruise controller, errors can lead to drastic consequences, such as loss of life
  - Applications in which the safety of the system has higher priority over other objectives are called safety-critical
  - Aircrafts, automobiles, medical devices are safety-critical applications
  - Detecting design errors in early stages using mathematical models is an important step for safety-critical applications

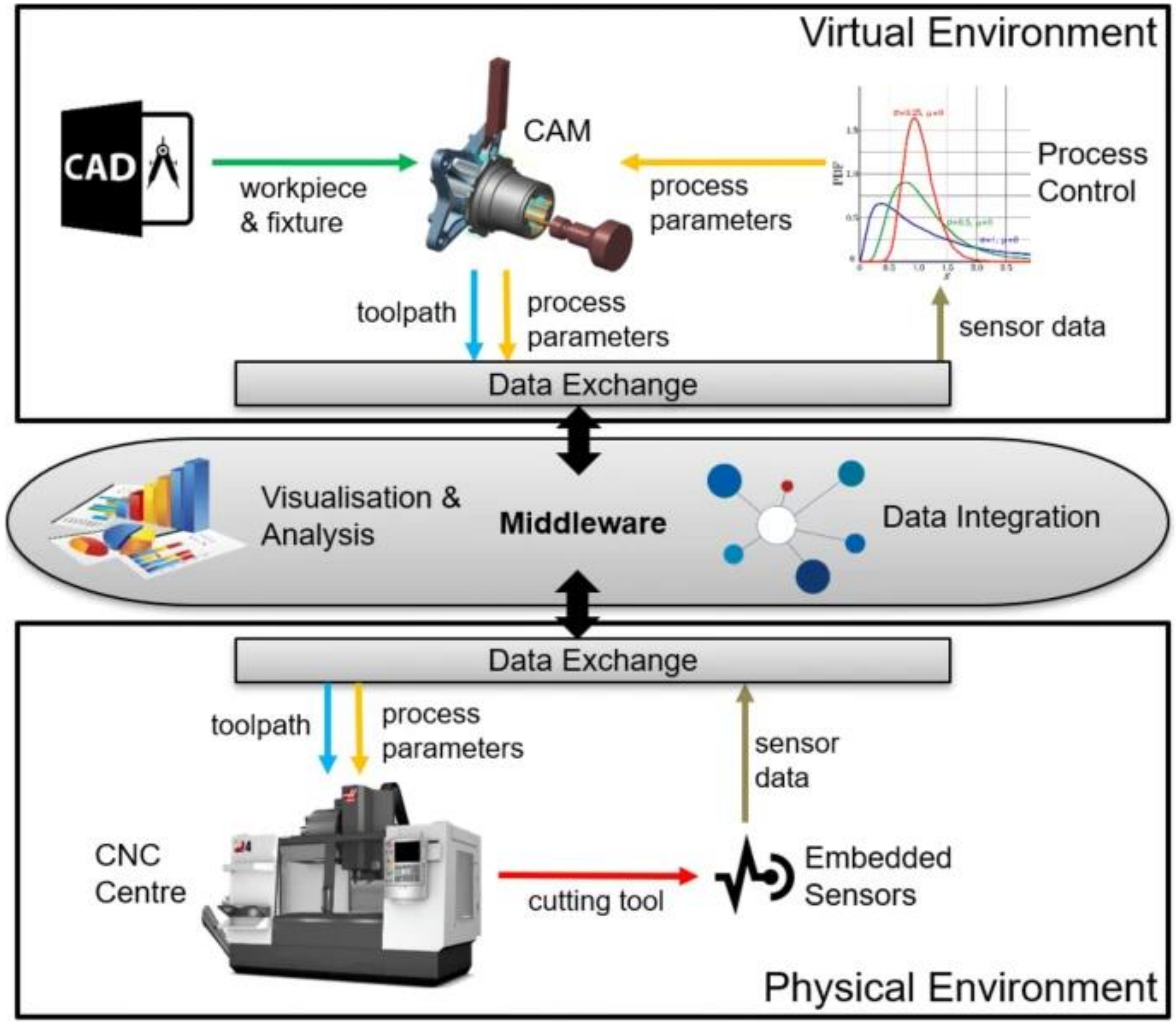
CPS-Application: Smart Grid

- **Smart meters**
  - Demand management with distributed generation
  - Automated distribution with intelligent sub-stations
  - Wide-area control of smart-grid



Source Jha, A.V., Appasani, B., Ghazali, A.N. *et al.* Smart grid cyber-physical systems: communication technologies, standards and challenges. *Wireless Netw* **27,** 2595–2613 (2021).

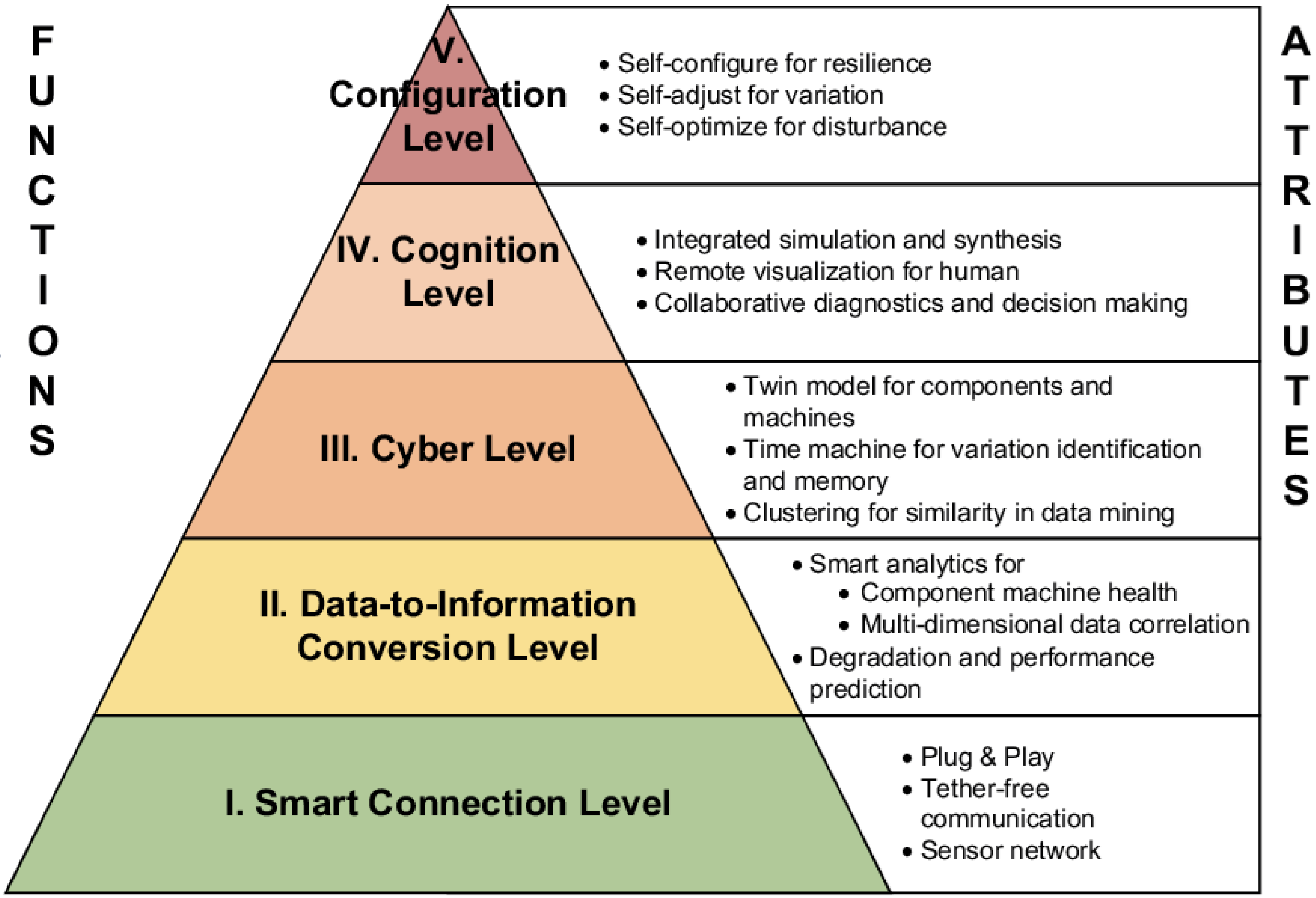
CPS-Application: Manufacturing



Source: https://devicesmart.wordpress.com/tag/cyber-physical-systems/

5C Architecture for Manufacturing CPS

- The *5-level* CPS architecture consists of methodologies and guidelines for step-by-step design and deployment of CPS for **manufacturing** from data acquisition stage to analysis and final value creation.
  - The 5 layers are
    - ❖ *Connection*
    - ❖ *Conversion*
    - ❖ *Cyber*
    - ❖ *Cognition*
    - ❖ *Configuration*



Source: Bagheri B. et al. , Cyber-physical Systems Architecture for Self-Aware Machines in Industry 4.0 Environment, IFAC-PapersOnLine

Source: Vogel-Heuser, Birgit; Lee, Jay; Leitão, Paulo (2015). Agents enabling cyber-physical production systems. At-Automatisierungstechnik. ISSN 0178-2312. 63:10, p. 777-789

5C Architecture for Manufacturing CPS

1. **Smart Connection:** *Acquiring accurate and reliable data from machines* and their components is the first step in developing a Cyber-Physical System application.
   - The *data* might be directly measured by *sensors* or obtained from *controller or enterprise manufacturing systems* such as ERP, MES
   - Two important factors at this level have to be considered.
     - Considering various types of data, a *seamless and tether-free method* to manage data acquisition procedure and transferring data to the central server is required Ex: protocols such as MTConnect are useful.
     - On the other hand, *selecting proper sensors* (type and specification) is the second important consideration.

2. Data-to-Information Conversion:

Meaningful information has to be inferred from the data.

- Currently, there are several tools and methodologies available for the data to information conversion level.
- In recent years, extensive focus has been applied to develop these algorithms specifically for prognostics and health management applications.
- By calculating *health value, estimated remaining useful life* and etc., the second level of *CPS architecture brings self-awareness to machines*.

5C Architecture for Manufacturing CPS

3. Cyber: The cyber level acts as central information hub in this architecture.

- Information is being pushed to it from every connected machine to form the *machines network*.
- Having massive information gathered, specific analytics have to be used to extract additional information that provide better insight over the status of individual machines among the fleet.
- These analytics provide *machines with self-comparison ability*, where the performance of a single machine can be compared with and rated among the fleet.
- On the other hand, similarities between machine performance and previous assets (historical information) can be measured to *predict the future* behavior of the machinery.

5C Architecture for Manufacturing CPS

4. Cognition:

- Implementing CPS upon this level generates a thorough knowledge of the monitored system.

- *Proper presentation of the acquired knowledge* to expert users supports the correct decision to be taken.
- Since comparative information as well as individual machine status is available, *decision* on priority of tasks to optimize the maintaining process can be made.
- For this level, *proper infographics are necessary* to completely transfer acquired knowledge to the users.

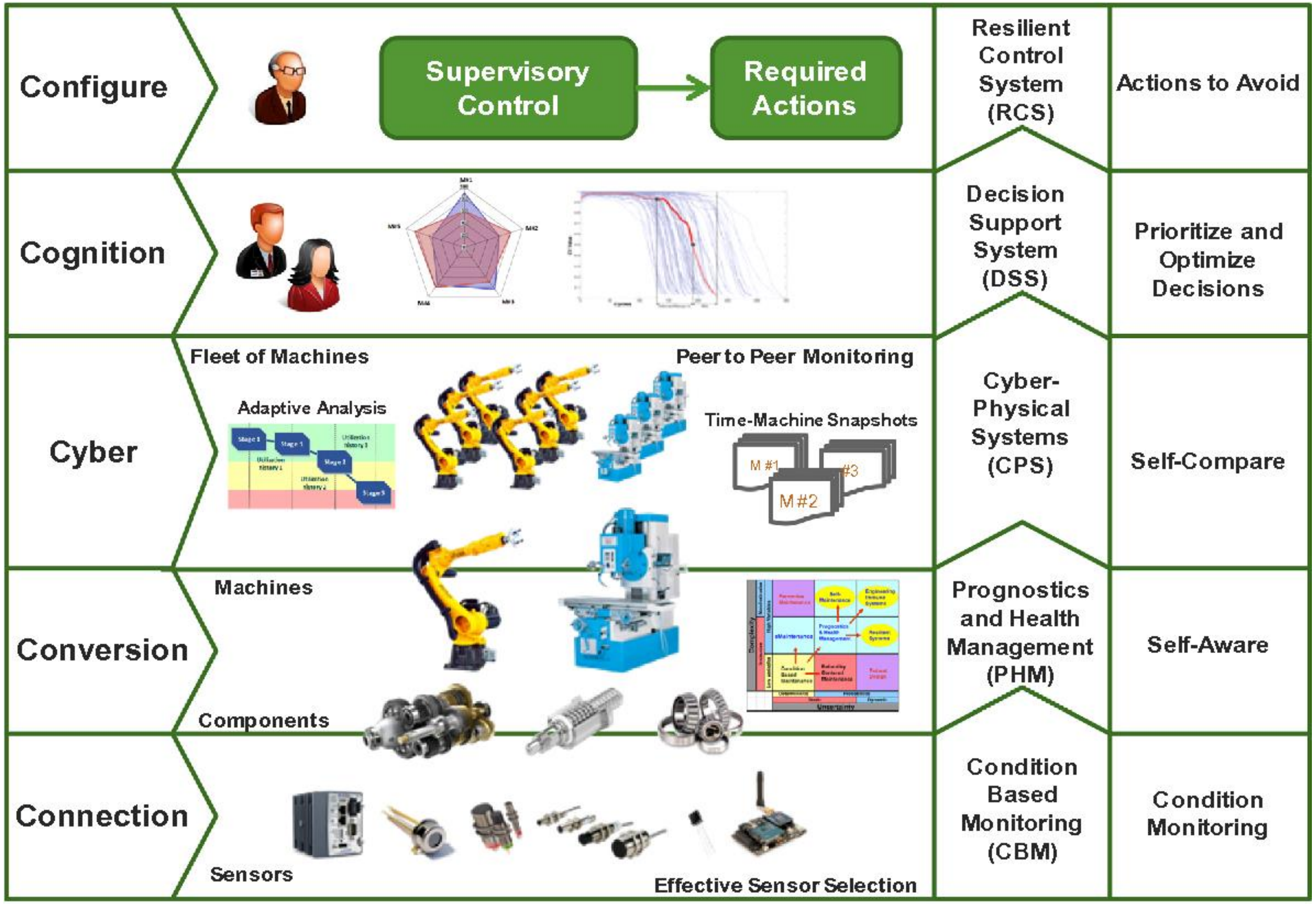
5C Architecture for Manufacturing CPS

5. Configuration:

- The configuration level is the feedback from cyber space to physical space and acts as supervisory control to make machines *self-configure and self-adaptive*.
- This stage acts as *resilience control system (RCS)* to apply the corrective and preventive decisions, which has been made in cognition level, to the monitored system.

5C Architecture of CPS

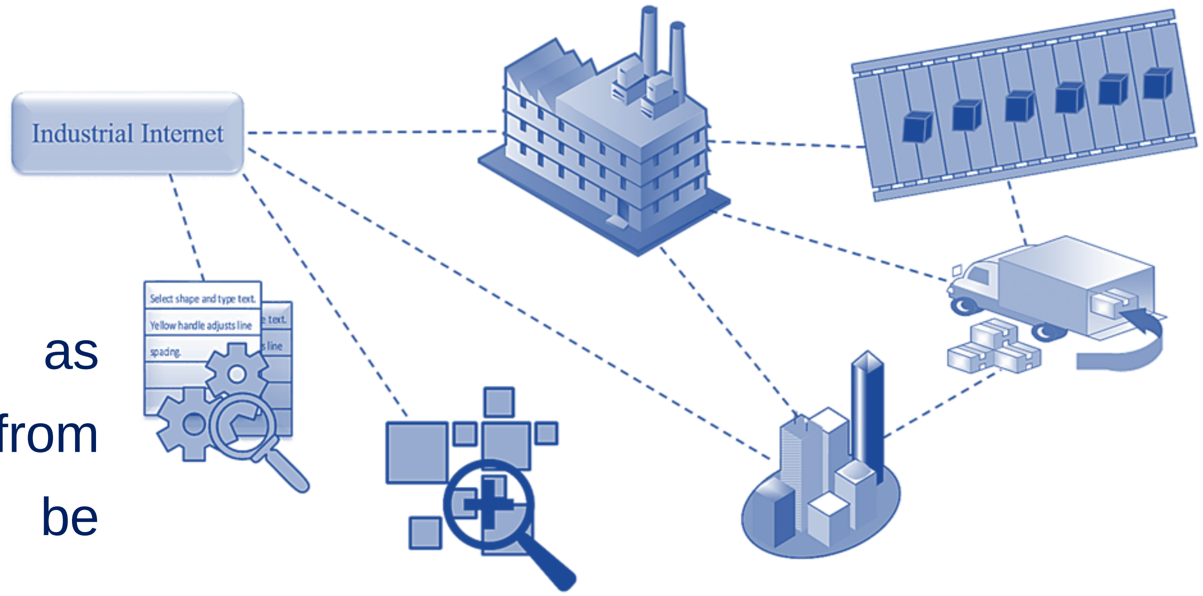
Applications and techniques associated with each level of the 5C architecture.



Source: Lee, J., Bagheri, B., & Kao, H. A. (2015). A cyber-physical systems architecture for industry 4.0-based manufacturing systems. Manufacturing letters, 3, 18-23.

Industrial Internet

- The term *Industrial Internet* was coined by the *U.S. corporation, GE*.
- Industrial Internet resulted from the *combination of physical and digital worlds*.
- As defined by GE, Industrial Internet is "the *convergence* of the global industrial systems with the *power of advanced computing, analytics, low-cost sensing*, and new levels of connectivity permitted by the Internet."
- The Industrial Internet-enabled organizations use *sensor nodes, software, and Machine-to-Machine (M2M) communication* to *collect data* from material things or devices.
- The interconnected devices in industries, such as automated assembly line, real-time data collected from sensor nodes, and their analysis together can be referred to as the *Industrial Internet*.

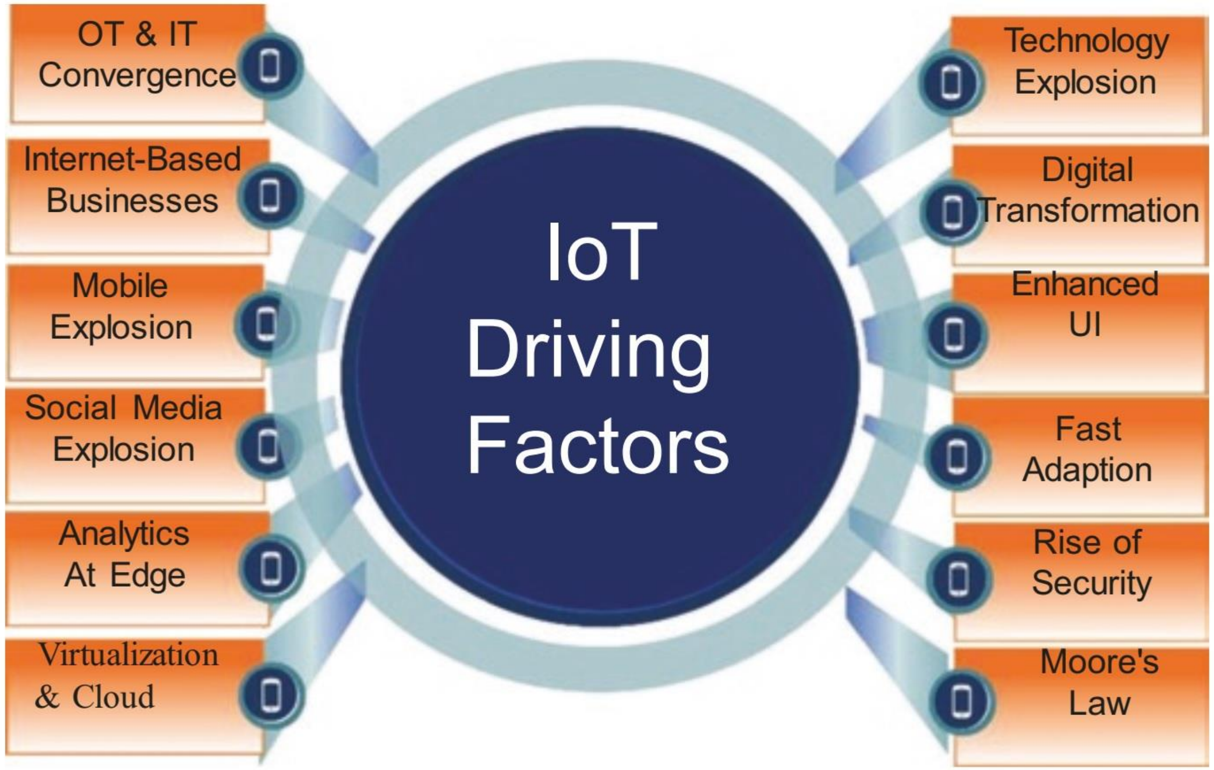


Industrial Internet.

Industrial Internet

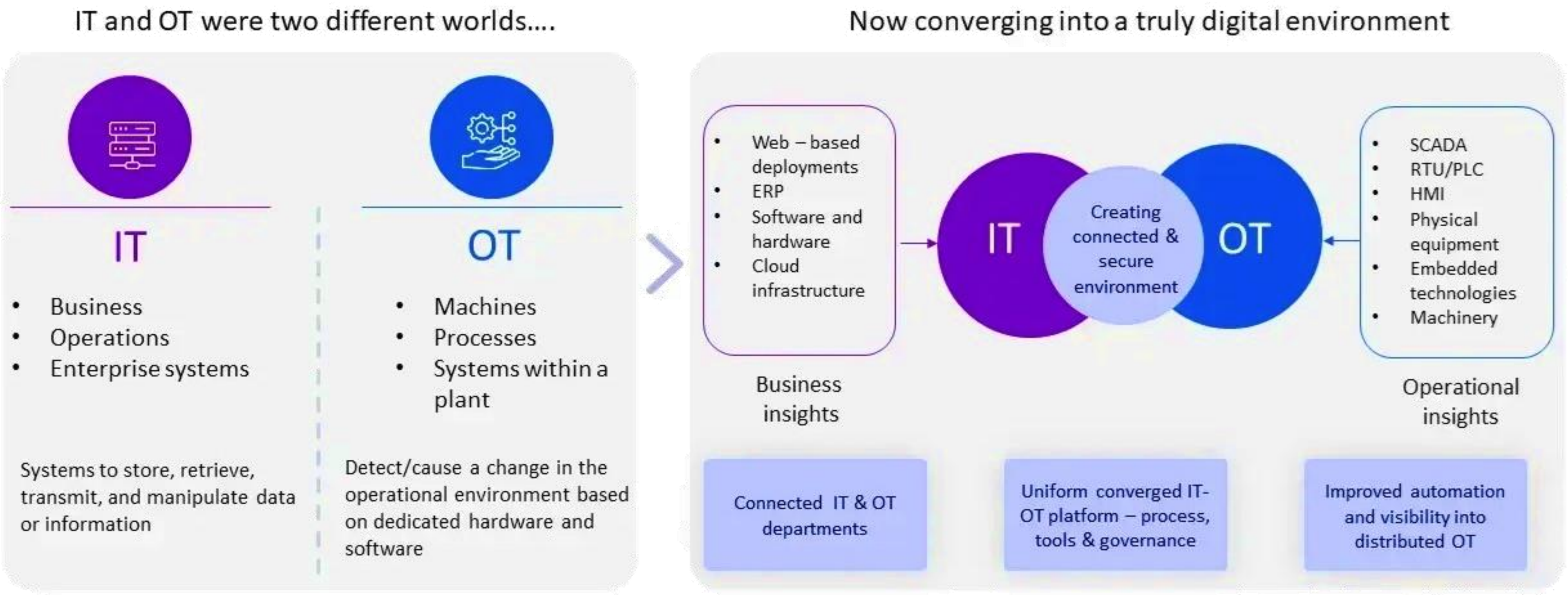
- Industrial Internet will lead to an *increase in the speed and efficiency* in a wide range of industries such as aviation, railways, mining, power generation, and healthcare systems.
- It will result in *improved job facilities, accelerate the productivity* of the manufacturing system, and promote all-round economic growth.
- According to GE, there exist *three phases* in the development of the Industrial Internet
  - ✓ **Industrial Revolution:** During the *first and second industrial revolution*, the productivity and mechanization of factories were initiated.
  - ✓ **Internet Revolution:** The *third industrial revolution* led to the development of *automation in the manufacturing system*, computers, and the emergence of the internet (World Wide Web).
  - ✓ **Industrial Internet:** The amalgamation of *CPS* and the *evolution of Internet-based technologies* led to the development of the Industrial Internet.

Operations Technology/Information Technology convergence

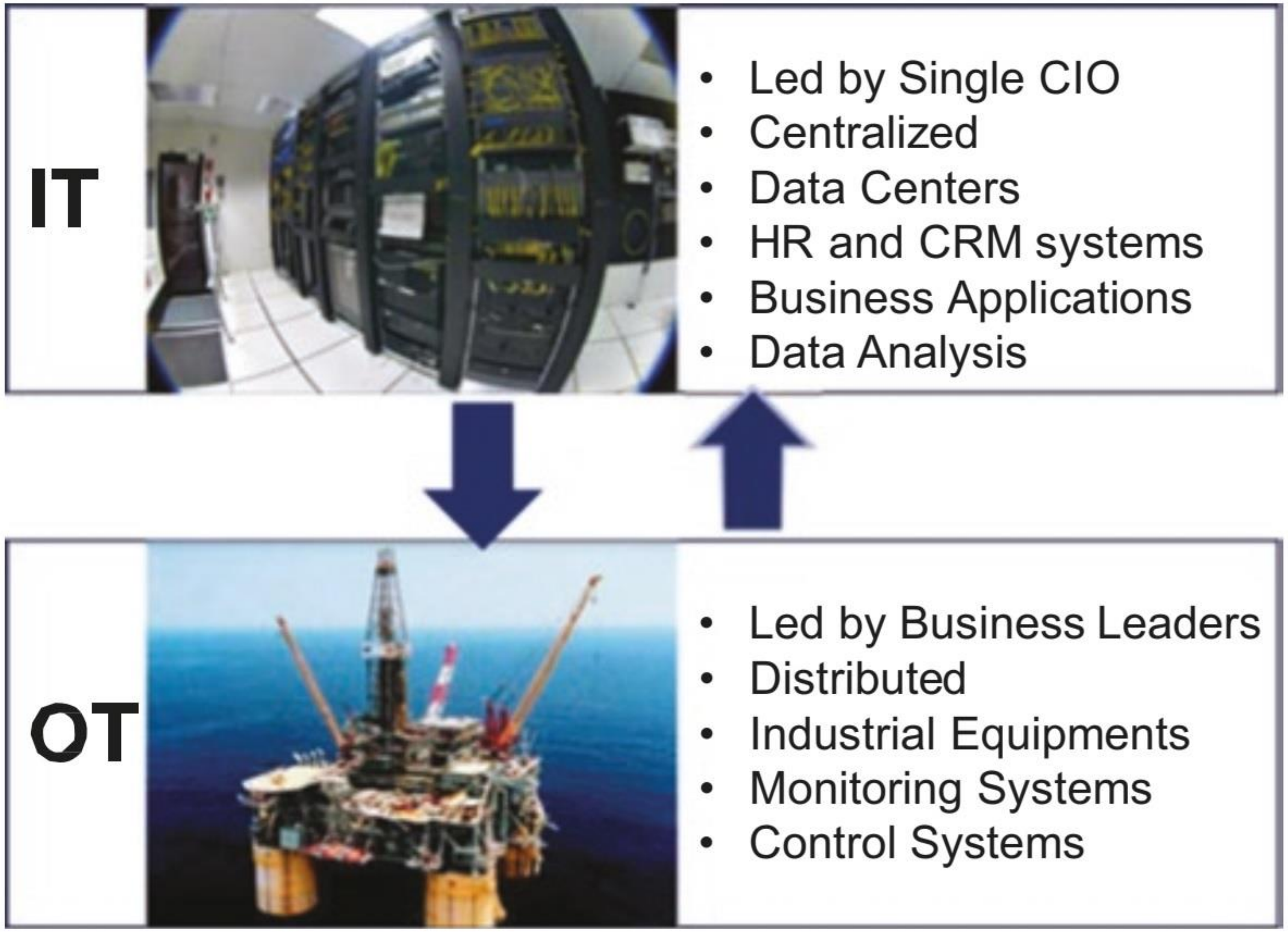


- OT relies on real-time data that drives safety, security, and control.
- Traditional IT departments simply lack the required resources to introduce IoT solutions in a timely fashion, effectively operate and monitor
- With the pressure of IoT technology adoption by cutting-edge businesses, OT is forced to accept a greater level of integration.

OT/IT convergence



OT/IT convergence



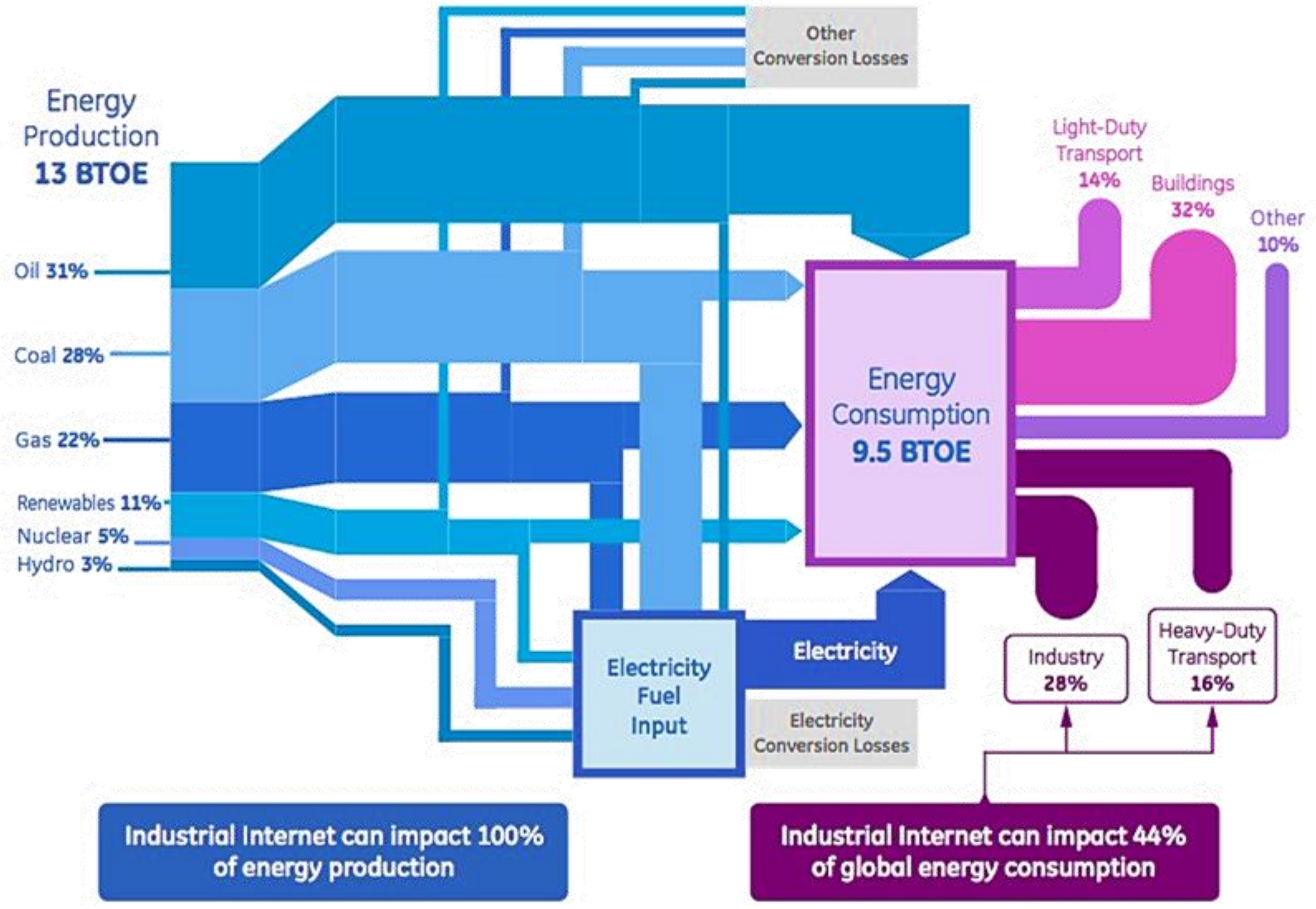
CRM- Customer Relationship Management

Industrial internet

- When accessing data from PLCs or industrial PCs, engineers usually have to deal with
  - ✓ vendor-specific industrial fieldbuses or
  - ✓ implement Ethernet-based data exchange mechanisms (e.g., over TCP/IP or UDP).
- There are two mechanisms for exchanging this data:

1. **a client-server model** in which clients use the dedicated services of the server; TCP and HTTPS
2. **a publisher-subscriber model** in which a server makes configurable subsets of information available to any number of recipients. AMQP or MQTT

Industrial Internet- Benefits to Industrial economy



Industrial sectors-

- Heavy Industries
- Transportation sector

BTOE: Bilion Tonnes of Energy

Industrial Internet- Benefits to Industrial economy

Heavy Industries

- Within the industrial sector, the heaviest energy consumers are the *steel and metals industries and the petrochemical industry*.
- Heavy industries represent about 50 percent of the industrial energy consumed.
- Recent studies indicated that if best practice technologies are deployed, *heavy industry energy consumption could be reduced by 15 to 20 percent*.
- The continued and expanded Industrial Internet deployment can support this effort through process integration, life-cycle optimization, and more efficient utilization and maintenance of equipment

Industrial Internet- Benefits to Industrial economy

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Transportation sector

- Using information technology and networked devices and systems to optimize transport appears to be one of the most exciting opportunities from the Industrial Internet.
- The global **transportation services sector** including land, air, marine, pipelines, telecommunications and supporting logistics services, represent *about 7 percent of global economic activity*.
- In commercial transport services like passenger aircraft, there are opportunities for optimizing operations and assets while improving service and safety.
- Fuel consumption optimization of fleet of Heavy-duty vehicles with wind and traffic information
- Assuming most of the large fleets and a portion of the light duty vehicle fleets can benefit, perhaps *14 percent of global transportation fuel demand can be impacted* by Industrial Internet technologies.

Industrial Internet- Benefits to Industrial economy

Power of one percent (1%)

- Industrial assets and facilities are typically highly customized to the needs of the sector.
- Benefits will vary and different aspects of the Industrial Internet are emphasized. However, there are common themes of **risk reduction, fuel efficiency, higher labor productivity, and reduced cost.**
- Each example highlights how small improvements, even as small as one percent, can yield enormous system-wide savings when scaled up across the sector.

Industrial Internet- Benefits to Industrial economy

Power of one percent (1%) in Commercial Aviation

- An intelligent aircraft will tell maintenance crews which parts are likely to need replacement and when.
- This will enable commercial airline operators to shift from current maintenance schedules that are based on the number of cycles to maintenance schedules that are based on actual need.
- The global commercial airline business is spending about $170 billion per year on jet fuel. If Industrial Internet technologies can achieve only one percent in cost reduction, this would represent nearly $2 billion per year
- Another potential benefit comes from avoided capital costs. If better utilization of existing assets from the Industrial Internet results in a one percent reduction in capital expenditures, the savings benefit could total $1.3 billion dollars per year

Industrial Internet- Benefits to Industrial economy

Power of one percent (1%) in Oil & Gas Development and Delivery

- The industry has moved over the last decade toward the adoption of selected technologies along the upstream value chain.
- Down-hole sensors tracking events in the wells, intelligent completions, optimizing product flow, and Oil well stimulation to increase productivity
- Predictive analytics to better understand and anticipate reservoir behavior
- *Temporal monitoring*, like 4-d seismic, to understand *fluid migration and reservoir changes* as a result of production efforts over time. These efforts in many cases have lowered costs, increased productivity, and expanded resource potential
- If only one percent of reductions in capital expenditure can be achieved by Industrial Internet technologies, in addition to what is already being deployed, this translates into more than $6 billion per year

Use cases- Oil & Gas Industry

- Oil and gas are among the most critical resources used in modern society.
- Today, the major focus of oil and gas companies is on ways to *reduce cost, improve efficiency and speed, and get more from existing investments.*
- Important key performance indicators (KPIs) of oil & gas industry *include controlling production costs and improving the overall health and safety of hazardous environments.*
- Highly subjected to cyber attacks, compromising security and generating losses
- *Role of IoT in the oil & gas industry:*
  - ✓ *Monitoring the status* or behavior of industrial devices in order to provide visibility and control
  - ✓ *Optimizing processes and resource use*
  - ✓ *Improving* business *decision making*

Use cases- Oil & Gas Industry: Domain Basics

Value chain through which oil and gas are transformed-

Upstream

- Focuses on operations related to *exploration, capital project development, and production* of crude oil and natural gas.
- In the case of offshore rigs, shipping is also considered.

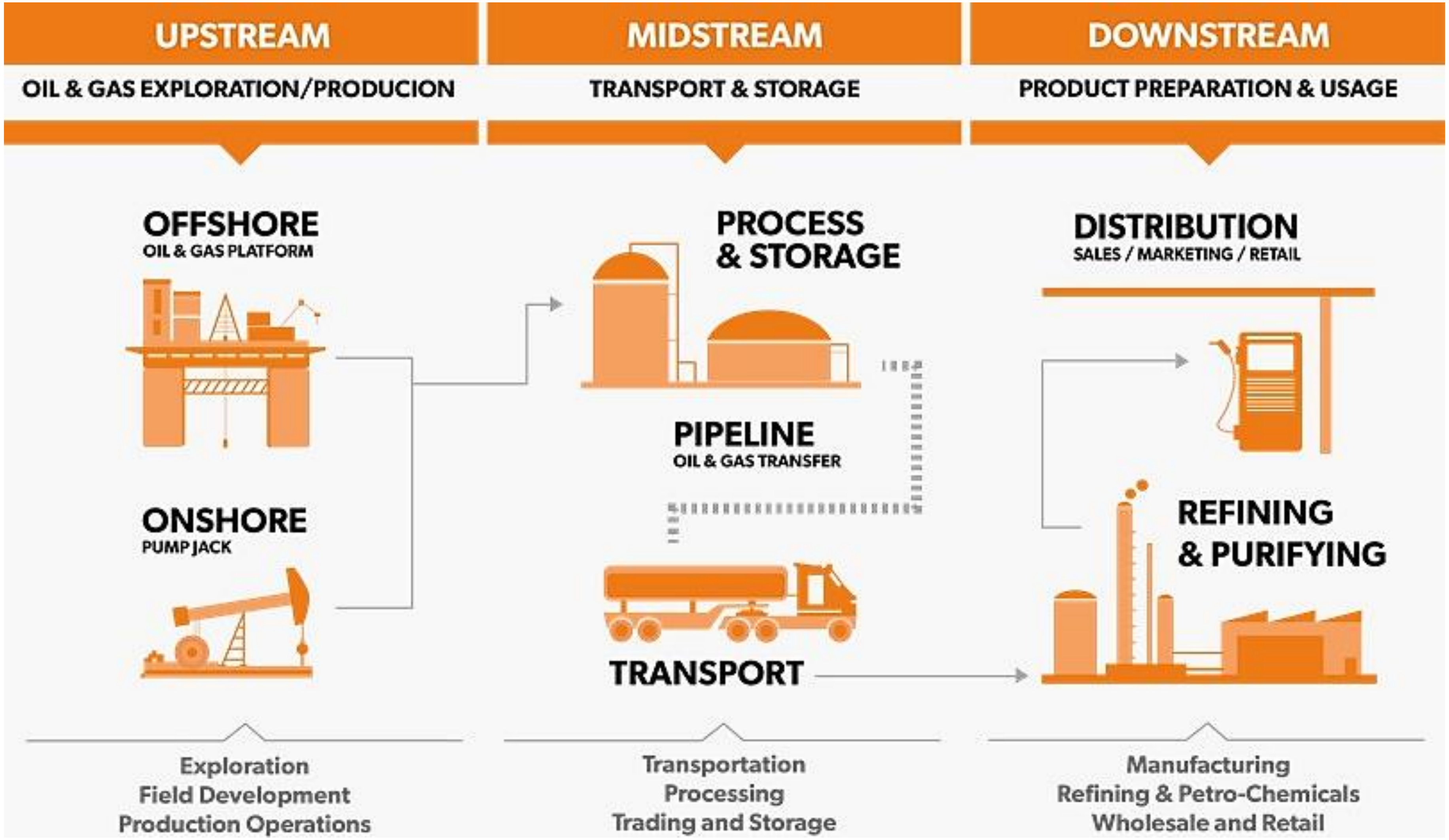
Midstream

- Focuses on operations related to *process (gas), transport (pipeline, tanker/barge, truck, and rail), and storage of oil and gas*.
- Considerations for pipeline installations consist of driving compressors and pumps, valve stations, and Pipeline Inspection Gauge (PIG) receive and launch facilities.
- In order to control and operate the pipeline, a SCADA system and pipeline management system are also required.
- Transporting gas and oil is thus a complex and expensive process.

Downstream

- Focusses on operations related to *refining, marketing, distribution, and commercialization*

Use cases- Oil & Gas Industry:Domain Basics



https://www.elandcables.com/the-cable-lab/faqs/faq-what-are-upstream-and-downstream-works-in-the-oil-gas-industry

Video: Fundamentals of upstream, midstream and downstream: https://www.youtube.com/watch?v=6ozmKhahk8M

Use cases- Oil & Gas Industry-Motivation for IIoT

Deepwater Horizon oil spill/BP oil spill

- Largest marine oil spill in history, caused by an *April 20, 2010*, explosion on the Deepwater Horizon oil rig—located in the *Gulf of Mexico*
- High pressure methane gas spilled into the drilling rig, where it ignited and exploded.
- The U.S. federal government estimated the total discharge of 210 million US gallons of oil

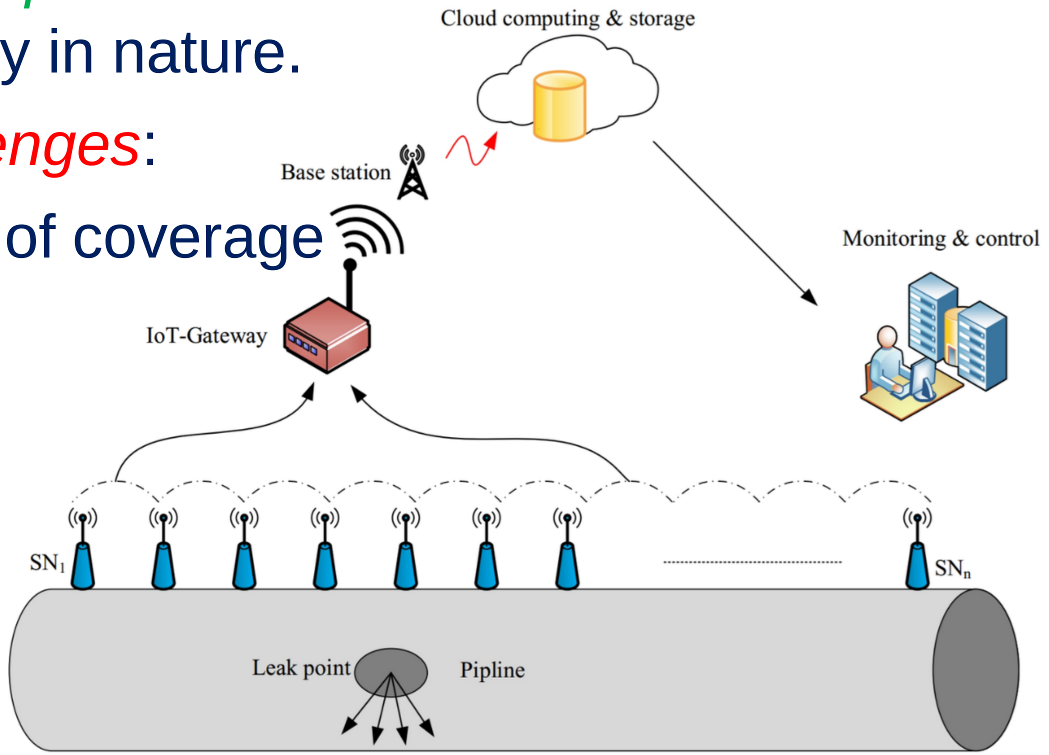
Different ways that oil & gas can implement IIoT

- Connected wells
- Connected Pipelines
- Connected Refineries
- Novel smart sensing methods

Use cases- Oil & Gas Industry

1. Connected Pipe lines

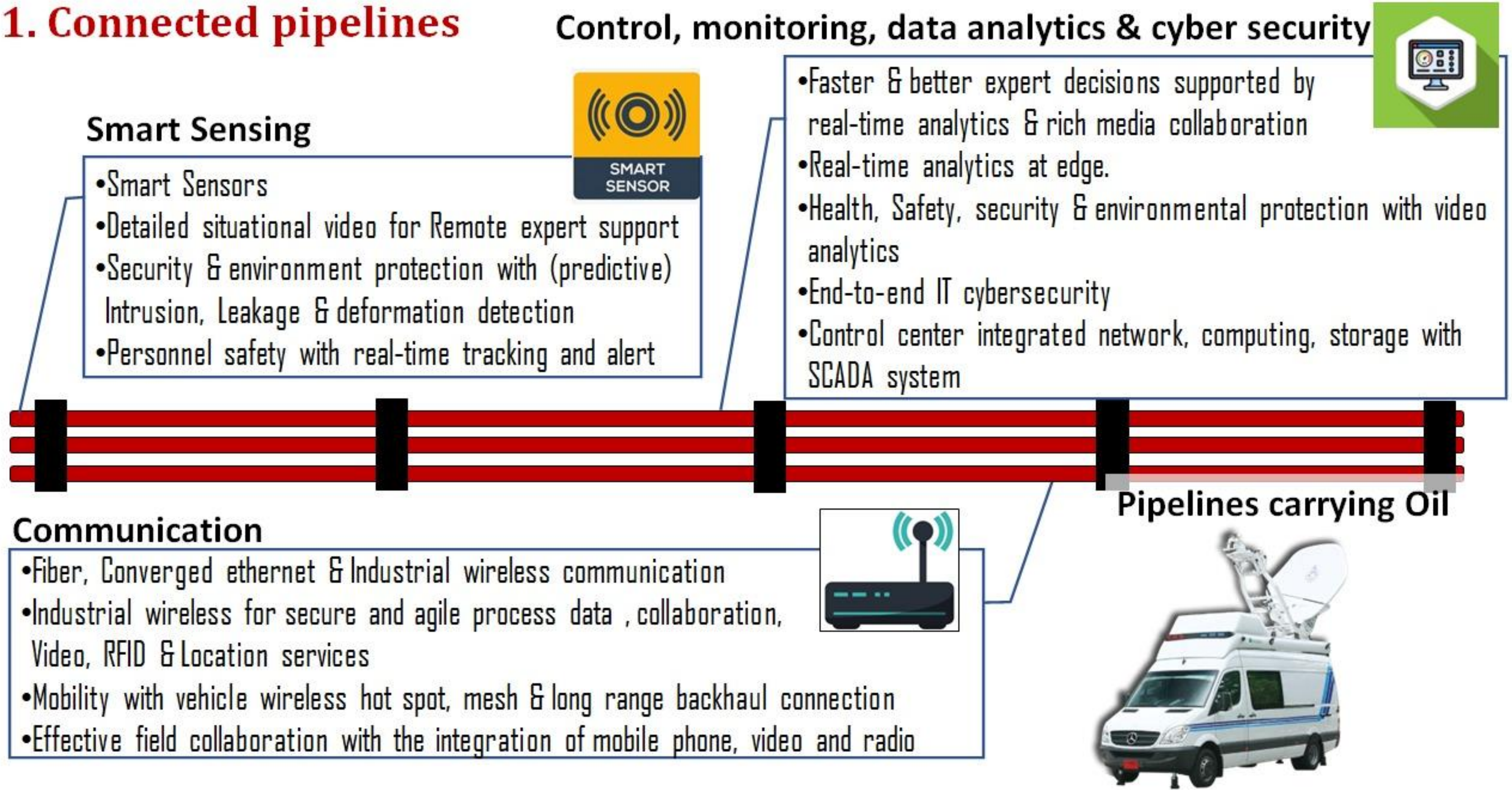
- Pipelines are important because they are links between the exploration, extraction, and refining operations.
- Pipelines ensure that product is *continually supplied and refined on a 24x7 basis*. The operational challenges are many, and they vary in nature.
- *The following are some examples of the challenges*:
  - Long distances and large geographic area of coverage
  - Harsh environments
  - Isolation from general infrastructure
  - Leaks
  - Earthquakes and landslides
  - Theft and vandalism



Wan, J., Yu, Y., Wu, Y., Feng, R., & Yu, N. (2011). Hierarchical leak detection and localization method in natural gas pipeline monitoring sensor networks. Sensors, 12(1), 189-214.

Use cases- Oil & Gas Industry

Use cases- Oil & Gas Industry



Use cases- Oil & Gas Industry

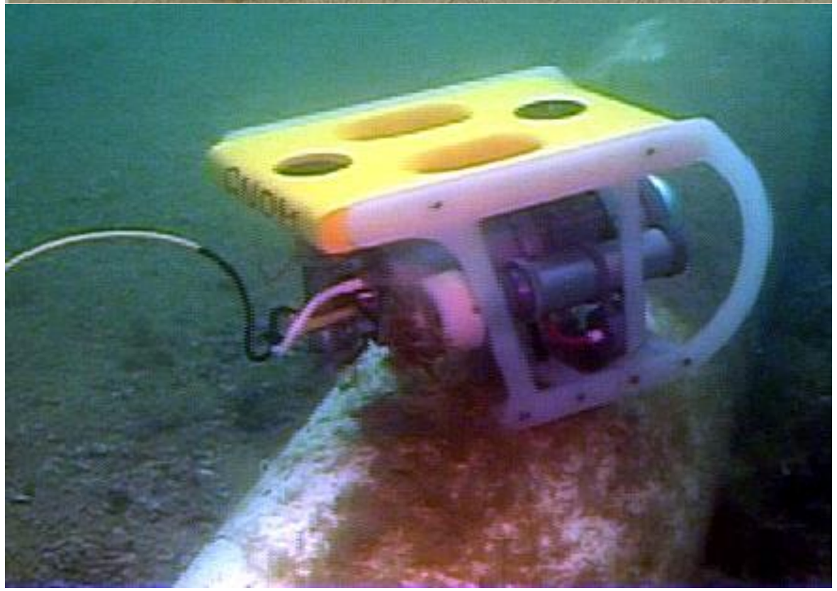
2. Smart sensing

Use of Remote Operated Vehicle (ROV)

- ROVs are used on multiple offshore wells, operating to depths in excess of 300 metres.
- Cable that connects the vehicle to its control craft is either severed or becomes entangled

Use of Unmanned Underwater Vehicles (UUVs)

- One third of the world's oil and gas fields are located offshore
- The UUV of today can house an array of new sensory systems such as next generation LIDAR, high-definition cameras, laser scanners and radiation detectors.



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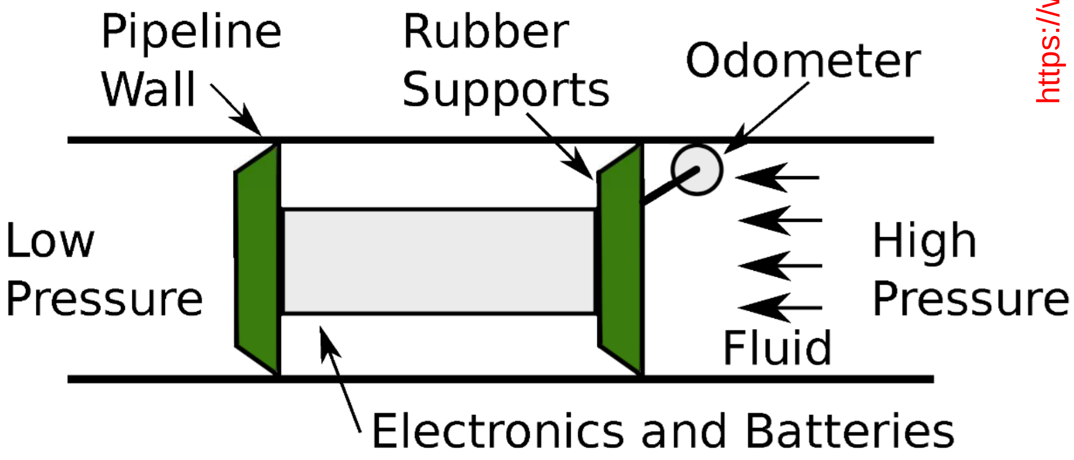
Conventional Cleaning PIG

- Pipeline Inspection Gauges(PIGs) are *inserted into a Pig Launcher and then pressurized flow is applied to the rear of the device.* The flow forces the PIG to move into the pipeline.
- The force applied by a PIG can be estimated by multiplying the cross sectional area by the pressure applied to the rear of the PIG.
- *The outside diameter of most PIGs will be sized to be larger than the internal bore.* This sizing approach enables the PIG to scrape and remove debris as it moves through the pipeline.



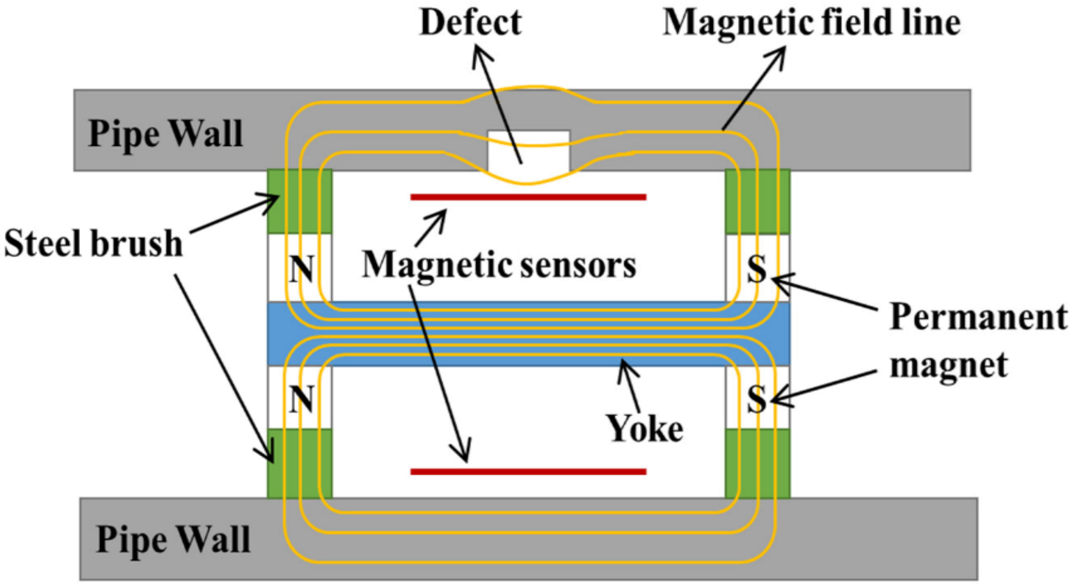
https://www.mdpi.com/1424-8220/18/9/3072/htm

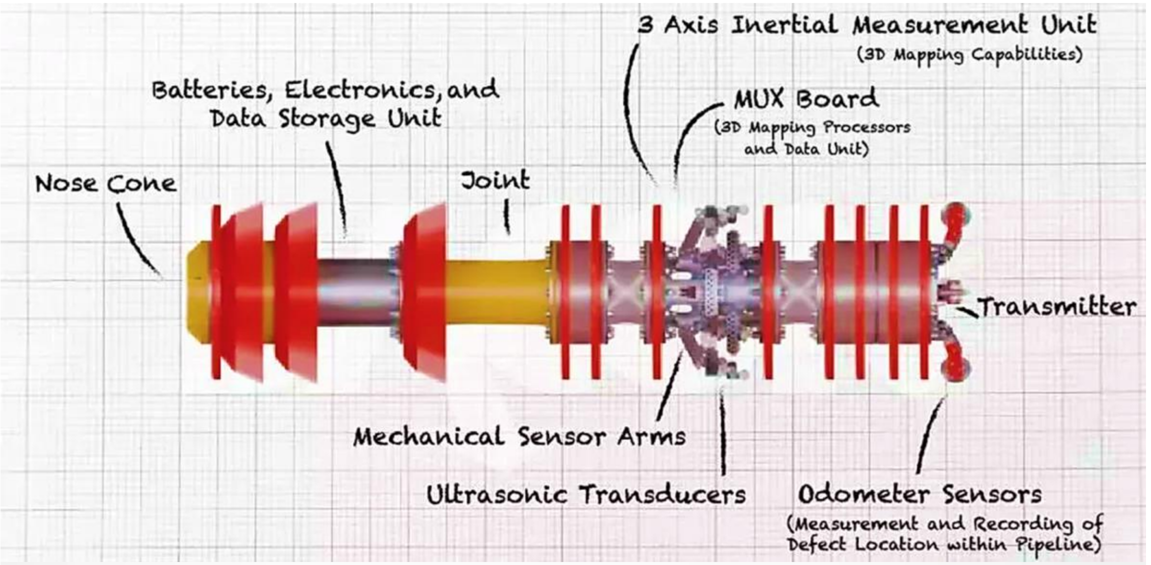
Use cases- Oil & Gas Industry

Smart PIG Anatomy

- There are *3 main types* of inspection technology used with smart pigging.

1. Ultrasound
2. Magnetic Flux Leakage,
3. Mechanical caliper sensors.



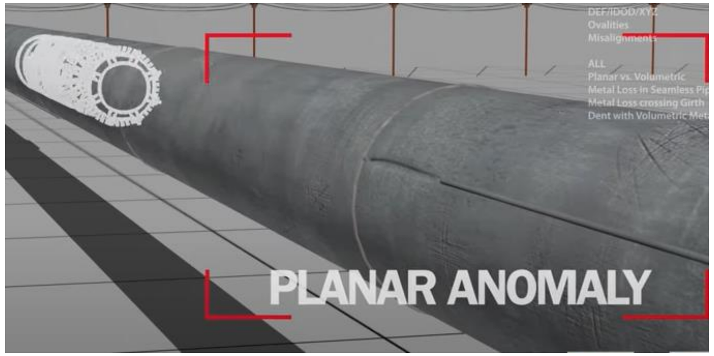


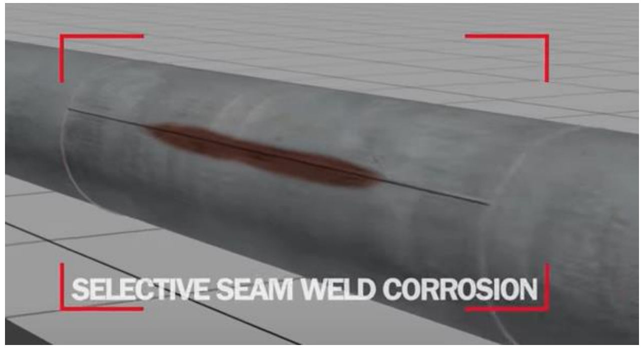
https://www.dexon-technology.com/pipeline-services/intelligent-pigging/pipeline-pigging/

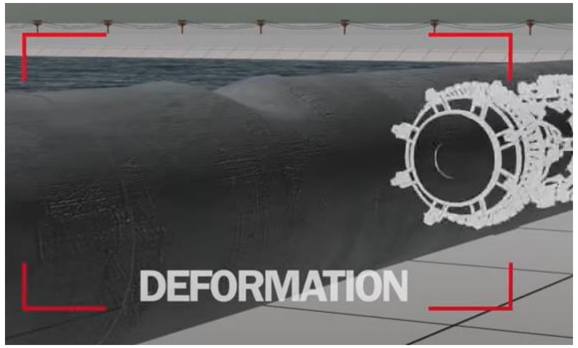
Use cases- Oil & Gas Industry

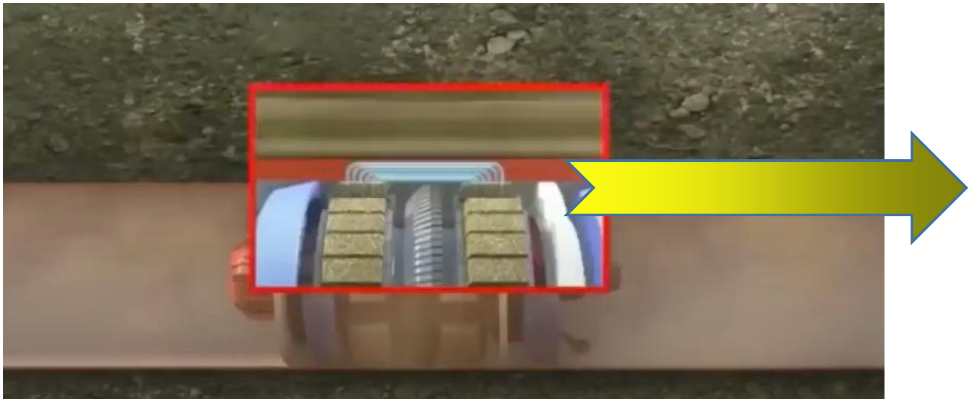
Smart Pipeline Inspection Gauge(PIG)

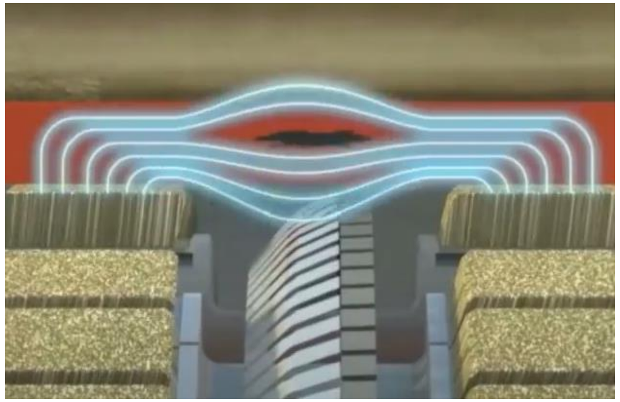
- Smart PIGs use nondestructive examination techniques such as ultrasonic testing and magnetic flux leakage(MFL) testing to inspect for *erosion corrosion, metal loss, pitting, weld anomalies, and hydrogen induced cracking, among others*

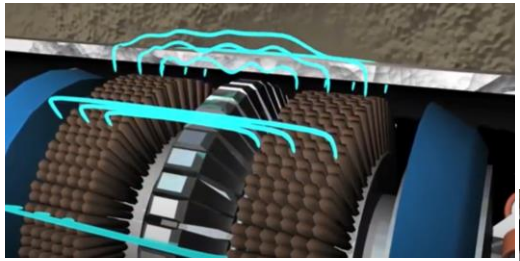






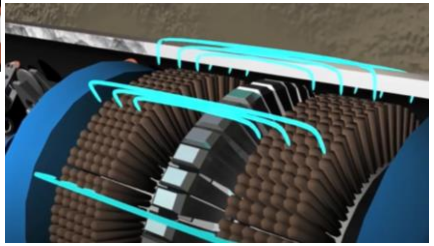






Anomaly

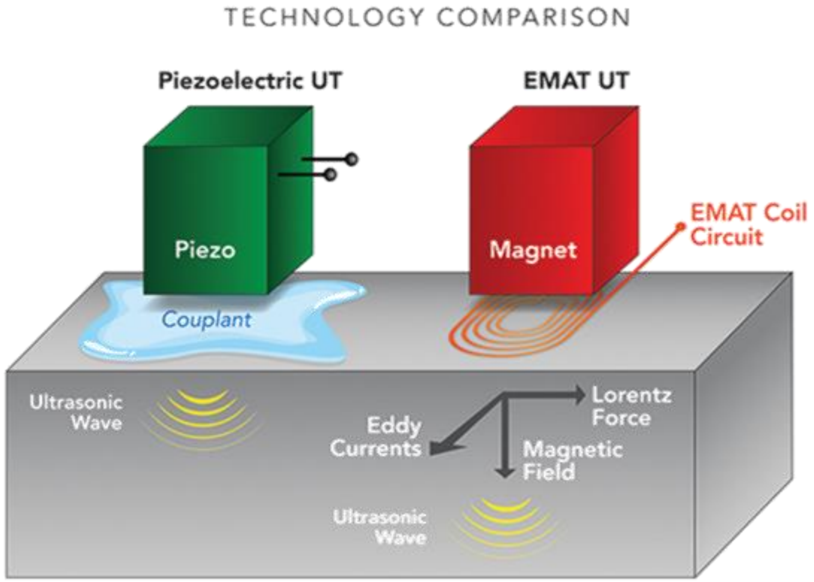
No Anomaly



https://www.youtube.com/watch?v=iJnO8exGgng

Use cases- Oil & Gas Industry

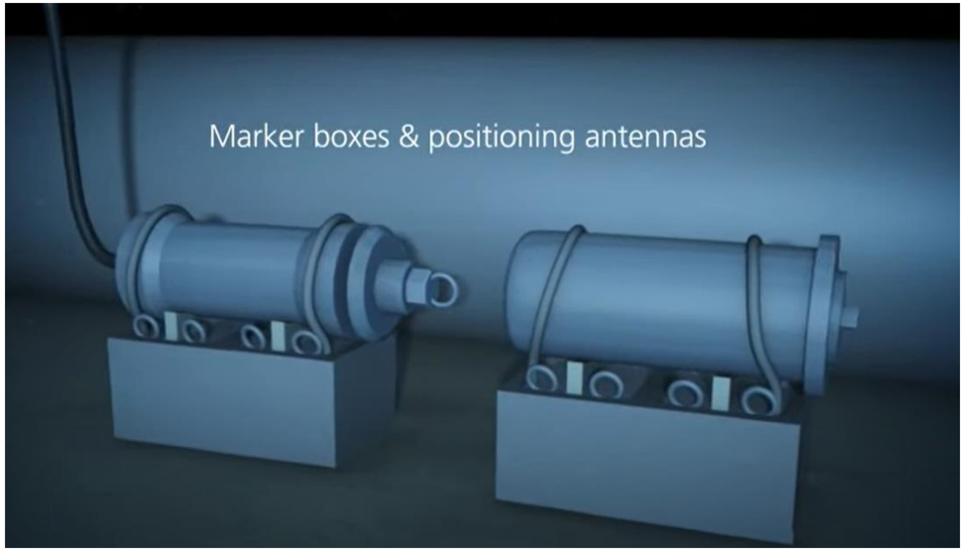
- PIGs use *powerful magnets to magnetize* the pipe wall. Tri axial hall sensors positioned between the magnetic poles then measure flux leakage originating from anomalies.
- The amount of flux leakage determines the precise length, width, and depth of anomalies for identification
- PIGs that house an *array of ultrasonic technique (UT)* probes provide accurate internal measurement of pipes but which *require a liquid medium to transmit sound waves*.
- *Electromagnetic Acoustic Transducer (EMAT)* inspection technology has the advantage over the standard UT systems of *not requiring a couplant* - or transmission medium- for the diffusion of sound waves.



Use cases- Oil & Gas Industry

Communication and DATA transmission of PIG

- PIGs are unable to directly communicate with the outside world due to the distance underground or underwater and/or the materials that the pipe is made of.
- For instance, *steel pipelines effectively prevent any significant radio communications* outside the pipe.
- The *PIG records its own movement* during the trip. This may be done by *odometers, gyroscope-assisted tilt sensors* and other technologies.



- Surface instruments equipped with sensors, which often have GPS capability, record and transmit time and location of the pig by *either audible, magnetic or radio-transmission means*. The pig itself cannot use GPS as the metal pipe blocks satellite signals.

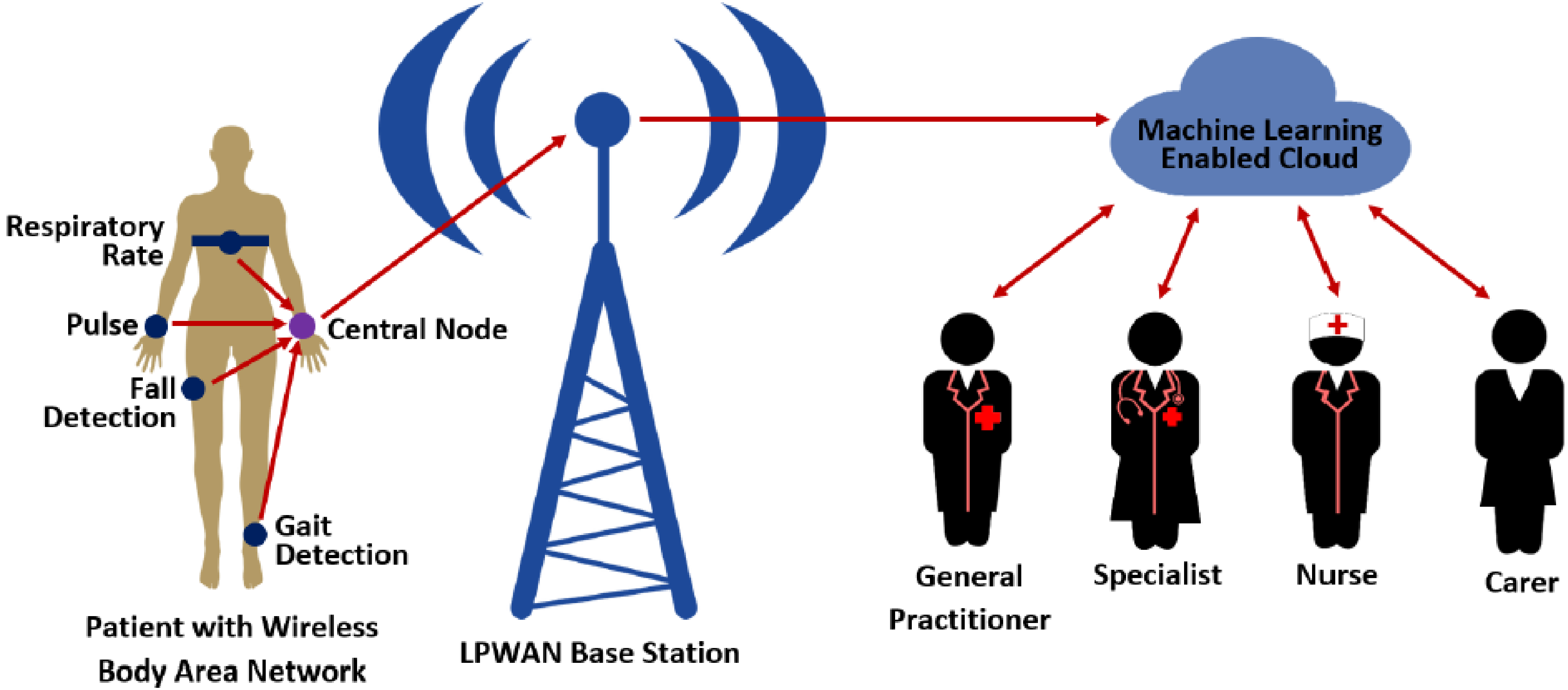
Use cases- Oil & Gas Industry

- After completion of the pigging run, data from external sensors is combined with the pipeline evaluation data from the pig to provide a location-specific defect map and characterization.
- The *data collected* provides information on the *location and severity of the defect*, thus allowing repair crews to act quickly.
- Performing regular pigging runs within a pipeline helps identify and repair defects at an early stage, before any leakage or environmental damage occurs.

Use cases- Healthcare

- Healthcare is an essential part of life.
- Ageing population and related raise in chronic disorders are putting strain on modern healthcare systems
- Demand for resources from hospital beds to doctors and nurses is extremely high
- A solution is required to reduce the pressure on healthcare systems while continuing to provide high-quality care to at-risk patients
- IoT has been widely identified as a potential solution to alleviate the pressures on healthcare systems
  - *Monitoring patients* with specific conditions, such as diabetes or Parkinson's disease
  - Aiding rehabilitation through constant monitoring of a patient's progress
  - *Remote monitoring for monitoring non-critical patients* at their homes instead of hospitals
  - *Provide better access* to healthcare for those living in *rural areas*
  - Enable elderly people to live independently at home for longer

I. A Model for Healthcare IoT



S. B. Baker, W. Xiang and I. Atkinson, "Internet of Things for Smart Healthcare: Technologies, Challenges, and Opportunities," in *IEEE Access*, vol. 5, pp. 26521-26544, 2017

Use cases- Healthcare

- Consists of 4 parts
  - Wearable sensors and Central Nodes
  - Short-range Communication
  - Long-range Communication
  - Secured cloud storage architecture & machine learning

1. Wearable sensors and central nodes

- Wearable sensor nodes are those that *measure physiological conditions*.
- Sensors include those that measure essential vital signs for determination of critical health - pulse, respiratory rate, and body temperature.
- Also includes sensors that could *measure blood pressure* and *blood oxygen levels*, as these parameters are often taken alongside the three vital signs.
- *Special-purpose sensors* such as blood-glucose, fall detection, and joint angle sensors could also be implemented for systems targeting a specific condition.
- A central node, preferred to be a smartphone, receives data from the sensor nodes, processes this information, may implement some decision making, and then forwards the information to an external location.

Use cases- Healthcare

2. Short-range Communication

- For sensors to communicate with the central node, a short range communications method is required.
- Important requirements to be considered while choosing a communication standard- *effects on the human body, security, and latency*
- *Should not cause any negative effects* on the patient's body that could cause additional health concerns for patients.
- Provide *strong security mechanisms* to ensure that sensitive patient data cannot be accessed by an attacker
- *Low-latency is essential* for time-critical systems, such as a system that monitors critical health and calls for an ambulance if the need arises.
    - Time delays could be the difference between life and death.
- *Eg. Bluetooth low energy, ZigBee*

Use cases- Healthcare

3. Long-range communications

- Data obtained by the central node is not useful unless something can be done with it.
- Data should be forwarded to a database where caretakers or doctors can securely access it.
- Important requirements to be considered while choosing a communication standard- *security, error-correcting capabilities, robustness against interference, low latency, and high availability*
- Strong security is important to ensure that sensitive patient data remains private and cannot be altered or imitated.
- *Low-latency is important* in time-critical applications
- *High-quality error-correcting* capabilities and significant robustness against interference are essential, as these ensure that the message sent is the same as the message received.
- *High availability is essential* to ensure that messages will be delivered at all times, regardless of where the patient is physically located.
- *Eg. SigFox, LoRaWAN, NB-IoT*

Use cases- Healthcare

4. Secured cloud storage architecture & machine learning

- *Medical information* obtained from patients must be *stored securely* for continued use.
- Doctors benefit from knowing a patient's medical history
- *Cloud storage* is the most viable method for storing large quantities of data.
- Machine learning methods are not effective unless large databases of information are available
- *Machine learning* offers the potential to *identify trends in medical data* that were previously unknown, provide treatment plans and diagnostics, and give recommendations to healthcare professionals that are specific to individual patients.
- *Cloud storage architectures should be designed* to support the implementation of machine learning on *big data sets*.

Use cases- Commercial Aviation-Applications

- *Applications of IoT* in Aviation Industry:

1. Climate control in cabin
2. Aircraft safety
3. Managing Traffic
4. Effective Maintenance
5. Improvement in Passenger experience
6. Personalization
7. Luggage management
8. Smart airports

https://www.airbus.com/en/newsroom/stories/2019-07-iot-aerospaces-great-new-connector

https://www.analyticssteps.com/blogs/8-applications-iot-aviation-industry

Use cases- Commercial Aviation-Existing Implimentations

- Rolls Royce is embedding IoT sensors across its product lines and manufacturing facilities
- Data generated by IoT sensors is aggregated and analyzed in the cloud and provides insight into the performance of its products — from jet engines and helicopter blades to pliveower generation systems and marine turbines.
- Data capability is rapidly evolving beyond just predicting equipment issues and maintenance requirements
- In-flight analytics- A modern passenger jet such as a Boeing 787 generates an average of 500GB of data per flight and several terabytes on long-haul routes.

https://www.i-cio.com/innovation/internet-of-things/item/how-iot-is-turning-rolls-royce-into-a-data-fuelled-business

Use cases- Commercial Aviation-Existing Implimentations

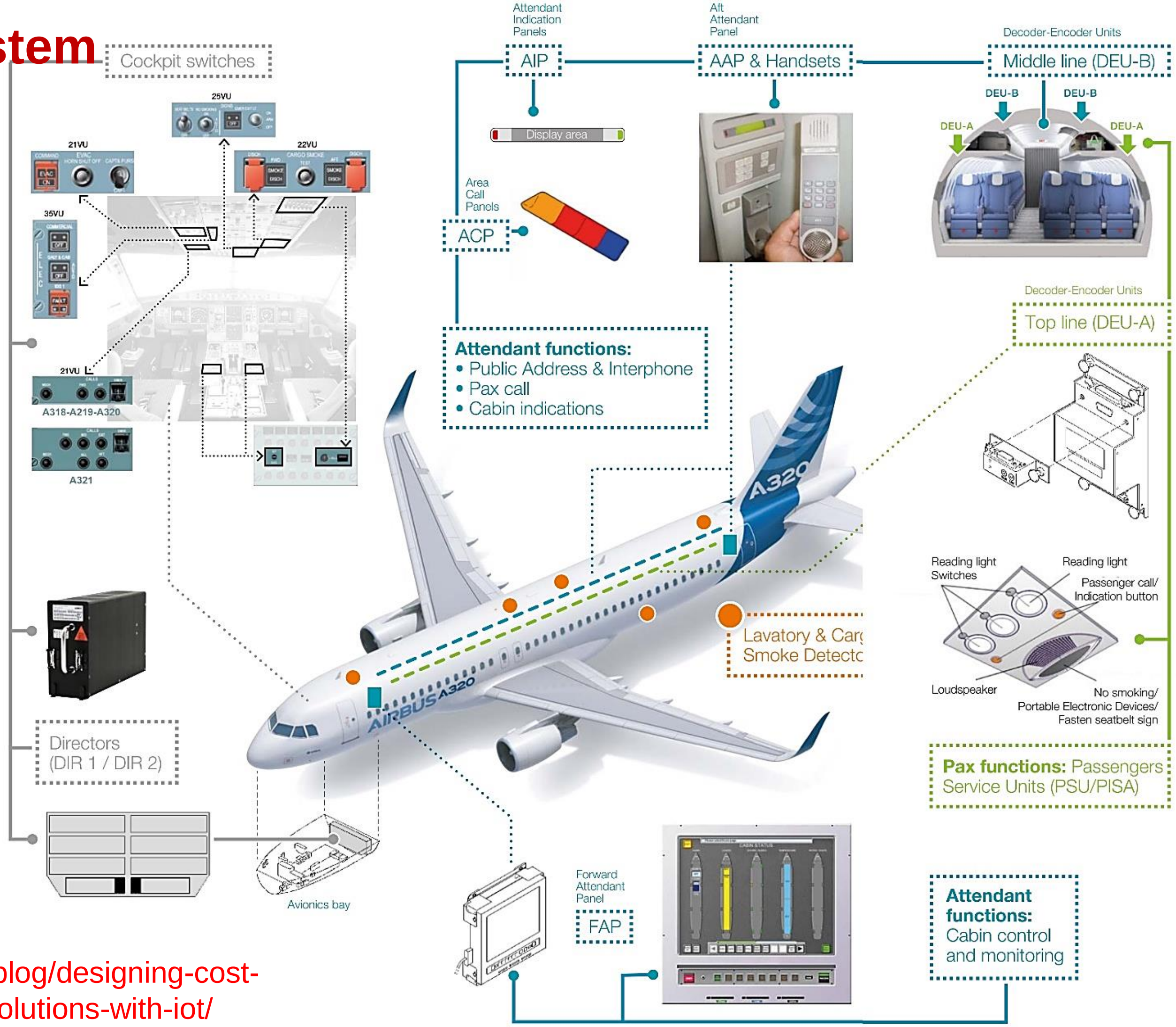
- The thousands of sensors in each Rolls-Royce engine track everything from fuel flow, pressure and temperature to the aircraft's altitude, speed and the air temperature, with data instantly fed back to Rolls-Royce operational centers.
- Rolls Royce's civil aircraft availability center is continuously monitoring data from 4,500 in-service engines.
- Microsoft Azure cloud is used for handling Big Data
- The production of 6,000 engine fan blades each year generates around 3 petabyes of data.

https://www.i-cio.com/innovation/internet-of-things/item/how-iot-is-turning-rolls-royce-into-a-data-fuelled-business

Design of an IoT-enabled aircraft cabin subsystem

❖ Aircraft cabin electronics include monitoring and controlling a *large number of interconnected* and *electrically powered equipment and subsystems* including

- •cabin lights
- •window shades
- •smoke detection
- •fire extinguishing systems
- •air conditioning
- •overhead cabin audio
- •water systems
- •waste systems
- •flight attendant panel
- •in-flight entertainment system



https://volansys.com/blog/designing-cost-effective-aerospace-solutions-with-iot/

https://aircraft.airbus.com/en/newsroom/news/2019-10-cabin-communication

Use cases- Commercial Aviation

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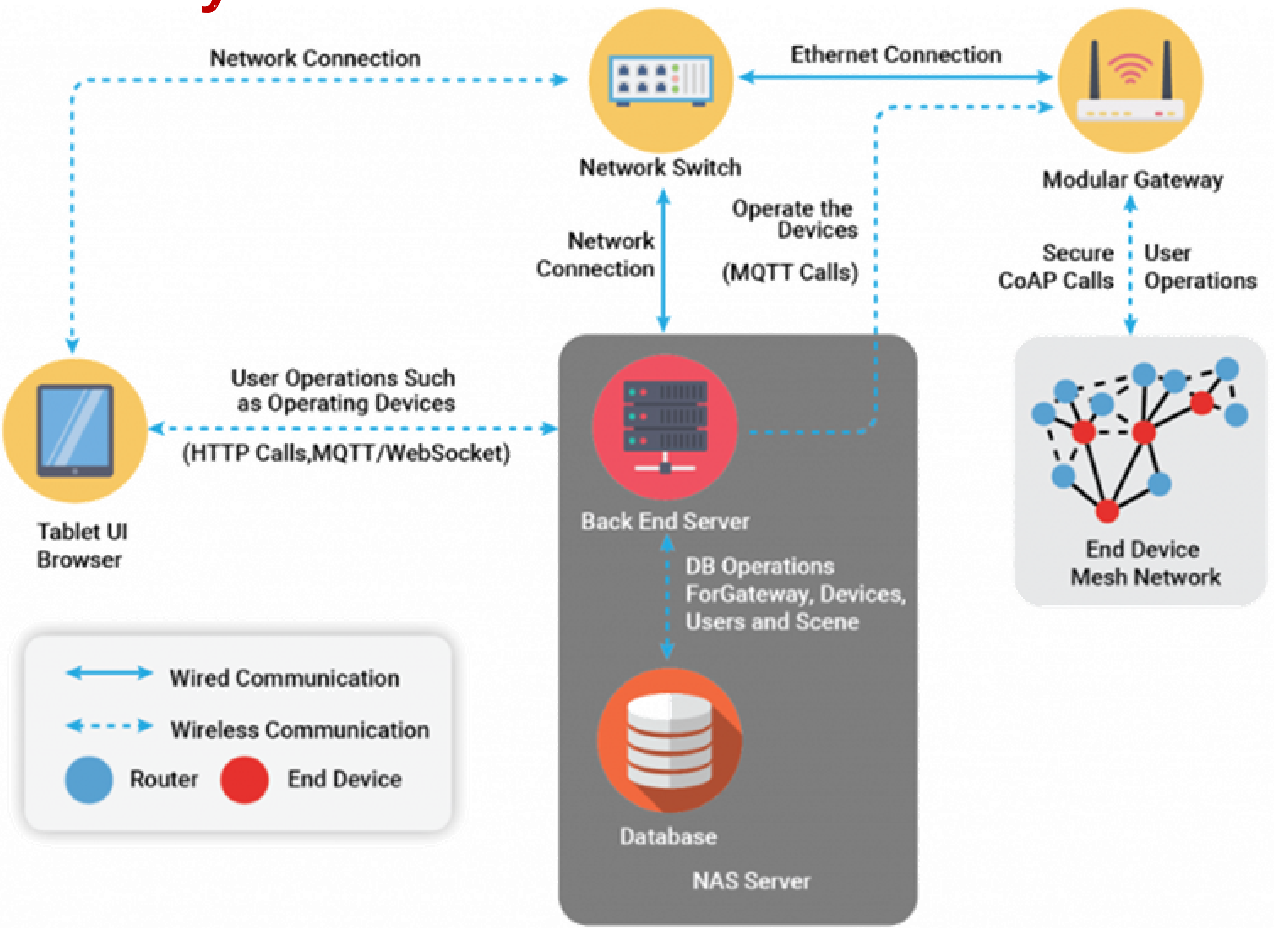
- ❖Large number of sensors and control switches are installed in aircraft cabin systems
- ❖Most of these sub systems have wired components, resuting in severe aircraft system design and maintenance problems
- ❖Main *drawback of wired systems* are
  - ✓Increase the wiring complexity, affects design, installation and debugging the systems
  - ✓Large number of wire create difficulties in maintenance of aircraft systems
  - ✓Wires contribute significantly to aircraft weight- reduce fuel efficiency
  - ✓Occupies space within the aircraft- makes its limited space narrow
- ❖ Using wireless smart sensors and control mechanisms in IoT aircraft engineering, design and maintenance cost can be considerably reduced

https://volansys.com/blog/designing-cost-effective-aerospace-solutions-with-iot/

Use cases- Commercial Aviation

Design of an IoT-enabled aircraft cabin subsystem



https://volansys.com/blog/designing-cost-effective-aerospace-solutions-with-iot/

- **CoAP- Contrained Application Protocol:** Internet application protocol for constrained devices. Constrained devices (nodes) communicates with wider internet using similar protocols. Used in low power lossy network
- **MQTT- Message Queuing telemetry Transport:** Light weight messaging protocol for use in cases where clients are constrained devices, which require small code foot print and are connected to unreliable networks with limited bandwidth resources.
- **HTTP-Hypertext Transfer protocol:** Designed for communicating between web browsers and web servers
- **Network switch:** A networking hardware that connects devices on a computer network by using packet switching for data transfer
- **Gateway:** Protocol converter. Connects two networks with different protocols
- **Websocket:**Two way interactive communication between browser & server
- **NAS-Network Attached Storage**

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- The IoT-enabled aircraft cabin subsystem consists of three parts: *end devices, mesh communication network, and information center*.
- End devices and routers will be connected together in *mesh network* using *6LoWPAN*, which is based on IEEE 802.15.4 wireless protocol.
  - **6LoWPAN-** Low energy Wireless Personal Area Network based on IPV6
  - **Mesh network -** whose nodes are all connected to each other (Topology)
- The end device can be configured with single or multiple different precision sensors and actuators used for the subsystem operation.
- End-device nodes are deployed in the monitoring and controlling area.
- End-device node constitutes wireless sensor networks and cooperatively senses information.