MTRN 3060: ROBOTICS and AUTOMATIONS
Week 8

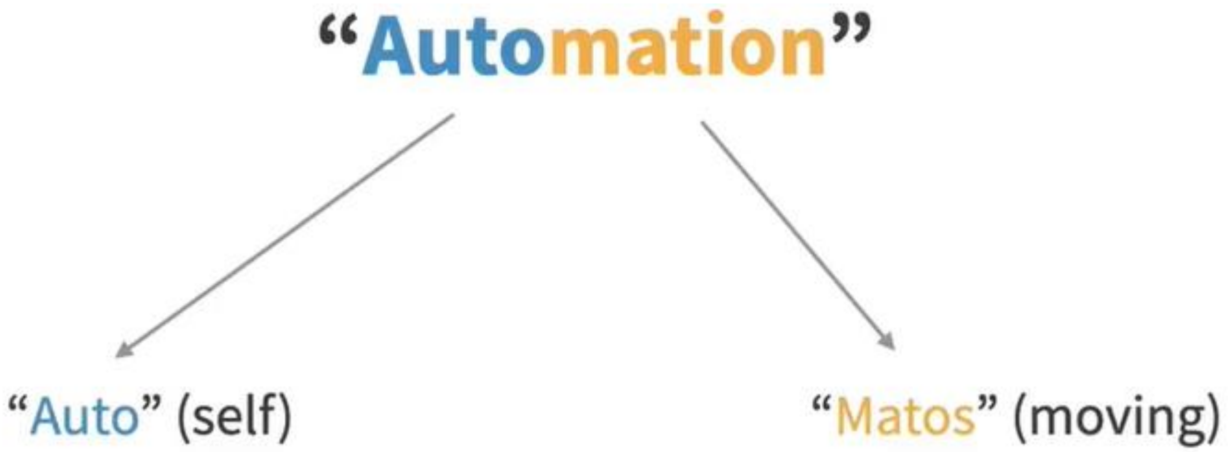
Industrial Automation Part II

Industry Automation

- Industrial automation refers to the use of control systems, machinery, and various technologies to automate and optimize industrial processes, tasks, and operations.

- The primary goal of industrial automation is to increase productivity, improve efficiency, enhance safety, and reduce human intervention in manufacturing and other industrial processes.

- To replace human and human thinking with computers, robots and machines within industrial settings.



Importance of Industrial Automation

Industrial automation plays a crucial role in modern manufacturing and industrial processes due to its numerous advantages and benefits. Here are some of the key importance of industrial automation:

1) Improved Efficiency: Automation systems can operate 24/7 without breaks, reducing downtime and increasing production efficiency. They can perform repetitive tasks with precision and consistency, which leads to higher throughput and reduced cycle times.

2) Enhanced Quality Control: Automation ensures that processes are executed with a high degree of accuracy and repeatability. This results in consistent product quality, reducing defects and variation in manufactured goods.

3) Increased Productivity: Automated systems can handle tasks at a faster pace than human operators. This increased productivity allows companies to produce more with the same or fewer resources, thereby boosting overall output and profitability.

4) Cost Reduction: Although the initial investment in automation can be significant, it often leads to long-term cost savings. Automation reduces labor costs, minimizes waste, and decreases energy consumption. It also helps avoid expenses related to errors, accidents, and product recalls.

5) Safety Improvement: Automation systems can handle dangerous, repetitive, or physically demanding tasks, reducing the risk of workplace injuries. Safety measures and interlocks can be integrated into automation systems to enhance workplace safety.

Importance of Industrial Automation

6) Flexibility and Scalability: Modern automation systems are designed to be flexible and easily adaptable to changes in production requirements. They can accommodate new product designs or variations with minimal reprogramming or retooling.

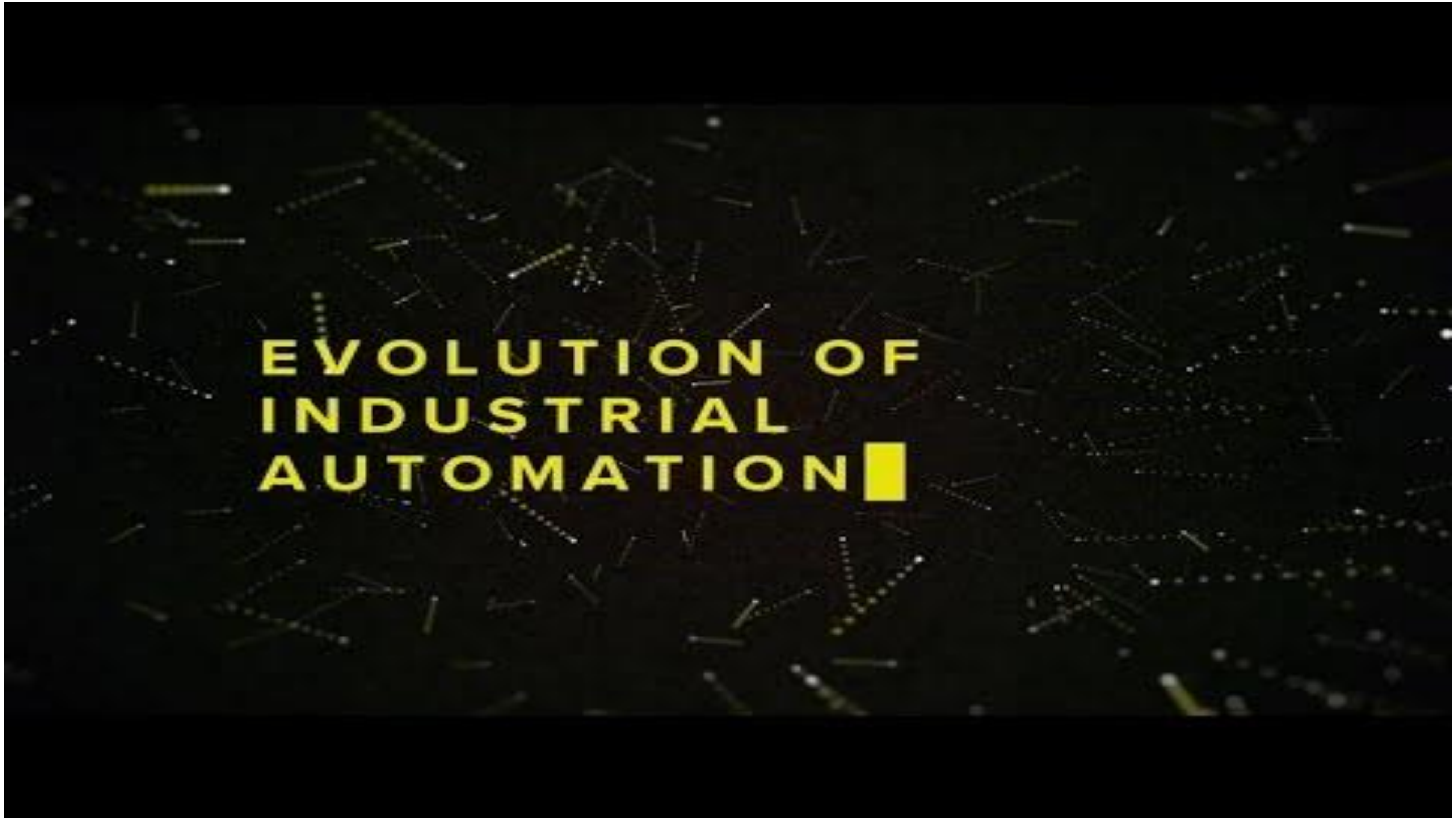
7) Data Collection and Analysis: Automation systems collect vast amounts of data during production. This data can be analyzed to identify trends, optimize processes, and predict maintenance needs, leading to more informed decision-making.

8) Conservation of Resources: Automation can help conserve valuable resources, such as raw materials, energy, and water. It optimizes resource usage and reduces waste, contributing to environmental sustainability.

9) Quality of Work Life: Automation frees human workers from mundane, repetitive tasks, allowing them to focus on more creative and value-added activities. This can lead to improved job satisfaction and opportunities for upskilling.

10) Adaptation to Technological Advances: As technology advances, automation systems can be easily upgraded or integrated with new technologies, ensuring that a company's processes remain up to date and future-proof.

Historical Evolution of Automation in Industries



https://www.youtube.com/watch?v=zcVHVux50QA&ab_channel=Yokogawa%3AIndustrialAutomation

Historical Evolution of Automation in Industries

Mechanisation in the Industrial Revolution (Late 18th Century - Early 19th Century): The Industrial Revolution marked the transition from manual labor to mechanized production. Water and steam power were harnessed to operate machinery in textile mills, leading to the automation of tasks that were previously done by hand. This era laid the foundation for industrial automation.

Introduction of the Assembly Line (Early 20th Century): Henry Ford's development of the assembly line in the early 20th century revolutionised manufacturing. It allowed for the mass production of automobiles and other products by dividing the production process into smaller, specialized tasks. This concept greatly increased efficiency and productivity.

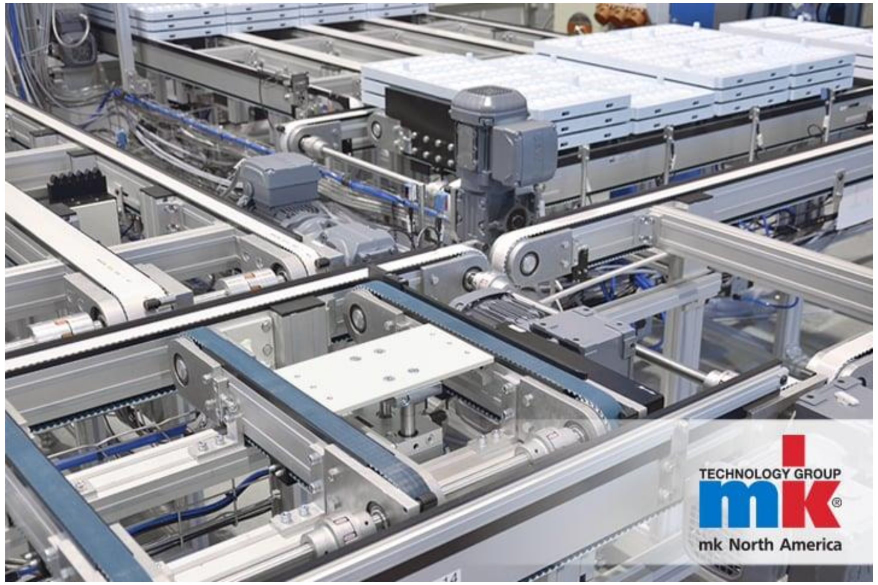
Emergence of Numerical Control (NC) and Computer Numerical Control (CNC) Machines (Mid-20th Century): NC machines, which used punched cards or tapes to control machining processes, were among the earliest computer-based automation systems. CNC machines took this a step further by incorporating computer control, enabling precise and automated machining of complex parts.

Introduction of Programmable Logic Controllers (PLCs) (Late 1960s): PLCs replaced complex relay-based control systems with solid-state devices and programmable logic. They made it easier to modify and control industrial processes, becoming a cornerstone of industrial automation.

Rise of Industrial Robotics (1980s): The 1980s saw significant advancements in industrial robotics.

Examples of Industry Automation

1) Conveyor Belt Systems: Conveyor systems are widely used in manufacturing and distribution to move products or materials from one location to another automatically. They can be configured with sensors and control systems to regulate the flow of items, sort products, and even package goods.



Examples of Industry Automation

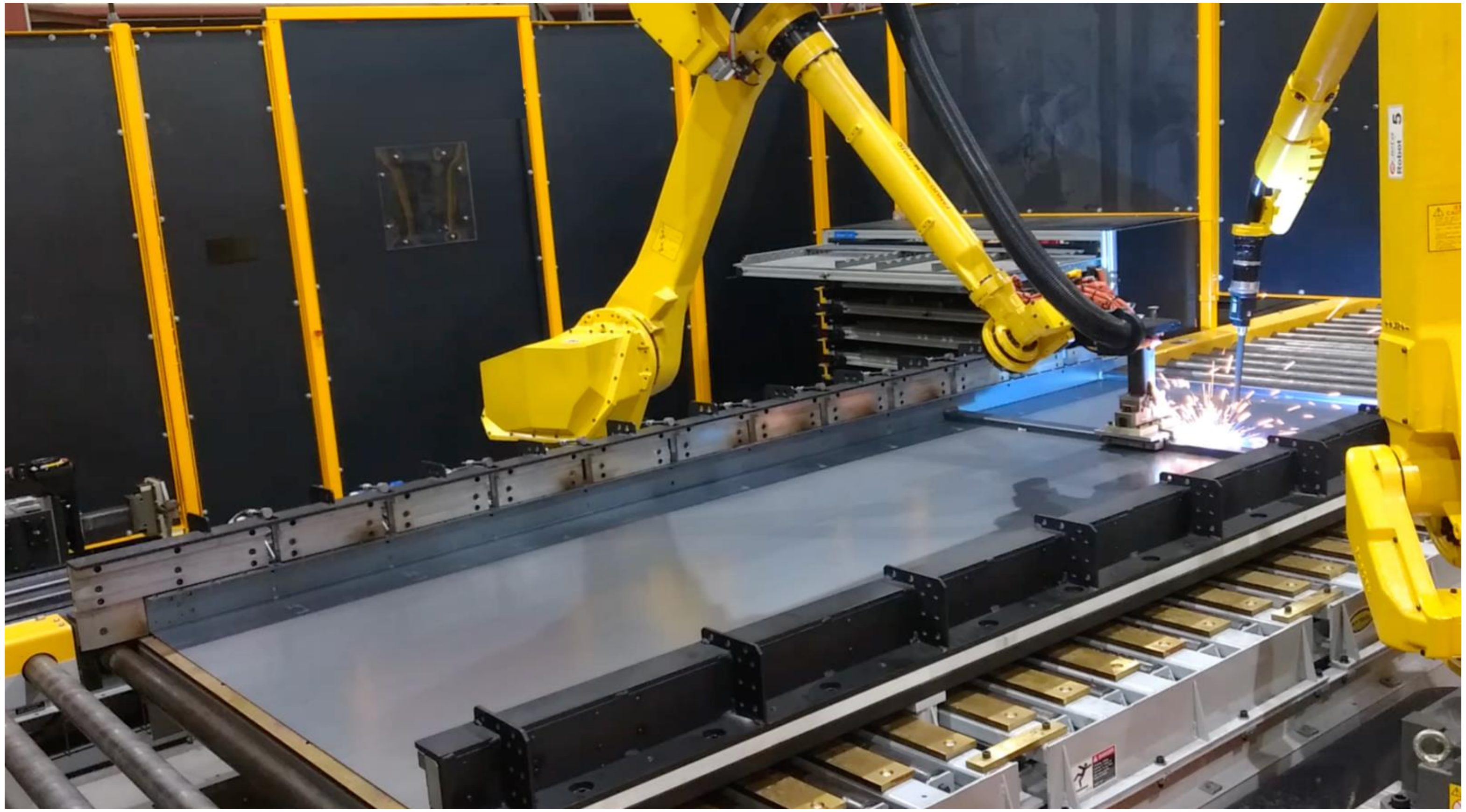
2) Automated Packaging Machines: Automated packaging machines are designed to fill, seal, and label products or packages automatically. They can handle a variety of products, from food items to pharmaceuticals, with precision and speed.

Examples of Industry Automation

3) CNC Machining: Computer Numerical Control (CNC) machines are used for precision machining tasks, such as cutting, drilling, and milling. Operators program CNC machines with specific instructions, and the machines carry out these tasks automatically, producing accurate and consistent parts.

Examples of Industry Automation

4) Automated Welding Systems: In industries like automotive and construction, automated welding systems use robotics and sensors to perform welding tasks with high precision and consistency. These systems can weld joints on various materials, improving the quality and efficiency of welding processes.



Examples of Industry Automation

5) Bottling and Filling Lines: In beverage and food production, automated bottling and filling lines are common. These systems automatically fill bottles or containers with liquids, such as soft drinks or sauces, and cap or seal them. Sensors and control systems ensure accurate filling levels and prevent overflows.

Examples of Industry Automation

5) Bottling and Filling Lines: In beverage and food production, automated bottling and filling lines are common. These systems automatically fill bottles or containers with liquids, such as soft drinks or sauces, and cap or seal them. Sensors and control systems ensure accurate filling levels and prevent overflows.

https://www.youtube.com/watch?v=kthIlLGl300&ab_channel=NICHROMEINDIALTD

What does an industrial automation system is consist of?

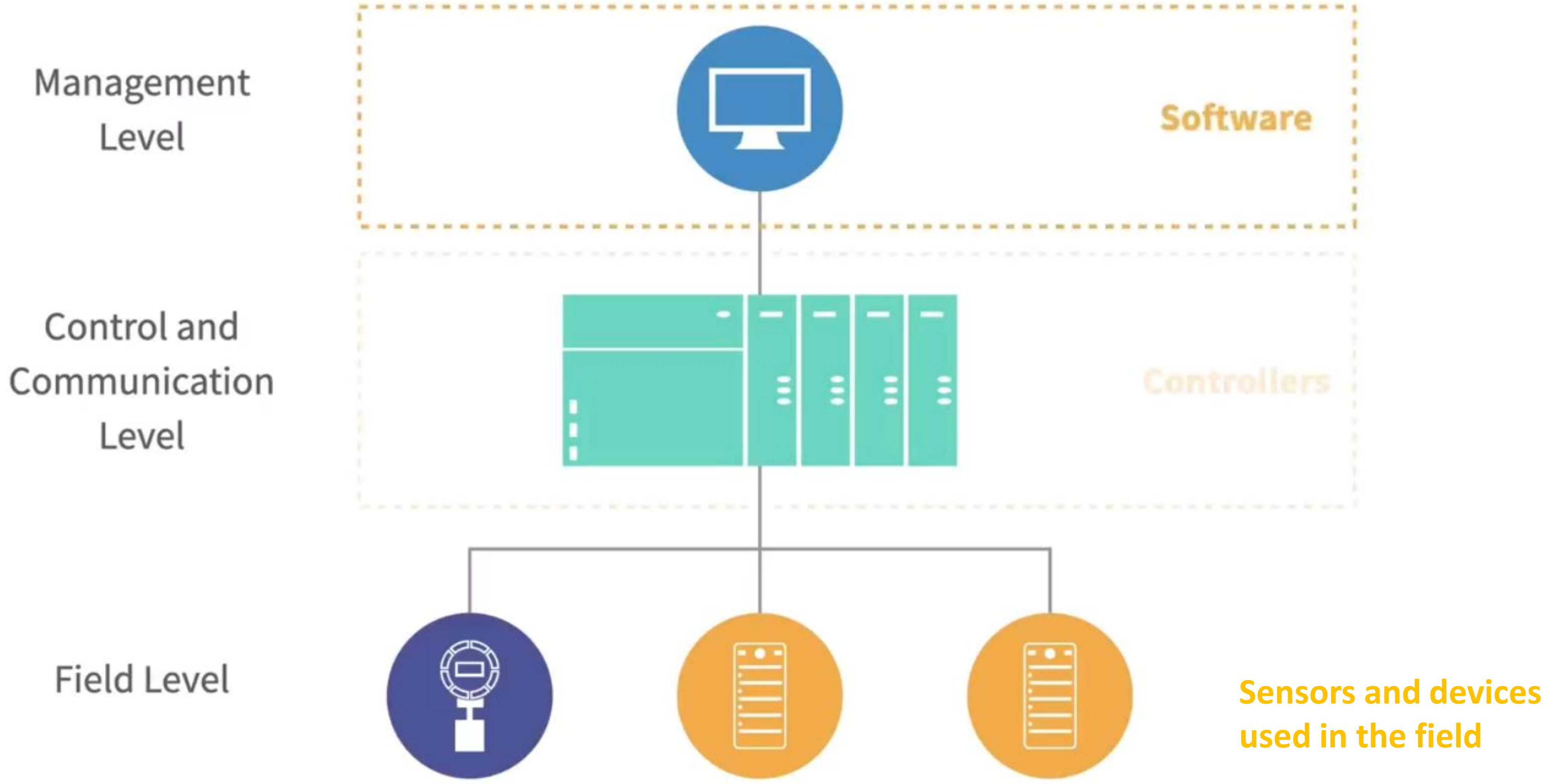
- Controllers (PLC, DCS)
- Field industrial devices (sensors)
- Industrial communication and networking
- Human-machine interface (HMI)
- Supervisory control and data acquisition software (SCADA)
- Personal computers (PC)

Assignment-ilearn submission

In recent years, Industry 4.0 and industrial automation have rapidly transformed manufacturing and various industries. These technological advancements have led to increased efficiency, improved quality, and cost savings for companies. Consider a particular robot in food production; aim of this assignment is to discuss The Role of Industrial Automation in Enhancing Food Production Quality and Safety. Answer to below topics:

- **Quality Assurance through Automation:** How does the integration of automation technologies, such as sensor-based monitoring and precision control systems, improve the quality and consistency of food production processes? Can you provide specific examples of how automation has been applied to ensure food quality in agriculture or food processing?
- **Food Safety Challenges:** What are the critical challenges in food safety, and how can automation mitigate them? Discuss the role of automation in monitoring and maintaining hygiene standards, traceability, and real-time data analysis to prevent contamination and ensure the safety of food products.
- **Balancing Automation and Human Expertise:** While automation offers significant benefits in food production, where do you see the continued importance of human expertise and oversight? How can industries strike a balance between automation and the human element to optimize food quality and safety?

Levels of Industrial Automation



Field level

Field Level: This is the lowest level in the automation hierarchy and is closest to the physical processes being controlled. It includes devices and components such as sensors, actuators, motor drives, switches, and instruments. At the field level, these devices collect data from the manufacturing or industrial processes and perform basic control actions, like opening or closing valves, adjusting motor speeds, or sensing temperature and pressure.

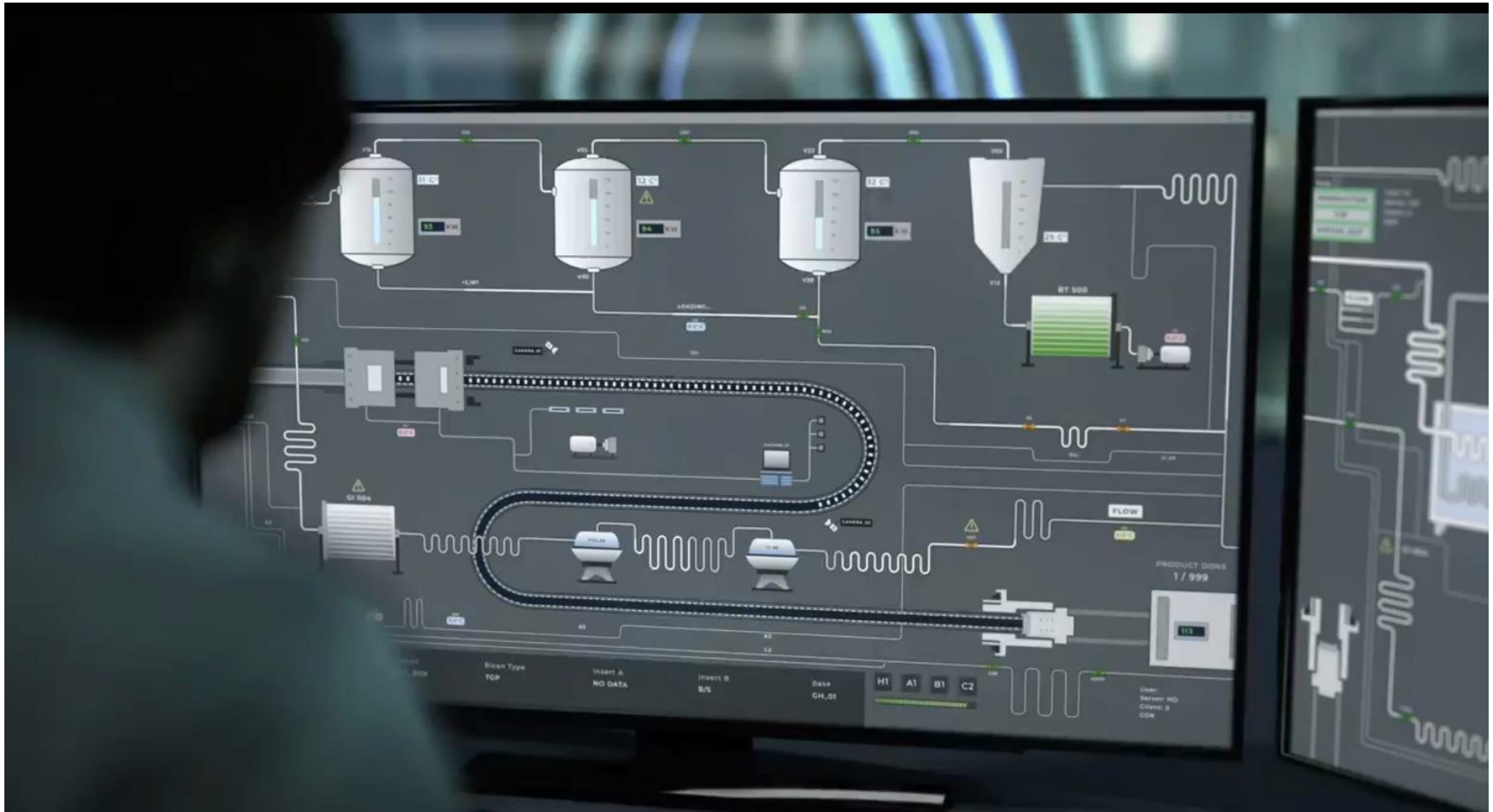
Field level

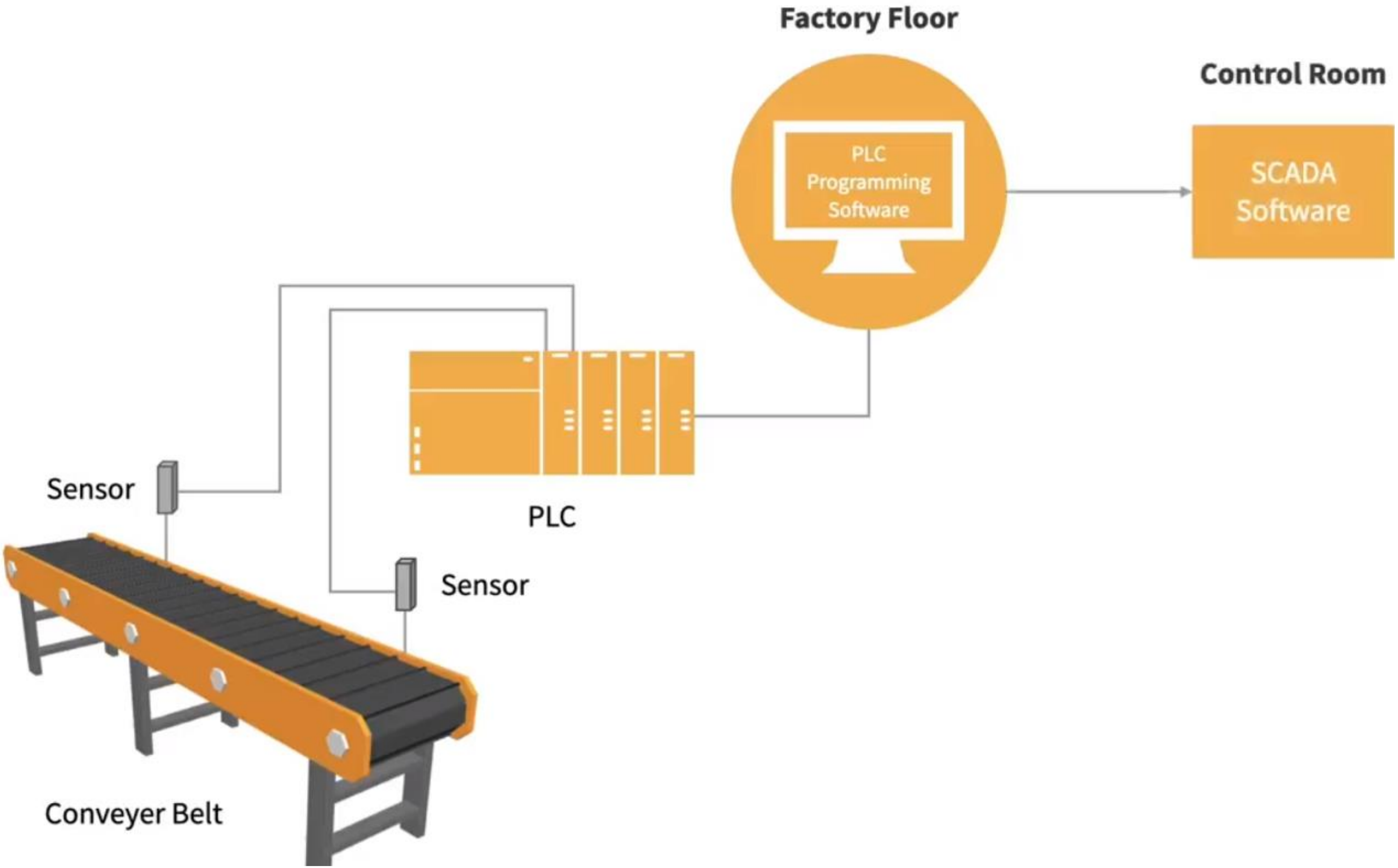
Control and Communication levels

Control Level: The control level is where the data collected from the field level is processed and used to control the various processes. It includes programmable logic controllers (PLCs), distributed control systems (DCS), and other automation controllers. These controllers make decisions based on the data received from the field level and send commands to the devices at the field level to maintain or optimize the processes.

Management (Enterprise) level

Enterprise Level: The highest level in industrial automation is the enterprise level. It involves the use of supervisory control and data acquisition (SCADA) systems, manufacturing execution systems (MES), and other software applications to provide a broader view of the entire industrial operation. Data collected from the control level is aggregated and analysed at this level to make strategic decisions, monitor performance, and optimize production processes.



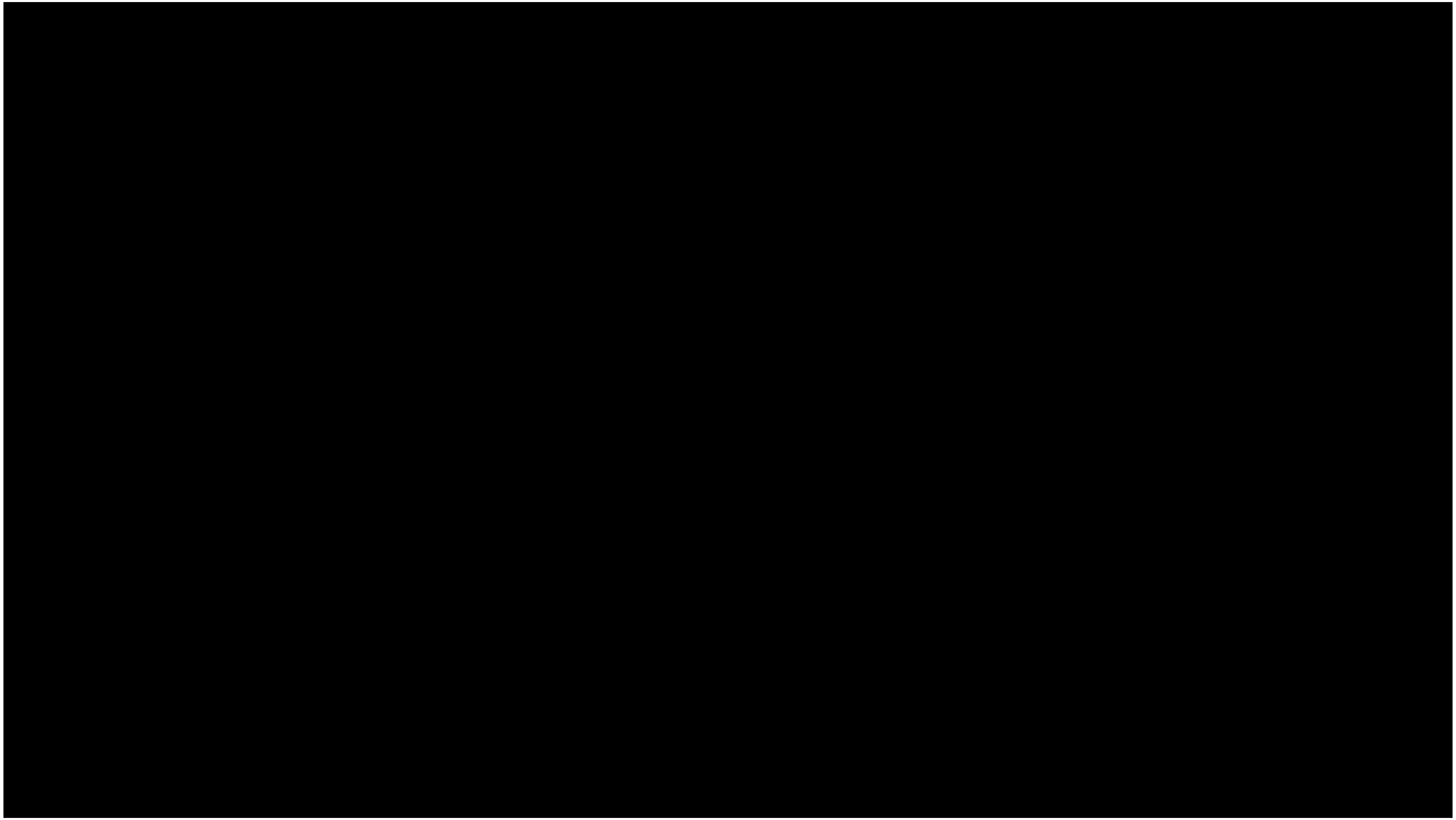

Factory Floor
Control Room
PLC
Programming
Software
SCADA
Software
Sensor
PLC
Sensor
Conveyer Belt

Supervisory Control and Data Acquisition (SCADA)

SCADA stands for Supervisory Control and Data Acquisition. It is a type of software and hardware system used for monitoring and controlling industrial processes and infrastructure in real-time. SCADA systems are commonly used in industries such as manufacturing, energy, water treatment, transportation, and more. key features and components of SCADA software include:

- **Data Acquisition:** SCADA software collects data from various sensors, instruments, and devices located in the field.
- **Real-Time Monitoring:** SCADA systems provide real-time monitoring of industrial processes.
- **Control:** In addition to monitoring, SCADA systems can also control industrial processes.
- **Alarming:** SCADA software includes alarm management features.
- **Data Logging and Storage:** SCADA systems often have data logging capabilities, which means they record historical data over time.
- **Security:** Security is a critical aspect of SCADA systems because they control and monitor essential infrastructure.
- **Communication:** SCADA software communicates with field devices and other components using various communication protocols, such as Modbus, DNP3, OPC, and more.
- **Remote Access:** SCADA systems often support remote access, allowing authorized personnel to monitor and control processes from off-site locations, which can be useful for maintenance and troubleshooting.

Supervisory Control and Data Acquisition (SCADA)



https://inductiveautomation.com/resources/article/what-is-scada

Components of SCADA Systems (HMI, RTUs, Communication Protocols)

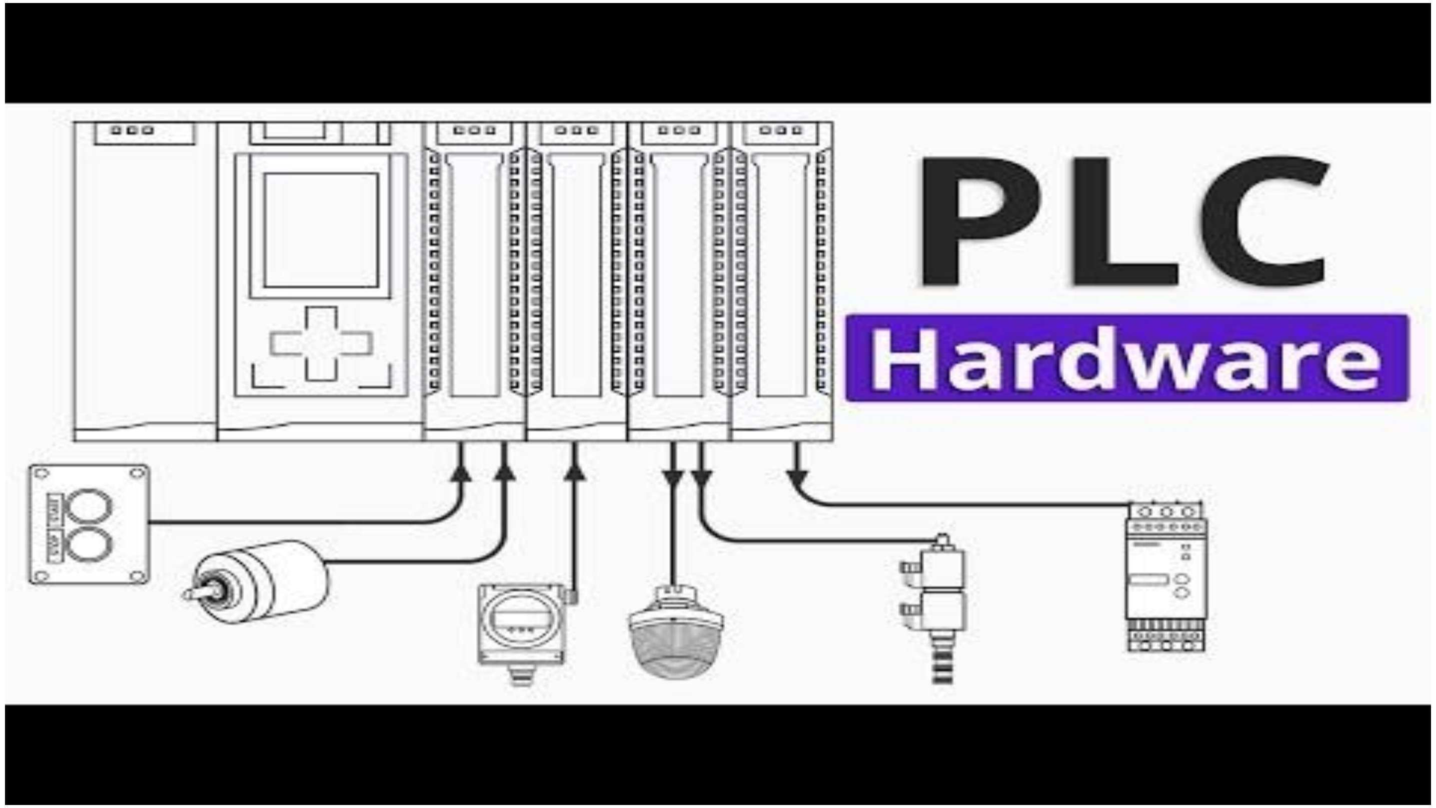
An industrial controller is a specialized device or system used in industrial automation to control and manage various processes and machinery in manufacturing, production, and other industrial settings. There are two main types of industrial controllers:

1) Programmable Logic Controller (PLC): PLCs are one of the most common types of industrial controllers. They are rugged, reliable, and highly versatile. PLCs use ladder logic, function block diagrams, or other programming languages to control machines and processes. They can handle a wide range of inputs and outputs, making them suitable for a variety of industrial applications.

2) Distributed Control System (DCS): DCS is a type of industrial controller typically used in large-scale and complex industrial processes, such as chemical plants, power generation facilities, and oil refineries.

Programmable Logic Controllers

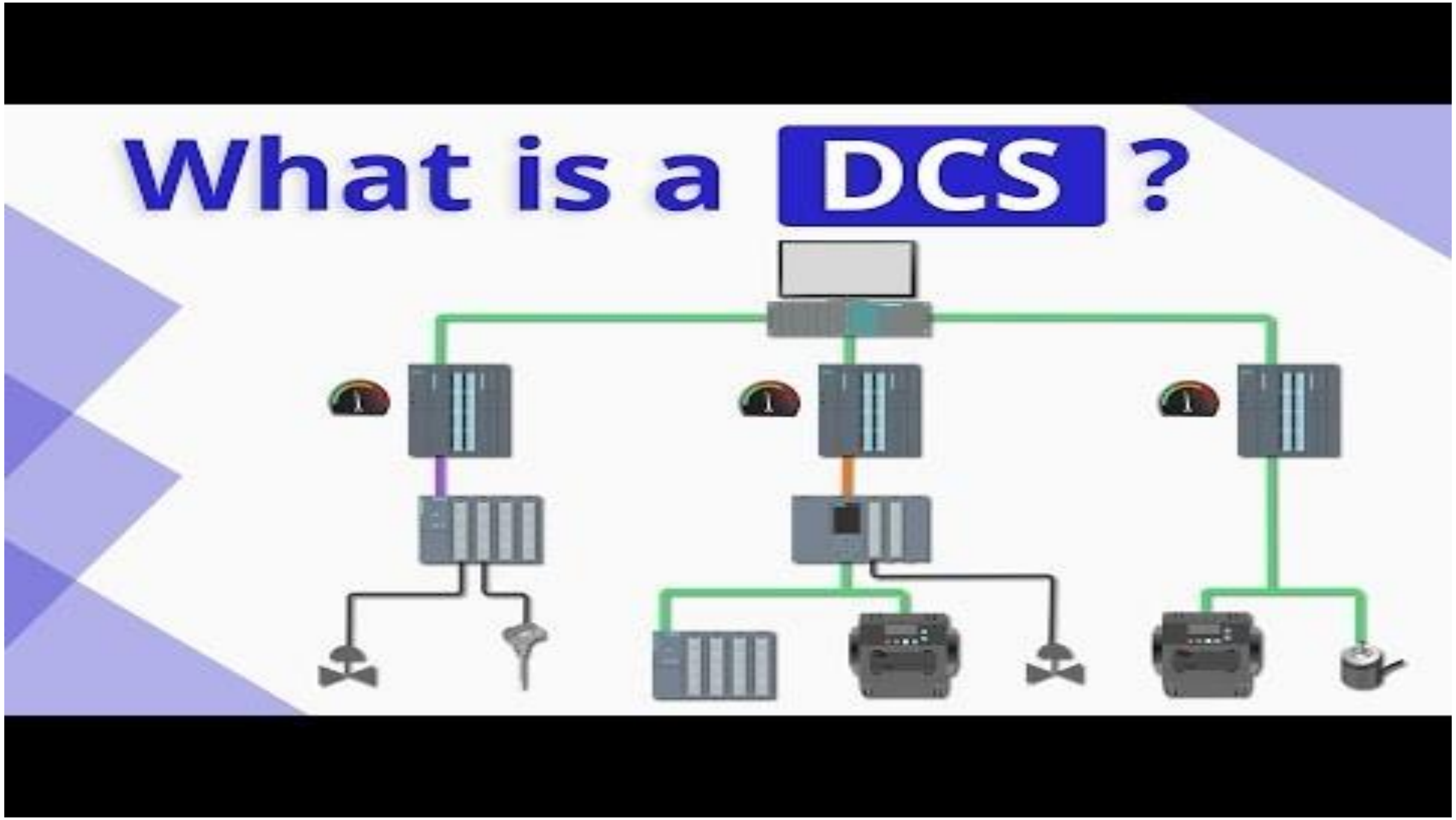
A Programmable Logic Controller (PLC) is a specialized industrial computer used for the automation and control of machinery and processes in manufacturing and industrial environments. PLCs are designed to perform a wide range of tasks, including monitoring inputs from sensors, making decisions based on logic programmed by a user, and controlling outputs to various devices and machines.



https://www.youtube.com/watch?v=pPUnihpL6UI&ab_channel=RealPars

Distributed Control System (DCS):

A Distributed Control System (DCS) is a specialized control system used in industrial automation and process control to monitor and control complex and distributed processes and machinery within various industries, including manufacturing, chemical processing, power generation, and oil refining.



https://www.youtube.com/watch?v=KCs0oaKjCMU&ab_channel=RadwellInternational

Scalable Control to Match Application Requirements

Different controllers to meet your discrete, process, motion and safety needs.

PRODUCTS

Large PLC Control Systems

Delivering powerful world-class capabilities for Process, safety and motion requirements in the most demanding applications.

V

PRODUCTS

Process Controllers

Accelerate your digital transformation with PlantPAx® 5.0 DCS version and unlock more opportunities with our ControlLogix® 5580 and CompactLogix™ 5380 Process controllers.

PRODUCTS

Small PLC Control Systems

Meet the demands of smart machines and equipment for manufacturing and choose from standard and safety-certified controllers in chassis-based, odular designs.

PRODUCTS

Micro PLC Control Systems

Your cost-effective micro PLC solution to basic and smart control for small to large standalone applications.

View Products

https://www.rockwellautomation.com/en-us.html

Role of Communication in Industrial Automation

Communication plays a pivotal role in industrial automation by enabling the exchange of data and information between various components, devices, and systems within an industrial environment. The effective communication of data is essential for achieving seamless automation, optimizing processes, and ensuring the reliability and safety of industrial operations. Here are the key roles of communication in industrial automation:

- Data Exchange
- Control and Monitoring
- Coordination
- Data Logging and Historian Systems
- Safety:
- Alerts and Alarms
- Maintenance and Diagnostics
- Integration
- Energy Management
- Supply Chain Integration
- Data Security

Safety in Industrial Automation (Industry speaker-Week 10)

The goal of functional safety is to use functions to reduce the risk of equipment causing harm to people, damage to property or society due to malfunction or incorrect operation. An example of a functional safety feature is using motor control devices on robots to avoid hazards by automatically stopping the motor.

Risk Assessment: Before implementing an automated system, a thorough risk assessment should be conducted. This involves identifying potential hazards, evaluating their severity, and determining the likelihood of occurrence. Risk assessments guide the development of safety measures.

Safety Standards and Regulations: Compliance with safety standards and regulations is crucial. Various organizations, such as the International Electrotechnical Commission (IEC) and the Occupational Safety and Health Administration (OSHA), provide standards and guidelines specific to industrial automation safety.

Safety Interlocks: Safety interlocks are mechanisms that prevent or stop machinery or processes when certain unsafe conditions are detected. These can include emergency stop buttons, safety gates, and light curtains. They are designed to protect personnel from harm.

Emergency Shutdown Systems: Emergency shutdown systems are essential in cases of critical failures or emergencies. They ensure that processes or equipment are rapidly shut down to prevent accidents or the spread of dangerous conditions.

Safety in Industrial Automation (Industry speaker-Week 10)

Safety PLCs: Some automation systems use specialized safety programmable logic controllers (PLCs) designed to handle safety-critical functions. These PLCs have redundancy and self-diagnostic capabilities to ensure high reliability.

Safety Sensors: Safety sensors and devices, such as safety mats, safety laser scanners, and safety switches, are used to detect the presence of personnel or obstructions in hazardous areas. They trigger safety interlocks or shutdowns when necessary.

Safety Training: Adequate training for personnel is crucial. Employees must be aware of potential hazards, safety procedures, and how to operate and maintain automated equipment safely.

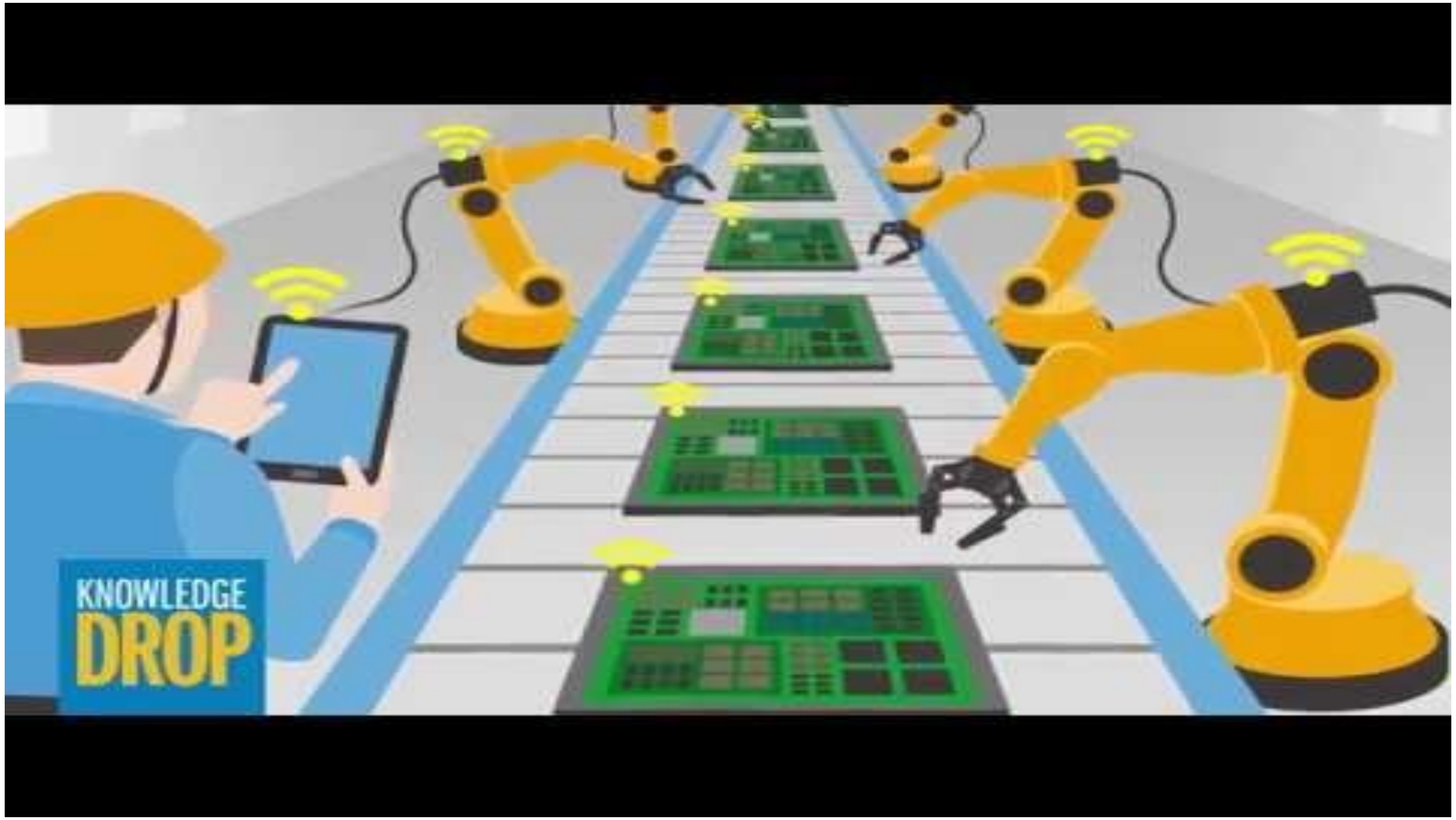
Hazardous Area Classification: In industries dealing with flammable or explosive materials, hazardous area classification identifies zones where specific safety measures and equipment, such as intrinsically safe instrumentation, are required.

Continuous Improvement: Safety in industrial automation is an ongoing process. Regular safety audits, incident investigations, and feedback from employees should drive continuous improvement efforts to identify and mitigate new risks.

Trends and Future of Industrial Automation

Industry 4.0 and Smart Manufacturing

IoT (Internet of Things) in Industrial Automation



https://www.youtube.com/watch?v=EV1Ygw6_rCs&ab_channel=Anixter

Artificial Intelligence and Machine Learning in Automation (Week 9)

Artificial Intelligence (AI) and Machine Learning (ML) are playing an increasingly significant role in automation across various industries. They offer the potential to enhance decision-making, optimize processes, improve efficiency, and enable automation systems to adapt and learn from data.

Lecture
Jacobians: Velocities and Static forces

Jacobians: Velocities and Static Forces (Chapter 5)

- Summary: Understand the connection between the Cartesian velocities at the end-effector and the velocities of the individual joints.

Learning objectives:

- **Determine the Jacobian Matrix:** Calculate the Jacobian matrix using both the velocities propagation method and the force/moment propagation method for analyzing robotic systems.
- **Recognize Singularities and Implement Avoidance Strategies:** Identify singular points within the robotic system and develop techniques to prevent and navigate through permanent singularities.
- **Perform Cartesian Velocities and Forces Transformation:** Execute transformations to convert velocities and forces between Cartesian and other coordinate systems in robotic applications.

Introduction

We will expand our consideration of robot manipulators beyond static-positioning problems. We will examine the notions of linear and angular velocity of a rigid body, and use these concepts to analyze the motion of a manipulator. We also will consider forces acting on a rigid body, then use these ideas to study the application of static forces with manipulators.

The field of kinematics of mechanisms will not be treated in great depth here. For the most part, the presentation is restricted to only those ideas which are fundamental to the particular problem of robotics.

Introduction

Jacobians: multidimensional matrices that relate the Cartesian velocities to the joint velocities.

Time variables:

(join angles) $\theta(t): \theta_i \longrightarrow (t) \longrightarrow \theta_f$

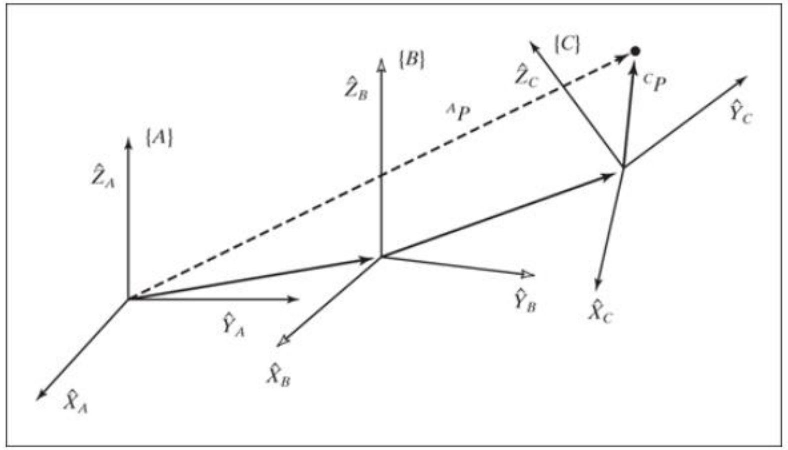
(Cartesian space) $x(t): xi \longrightarrow (t) \longrightarrow x_f$

- Derivative with respect to time

$$\frac{d\theta}{dt} = \dot{\theta}$$

$$\frac{dX}{dt} = \dot{X}$$

Reminder from chapter 2



Frame {*C*} is known relative to frame {*B*}, and frame {*B*} is known relative to frame {*A*}. We can transform ^CP into ^BP as

$$^BP = {}^B_CT\ {}^CP;$$

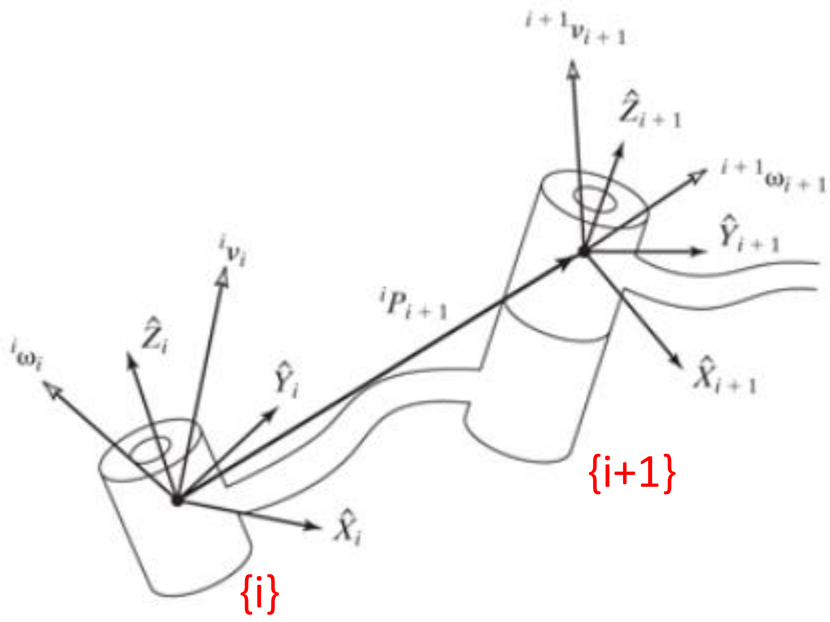
then, we can transform ^BP into ^AP as

$$^AP = {}^A_BT\ {}^BP.$$

Velocity vector is a free vector which means all that counts is the magnitude and direction, so only the rotation matrix relating the two systems is used in transforming. The relative locations of the origins do not enter into the calculation.

$$^AV = {}^A_BR\ {}^BV.$$

Jacobian using Velocity Propagation method



Linear velocity of the origin of link frame {i}: V_i
Angular velocity of the origin of link frame {i}: W_i

Rotational velocities can be added when both ω vectors are written with respect to the same frame. Therefore, the angular velocity of link *i+1* is the same as that of link *i*, plus a new component caused by rotational velocity at joint *i+1*. This can be written in terms of frame {i} as

$$ {}^{i}\omega_{i+1} = {}^{i}\omega_i + {}^{i}_{i+1}R\,\dot{\theta}_{i+1}\,{}^{i+1}\widehat{Z}_{i+1}. $$

$$ \dot{\theta}_{i+1}\,{}^{i+1}\widehat{Z}_{i+1} = {}^{i+1}\begin{bmatrix} 0 \\ 0 \\ \dot{\theta}_{i+1} \end{bmatrix} $$

Jacobian using Velocity Propagation method

We have made use of the rotation matrix relating frames {i} and {i+1} in order to represent the added rotational component due to motion at the joint in frame {i}. The rotation matrix rotates the axis of rotation of joint i+1 into its description in frame {i}, so that the two components of angular velocity can be added.

By premultiplying both sides of equation by ${}^{i+1}_{i}R$, we can find the description of the angular velocity of link i+1 with respect to frame

Angular velocities for revolute joints

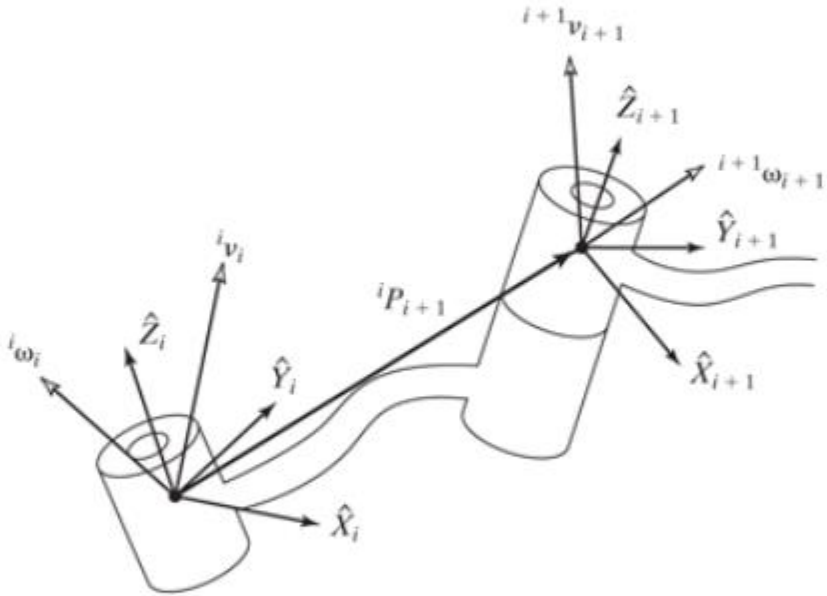
$$ {}^{i+1}\omega_{i+1} = {}^{i+1}_{i}R\, {}^{i}\omega_i + \dot{\theta}_{i+1}\, {}^{i+1}\hat{Z}_{i+1} $$

Angular velocities for prismatic joints

$$ {}^{i+1}\omega_{i+1} = {}^{i+1}_{i}R\, {}^{i}\omega_i $$

$$ \dot{\theta}_{i+1}\, {}^{i+1}\hat{Z}_{i+1} = {}^{i+1}\begin{bmatrix} 0 \\ 0 \\ \dot{\theta}_{i+1} \end{bmatrix} $$

Jacobian using Velocity Propagation method



The linear velocity of the origin of frame {i+1} is the same as that of the origin of frame {i}, plus a new component caused by rotational velocity of link i.

$$ {}^{i}v_{i+1} = {}^{i}v_i + {}^{i}\omega_i \times {}^{i}P_{i+1}. $$

Premultiplying both sides by ${}^{i+1}_{i}R$, we compute

$[S({}^{i}\omega_i)]$

Linear velocities for revolute joints

$$ {}^{i+1}v_{i+1} = {}^{i+1}_{i}R({}^{i}v_i + {}^{i}\omega_i \times {}^{i}P_{i+1}) $$

$$ \dot{\theta}_{i+1}\, {}^{i+1}\hat{Z}_{i+1} = {}^{i+1}\begin{bmatrix} 0 \\ 0 \\ \dot{\theta}_{i+1} \end{bmatrix} $$

$[S({}^{i}\omega_i)]$

Linear velocities for prismatic joints

$$ {}^{i+1}v_{i+1} = {}^{i+1}_{i}R({}^{i}v_i + {}^{i}\omega_i \times {}^{i}P_{i+1}) + \dot{d}_{i+1}\, {}^{i+1}\hat{Z}_{i+1} $$

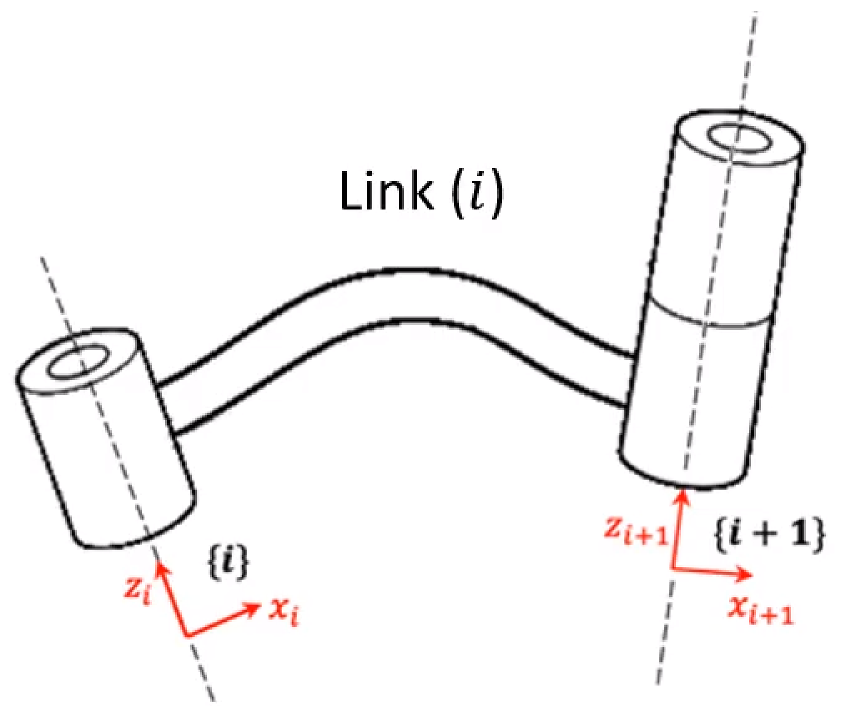
$$ [S({}^{i}\omega_i)] = \begin{bmatrix} 0 & -\omega_z & \omega_y \\ \omega_z & 0 & -\omega_x \\ -\omega_y & \omega_x & 0 \end{bmatrix} $$

Summary

If joint $(i+1)$ is a **revolute joint**:

$$[{}^{i+1}v_{i+1}] = [{}^{i+1}_{i}R]([{}^{i}v_{i}] + [S({}^{i}\omega_{i})][{}^{i}P_{i+1}])$$

$$[{}^{i+1}\omega_{i+1}] = [{}^{i+1}_{i}R][{}^{i}\omega_{i}] + {}^{i+1}\begin{bmatrix} 0 \\ 0 \\ \dot{\theta}_{i+1} \end{bmatrix}$$



If joint $(i+1)$ is a **prismatic joint**:

$$[{}^{i+1}v_{i+1}] = [{}^{i+1}_{i}R]([{}^{i}v_{i}] + [S({}^{i}\omega_{i})][{}^{i}P_{i+1}]) + {}^{i+1}\begin{bmatrix} 0 \\ 0 \\ \dot{d}_{i+1} \end{bmatrix}$$

$$[{}^{i+1}\omega_{i+1}] = [{}^{i+1}_{i}R][{}^{i}\omega_{i}]$$

$[S(\omega)]$ → A skew-symmetric matrix which takes the following form:

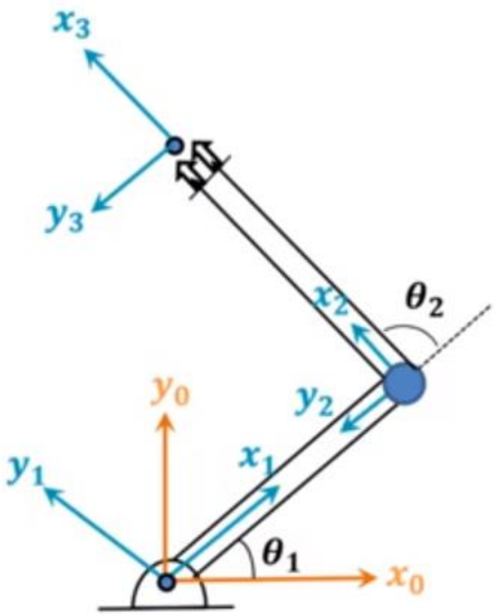
$$[S(\omega)] = \begin{bmatrix} 0 & -\omega_z & \omega_y \\ \omega_z & 0 & -\omega_x \\ -\omega_y & \omega_x & 0 \end{bmatrix}$$

Jacobian matrix

$$[\,{}^{3}\omega_3] = \underbrace{\begin{bmatrix} 0 & 0 \\ 0 & 0 \\ 1 & 1 \end{bmatrix}}_{[\mathbf{J}_\omega]} \begin{bmatrix} \dot{\theta}_1 \\ \dot{\theta}_2 \end{bmatrix}$$

$$[\,{}^{3}v_3] = \underbrace{\begin{bmatrix} L_1 s_2 & 0 \\ L_1 c_2 + L_2 & L_2 \\ 0 & 0 \end{bmatrix}}_{[\mathbf{J}_v]} \begin{bmatrix} \dot{\theta}_1 \\ \dot{\theta}_2 \end{bmatrix}$$

$${}^{3}\begin{bmatrix} [v_3] \\ [\omega_3] \end{bmatrix} = \underbrace{\begin{bmatrix} L_1 s_2 & 0 \\ L_1 c_2 + L_2 & L_2 \\ 0 & 0 \\ 0 & 0 \\ 0 & 0 \\ 1 & 1 \end{bmatrix}}_{[\mathbf{J}]} \begin{bmatrix} \dot{\theta}_1 \\ \dot{\theta}_2 \end{bmatrix}$$



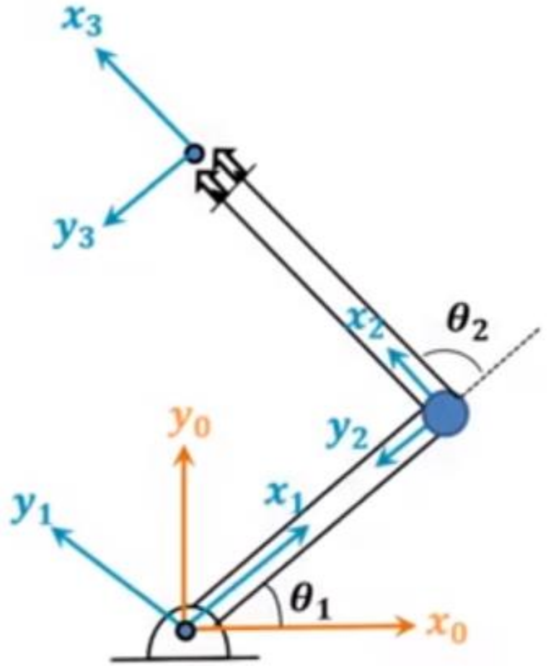
In robotics the Jacobian matrix [J] relates the end-effector velocity to the joint rates.

Jacobian matrix

$$\left[{}^{3}v_3\right] = \boxed{\begin{bmatrix} L_1 s_2 & 0 \\ L_1 c_2 + L_2 & L_2 \\ 0 & 0 \end{bmatrix}} \begin{bmatrix} \dot{\theta}_1 \\ \dot{\theta}_2 \end{bmatrix} \Rightarrow {}^{3}[\mathbf{J}_v]$$

$${}^{3}\begin{bmatrix} \dot{x}_3 \\ \dot{y}_3 \\ \dot{z}_3 \end{bmatrix} = \begin{bmatrix} L_1 s_2 & 0 \\ L_1 c_2 + L_2 & L_2 \\ 0 & 0 \end{bmatrix} \begin{bmatrix} \dot{\theta}_1 \\ \dot{\theta}_2 \end{bmatrix}$$

$${}^{3}\begin{bmatrix} \dot{x}_3 \\ \dot{y}_3 \end{bmatrix} = \boxed{\begin{bmatrix} L_1 s_2 & 0 \\ L_1 c_2 + L_2 & L_2 \end{bmatrix}} \begin{bmatrix} \dot{\theta}_1 \\ \dot{\theta}_2 \end{bmatrix} \Rightarrow {}^{3}[\mathbf{J}_v]_{2\times 2}$$



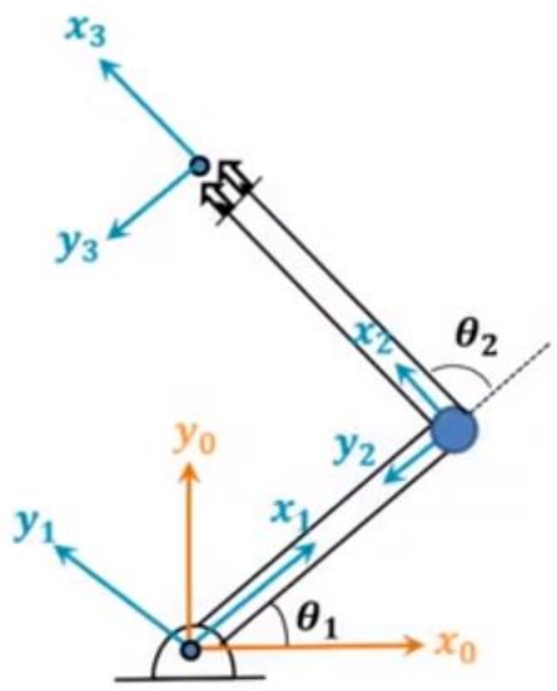
Jacobian matrix

$$\left[{}^{3}v_3\right] = \boxed{\begin{bmatrix} L_1 s_2 & 0 \\ L_1 c_2 + L_2 & L_2 \\ 0 & 0 \end{bmatrix}} \begin{bmatrix} \dot{\theta}_1 \\ \dot{\theta}_2 \end{bmatrix}$$

$${}^{3}[\mathrm{J}_v]$$

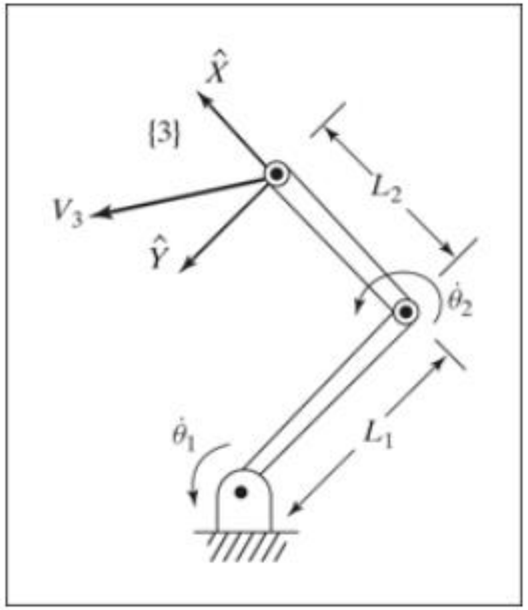
$${}^{3}[\mathrm{J}_v] = \begin{bmatrix} L_1 s_2 & 0 \\ L_1 c_2 + L_2 & L_2 \\ 0 & 0 \end{bmatrix}$$

$${}^{0}[\mathrm{J}_v] = [{}^{0}_{3}R]\ {}^{3}[\mathrm{J}_v]$$



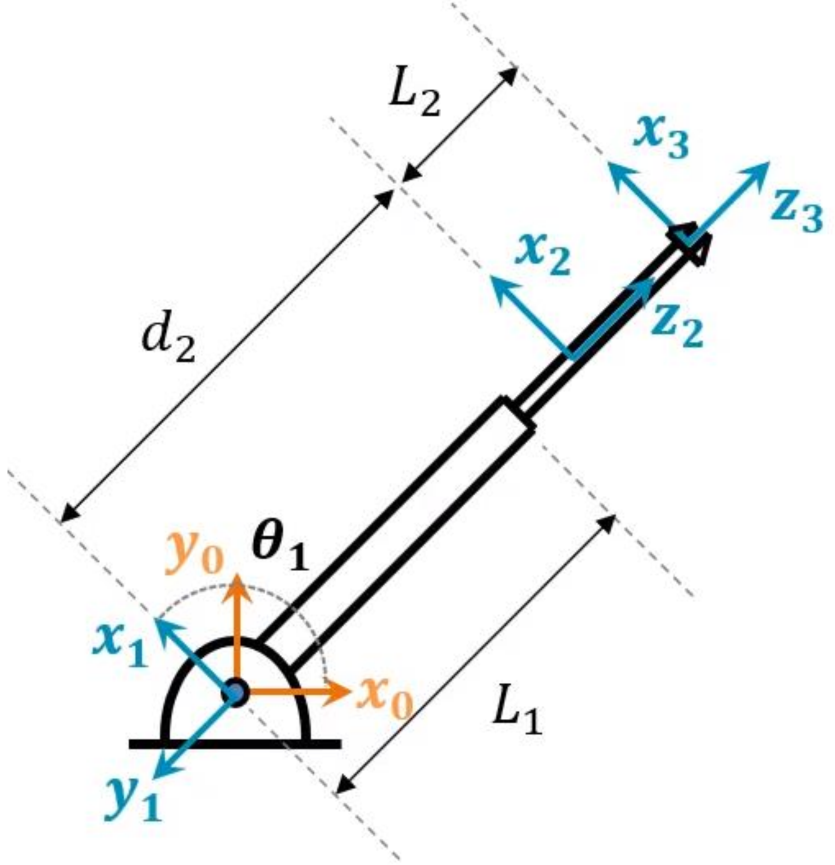
Example

A two-link manipulator with rotational joints is shown in below figure. Calculate the linear and angular velocities of the tip of the arm based on frames {0} and {3}, then find the Jacobian matric relative to frames {0} and {3}.



Example

For the planar 2 DOF RP robotic arm, calculate the velocity of each link and that of the end-effector as a function of the joint rates. then find the Jacobian matric relative to frames {0} and {3}.



End of Week 8