# INTRODUCTION TO ROBOTICS

## (Manipulation and Locomotion)

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# COURSE DESCRIPTION

This course covers the design, construction, operation and control of electro-mechanical system that has the capability to replace human effort. This includes its kinematics, differential motion, statics, dynamics and compliance control.

To equip students the ability to design robotic systems capable of carrying out complex series of actions such as object manipulations of different shapes, sizes, weights and materials through, but not limited to grasping, pushing, sliding, tipping, rolling and throwing and robot movement from one place to another through various types of locomotion such as walking, running, rolling, hopping, swimming and the like.

# MIDYEAR SCHEDULE

| | |
|---|---|
| MIDTERM EXAM | JUNE 29 - JULY 4 |
| MIDTERM GRADES: | JULY 11 |
| FINAL EXAM | JULY 20 - JULY 25 |
| FINAL GRADES: | AUG 3 |

# GRADING SYSTEM

| | |
|---|---|
| ASSIGNMENTS | 10% |
| QUIZZES | 40% |
| EXAMINATION | 30% |
| PROJECT | 20% |

## HISTORICAL DEVELOPMENT

The industrial revolution introduced automation to improve productivity and reduce human labor. However, the **modern era of industrial robots** began during the mid-20th century with the development of programmable machines capable of performing repetitive manufacturing tasks with high precision.

# ERA OF INDUSTRIAL ROBOTS

A robot is a **programmable machine** that performs tasks automatically or with minimal human intervention.

# ERA OF INDUSTRIAL ROBOTS

## GEORGE C. DEVOL (1954)

- Invented the **first programmable industrial robot.**
- Introduced the **Teach-and-Playback** concept.

**Teach → Store → Repeat**

Devol's industrial robots have their origins in two preceding technologies: **numerical control** for machine tools, and **remote manipulation.**

# ERA OF INDUSTRIAL ROBOTS

## NUMERICAL CONTROL

Machines follow stored instructions automatically.

## REMOTE MANIPULATION

Human controls a robot from a safe distance.

**Numerical control + Remote manipulation = Industrial Robots**

# FIRST GENERATION (1950S-1960S)

**Characteristics:**

- Programmed using fixed sequences of motions.
- Operated without environmental sensing.
- Performed repetitive and monotonous tasks.
- Relied on open-loop control systems.

**Common Applications:**

- Material handling
- Pick-and-place operations
- Machine loading and unloading
- Die casting

**Limitations:**

- No intelligence or decision-making capability.
- Unable to detect obstacles or changes in the environment.
- Required manual reprogramming for new tasks.


**Kawasaki-Unimate**

The Kawasaki-Unimate was the first industrial robot manufactured in Japan in 1969, marking the beginning of Japan's industrial robotics industry.

# SECOND GENERATION (1970S-1980S): SENSOR-BASED ROBOTS

**Characteristics:**

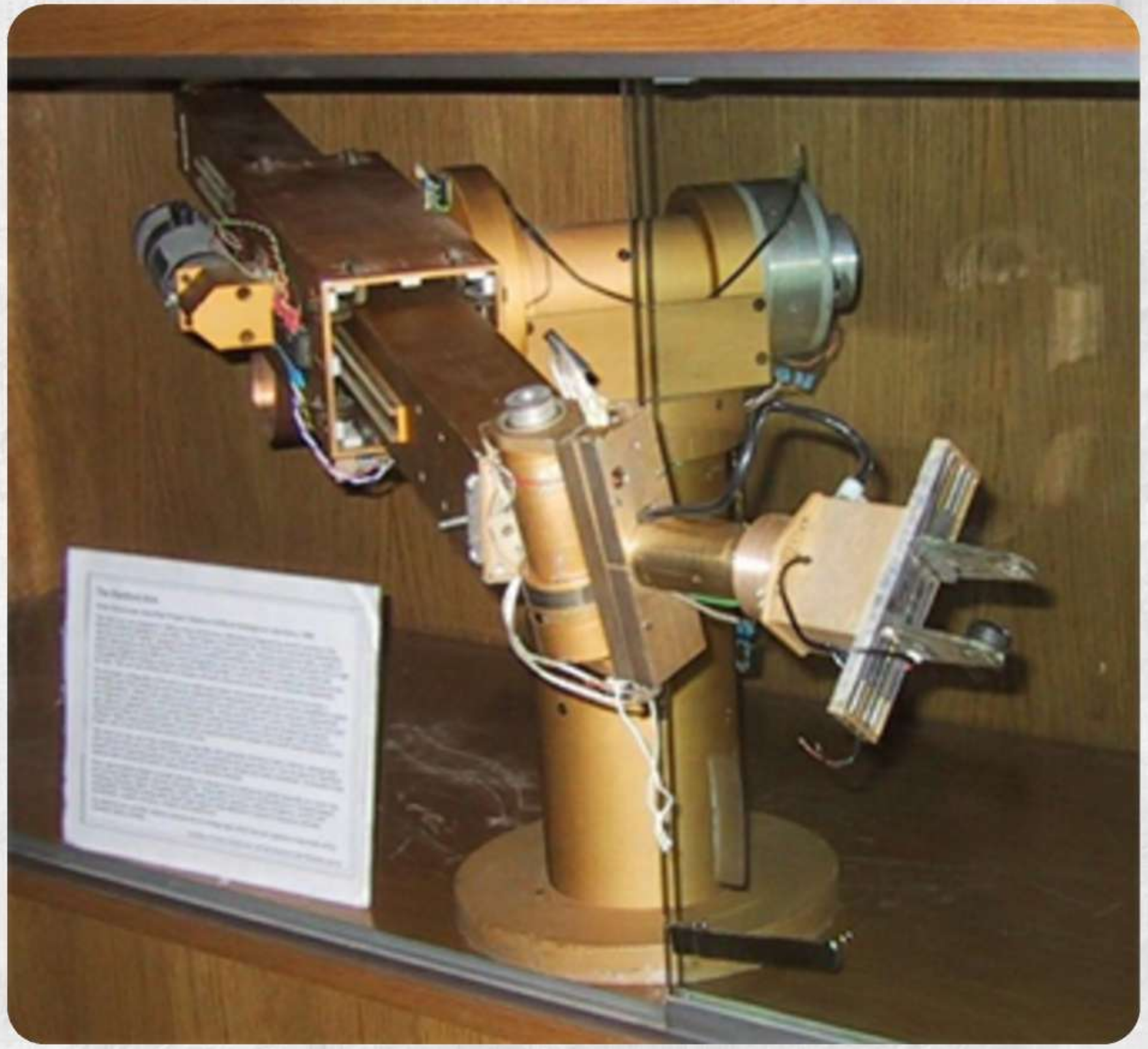
- Equipped with sensors such as vision systems and force sensors.
- Used closed-loop feedback control.
- Greater precision and repeatability.
- Improved interaction with the environment.

**Common Applications:**

- Arc welding
- Spot welding
- Spray painting
- Automated assembly
- Inspection and quality control

**Advantages:**

- Higher accuracy and consistency.
- Reduced production errors.
- Increased flexibility compared to first-generation robots.



**The Stanford Arm**

This robot was the first prototype of a robot actuated by electric motors (6 DC motors) and controlled by a PDP-6 microprocessor.

# THIRD GENERATION (1990S-PRESENT): INTELLIGENT ROBOTS

**Characteristics:**

- Integration of artificial intelligence and machine learning.
- Computer vision for object recognition and inspection.
- Adaptive programming and decision-making.

**Common Applications:**

- Flexible manufacturing systems
- Electronics assembly
- Warehouse automation
- Medical robotics
- Autonomous inspection systems

**Advantages:**

- Increased flexibility and adaptability.
- Reduced programming complexity.
- Enhanced safety through collaborative operation.
- Ability to perform customized manufacturing tasks.


**Universal Robots UR5 Cobot**

This robot works alongside humans in assembly lines, assisting with pick-and-place, packaging, and machine tending without requiring safety cages.

# FOURTH GENERATION (INDUSTRY 4.0): SMART AND CONNECTED ROBOTS

**Characteristics:**

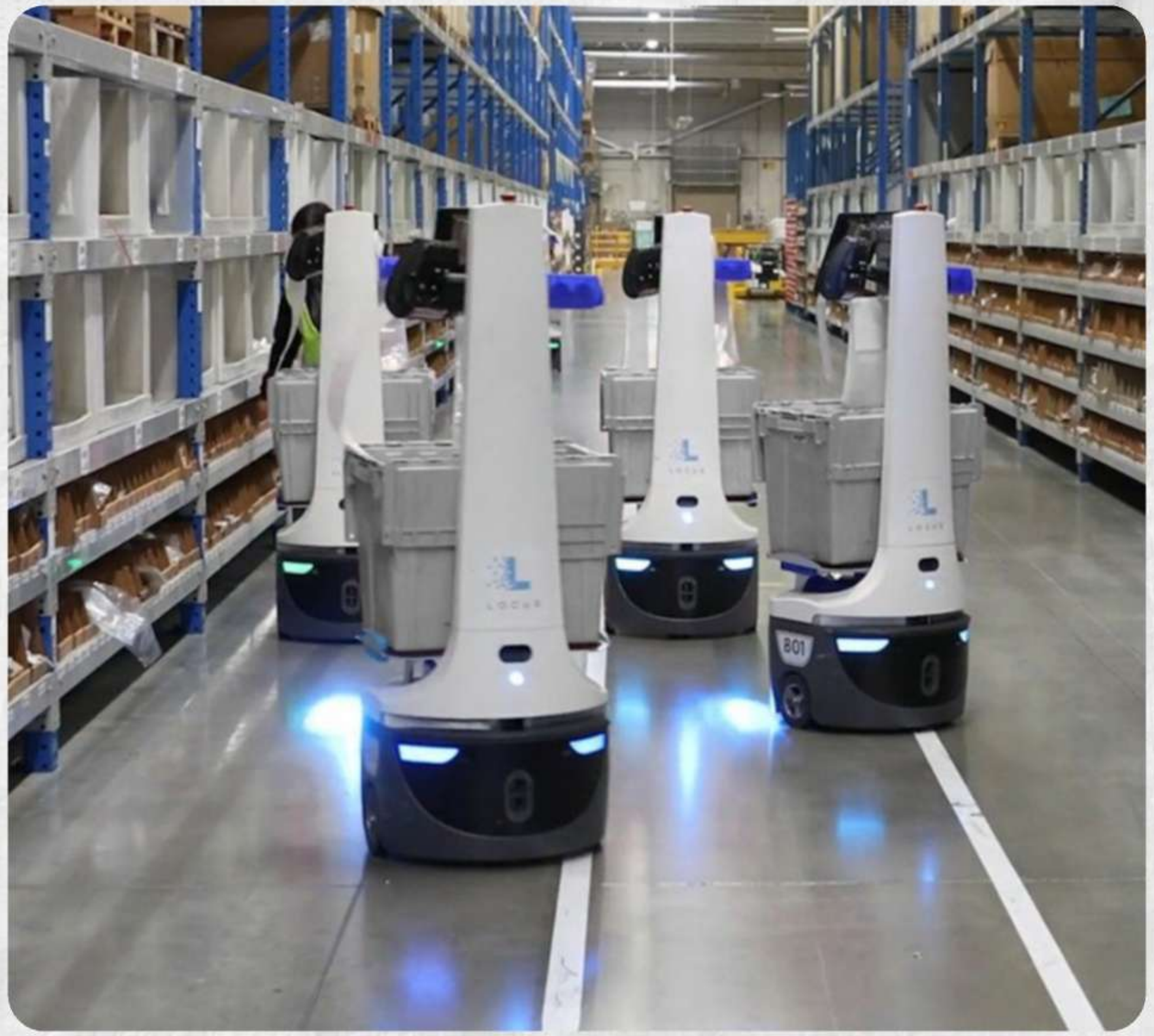
- AI, Machine Learning, Internet of Things (IoT) connectivity.
- Cloud-based data storage and processing.
- Big data analytics for process optimization.
- Autonomous decision-making using AI.
- Predictive maintenance through continuous monitoring.

**Common Applications:**

- Smart factories and intelligent production lines
- Digital twin simulations
- Autonomous mobile robots (AMRs)

**Advantages:**

- Real-time monitoring and optimization.
- Reduced machine downtime through predictive maintenance.
- Improved energy efficiency and productivity.



**Autonomous Mobile Robots (AMRs)**

These robots used in modern warehouses, such as those that transport inventory between storage and packing stations, navigate

## FIRST GENERATION (1950s–1960s)

### Programmable Manipulators


- Introduction of programmable manipulators.
- Primarily used for material handling.
- Limited sensing capabilities.

**Applications**

Material Handling · Pick-and-Place Operations · Machine Loading · Die Casting

**Key Feature:** Fixed sequence, no feedback

## SECOND GENERATION (1970s–1980s)

### Sensor-Based Robots

- Equipped with sensors and feedback control.
- Performed welding, painting, and assembly tasks.
- Improved accuracy and reliability.

**Applications**

Welding · Painting · Assembly · Inspection

**Key Feature:** Feedback control and sensors

## THIRD GENERATION (1990s–PRESENT)

### Intelligent Robots


- Integration of artificial intelligence and computer vision.
- Flexible manufacturing systems.
- Human-robot collaboration (Cobots).

**Applications**

Flexible Manufacturing · Electronics Assembly · Warehouse Automation · Medical Robotics

**Key Feature:** Intelligence, adaptability, and collaboration

## FOURTH GENERATION (INDUSTRY 4.0)

### Smart and Connected Robots


- Connected through the Internet of Things (IoT).
- Cloud computing and big data integration.
- Autonomous decision-making and predictive maintenance.

**Applications**

Smart Factories · Autonomous Logistics · Digital Twin · Predictive Maintenance

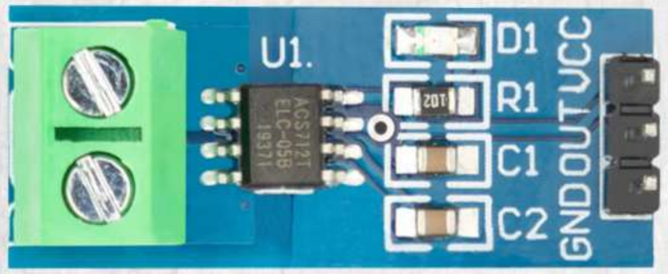
**Key Feature:** Connectivity, autonomy, and data-driven decisions

**Robotics** is an interdisciplinary field that combines **mechanical engineering, electrical engineering, electronics, computer science, artificial intelligence, and control systems** to design and develop robots capable of performing various tasks autonomously or semi-autonomously.

# SENSORS

**A sensor is a device that detects, measures, or responds to a physical, chemical, or environmental condition and converts that information into a signal that can be interpreted by humans or electronic systems.**

*Examples: Camera, Proximity sensor, Force sensor  and Temperature sensor*



# ACTUATORS

An actuator is a device that converts an electrical, hydraulic, pneumatic, or mechanical signal into physical movement or action. It serves as the output component of a system, performing a specific task based on commands received from a controller or processing unit.

servo motor actuator

stepper motor actuator

torque motor

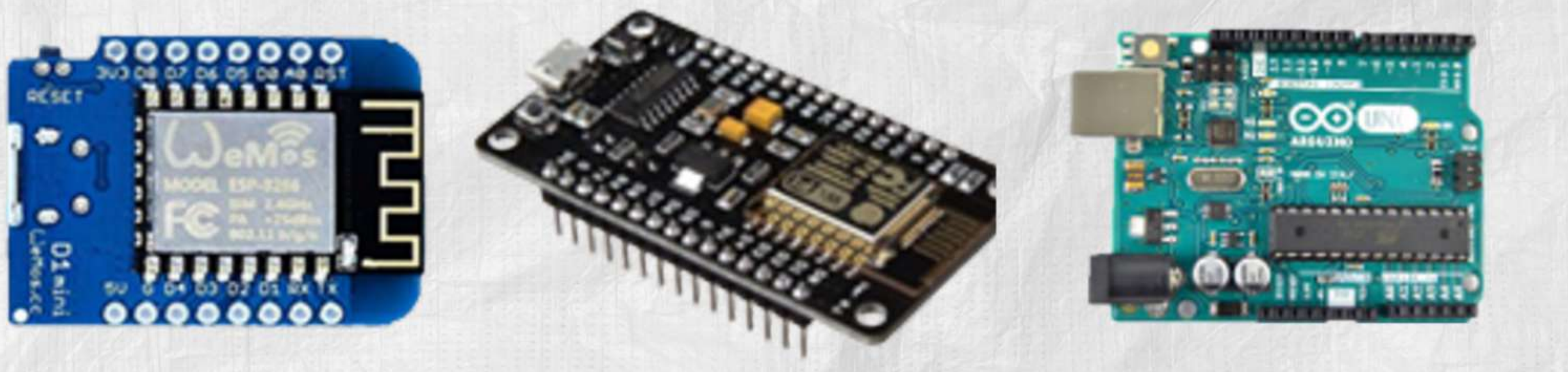
pneumatic rotary actuator

hydraulic rotary actuator

# CONTROLLER

**A controller is a device or system that receives input data from sensors, processes the information, and sends commands to actuators to perform specific actions. The controller serves as the brain of an automated system, making decisions based on sensor inputs and desired operating conditions.**

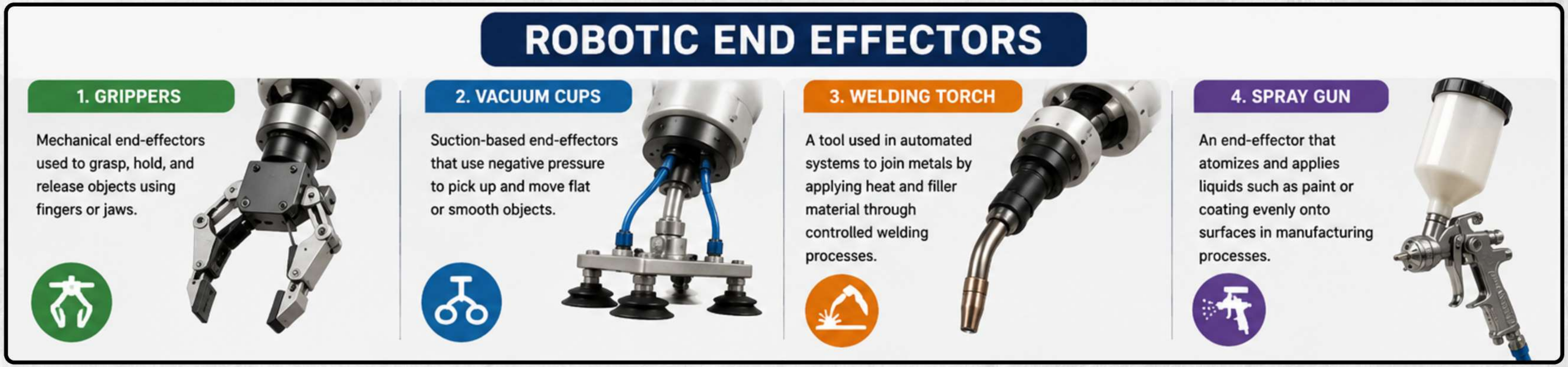

single board




microcontroller

# END EFFECTOR

***An end effector is the device attached to the end of a robotic arm that interacts directly with the environment to perform tasks such as gripping, cutting, welding, or assembling objects.***



# MANIPULATION AND DEXTERITY

# MANIPULATION

Manipulation refers to a **robot's ability to interact physically with objects in its environment.** This includes the processes of grasping, moving, positioning, orienting, assembling, and modifying objects using its mechanical structure and end-effector (such as grippers or tools).

**In robotics, manipulation is one of the core capabilities that allows robots to perform useful physical tasks in real-world applications. It involves coordination between sensors, actuators, and control systems to ensure accurate object handling.**

## COMMON EXAMPLES OF ROBOTIC MANIPULATION:

- Picking and placing objects from a conveyor belt
- Sorting packages in warehouses or logistics centers
- Assembling mechanical or electronic components
- Welding, cutting, or painting industrial parts
- Loading and unloading materials in manufacturing lines

## KEY REQUIREMENTS FOR EFFECTIVE MANIPULATION:

- Accurate object detection and localization
- Stable gripping or contact force control
- Path planning for movement
- Feedback control using sensors
- Appropriate end-effector selection

# DEXTERITY

Dexterity refers to a **robot's ability to perform precise, flexible, and highly coordinated movements,** similar to the skill and control of a human hand. It focuses not just on movement, but on fine motor control, adaptability, and precision in complex tasks.

**A robot with high dexterity can adjust its movements in real time and handle tasks that require sensitivity, accuracy, and multi-directional control.**

# CAPABILITIES OF HIGHLY DEXTEROUS ROBOTS:

- Handling fragile or delicate objects (e.g., glass, eggs, microchips)
- Assembling miniature or tightly spaced components
- Performing surgical operations in medical robotics
- Using tools such as screwdrivers, drills, or surgical instruments with precision
- Operating in confined or complex environments

# RELATIONSHIP BETWEEN MANIPULATION AND DEXTERITY

Manipulation and dexterity are closely related but not identical:

- Manipulation focuses on what the robot does (grasping, moving, assembling).
- Dexterity focuses on how skillfully it does it (precision, adaptability, smoothness).

A robot can perform manipulation tasks without high dexterity, but advanced applications (like surgery or micro-assembly) require both strong manipulation ability and high dexterity.

# FACTORS AFFECTING DEXTERITY

Several technical and mechanical factors determine how dexterous a robot is:

**a. Degrees of Freedom (DOF)**
- Refers to the number of independent movements a robot joint can perform
- Higher DOF allows more flexible and human-like motion

**b. Sensor Accuracy**
- High-quality sensors improve feedback on position, force, and environment
- Enables precise adjustments during tasks

## c. Control Algorithms

- Advanced algorithms (e.g., PID control, AI-based control, motion planning)
- Improve smoothness, stability, and precision of movements

## d. End-Effector Design

- The tool attached to the robot (gripper, suction cup, welding torch, etc.)
- Directly affects how well objects are handled

## e. Joint Flexibility and Mechanical Design

- Mechanical structure determines range of motion and adaptability
- Flexible joints improve maneuverability in complex environments

# IMPORTANCE IN ROBOTICS APPLICATIONS

Manipulation and dexterity are essential in modern robotics applications such as:

- Industrial automation and manufacturing
- Medical and surgical robotics
- Logistics and warehouse systems
- Space exploration and remote handling systems
- Service and assistive robotics

# LOCOMOTION AND NAVIGATION

# LOCOMOTION

**Locomotion is the ability of a robot or any living organism to move from one location to another. It involves the mechanisms and methods used to produce movement, allowing the robot to travel through its environment.**

# NAVIGATION

**Navigation is the process by which a robot determines its current position, understands its surroundings, plans a path, and moves safely toward a desired destination while avoiding obstacles.**


ILIFE

# JOINT PRIMITIVES

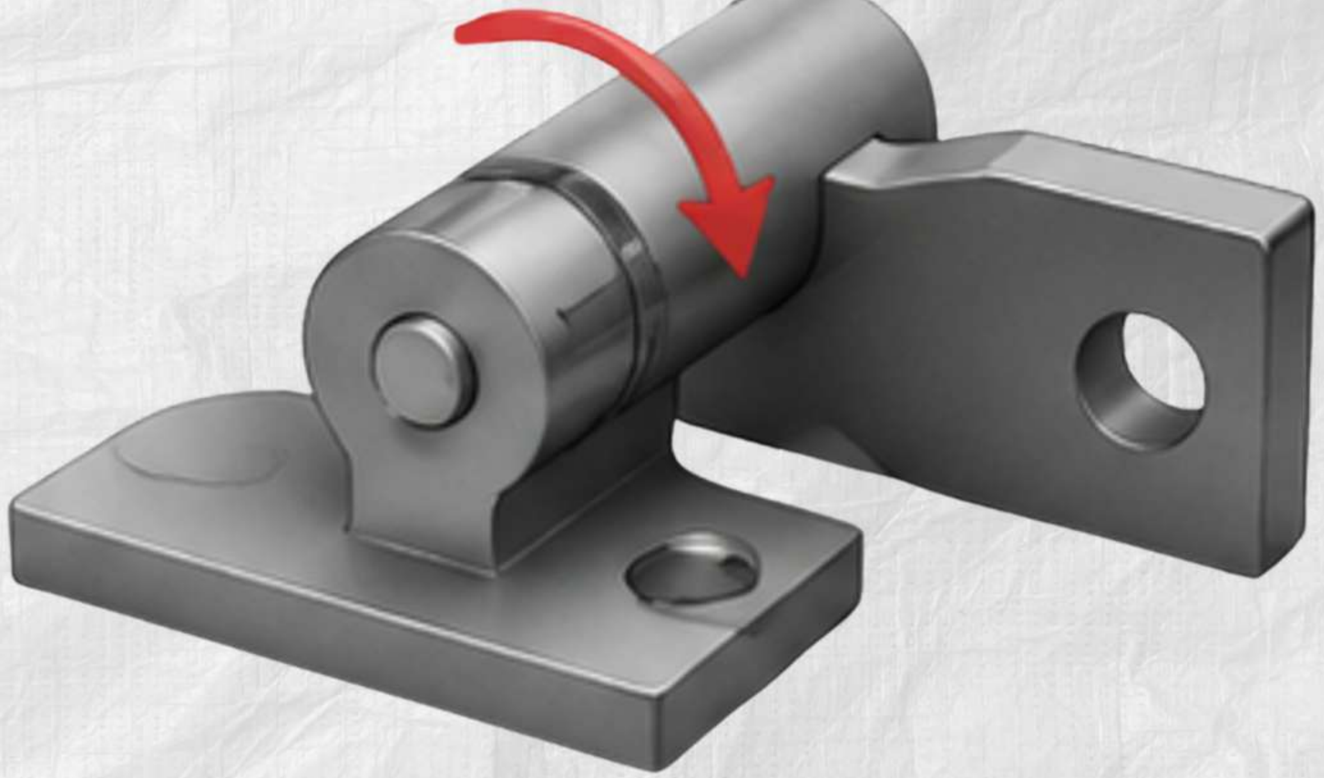
**Joint primitives are the *basic types of joints* that connect robot links and allow movement between them. They determine how one part of the robot moves relative to another.**

# COMMON TYPES OF JOINT PRIMITIVES

## 1. REVOLUTE JOINT (R)

**The revolute joint is a foundational connection type that permits only one specific movement: pure rotation.**

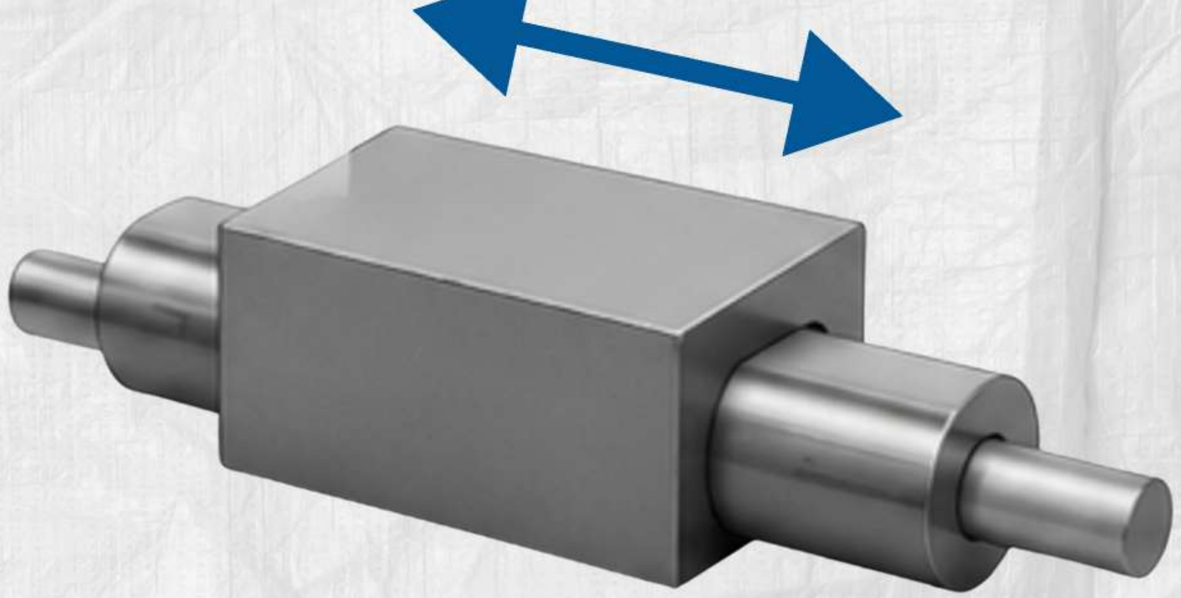
**The joint rotates in a circular motion, just like a hinge. It has one degree of freedom (1 DOF) because it can only rotate about one axis.**



# 2. PRISMATIC JOINT (P)

***A Prismatic Joint (P) is a joint that allows linear or sliding motion along a straight line without any rotation.***

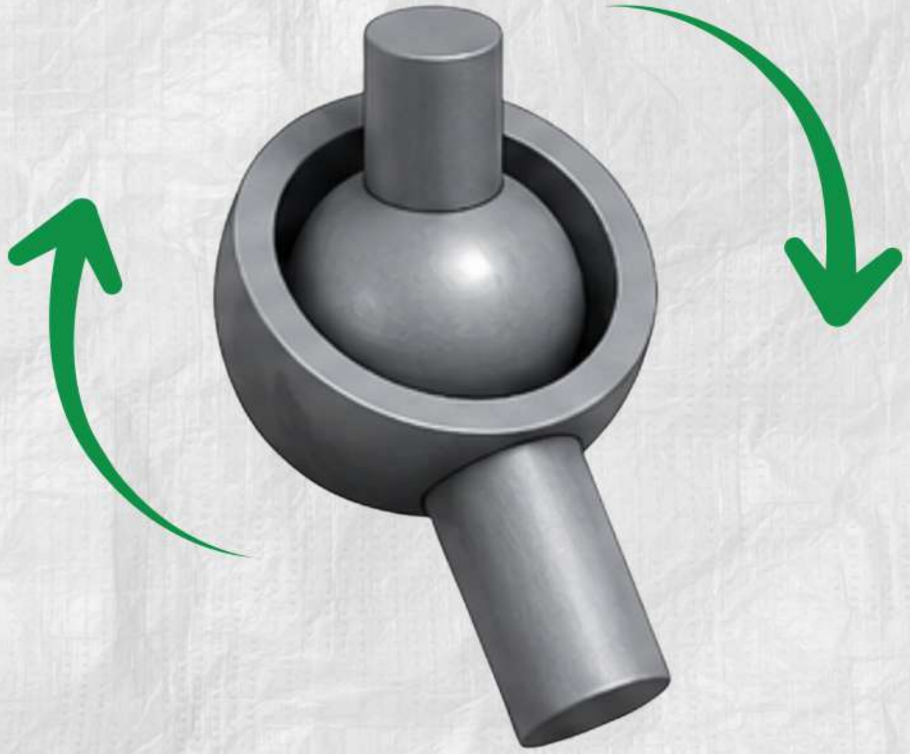
***The joint moves back and forth along one axis. Like the revolute joint, it has one degree of freedom (1 DOF), but its motion is translational instead of rotational.***



# 3. SPHERICAL JOINT

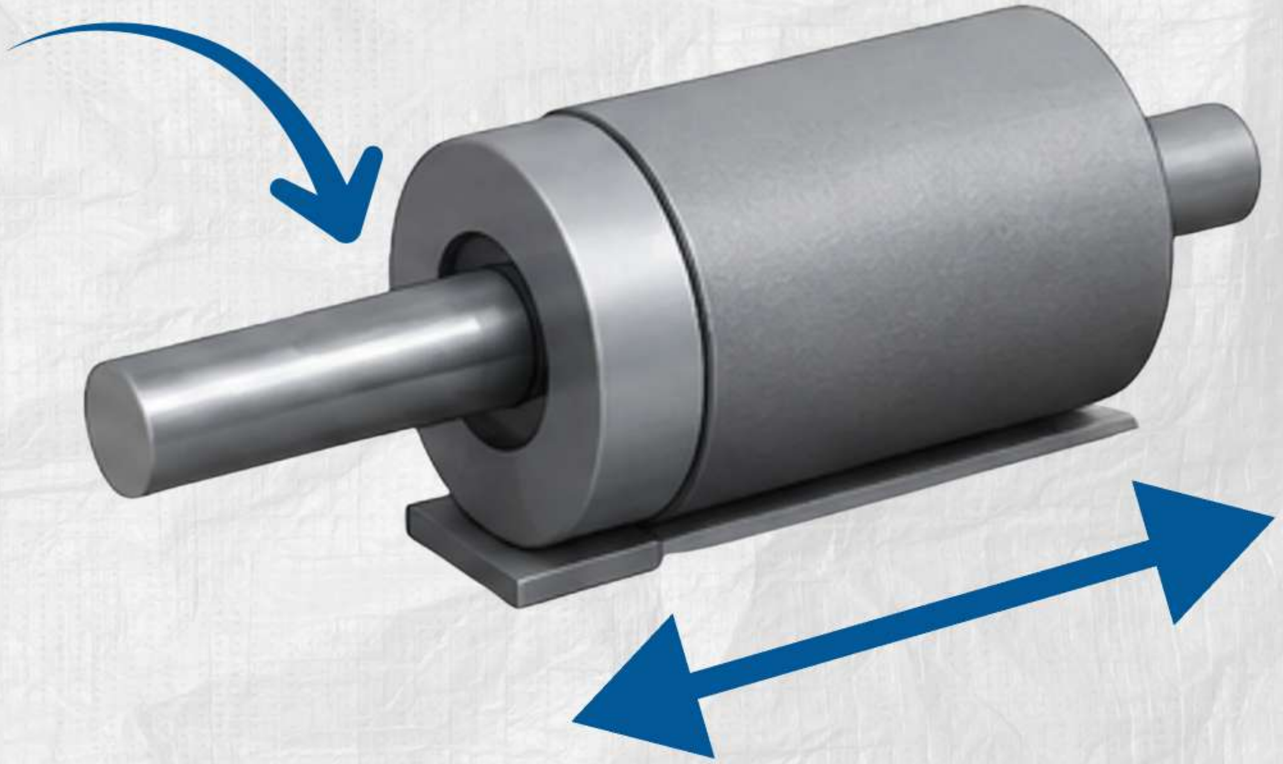
***A Spherical Joint, also called a ball-and-socket joint, allows rotation in multiple directions about a single point.***

***It can rotate around three perpendicular axes, giving it three degrees of freedom (3 DOF).This provides a very wide range of motion.***



# 4. CYLINDRICAL JOINT

A Cylindrical Joint **combines rotational motion** and **linear sliding motion** along the same axis.



It allows two types of movement:

- Rotation around an axis
- Sliding along that same axis

Because it performs two independent motions, it has **two degrees of freedom (2 DOF).**

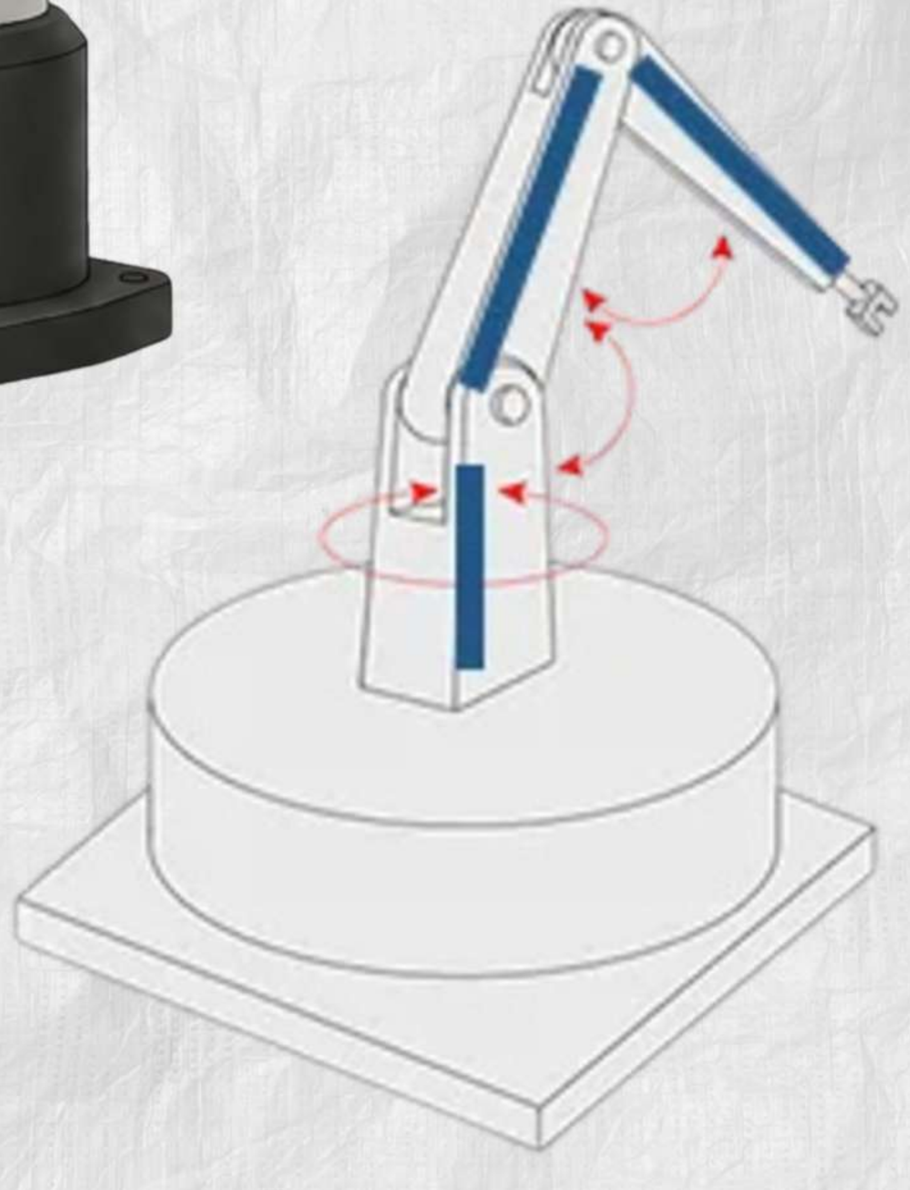
# SERIAL AND PARALLEL LINKAGES

**A linkage is a collection of rigid links connected by joints to produce motion.**

**Robotic manipulators are commonly classified as serial or parallel based on how their links are connected.**

# SERIAL LINKAGES

A serial linkage consists of links connected one after another in a chain, from the base to the end effector.

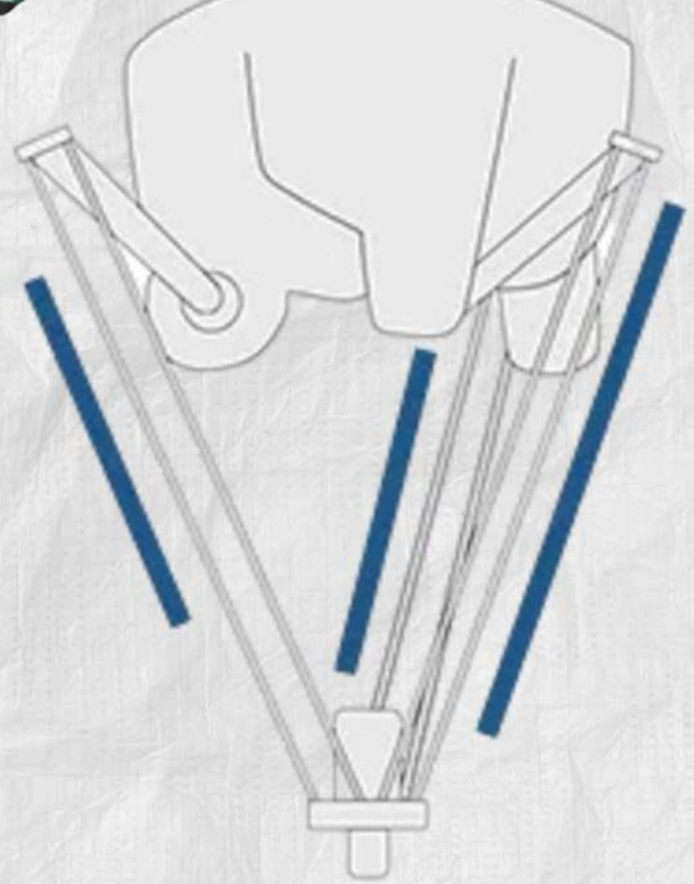


Characteristics:

- Simple design
- Large workspace
- High flexibility
- Errors can accumulate along the joints

# PARALLEL LINKAGES

A parallel linkage has **multiple arms connected simultaneously** between the base and the moving platform, supporting it together.



Characteristics:

- High stiffness
- High accuracy
- Can carry heavier loads
- Smaller workspace than serial robots

# END OF MODULE 1

(Manipulation and Locomotion)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