

## **Module : 4**

### **Introduction to Robotics:**

Robotics is a multidisciplinary field of science and technology that focuses on the design, construction, operation, and application of robots. Robots are autonomous or semi-autonomous machines that can perform tasks in the physical world, often replacing or assisting humans in tasks that are repetitive, dangerous, or require precision beyond human capabilities.

### **Key Components of Robotics:**

**Mechanical Design:** The physical structure of a robot, including its body, limbs, and joints, is crucial. The design must consider factors like mobility, stability, and the ability to interact with the environment.

**Sensors:** Robots use various sensors to gather information about their surroundings. These sensors can include cameras, ultrasonic sensors, LIDAR, and touch sensors, enabling the robot to perceive and navigate the world.

**Actuators:** Actuators are the components responsible for moving the robot's parts. They can be motors, pneumatic systems, or other mechanisms that translate electrical signals into mechanical actions.

**Control Systems:** The control system of a robot comprises hardware and software that manage its behavior. Algorithms and programming enable the robot to make decisions and carry out tasks.

**Power Supply:** Robots require a source of energy to operate. This can be in the form of batteries, electrical outlets, or other power sources, depending on the robot's design and purpose.

**Programming:** Writing code for a robot is a fundamental aspect of robotics. This code instructs the robot on how to react to sensor inputs and execute actions. Programming languages like C++, Python, and ROS (Robot Operating System) are commonly used.

### **Types of Robots:**

**Industrial Robots:** These robots are used in manufacturing and assembly lines to perform repetitive and precise tasks, such as welding, painting, or product assembly.

**Service Robots:** Service robots are designed to assist humans in various applications, including healthcare (surgical robots), household chores (vacuum cleaners), and even entertainment (robotic toys).

**Mobile Robots:** These robots are capable of moving around in their environment and are often used for tasks like exploration, surveillance, and logistics. Examples include drones and autonomous vehicles.

**Humanoid Robots:** Humanoid robots are designed to resemble humans in appearance and, to some extent, in behavior. They are used in research, entertainment, and even as companions for the elderly.

**Research Robots:** These robots are used by scientists and researchers to study robotics, artificial intelligence, and other fields. They often serve as platforms for experimenting with new technologies and algorithms.

### **Applications of Robotics:**

The applications of robotics are vast and continually expanding. Some notable examples include:  
**Manufacturing:** Robots automate production processes in industries like automotive, electronics, and aerospace, improving efficiency and precision.

**Healthcare:** Surgical robots assist in minimally invasive surgeries, while robotic exoskeletons aid rehabilitation and mobility for individuals with disabilities.

**Agriculture:** Agricultural robots perform tasks such as planting, harvesting, and monitoring crops, increasing farm productivity.

**Exploration:** Robots are used in space exploration (e.g., Mars rovers) and underwater exploration (e.g., remotely operated vehicles).

**Logistics and Warehousing:** Autonomous robots are employed in warehouses for tasks like picking and packing, optimizing supply chain operations.

**Military and Defense:** Drones and unmanned ground vehicles are used for reconnaissance, surveillance, and bomb disposal in military applications.

In conclusion, robotics is a dynamic and interdisciplinary field that combines mechanical engineering, electronics, computer science, and artificial intelligence to create machines that can perform a wide range of tasks autonomously or under human guidance. It continues to advance rapidly, with new applications and innovations emerging regularly.

## **Components of a Robot**

A robot is a complex machine composed of various components that work together to enable its functionality. The specific components of a robot may vary depending on its type and purpose, but here are some of the fundamental components commonly found in many robots:

**Mechanical Structure:** The physical framework of a robot, often consisting of rigid materials like metal or plastic. This structure provides the robot with its shape, stability, and the ability to interact with the environment. It includes components such as the robot's body, arms, legs, wheels, or any other physical parts that facilitate movement and manipulation.

**Actuators:** Actuators are responsible for converting energy into motion. They are the "muscles" of the robot and enable it to move its joints, limbs, or other parts. Common types of actuators include:

**Electric Motors:** Used for rotating joints and wheels.

**Pneumatic Actuators:** Utilize compressed air to create motion.

**Hydraulic Actuators:** Employ pressurized fluids (usually oil) to move.

**Solenoids:** Electromagnetic devices that create linear motion.

**Sensors:** Sensors are essential for a robot to perceive and interact with its environment. They collect data about external conditions and provide feedback to the robot's control system.

**Common types of sensors include:**

**Cameras:** Capture visual information for tasks like object recognition and navigation.

**Ultrasonic Sensors:** Measure distances by emitting sound waves.

**Infrared Sensors:** Detect heat or proximity to objects.

**LIDAR (Light Detection and Ranging):** Uses laser beams to create detailed 3D maps of the surroundings.

**Touch Sensors:** Detect physical contact with objects or surfaces.

**Control System:** The control system is the "brain" of the robot, responsible for processing sensory information and making decisions. It consists of both hardware (microcontrollers or

processors) and software (algorithms and code). The control system determines how the robot responds to its environment and executes tasks.

**Power Supply:** Robots need a source of energy to operate. This can be in the form of batteries, rechargeable cells, electrical outlets, or other power sources, depending on the robot's design and intended use.

**End-Effector:** The end-effector is the part of the robot that interacts directly with objects or the environment to perform specific tasks. Examples include grippers for picking up objects, welding tools for industrial robots, or surgical instruments for medical robots.

**Communication Interface:** Many robots are equipped with communication interfaces that allow them to interact with humans or other devices. This can include Wi-Fi, Bluetooth, or wired connections for remote control, data exchange, and programming.

**Feedback Mechanisms:** Feedback mechanisms provide information to the control system about the robot's own state and performance. This information can be used for error correction and ensuring the robot's movements and actions are accurate and safe.

**Safety Features:** Depending on the application, robots may include safety features such as emergency stop buttons, collision detection sensors, and fail-safe mechanisms to prevent accidents and protect human operators.

**Chassis or Base:** This component provides the foundation for the robot's mobility. It may include wheels, tracks, or legs, depending on the type of locomotion required.

**Navigation and Localization Systems:** Some robots, particularly those used in autonomous navigation, may include GPS systems, inertial measurement units (IMUs), and odometry sensors to determine their position and navigate their environment accurately.

These components work in harmony to enable a robot to perform its designated tasks, whether it's in manufacturing, healthcare, exploration, or any other field where robotics is applied. The specific combination and configuration of these components depend on the robot's intended function and design.

## **Classification of Robots**

Robots can be classified into various categories based on different criteria such as their application, mobility, control, and physical attributes. Here are some common classifications of robots:

### **Based on Application:**

**Industrial Robots:** These robots are primarily used in manufacturing and assembly lines for tasks such as welding, painting, and material handling.

**Service Robots:** Designed to assist or entertain humans, these robots can be further divided into:

**Medical Robots:** Used in surgeries, diagnostics, and patient care.

**Domestic Robots:** Perform household chores like vacuuming, mowing the lawn, or cleaning.

**Entertainment Robots:** Include robotic toys and companion robots.

**Agricultural Robots:** Used in farming and agriculture for tasks like planting, harvesting, and monitoring crops.

**Space and Exploration Robots:** Deployed for space missions and planetary exploration, like Mars rovers.

**Military and Defense Robots:** Used for reconnaissance, surveillance, bomb disposal, and battlefield operations.

**Search and Rescue Robots:** Designed to locate and rescue people in disaster-stricken areas.

**Educational and Research Robots:** Used in research, experimentation, and educational purposes to study robotics and artificial intelligence.

### **Based on Mobility:**

**Stationary Robots:** Fixed in one place and perform tasks within a defined workspace.

**Mobile Robots:** Have the ability to move around and operate in various environments. These can be further categorized as:

**Wheeled Robots:** Use wheels for mobility, suitable for indoor environments.

**Legged Robots:** Have legs for navigation and are often used in rough terrains.

**Aerial Robots:** Include drones and flying robots.

**Underwater Robots:** Designed for operations in aquatic environments, such as remotely operated vehicles (ROVs).

### **Based on Control:**

**Autonomous Robots:** Capable of operating independently with little to no human intervention. They rely on sensors and onboard intelligence to make decisions.

**Teleoperated Robots:** Controlled remotely by a human operator who provides real-time guidance and input.

**Semi-Autonomous Robots:** Operate autonomously to some extent but may require occasional human intervention or supervision.

### **Based on Physical Attributes:**

**Humanoid Robots:** Designed to resemble humans in form and sometimes in behavior, with a head, torso, arms, and legs.

**Non-Humanoid Robots:** Have shapes and structures that do not resemble humans. These can include manipulator arms, robotic vehicles, and more.

### **Based on Complexity:**

**Simple Robots:** Execute basic, predefined tasks with limited functionality and capabilities.

**Complex Robots:** Equipped with advanced sensors, AI, and capabilities for more intricate tasks and adaptability.

### **Based on Number of Axes:**

**3-Axis Robots:** Operate in three dimensions and are often used for tasks requiring simple movements.

**6-Axis Robots:** Provide greater flexibility and precision in their movements and are commonly used in industrial applications like welding and painting.

### **Based on Use of Artificial Intelligence (AI):**

**AI-Powered Robots:** Employ machine learning and AI algorithms to make decisions, adapt to changing environments, and learn from experience.

These classifications are not mutually exclusive, and a single robot can belong to multiple categories depending on its characteristics and intended use. The field of robotics continues to

evolve, with new types and classifications of robots emerging as technology advances and applications expand.

### **Industrial Robot Applications**

Industrial robots are versatile machines used in various applications across manufacturing and automation industries. They are designed to perform tasks with precision, speed, and reliability, making them valuable tools for improving productivity and efficiency. Here are some common industrial robot applications:

#### **Material Handling and Pick-and-Place Operations:**

- Loading and unloading materials from conveyors, trucks, or pallets.
- Sorting, stacking, and palletizing products in warehouses and factories.

#### **Assembly and Disassembly:**

- Assembling complex products like automobiles, electronics, and appliances.
- Disassembling products for recycling or refurbishment.

#### **Welding and Joining:**

- Arc welding, spot welding, and laser welding of metal components.
- Brazing and soldering in electronics and plumbing industries.

#### **Painting and Coating:**

- Applying paint, coatings, and sealants to products and surfaces.
- Ensuring consistent and uniform coverage for quality finishes.

#### **Machine Tending:**

- Loading and unloading parts into CNC machines, injection molding machines, and 3D printers.
- Monitoring and maintaining the production process.

#### **Quality Inspection:**

- Using vision systems and sensors to inspect products for defects.
- Rejecting or diverting defective items from the production line.

#### **Packaging and Palletizing:**

- Packaging products into boxes, bags, or containers.
- Building pallets with neatly arranged products for shipping.

#### **Material Removal and Finishing:**

- Cutting, grinding, milling, and polishing of materials.
- Deburring, sanding, and shaping parts for precision and aesthetics.

#### **Testing and Measurement:**

- Conducting tests on products, such as pressure testing, leak testing, or electrical testing.
- Measuring dimensions and tolerances to ensure product accuracy.

#### **Food Processing:**

- Handling, cutting, and packaging food products.
- Sorting and inspecting fruits, vegetables, and meat products.

#### **Pharmaceutical and Chemical Industry:**

- Handling and dispensing chemicals and pharmaceutical ingredients.
- Filling and capping bottles and vials.

#### **Electronics Manufacturing:**

- Placing components on circuit boards.

- Conducting soldering and reflow soldering processes.

#### Agriculture:

- Planting, harvesting, and sorting crops.
- Managing tasks like fruit picking and vineyard maintenance.

#### Medical Applications:

- Assisting in surgeries with precise movements.
- Handling and sorting medical instruments and supplies.

#### Aerospace Industry:

- Machining, drilling, and riveting aircraft components.
- Inspecting and maintaining aircraft structures.

#### Construction and Demolition:

- Bricklaying and concrete pouring.
- Demolishing structures with controlled precision.

#### Defense and Military:

- Bomb disposal and hazardous material handling.
- Surveillance and reconnaissance.

#### Entertainment Industry:

- Special effects in movies and theme park attractions.
- Animatronics for shows and events.

#### Logistics and Warehousing:

- Automated guided vehicles (AGVs) and mobile robots for material transport.
- Inventory management and order fulfillment.

#### Energy and Utilities:

- Inspecting and maintaining power lines and equipment.
- Handling radioactive materials in nuclear facilities.

These are just some of the many applications of industrial robots. As technology continues to advance, robots are becoming even more versatile and capable, leading to the exploration of new and innovative uses in various industries.

## **Robot Accuracy and Repeatability**

Robot accuracy and repeatability are two critical performance metrics used to evaluate the precision and reliability of industrial robots. These metrics are essential because they directly impact the robot's ability to perform tasks with consistency and reliability. Here's an explanation of each concept:

### **Accuracy:**

- Accuracy refers to how closely a robot can achieve its intended target or position in a single attempt. It measures the robot's ability to reach a specific point or perform a task with minimal deviation from the desired position or trajectory.



- Accurate robots are essential for tasks where precision is crucial, such as microelectronics assembly, medical surgery, and quality inspection.
- Accuracy can be affected by factors such as mechanical wear and tear, calibration errors, and environmental conditions (e.g., temperature, humidity, and vibration).

#### **Repeatability:**

- Repeatability measures the robot's ability to return to the same position or follow the same path consistently when the same task is performed repeatedly.
- It quantifies the robot's reliability and consistency in performing tasks over time, regardless of external factors or variations.
- Repeatability is particularly important in manufacturing processes, where the same operation needs to be performed on numerous identical parts or products.
- Factors affecting repeatability include backlash in the robot's joints, control system precision, and the quality of sensors and feedback devices.

To assess and specify accuracy and repeatability, manufacturers and users typically use the following methods and standards:

#### **Testing and Measurement:**

- Robot accuracy and repeatability are often evaluated through careful testing and measurement using precision equipment, such as laser trackers or coordinate measuring machines (CMMs).
- During testing, the robot is instructed to move to specific positions, and the actual positions are compared to the desired ones. The discrepancies are used to determine accuracy and repeatability.

#### **ISO Standards:**

- The International Organization for Standardization (ISO) has established standards for defining and measuring robot performance, including accuracy and repeatability. ISO 9283, for instance, provides guidelines for evaluating the performance of industrial robots.

#### **Calibration:**

- Regular calibration of robots is essential to maintain and improve their accuracy and repeatability. During calibration, errors in the robot's kinematic model and sensor measurements are identified and corrected.

#### **Feedback Systems:**

- Many industrial robots use feedback devices like encoders and resolvers to continuously monitor joint positions and correct for errors in real-time, enhancing both accuracy and repeatability.

#### **Maintenance and Preventive Measures:**

- Proper maintenance and preventive measures, such as lubrication, alignment checks, and component replacement, can help ensure that a robot maintains its specified performance over time.

In summary, accuracy and repeatability are crucial attributes for industrial robots in various applications. They determine the robot's ability to perform tasks precisely and consistently, impacting product quality, process efficiency, and overall operational success. Regular testing, calibration, and maintenance are essential to achieving and maintaining the desired levels of accuracy and repeatability in industrial robot systems.

### **Different Types of Robotics**

Robotics is a multidisciplinary field that encompasses various types of robots designed for specific applications and tasks. Here are different types of robotics based on their functionality and application areas:

#### **Industrial Robotics:**

- Industrial robots are used in manufacturing and production settings for tasks like welding, assembly, painting, and material handling. They are designed for precision, speed, and reliability in factory environments.

#### **Medical Robotics:**

- Medical robots are employed in healthcare settings for procedures such as surgery, rehabilitation, and diagnostics. They enhance surgical precision, enable minimally invasive surgery, and assist in tasks like drug dispensing.

#### **Agricultural Robotics:**

- Agricultural robots, often called agribots, are used in farming and agriculture. They perform tasks such as planting, harvesting, weeding, and monitoring crop conditions. Drones are also used for aerial monitoring.

#### **Service Robotics:**

- Service robots are designed to assist humans in various non-industrial settings. They include robots used in home automation, eldercare, hospitality, and customer service, like robot vacuums, delivery robots, and social robots.

#### **Autonomous Vehicles:**

- Autonomous vehicles, including self-driving cars and autonomous drones, are equipped with sensors and AI algorithms to navigate and make decisions without human intervention. They have applications in transportation, logistics, and surveillance.

#### **Space Robotics:**

- Space robots are used in space exploration and operations. They include robotic arms on spacecraft, rovers like NASA's Mars rovers, and robotic missions to repair or maintain satellites.

#### **Military and Defense Robotics:**

- Military robots are used for reconnaissance, bomb disposal, surveillance, and combat. Unmanned aerial vehicles (UAVs), unmanned ground vehicles (UGVs), and remotely operated vehicles (ROVs) are examples.

#### **Search and Rescue Robots:**

- Search and rescue robots are designed to assist first responders in locating and helping people in disaster-stricken or hazardous environments. They often have features like cameras, sensors, and mobility in rough terrain.

#### **Educational and Research Robotics:**

- Educational and research robots are used in academic and research institutions to teach robotics principles, conduct experiments, and explore new robotics technologies.

#### **Entertainment Robotics:**

- Entertainment robots are designed for amusement and entertainment purposes. Examples include robotic toys, animatronic characters in theme parks, and robots used in interactive exhibits.

#### **Underwater Robotics:**

- Underwater robots, or remotely operated vehicles (ROVs), are used for deep-sea exploration, underwater research, and tasks like underwater welding and maintenance of offshore structures.

#### **Aerial Robotics:**

- Aerial robots, such as drones or unmanned aerial vehicles (UAVs), are used for a wide range of applications, including aerial photography, surveillance, agriculture, and environmental monitoring.

#### **Consumer Robotics:**

- Consumer robotics encompasses robots designed for personal use in homes. This category includes robot vacuum cleaners, personal assistant robots, and smart home devices.

#### **Construction Robotics:**

- Construction robots assist in building tasks like bricklaying, concrete pouring, and 3D printing of structures. They improve efficiency and safety in the construction industry.

#### **Robotic Exoskeletons:**

- Robotic exoskeletons are wearable devices that enhance human capabilities, providing assistance to people with mobility impairments or augmenting the strength and endurance of workers in physically demanding jobs.

These are just some of the many types of robotics that exist, each tailored to specific applications and industries. As technology advances, robotics continues to expand into new areas, leading to innovative robotic solutions for a wide range of tasks and challenges.

### **Various Generations of Robots.**

Robots have evolved over the years, and their development can be categorized into several generations. Each generation represents significant advancements in robotics technology, capabilities, and application areas. Here are the various generations of robots:

#### **First Generation (1940s-1950s):**

- The first-generation of robots were primarily industrial robots used in manufacturing.

- They were large, stationary machines often used for tasks like welding, painting, and material handling.
- They had limited mobility and were usually hardwired for specific tasks.

#### **Second Generation (1960s-1970s):**

- Second-generation robots saw improvements in control systems and sensors.
- They could be programmed with more flexibility, allowing them to perform a range of tasks.
- These robots were still mainly used in industrial settings but were more adaptable.

#### **Third Generation (1980s-1990s):**

- The third generation brought about advancements in robot programming and control, including the use of microprocessors.
- They became more versatile, capable of handling complex tasks and interacting with their environment.
- Robots in this generation began to find applications outside of manufacturing, such as in healthcare and research.

#### **Fourth Generation (2000s-2010s):**

- The fourth generation of robots marked the rise of autonomous robots with advanced sensors and artificial intelligence.
- These robots could perceive and adapt to their surroundings, making them suitable for tasks like exploration, search and rescue, and autonomous vehicles.
- Human-robot collaboration also became a focus, with robots working alongside humans in various industries.

#### **Fifth Generation (2010s-Present):**

- Fifth-generation robots are characterized by significant advancements in machine learning, deep learning, and natural language processing.
- They can understand and respond to human commands and interact with humans more naturally.
- These robots are used in applications like virtual assistants, autonomous vehicles, and advanced healthcare.

#### **Future Generations (Anticipated):**

- The future of robotics is expected to bring about even more advanced generations of robots.
- This may include robots with enhanced cognitive abilities, emotional intelligence, and a deeper understanding of their environments.
- Applications could expand into fields such as personal robotics, space exploration, and environmental monitoring.

It's important to note that the evolution of robots is ongoing, and the boundaries between generations can sometimes blur, as some robots incorporate features and technologies from multiple generations. Additionally, the development of robots is influenced by advancements in various fields, including artificial intelligence, materials science, and electronics, which continue to push the boundaries of what robots can do and where they can be applied.

## Robot Control Systems

Robot control systems are the software and hardware components that manage the operation of robots. These systems are responsible for controlling the movement, behavior, and interaction of robots with their environment. There are various types of robot control systems, depending on the complexity of the robot and its intended applications. Here are some common types of robot control systems:

### **Open-Loop Control:**

- In open-loop control, the robot performs a sequence of predefined actions without feedback from its sensors.
- These systems are simple and are often used in applications where precise control is not critical, such as basic material handling.

### **Closed-Loop Control:**

- Closed-loop control systems use feedback from sensors to continuously adjust the robot's actions, making them more precise and adaptive.
- Proportional-Integral-Derivative (PID) controllers are commonly used in closed-loop control to regulate parameters like position, velocity, and torque.

### **Motion Control Systems:**

- Motion control systems are responsible for managing the robot's movement, including joint angles, trajectory planning, and speed control.
- These systems ensure that the robot follows a specified path accurately and smoothly.

### **Path Planning and Trajectory Generation:**

- Path planning algorithms calculate the optimal path for the robot to reach its target, taking into account obstacles and constraints.
- Trajectory generation systems generate smooth trajectories that the robot can follow to execute complex movements.

### **Robot Operating Systems (ROS):**

- ROS is a popular open-source middleware framework that provides a comprehensive set of tools and libraries for developing and controlling robots.
- It includes features for hardware abstraction, communication between robot components, and sensor integration.

### **Sensor Integration:**

- Robots use various sensors, such as cameras, LiDAR, encoders, and force/torque sensors, to perceive their environment.
- Sensor integration systems process data from these sensors to provide valuable information for robot control.

### **Behavior-Based Control:**

- Behavior-based control systems enable robots to exhibit complex behaviors by combining multiple simple behaviors.
- These systems use rule-based logic to switch between behaviors based on sensory input and predefined rules.

**Inverse Kinematics and Dynamics:**

- Inverse kinematics algorithms calculate joint angles or positions needed to achieve a desired end-effector position.
- Inverse dynamics algorithms calculate the joint torques or forces required to follow a specified trajectory.

**Machine Learning and AI-Based Control:**

- Machine learning and AI techniques, such as reinforcement learning and neural networks, are used to enable robots to learn and adapt to their environment.
- They can be used for tasks like grasping objects, recognizing patterns, and making decisions.

**Human-Robot Interaction (HRI):**

- HRI control systems enable robots to interact with humans safely and effectively.
- These systems include features like natural language processing, gesture recognition, and emotion detection.

**Safety Systems:**

- Safety control systems ensure that robots operate safely by monitoring for unexpected events and stopping or adjusting the robot's actions if necessary.
- This includes features like collision detection and emergency stop mechanisms.

**Real-Time Control:**

- Real-time control systems are essential for applications that require low-latency responses, such as robotic surgery or autonomous vehicles.
- They ensure that the robot can react to changing conditions quickly and accurately.

The choice of control system depends on the specific robot's application, complexity, and requirements. Advanced robots often incorporate a combination of these control systems to perform complex tasks with precision and adaptability.