Robotics

Unit I

Need and importance of Robotics

Robots – is the study, design and construction of a machine capable of executing many activities more efficiently and quickly than people.
Computer, mechanical, electrical and electronic engineering are all used in robotics.

- Robotics includes designing, developing and programming a physical robot capable of performing various complex and time-consuming tasks.

~~Robotics and its Applications~~

★ ~~Factors~~ Productivity

Reasons why robotics is important –

① **Automation** — Robots can perform repetitive tasks quickly and accurately without getting tired or making mistakes. This can increase productivity and efficiency, reduce costs, and improve the quality of products and services.

② **Safety** – Robots can be used to perform dangerous tasks, such as working in hazardous environments like nuclear power plants or performing rescue operations in disaster zones. This reduces the risk of injury or death for humans.

③ **Precision** – Robots can perform tasks with precision that is impossible for humans such as microsurgery or assembling tiny components in electronics.

④ **Accessibility** – Robots can perform tasks that are physically impossible for humans, such as exploring space or deep sea exploration.

⑤ **Innovation** – Robotics is an exciting field that drives innovation and advances in technology.

→ It has the potential to revolutionize many industries and create new ones.

6. Flexibility - Robots can be programmed to perform a wide range of tasks, making them adaptable to different environments and industries.

7. Cost Savings - Robotic automation can help reduce labor costs and increase efficiency, resulting in cost savings for businesses.

8. Improved quality - ↑ degree of accuracy & consistency

9. Enhanced Speed - quicker completion of tasks

10. Learning & Innovation - encourages creativity & innovation

11. Collaborative Robots - designed to work alongside humans in a safe and productive manner. This allows for the combination of human intelligence with robotic precision & efficiency.

12. Healthcare & Assistance - surgery, physical therapy & assistive care for the elderly & disabled.

13. Space Exploration - to explore & collect data in space, where human presence is not safe/feasible.

14. Environmental Protection - cleaning up pollution and monitoring widlife populations.

Basic Concepts

Robot - A robot is a mechanical or virtual device that is designed to perform tasks autonomously or semi-autonomously. It can be programmed to interact with the physical world and make decisions based on sensory input.

Sensors - Sensors are devices that provide robots with info about their environment. Common types of sensors used in robotics include cameras, and touch sensors.

These sensors allow robots to perceive object, detect obstacles, and gather data for decision-making.

Actuators – devices that enable robots to physically interact with the world. They convert electrical signals into mechanical motion. (Ex – motors, servos, pneumatic and hydraulic actuators) They are responsible for controlling the movement of robot joints and links.

Control Systems – they are the software and hardware components that regulate and coordinate the behaviour of robots. They receive input from sensors, process it, and generate commands for the actuators. Control systems can range from simple on-off control to more complex feedback control loops.

Kinematics – it is the study of motion in robotics. It involves describing the position, velocity and acceleration of robot parts, such as joints and end effectors, without considering the forces that cause the motion. It plays a crucial role in robot path planning and trajectory generation.

Dynamics – It deals with the forces and torques that affect robot motion. It considers how the motion of a robot is influenced by external forces, gravity and internal forces exerted by actuators. Understanding robot dynamics is imp for stability analysis, torque control and collision avoidance.

Robot Programming – involves writing instructions that define the behaviour of a robot. It can range from low-level programming, such as controlling individual motors, to high-level prog., such as task planning and decision-making algos.

Programming langs used in robotics include C++, Python, MATLAB and ROS (Robot Operating System).

Localizn & Mapping – Localization is the process of determining a robot's position and orientation in its env. Mapping involves building a repn of the robot's env. These concepts are essential for robot navigation and autonomous exploration.

Path Planning – refers to the process of finding a collision-free path for a robot to move from one locn to another. It takes into account the robot's kinematics, obstacles in the env, and any constraints on the motion.

Path planning algos helps robots navigate efficiently and avoid collisions.

Human-Robot Interaction - focuses on enabling robots to interact with humans in a safe and intuitive manner. It includes areas such as NLP, gesture recognition and social robotics. The goal is to make robots more user-friendly and capable of understanding and responding to human commands & behaviours.

Manipulator - allow robot to interact physically with objects. It typically consist of joints and links, forming a robotic arm. Manipulators are used for tasks like picking up objects, moving them and performing precise actions.

End Effector - it is the tool or device attached to the end of a robot's manipulator. It enables the robot to perform specific tasks, such as gripping objects, welding, cutting or spraying.
Ex - grippers, welding torches, and vacuum suction cups.

Grippers - are end-effectors designed to grasp and manipulate objects. They come in various forms such as mechanical claws, suction cups or electromagnets, depending on appⁿ requirements.

Trajectory Planning - involves determining a smooth and feasible path for the robots end-effector to follow. It takes into account factors like joint limits, obstacle avoidance and velocity constraints to generate a motion plan.

Types of Robots

① Industrial Robots - used in industrial settings for tasks such as assembly, welding, painting and material handling. They are typically large, powerful and capable of precise and repetitive movements.

② Service Robots - designed to interact with and assist humans in various settings. They can be found in industries such as healthcare, hospitality, retail and agri.
Ex - cleaning robots, personal assistant robots, and delivery robots.

③ <u>Mobile Robots</u> - capable of moving around and navigating their env. They can be wheeled, legged or aerial robots.
Ex - autonomous vehicles, drones and exploration robots used in space or underwater.

④ <u>Collaborative Robots (Cobots)</u> - designed to work alongside humans in a collaborative manner. They are equipped with safety features and are programmed to interact and assist humans in tasks such as assembly, packaging or inspection.

⑤ <u>Humanoid Robot</u> - designed to resemble humans in appearance and behaviour. They often have a human-like body structure with legs, arms and a head. Humanoid robots are developed for research, entertainment and social interaction purposes.

⑥ <u>Medical Robots</u> - used in healthcare settings to assist in surgical procedures, rehabilitation, diagnostics, and patient care.
Ex - surgical robots, exoskeletons and robot-assisted prosthetics.

⑦ <u>Autonomous Robots</u> - capable of operating independently, making decisions, and performing tasks without constant human intervention. They often incorporate technologies such as AI, ML and computer vision.

⑧ <u>Educational Robots</u> - designed to teach and introduce robotics concepts to students of all ages. They are typically user-friendly and offer hands-on learning experiences to develop programming, problem-solving and engineering skills.

⑨ <u>Entertainment Robots</u> - created for recreation purposes. They can be found in theme parks, interactive exhibits, and consumer products like robotic toys and companions.

⑩ <u>Military & Defence Robots</u> - used for tasks such as reconnaissance, bomb disposal, and surveillance in military operations. They can be ground-based, aerial ~~and~~ or underwater robots.

Classification of Industrial Robots

→ they can be classified into different categories based on their structure, config and appⁿ.

Based on Mechanical Structure

① **Cartesian Robot** – Also known as rectilinear or gantry robots.
↳ have 3 linear axes (X, Y, Z) that are ⊥ to each other. They move along straight lines are suitable for appⁿs requiring precise and linear movements, such as pick-and-place operations and assembly tasks.

② **SCARA Robots** – Selective Compliance Articulate Robot Arm
↳ have 2 ∥ rotary joints and one linear joint, providing a combⁿ of rotational and vertical movements.
→ used in assembly, material handling & packaging.

③ **Articulated Robots** – have a similar structure to a human arm with multiple rotary joints. They offer high flexibility and can perform complex movements and tasks.
→ used in welding, painting, material handling & assembly appⁿs.

④ **Delta Robots** – also known as parallel robots, have a unique design consisting of multiple arms connected to a common base. They excel in high-speed and precise movements, making them suitable for appⁿs like packaging, sorting and food processing.

⑤ **Cylindrical Robots** – have a cylindrical workspace and use a combⁿ of linear and rotary movements. They are often used for tasks that require vertical assembly or handling operations.

⑥ **Polar Robots** – use a combⁿ of rotary & linear movements to operate in a spherical workspace. They are suitable for tasks that require access to objects from different angles, such as assembly & machining.

Based on Appⁿ

① **Material Handling Robots** – used for tasks such as picking, placing, sorting & moving objects within a manufacturing env.

② Welding Robots - specifically designed for automated welding processes, including arc welding, spot welding and laser welding.

③ Painting Robots - used for automated painting app^ns, providing consistent & precise coating on various surfaces.

④ Assembly Robots - employed for automated assembly of products, including fastening components, inserting parts, and performing intricate assembly operations.

⑤ Packaging Robots - handle packaging tasks such as picking, placing, stacking & sealing products in industries like food & beverage, pharmaceuticals & consumer goods.

⑥ Inspection & Testing Robots - equipped with sensors and vision systems to perform quality control inspections, measurements & testing on products.

Based on Mobility

① Stationary Robots - fixed in place & operate within a specific workspace.
→ used in assembly, welding, material handling

② Mobile Robots - equipped with wheels, tracks/legs that allow them to move autonomously within a manufacturing facility.
→ used for material transp^n, navigation in complex spaces.

Based on Payload capacity

① Small Payload Robots - lower payload capacity (few kgs to ~ 10 kgs)
↳ for light-duty app^ns (material handling, assembly)

② Medium Payload Robots - higher loads (10 kgs - few 100 kgs)
↳ for app^ns that req. more strength and stability (welding)

③ Heavy Payload Robots - high payload capacity (few 100 kg - several tons)
↳ used for lifting heavy objects, large-scale material handling, heavy duty manufacturing operations.

Structure of Industrial Robots

Industrial robots typically consist of several key elements -

① Manipulator - it is the main body of the robot, also referred as the robot arm.

→ responsible for the robot's movements & consists of a series of connected links and joints.

→ ~~...~~ can vary in structure, such as being Cartesian, articulated, SCARA, or other configurations, depending on the desired range of motion and app^n requirements.

② Joints - movable connections betn links of robot arm.

- allow robot of achieve different configurations and perform various movements.

→ can be revolute (rotational), prismatic (linear), or $comb^n$ of both.

→ no. & types of joints determine the Degrees of freedom of robot.

③ End-Effector - also known as robot's tool or hand.

↳ component attached to the end of the robot arm.

→ interacts with workpiece or env to perform specific tasks.

→ can take various forms depending on app^n such as grippers, welding torches, suction cups or specialized tools.

④ Actuators — devices responsible for powering and controlling the movements of the robot.

→ convert electrical, hydraulic, or ~~pn~~ pneumatic energy into ~~...~~ mechanical motion.

→ Ex → Electric motors, hydraulic cylinders, pneumatic actuators used as actuators.

⑤ Sensors - provide robot with ability to perceive and interact with its env.

→ include position encoders, force/torque sensors, proximity sensors, vision systems & tactile sensors.

→ enable robot to gather feedback, detect objects, monitor forces and ensure accurate positioning.

⑥ Control System - consists of hardware and software components that govern the robot's operation.
→ includes robot controller, which receives commands and generates control signals to actuate the robot's actuators.
→ may also incorporate algos for motion planning, trajectory control, and sensor integration.

⑦ Power Supply - Industrial robots req power supply to operate their actuators, control system and auxiliary components.
→ include electrical power for electric motors or pneumatic/hydraulic power sources for systems that use fluid-based actuators.

⑧ Safety Features - to ensure the protecⁿ of human operators and prevent accidents.
→ can include emergency stop buttons, safety interlocks, protective barriers and motion monitoring systems.

Terminologies of Robot Motion

① Joint ~~coordinate~~
② Axis - line/direction around which a joint can rotate or translate
→ each joint corresponds to one axis of motion.
→ Ex - robot with 3 rotational joints would have 3 rotational axes.

③ Pose - position & orientation of a robot's end-effector or tool in 3-D space.
→ represented by Cartesian coordinates (x, y, z) & orientation represented by Euler angles / quaternions.

④ Forward Kinematics - process of determining the position & orientⁿ of the end-effector based on joint angles or displacements of robot.
→ calculates how robot's joints move to achieve a specific end-effector pose.

⑤ Inverse Kinematics - involves computing joint angles/displacements req to achieve a desired end-effector position and orientⁿ.
→ used to control robot's motion by specifying where the end-effector should be, and robot calculates the appropriate joint values.

⑥ Trajectory - path followed by robot's end-effector over time
→ defines sequence of poses that robots needs to go through to reach a specific goal.

⑦ Path Planning

⑧ Joint Space - config^n space defined by joint values of a robot.
→ represents all possible joint config^ns the robot can achieve.
→ Planning & control algos often operate in joint space.

⑨ Cartesian Space - 3-D space in which robot's end-effector moves.
→ defined by Cartesian coordinates (x, y, z) & can be used to represent the position & orient^n of end-effector.

⑩ Velocity - rate of change of position/orient^n of robot's end-effector over time.
→ describes how fast the robot is moving & in what direc^n.

⑪ Acceleration - rate of change of velocity of robot's end effector.
→ represents how quickly velocity of robot is changing.

⑫ Joint Limits - range of allowed motion for each joint of a robot.
→ define maximum and minimum values that the joint angles / displacements can take.

⑬ Singularity - config^n in which a robot's arm loses one/more degrees of freedom
→ can occur when joints align in a specific way, resulting in a loss of motion / unstable behaviour.

⑭ Kinematic Constraints - limitations on range of motion of robot due to its mechanical structure.
→ define allowable joints angles to prevent collisions with env.

⑮ Workspace - vol^m of region in which robot's end-effector can reach.
→ defines physical limits of robot's motion in 3D

⑯ Feedback Control - continuously monitoring robot's position, velocity & other variables & using info to adjust control systems in real-time.
enables robot to correct errors & maintain accurate & stable position

(17) Interpolation - process of estimating intermediate positions / orientations btn 2 known pts.
→ used to generate smooth trajectories & to fill gaps btn discrete motion points.

(18) Dead ~~Recon~~ Reckoning - technique used to estimate current position of robot by integrating its known starting position with info on velocity & elapsed time.
→ used in mobile robots to estimate their position when absolute position measurements are unavail.

Motion Characteristics

→ refers to the specific attributes and behaviours exhibited by robots during their movement.

(1) Speed - rate at which a robot moves.
— distance covered per unit of time, such as m/s, etc.
— affects efficiency & cycle time of robot operations and needs to be carefully controlled to ensure safe & accurate motion.

(2) Acceleration - measures how quickly a robot changes its velocity.
→ quantifies the rate of change of speed over time.
→ controlling accn is essential for achieving smooth and controlled motion, reduced stress on robot's mechanical components, and ensuring safe operation.

(3) Deceleration - -ve accn or braking, rate at which a robot ↓ its velocity.
— important for smooth & precise stopping or slowing down of robot's motion, preventing overshooting / abrupt movements.

(4) Jerk - rate of change of accn over time.
— characterizes the smoothness / abruptness of changes in accn.
— minimizing jerk is crucial for achieving smooth and comfortable robot motion, reducing vibrations and jerky movements that can affect precision or cause discomfort to operators.

(5) Trajectory - includes info about info position, velocity & accn of end-effector at each pt along path.
well-planned trajectory ensures efficient & accurate robot motion, taking into account workspace constraints, obstacles & task reqs.

⑥ Smoothness – refers to absence of sudden changes, oscillations, or discontinuities in robot's motion.

→ smooth motion is desirable for achieving precise & controlled movements, reducing wear & tear on robot's mechanical components, & providing ~~a~~ comfortable & safe working env.

⑦ Accuracy – ability of a robot to achieve its desired positions and orientations precisely.

→ influenced by factors such as sensor accuracy, control system performance, calibration, mechanical stability.

→ High accuracy is crucial for tasks that req precise positioning, such as assembly, machining, and inspection.

⑧ Repeatability – ability of a robot to consistently return to the same position or follow the same trajectory when performing a task multiple times.

→ quantifies the variation in the robot's motion when executing the same commands.

→ imp for tasks that req high precision & consistency, such as pick-and place operations & machining.

⑨ Agility – refers to ability of a robot to change its motion quickly and responsively.

→ Agile robots can adapt to dynamic env, handle unexpected events, and perform agile motions such as quick repositioning, avoiding obstacles, or reacting to changes in the task or env.

⑩ Coordination – ability of multiple robot components or multiple robots to work together seamlessly & efficiently.

→ involves synchronized motion, cooperative manipulation, and coordination of actions to achieve a common goal.

→ crucial for tasks that req collaboration betⁿ robots or multiple robot arms.

Resolution

→ refers to the level of detail or precision with which a robotic system can perceive, measure or control variables.

→ imp parameter that determines the accuracy and quality of robotic operations.

① Sensory Resol^n — ability of a robot's sensors to perceive & detect fine details or variations in the env.

→ Ex — in vision systems, higher resol^n cameras can capture more detailed images, enabling the robot to recognize smaller objects or finer features.

~~ocular~~ Similarly sensors such as force/torque sensors or tactile sensors can provide more precise measurements of forces or contact info during manipulation tasks.

② Positional Resol^n — refers to the level of precision with which a robot can measure or control its position.

→ associated with the resol^n of encoders or sensors used to determine joint angles or end-effector positions.

→ Higher positional resol^n allows for more accurate and fine-grained control of robot motion, enabling precise positioning and manipulation tasks.

③ Control Resol^n — relates to granularity/precision of the control commands sent to the robot's actuators.

→ determines how finely robot can adjust its movements or exert forces in response to control signals.

→ Higher control resol^n results in smoother & more accurate motion, allowing for precise control of speed, acc^n & torque.

④ Trajectory Resol^n — refers to level of detail with which robot can follow a predefined trajectory.

→ determines how closely robot can approximate the desired trajectory, whether it is a straight line, curve or a complex path.

→ Higher trajectory resolⁿ enables robot to achieve smoother & more accurate motion along desired trajectory.

(5) Planning Resolⁿ – associated with level of detail in planning algos used by robot.

→ affects ability to generate precise and fine-grained motion plans, such as collision avoidance, path planning or trajectory generation.

→ Higher planning resolⁿ allows for more intricate and optimized motion planning, resulting in efficient & safe robot operations.

Accuracy

→ refers to ability of robot to perform tasks with precision and consistency, achieving the desired results within specified tolerances.

→ measure of how closely the robot's actions align with the intended goal / specification.

→ ~~sem~~ crucial characteristic in various robotic appⁿs, particularly those that req precise positioning, manipulation or control.

(1) Positional Accuracy – ~~to~~ refers to how closely the robot can achieve a desired position in space.

→ involves ability to reach and maintain specific coordinates or locations within the robot's workspace.

→ Higher PA ensures that robot can consistently position its end-effector or joints at the intended targets, minimizing deviations and errors.

(2) Path A. – refers to how closely the robot follows a predefined trajectory or path.

→ involves achieving the desired path with minimal deviation, ensuring that the robot's movement is precisely controlled along the intended route.

→ critical in tasks such as welding, painting or machining, where robot must follow a precise path to achieve the desired outcome.

③ Repeatability — High repeatability ensures the robot can consistently reproduce its actions, enabling precise and consistent results. → in motion characteristics

④ End-Effector A. — ability of robots end-effector, such as gripper or tool to precisely interact with objects or perform tasks.
→ involves achieving accurate grasping, placement, ~~or proper~~ manipulation of objects, ensuring that the desired actions are executed with precision.

⑤ Sensor Accuracy — crucial for providing accurate feedback & perception to robot.
→ vision systems, force/torque sensors, distance sensors contribute to overall accuracy of robot's perception & control.
→ High sensor accuracy ensures that robot can make precise decisions based on reliable sensory info.

⑥ Control System A. — accuracy of the robot's control algos & feedback mechanisms.
→ involves ability to accurately measure & control joint angles, velocities, forces & torques.
→ High-precision control system ensures that the robot's movements are controlled with accuracy and responsiveness.

Repeatability
→ ability of a robot to consistently and accurately return to the same position or follow the same trajectory when executing a task multiple times.
→ quantifies the variation or deviation in the robot's motion when performing repetitive actions under same conditions.
→ crucial in appl^ns that require precise and consistent performance.

① Precision and Consistency — Repeatability (R) measure the precision & consistency of a robots performance.

→ assesses how closely the robot can reproduce its actions, including positioning, path following, or manipulation, when given the same commands or inputs repeatedly.

→ High R. indicates that robot can consistently achieve the desired results, reducing variations & errors.

② Measurement & Tolerance - R is typically specified within a defined tolerance or measurement range.

→ quantifies max allowable deviation from desired position. (Ex - if robot has R of ±0.1mm, means its actual position may vary up to 0.1 mm from intended position.)

→ tolerance depends on appⁿ req & level of precision needed.

③ Factors Affecting R - mechanical factors such as backlash, joint stiffness & thermal expansion.

→ control factors such as servo tuning, control algo accuracy and sensor resolⁿ.

→ Design Considerations including selection of components & materials can also impact R.

④ Caliberation & Maintenance - ~~[illegible]~~ calibⁿ involves aligning & fine-tuning the robot's sensors, actuators, and control system to minimize errors & variations.

→ Regular maintenance & inspection of robot's mechanical components, such as joints, gears & linkages are also essential to ensure optimal R. over time.

⑤ Appⁿ - in tasks such as assembly, pick & place operations, machining, quality inspection, robotic welding.

→ here precise & consistent positioning / manipⁿ is req to achieve accurate and reliable results.

→ High R ensures that robot can perform these tasks repeatedly without significant errors.

⑥ Repeatability vs Accuracy - R → focuses on consistency of robot's performance.

A → refers to how closely the robot's actions align with desired goal.

→ robot can have ↑ R but ↓ A if it consistently reaches the same incorrect position.

→ robot can have ↓ R but ↑ A if it can consistently reach different correct positions.

Robot Applications

① Manufacturing – Industrial robots for tasks such as assembly, welding, painting, material handling, ~~pckg~~ & packaging.

→ can operate with ↑ precision, speed & repeatability improving productivity & efficiency in prodⁿ lines.

② Logistics & Warehousing – robots employed in warehouses & distⁿ centers for tasks like order fulfillment, sorting, palletizing and inventory management. Autonomous mobile robots and robotic arms equipped with sensors & vision systems can navigate warehouse env, locate items, and transport goods with minimal human intervention.

③ Healthcare – in surgical procedures, rehabilitation and patient care.

→ Surgical robot assist surgeons in performing minimally invasive surgeries with enhanced precision.

→ Robotic exoskeletons help patients with mobility impairments regain movement & strength.

④ Agriculture – or agribots, used in tasks such as harvesting crops, planting seeds, pruning and monitoring crop health.

→ can autonomously navigate fields, identify ripe produce, & perform labor-intensive tasks.

⑤ Service & Hospitality – at hotels, restaurants & retail stores.

→ act as receptionists, waiters or inventory assistants.

→ interact with customers, provide info, deliver items, enhance customer experience.

⑥ <u>Exploration & Space</u> – allows us gather data and perform tasks in env where humans cannot easily venture.

→ robotic roves for planetary exploration

→ robotic arms & manipulators – used in sample collecⁿ & repairs on space stations.

⑦ <u>Edⁿ & Research</u> – to teach robotics concepts & conduct experiments.

⑧ <u>Defence & Security</u> – Military robots for bomb disposal, surveillance and battlefield support.

– Unmanned Aerial Vehicles (UAVs), U. Ground V. (UGV) and U. Underwater V. (UUV) to carry out missions in dangerous or inaccessible envs.

⑨ <u>Entertainment</u> – for performances, interactive experiences, & attractions

→ can take form of humanoid robots or robotic characters that entertain & engage audiences in theme parks, museums & entertainment venues.

⑩ <u>Home</u> – vacuuming, lawn mowing & companion robots that provide assistance to individuals.