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STUDY NOTES

ROBOTICS AND AUTOMATION

Unit I — Fundamentals of Robotics

Topics Covered (03 Hours)

Definitions of Industrial Robot (RIA, ISO Standards)
Differences between Robots and Simple Automation Systems
Isaac Asimov's Laws of Robotics & Ethics Overview
Types and Classifications of Robots (Power, Coordinate, Control)
Robot Configurations: Cartesian, Cylindrical, and Spherical
Robot Configurations: Articulated / Anthropomorphic & SCARA
Core Robot Components (Manipulator, Actuator, Controller, End-Effector)
Robot Degrees of Freedom (DoF) & Mobility Computations
Work Volume and Work Envelope Specifications
Robot Joint Types (Prismatic, Revolute, Spherical) & Symbols
Robot Coordinate Reference Frames (Base, Joint, Tool, World)

Compiled in a simple, easy-to-understand, book style format
for students of Computer Science and Engineering

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1.1 Robot Definitions & Laws of Robotics

Robotics is the interdisciplinary branch of engineering and science that includes mechanical engineering, electrical engineering, computer science, and other subjects. It deals with the design, construction, operation, and use of robots, as well as computer systems for their control, sensory feedback, and information processing.

Definitions of Industrial Robot

An industrial robot is a programmable manipulator designed to perform various manufacturing tasks. We define it using two key international standard bodies:

RIA (Robotics Industries Association) Definition
An industrial robot is a reprogrammable, multifunctional manipulator designed to move materials, parts, tools, or special devices through variable programmed motions for the performance of a variety of tasks.

ISO 8373 Definition
An automatically controlled, reprogrammable, multipurpose manipulator programmable in three or more axes, which can be either fixed in place or mobile for use in industrial automation applications.

Robots vs. Simple Automation Systems

It is essential to distinguish between a robot and simple industrial automation (like a conveyor belt or automatic capping machine). Simple automation is rigid: it is designed to perform a single, repetitive task and cannot be easily reprogrammed for a different task. A robot, by contrast, is flexible and multipurpose. By changing its software code, a robot can transition from welding car frames to painting them, or to packing goods. Furthermore, robots utilize sensor feedback to adapt to variations in their environment, whereas simple automation operates blindly.

Isaac Asimov‘s Laws of Robotics

To guide the ethical design and interaction of robots with humans, science-fiction author Isaac Asimov formulated the Three Laws of Robotics in 1942. Later, he added the Zeroth Law to prioritize humanity as a whole:

- **Zeroth Law:** A robot may not harm humanity, or, by inaction, allow humanity to come to harm.
- **First Law:** A robot may not injure a human being or, through inaction, allow a human being to come to harm (unless this violates the Zeroth Law).

- **Second Law:** A robot must obey the orders given it by human beings except where such orders would conflict with the First or Zeroth Law.
- **Third Law:** A robot must protect its own existence as long as such protection does not conflict with the First, Second, or Zeroth Laws.

1.2 Robot Classification & Configurations

Robots are classified based on their drive systems, coordinates, control methods, and physical structures.

Classification Schemes

- **By Drive Power:** Hydraulic (uses pressurized fluid, provides massive force for heavy lifting but prone to leaks), Pneumatic (uses compressed air, fast and cheap but difficult to position accurately due to air compressibility), and Electric (uses servo or stepper motors, highly precise, clean, and dominant in modern industrial assembly).
- **By Control Method:** Non-Servo (open-loop, moves to hard stops, simple pick-and-place) and Servo (closed-loop, uses encoder feedback to monitor and correct path in real-time).
- **By Application:** Assembly, welding, spray painting, palletizing, surgical assistance, and space exploration.

Robot Physical Configurations (Topologies)

The configuration of a robot manipulator is defined by its joint sequence. We use 'P' to denote Prismatic (sliding/linear) joints and 'R' to denote Revolute (rotational) joints. The five standard configurations are:

1. Cartesian Coordinate Configuration (PPP)

Consists of three prismatic joints aligned with the orthogonal X, Y, and Z axes. The manipulator moves in straight linear lines. It offers a box-shaped work envelope, high structural rigidity, and simple control equations. However, it requires a large amount of physical workspace relative to its reach. Used in overhead gantry cranes, 3D printers, and CNC machines.

2. Cylindrical Coordinate Configuration (RPP)

Consists of a revolute base joint (rotation) followed by two prismatic joints (vertical elevation and radial reach). It has a cylinder-shaped work envelope. Used for loading and unloading rotary machinery.

3. Spherical / Polar Coordinate Configuration (RRP)

Consists of two revolute joints (base rotation and elevation tilt) followed by one prismatic joint (radial extension). It has a spherical work envelope. A classic example is the Unimate robot, the first industrial robot.

4. Articulated / Anthropomorphic Configuration (RRR)

Consists of three revolute joints (resembling a human waist, shoulder, and elbow). It has an irregular, spherical work envelope. It offers maximum flexibility, allowing the robot to reach around obstacles. However, the control mathematics (inverse kinematics) are highly complex. Used in automotive assembly lines.

5. SCARA Configuration (RRP variant)

SCARA stands for Selective Compliance Assembly Robot Arm. It has two parallel revolute joints providing horizontal compliance, and one prismatic joint providing vertical movement. It is extremely rigid in the vertical axis but flexible in the horizontal plane. Used for high-speed pick-and-place electronic assembly.

1.3 Robot Components, DoF, and Coordinates

To function, a robot relies on an architecture of mechanical links, electrical controllers, and sensors.

Core Components

- **1. Manipulator:** The physical arm structure consisting of rigid links connected by joints.
- **2. Actuators:** The muscle of the robot, converting electrical, hydraulic, or pneumatic energy into physical movement (e.g., DC servo motors, stepper motors).
- **3. Controller:** The brain of the robot. A specialized computer that reads program instructions, processes sensor feedback, and calculates the electrical signals to drive the actuators.
- **4. End Effector:** The tool mounted at the end of the manipulator wrist, which interacts with the environment (e.g., grippers, welding torches, paint sprayers).
- **5. Sensors:** Provide feedback about the robot's state (internal sensors like encoders) and environment (external sensors like cameras and proximity sensors).

Robot Degrees of Freedom (DoF)

The Degrees of Freedom (DoF) is the number of independent parameters (coordinates) that define the position and orientation of the robot in space. A free rigid body in 3D space has 6 DoF: 3 translation DoF (X, Y, Z) and 3 rotation DoF (Roll, Pitch, Yaw). For a manipulator, the DoF is typically equal to the number of active joints.

Work Volume and Work Envelope

The Work Envelope (or Work Volume) is the total physical space that the robot manipulator can reach. It is determined by the configuration, length of the links, and joint rotation limits. The shape can be box-like (Cartesian), cylindrical, spherical, or irregular (articulated).

Robot Coordinate Reference Frames

To program robot motion, we define four main coordinate reference frames:

- **Base Coordinate Frame:** Centered at the physical base of the robot. It is the fixed reference frame for all movement calculations.
- **Joint Coordinate Frame:** Defined in terms of the individual joint angles (revolute) or link extensions (prismatic). Programmers use this to rotate specific joints directly.
- **Tool Coordinate Frame:** Centered at the end-effector (tool tip). Very useful when teaching paths (e.g., moving 'forward' along the axis of a drill bit).
- **World Coordinate Frame:** A global reference frame defining the entire work cell space, including other machines, conveyors, and safety barriers.

Unit Summary

This unit explored the basic concepts of industrial robotics.

- Industrial robots are programmable, multipurpose manipulators defined by RIA and ISO standards.
- Isaac Asimov's laws define ethical constraints for robot designs.
- Robots are classified by coordinates, drive power, control style, and joint sequences.
- Physical configurations include Cartesian (PPP), Cylindrical (RPP), Polar (RRP), Articulated (RRR), and SCARA.
- Core components include manipulators, actuators, controllers, end-effectors, and sensors.
- Degrees of Freedom (DoF) specify mobility. Work envelopes define reachable physical spaces.
- Coordinate frames include Base, Joint, Tool, and World reference frames.