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1. INTRODUCTION TO ROBOTICS

1.1 Overview

- Robotics is a field that involves the design, construction, and use of robots to perform tasks, often autonomously or with minimal human intervention.
- Types of Automation - Fixed Automation, Programmable Automation, Flexible Automation

1.2 Components of Robots

- Manipulators, Sensors
- End effectors, Actuators
- Locomotive devices, Controller
- Encoders, Transmission, Software

1.3 Need of Industrial Robots

- Improve efficiency and productivity in manufacturing processes.
- Enhance precision and consistency in repetitive tasks.
- Reduce labor costs and minimize human error.
- Increase safety by handling hazardous or strenuous tasks.

1.4 Laws of Robotics

Asimov's Three Laws of Robotics

- Governs robot behavior with respect to human safety and obedience.

Ethical Guidelines

- Formal laws to control the deployment and impact of robotics in society.

Safety Standards

- Rules to ensure the safe operation and integration of robots, especially in industrial and public spaces.

1.5 Career Opportunities

- Robotics Engineer
- Automation Specialist
- Robotics Software Developer
- Research Scientist

2. HISTORY OF ROBOTICS

2.1 Origin of a Robot

- The concept of robots dates back to ancient myths and automata, with early mechanical devices built to mimic human or animal movements.
- In the 20th century, technological advancements in electronics and computing led to the development of programmable machines.
- The term "robot" was coined by Czech writer Karel Čapek in his 1920 play R.U.R. (Rossum's Universal Robots).
- The first industrial robots were developed in the 1950s, marking the beginning of automation in manufacturing.

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2.2 Various Generations of Robots

- **First Generation:** Simple, mechanical robots used for repetitive tasks in industrial settings.
- **Second Generation:** Programmable robots with sensors and more flexible control systems for a broader range of tasks.
- **Third Generation:** Autonomous robots using advanced AI and machine learning for decision-making and adaptability.
- **Fourth Generation:** Collaborative robots (cobots) designed to work alongside humans in shared workspaces with enhanced safety and interaction.

3. ROBOT CLASSIFICATIONS

3.1 Classification by Control System

- **Open-loop control:** No feedback, operates on fixed commands.
- **Closed-loop control:** Uses feedback for real-time adjustments.
- **Hybrid control:** Combines open-loop and closed-loop methods.
- **Adaptive control:** Adjusts to changes in task or environment.

3.2 Classification by Co-ordinate System

- **Cartesian:** Movements along X, Y, and Z axes.
- **Polar:** Rotational base with a radial arm.
- **Cylindrical:** Combines linear and rotational movements.
- **Spherical:** Radius, angle, and height for movement.

3.3 Degrees of Freedom (DOF)

- **Overview:** Robot's ability to move independently in space, determining its range of motion and flexibility for performing tasks.
- **Common Configurations:** A typical robotic arm has 6 DOF, enabling movement along three axes (X, Y, Z) and rotation around three axes (pitch, yaw, roll) for full spatial control.
- **Degrees:** Waist, Shoulder I Elbow, Pitch I Roll, Yaw
- **Flexibility and precision:** Higher DOF allow robots to perform more complex tasks with greater precision and flexibility, such as assembly, welding, or surgery.

3.4 Types of Joints

- Prismatic Joint - Linear Joint
- Revolute Joint - Rotational Joint, Twist Joint ,Revolving Joint
- Spherical Joint
- Cylindrical Joint
- Universal Joint

3.5 Anatomy of Robot

- Base
- Link
- Joint
- End effector

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3.6 Work Volume

- Work volume refers to the 3D space a robot can access and perform tasks within.
- It is influenced by the robot's design, including the type of joints and range of motion.
- Different robots have different work volumes, such as spherical, cylindrical, or rectangular.
- The robot's reach defines the maximum distance its end effector can operate from its base.

3.7 Types of Industrial Robot

- Cartesian Robots
- Vertical Articulated Robots
- Selective Compliance Assembly Robot Arm (SCARA) Robots
- Delta Robots

4. ROBOT APPLICATIONS

4.1 Overview

- **Payload:** The maximum weight an industrial robot can handle while performing a task.
- **Repeatability:** The ability of a robot to return to the same position consistently under the same conditions.
- **Accuracy:** The degree to which a robot's movement matches the intended position or path.

4.2 Material Handling Operations

- **Overview:** Material handling robots automate tasks like moving, sorting, and packaging materials, increasing productivity and reducing manual labor.
- **Loading and unloading:** Robots efficiently load and unload goods from conveyors, pallets, or machines, optimizing workflows in industries like manufacturing and logistics.
- **Pick and place:** Robots pick up items from one location and place them in another with high precision, ideal for packaging, sorting, and assembly.
- **Flexible handling:** With adaptable grippers and sensors, robots handle various materials, from small components to heavy objects, across diverse industries.

4.3 Process Operations

Arc Welding

- Arc welding robots automate the process of joining metals using an electric arc, ensuring precision and consistency in high-volume manufacturing.
- Robots provide accurate welds with consistent heat control, reducing defects and ensuring strong joints in automotive and aerospace industries.
- Automation of arc welding speeds up production cycles, allowing for continuous operation and reducing downtime.
- Features - Work Volume, DOF, Motion Control System, Precision of Motion, Programming

Spot Welding

- Spot welding robots automate the process of joining metal sheets using heat and pressure at specific points, commonly used in automotive and manufacturing industries.
- Robots deliver fast, consistent welds with high accuracy, ensuring strong and uniform connections in mass production.
- Automation reduces the need for manual labor, enhancing production efficiency and lowering operational costs.
- Robots handle the heat-intensive spot welding process, improving worker safety by reducing exposure to dangerous conditions.

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4.4 Assembly & Inspection Operations

- Robots perform precise assembly tasks, ensuring consistency and accuracy.
- They inspect parts using sensors and vision systems for quality control.
- Robots can handle repetitive and hazardous tasks, improving safety.
- They enable high-speed operations, reducing production time.

5. INDUSTRIAL ROBOTS

5.1 Selective Compliance Assembly Robot Arm (SCARA) Robots

- **Overview:** SCARA robots are known for their horizontal arm configuration, offering high-speed, precise movements in assembly and pick-and-place tasks.
- **High speed and accuracy:** SCARA robots are ideal for tasks requiring rapid, precise motion, such as electronics assembly, packaging, and sorting.
- **Compact design:** Their compact structure allows for efficient use of space, making them suitable for high-density production environments.
- **Limited vertical flexibility:** SCARA robots are best for horizontal movements and tasks with limited vertical range, making them less versatile than multi-axis robotic arms.

5.2 Articulated Robots

- **Overview:** Articulated robots have multiple joints, resembling a human arm, and are highly versatile for tasks requiring complex movement and flexibility.
- **Multi-degree of freedom:** These robots typically have 6 or more degrees of freedom, allowing them to perform intricate tasks like welding, painting, and assembly.
- **High flexibility:** Ideal for operations in confined spaces or where multiple axes of motion are needed, such as in automotive and heavy manufacturing.
- **Precision and adaptability:** Articulated robots offer high precision, making them suitable for tasks that demand both speed and accuracy in dynamic environments.

5.3 Cartesian Robots

- **Overview:** Cartesian robots, also known as gantry robots, operate along three linear axes (X, Y, Z) to perform precise and repeatable tasks.
- **Simple design:** Their straightforward structure allows for easy setup and maintenance, making them ideal for basic pick-and-place or 3D printing applications.
- **High precision:** Cartesian robots offer excellent accuracy in tasks like material handling, assembly, and packaging due to their rigid frame and controlled movements.
- **Versatility:** With customizable workspaces, they can handle a wide range of tasks, especially in industries like electronics, pharmaceuticals, and packaging.

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6. ROBOT KINEMATICS

6.1 Kinematics Chains

- **Overview:** Kinematic chains describe the interconnected components of a robotic system, where each link is connected by joints to enable movement and task execution.
- **Types of chains:** They can be open (with a starting and ending link) or closed (forming a loop), depending on the robot's design and functionality.
- **Motion control:** Kinematic chains help define the movement paths and degrees of freedom of a robot, essential for controlling the robot's position and orientation.
- **Analysis tool:** Used in robotic design and simulation, kinematic chains help analyze and optimize the motion of robots for tasks like assembly or welding.

6.2 DH Notation

- **Overview:** Denavit-Hartenberg (DH) notation is a systematic method used to describe the kinematics of robotic arms by defining the relationship between consecutive links.
- **Four parameters:** DH notation uses four parameters—link length, link twist, joint angle, and joint offset—to represent the transformation between adjacent links.
- **Simplifies calculations:** It simplifies the complex calculations involved in determining the position and orientation of a robot's end-effector.
- **Standardized framework:** DH notation provides a standardized way of modeling robot motion, facilitating easier analysis, design, and control of robotic systems.

6.3 Forward Kinematics

- **Overview:** Forward kinematics involves calculating the position and orientation of a robot's end-effector based on known joint parameters (angles, lengths) and link configurations.
- **Uses DH parameters:** It often uses Denavit-Hartenberg (DH) notation to represent the relationship between robot joints and links for efficient calculation.
- **Direct Calculation:** Forward kinematics provides a direct method to determine the robot's end-effector position given the joint values, without needing to know the inverse solution.
- **Application:** Commonly used in robot control and simulation to predict the workspace and movement trajectory of a robot based on input joint angles.

6.4 Inverse Kinematics

- **Overview:** Inverse kinematics involves calculating the required joint angles to achieve a desired position and orientation of a robot's end-effector.
- **Solving for joint variables:** Unlike forward kinematics, which determines end-effector position from joint angles, inverse kinematics works in reverse, determining joint angles from the end-effector's target location.
- **Multiple solutions:** There may be multiple or no solutions for a given target position, requiring additional methods to resolve ambiguities, such as optimization techniques.
- **Application:** Used in robotic motion planning and control, inverse kinematics helps robots reach specific points in their workspace for tasks like assembly or pick-and-place.

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7. ROBOANALYZER

7.1 Introduction

- **Overview:** RoboAnalyzer is a software tool used for analyzing, simulating, and visualizing the kinematics and dynamics of robotic systems.
- **Kinematic analysis:** It allows users to perform both forward and inverse kinematics calculations, helping to determine robot motion and configurations.
- **3D visualization:** RoboAnalyzer provides a 3D graphical interface to simulate and visualize robotic arm movements, improving design and testing processes.
- **Educational tool:** Widely used in academia and industry, it helps students and professionals understand complex robotic concepts through interactive simulations.

7.2 Virtual Models of Industrial Robots

- **Overview:** Virtual models of industrial robots are digital representations used to simulate, analyze, and optimize robotic systems in a virtual environment before physical implementation.
- **Simulation and Testing:** These models enable the testing of robotic movements, control algorithms, and interactions with objects, helping to predict real-world performance and reduce errors.
- **Cost and Time Efficiency:** Virtual modeling reduces the need for physical prototypes, saving time and costs associated with trial and error in real-world testing.
- **Optimization:** They assist in optimizing robot movements, paths, and task execution for maximum performance and minimal downtime.

7.3 Kinematic Analysis of Industrial Robots

- **Define Robot Configuration:** Identify the robot's joints, link lengths, and types (e.g., revolute or prismatic joints) to establish the robot's structure.
- **Establish Coordinate Frames:** Assign coordinate frames to each joint and link using the Denavit-Hartenberg (DH) convention to describe the robot's geometry.
- **Write Transformation Matrices:** Calculate the transformation matrices between adjacent links, representing the rotation and translation at each joint.
- **Forward Kinematics:** Determine the position and orientation of the end-effector (tool) based on given joint variables (angles or displacements).
- **Inverse Kinematics:** Calculate the joint variables needed to achieve a specific end-effector position and orientation.
- **Velocity and Acceleration Analysis:** Analyze the robot's velocity and acceleration, using Jacobian matrices to relate joint velocities to end-effector velocities.
- **Check Constraints:** Ensure the robot's movements are feasible and meet constraints like joint limits, workspace boundaries, and singularities.

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8. ROBOT PROGRAMMING

8.1 CPRog Robot Control Software

Overview:

- CPRog is a graphical control and programming environment used for industrial robots, specifically those in the Commonplace Robotics lineup
- It includes tools for simulation, programming, and robot interaction.
- CPRog is closely related to igus Robot Control (iRC) but designed for different sets of robots..

Key Features

- User-Friendly Interface: User-Friendly Interface: Graphical interface for easy robot programming, with drag-and-drop features for movement control
- Offline Programming & Simulation: Allows testing of programs in a virtual environment to avoid errors on physical robots
- Motion Control: Supports complex robotic motions, path planning, and task sequencing for automation
- Logic Programming: Integrates logic sequences for controlling outputs (e.g., gripper activation, dispensing actions) based on robot positions
- Error Handling: Provides debugging tools for monitoring, troubleshooting, and identifying movement or logic issues
- Customization: Enables integration of sensors or external components for specific automation needs
- External Communication: Connects robots with sensors or controllers for more complex tasks

Application

- Assembly Line Automation: Ideal for repetitive tasks like assembly and sorting.
- Pick-and-Place: Ensures precise material handling and object placement
- Quality Control: Used in visual inspection and automated checks in manufacturing

8.2 Robot Simulation using CPRog

Overview

- Robot Simulation using CPRog involves creating and testing robotic tasks in a virtual environment before executing them on actual hardware.
- This process is critical for ensuring efficiency, safety, and error-free operation in real-world scenarios.

Application

- Virtual Testing: Users can simulate robot movements and tasks to verify their functionality and avoid errors before deployment on physical robots
- Real-time Feedback: Simulation provides immediate feedback on the robot's actions, such as path deviations, potential collisions, or violations of safety constraints
- Task Visualization: The 3D environment allows users to visualize robot movements, tool actions, and end-effector positions to confirm task accuracy
- Safety Checks: Virtual simulations help in identifying motion limits, potential programming errors, and optimizing task workflows without any physical risks

Benefits of Simulation

- Cost-Effective: Saves costs related to robot downtime, trial-and-error programming, and material waste
- Optimized Performance: Enables fine-tuning of robot motions and behavior to achieve the best possible performance before actual deployment
- Improved Programming Efficiency: With the ability to simulate complex processes, programmers can optimize code, minimize debugging time, and refine logic before physical execution

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CAPSTONE PROJECTS

1 **Kinematic Analysis of ARISTO Robot using Robo Analyzer**

- Calculate the position and orientation of the robot's end effector based on given joint parameters to understand its workspace.
- Analyze and plan trajectories for the robot's end effector, ensuring smooth and efficient movements through its workspace
- Provide a practical platform for engineers to learn about robot kinematics and simulation techniques using RoboAnalyzer.

2 **Kinematic Analysis of STANFORD Robot using Robo Analyzer**

- Calculate the position and orientation of the end effector based on joint parameters, helping to understand the robot's reach and workspace.
- Determine the necessary joint angles to achieve specific end effector positions and orientations, facilitating motion planning and control.
- Evaluate the linear and angular velocities of joints and the end effector to assess the dynamics of robot motion.

3 **Kinematic Analysis of a 6-DOF Industrial Robot using Robo Analyzer**

- The first step is to define the robot model within RoboAnalyzer. For a 6-DOF robot, you'll input the DH (Denavit-Hartenberg) parameters for the robot's joints and links.
- Enter the joint parameters (angles or displacements) into RoboAnalyzer.
- Use the software's forward kinematics tool to calculate the transformation matrices.
- Visualize the end effector's position and trajectory in the robot's workspace.
- Specify the target position and orientation for the end effector in RoboAnalyzer.
- Use the inverse kinematics tool to find the joint angles corresponding to the target pose.
- Verify if the solution is valid or if there are multiple solutions.

LIVE PROJECTS

Gantry Robot Kinematic Analysis using Roboanalyzer and CPRog

- The Gantry Robot Kinematic Analysis project utilizes RoboAnalyzer to model and analyze the kinematics of the robot's movement.
- By using RoboAnalyzer's capabilities, joint parameters and link configurations are optimized to achieve precise positioning.
- The project employs CPROG for programming and simulating the robot's motion, ensuring smooth operation in real-world applications.
- Forward and inverse kinematics are calculated to determine the required joint angles for specific end-effector positions.
- This analysis helps in refining the robot's design, enhancing performance, and minimizing errors in automated tasks.