Sensors and Robotics Technology

Introduction to Robotic Unit - 3

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The Motion Subsystem of a Robot

- The motion subsystem is the backbone of a robot, enabling it to move and interact with its environment. It's composed of several key components working in tandem.
  - Actuators
  - Transmissions
  - Joints
  - Links
  - Sensors
  - Control Systems

Transmissions

- **Gears:** Reduce speed and increase torque, or vice versa, depending on the application.
- **Belts and Pulleys:** Provide flexible connections between shafts.
- **Cams:** Convert rotary motion into linear or intermittent motion.

Joints & Links

- **Revolute Joints:** Allow rotational movement around an axis.
- **Prismatic Joints:** Allow linear movement along an axis.
- **Spherical Joints:** Allow rotational movement around multiple axes.
- **Cylindrical Joints:** Combine revolute and prismatic joints for both rotational and linear movement.
- Rigid structures that connect joints and form the robot's body.

Control Systems

- **Microcontrollers or Computers:** Process sensor data and send commands to actuators.
- **Control Algorithms:** Determine the robot's movements based on desired tasks and sensor feedback.

The Recognition Subsystem of a Robot

- The recognition subsystem is a crucial component of a robot, enabling it to perceive and understand its environment. It involves processing sensory data to identify objects, people, and other features.
- Sensors
- Signal Processing
- Pattern Recognition
- Object Recognition
- Scene Understanding
- Decision-Making

Sensors

- **Cameras:** Capture visual information, including color, texture, and depth.
- **Lidar (Light Detection and Ranging):** Measures distance to objects using laser light.
- **Radar (Radio Detection and Ranging):** Detects objects using radio waves.
- **Sonar (Sound Navigation and Ranging):** Measures distance using sound waves.
- **Infrared Sensors:** Detect heat radiation.
- **Tactile Sensors:** Detect touch and pressure.

Signal Processing

- **Data Acquisition:** Gathering raw sensor data.
- **Noise Reduction:** Filtering out unwanted noise or interference.
- **Feature Extraction:** Identifying distinctive characteristics of objects or patterns.

Pattern Recognition

- **Machine Learning Algorithms:**
  - **Supervised Learning:** Training the system with labeled data to recognize patterns.
  - **Unsupervised Learning:** Identifying patterns without labeled data.
  - **Reinforcement Learning:** Learning through trial and error, receiving rewards or penalties for actions.
- **Neural Networks:** Simulating the human brain's structure for complex pattern recognition.
- **Statistical Methods:** Using probability and statistics to analyze data.

Object Recognition

- **Template Matching:** Comparing images to predefined templates.
- **Feature-Based Recognition:** Identifying key features of objects and comparing them to known patterns.
- **3D Object Recognition:** Using depth information to recognize objects in three dimensions.

Scene Understanding

- **Semantic Segmentation:** Assigning labels to each pixel in an image, identifying objects and their categories.
- **Object Detection:** Locating and identifying objects within an image or scene.
- **Pose Estimation:** Determining the position and orientation of objects.

Decision-Making

- **Action Planning:** Determining appropriate actions based on recognized objects and the robot's goals.
- **Behavior Generation:** Creating a sequence of actions to achieve a desired outcome.

The Control Subsystem of a Robot

- The control subsystem is the brain of a robot, responsible for coordinating its actions and ensuring it performs tasks efficiently and safely. It receives sensory data, processes it, and sends commands to the motion subsystem to control the robot's movements.
  - Sensors
  - Microcontrollers or Computers
  - Control Algorithms
  - Communication Interfaces
  - Software

Control Algorithms

- **Open-Loop Control:** Commands are sent to actuators without feedback, suitable for simple tasks.
- **Closed-Loop Control:** Feedback from sensors is used to adjust commands, ensuring accurate and precise control.
- **PID (Proportional-Integral-Derivative) Control:** A common control algorithm that balances responsiveness and stability.
- **State-Space Control:** A more advanced method that models the robot's behavior as a system of equations.
- **Adaptive Control:** Adjusts control parameters based on changing conditions.

Communication Interfaces

- **Wired or Wireless Networks:** Connect the robot to other devices or systems.
- **Human-Machine Interfaces (HMIs):** Allow operators to interact with the robot.

Software

- **Programming Languages:** C++, Python, Java, and others are used to develop control software.
- **Robot Operating System (ROS):** A popular open-source framework for robot software development.

Robot Specifications

- When evaluating a robot, several key specifications provide insights into its capabilities and suitability for specific applications.
- Robot Specifications
  - Number of Axes
  - Load Carrying Capacity
  - Reach
  - Stroke
  - Repeatability
  - Precision
  - Accuracy

Number of Axes

- **Definition:** The number of independent directions of movement a robot can control.
- **Significance:** More axes generally provide greater flexibility and versatility.
- **Common Configurations:**
  - **Cartesian:** 3 axes (x, y, z)
  - **Cylindrical:** 3 axes (1 linear, 2 rotational)
  - **Spherical:** 3 axes (2 rotational, 1 linear)
  - **Articulated Arm:** Typically 6 or more axes, similar to a human arm

Load Carrying Capacity

- **Definition:** The maximum weight a robot can lift or handle without compromising its performance.
- **Significance:** Determines the types of tasks a robot can perform, such as heavy-duty manufacturing or delicate assembly.
- **Units:** Kilograms or pounds

Reach

- **Definition:** The maximum distance a robot's end-effector can travel from its base.
- **Significance:** Impacts the workspace and the size of objects a robot can manipulate.
- **Units:** Meters or feet

Stroke

- **Definition:** The maximum linear distance a robot can move along a specific axis.
- **Significance:** Relevant for robots with linear axes, such as Cartesian or cylindrical robots.
- **Units:** Meters or feet

Repeatability

- **Definition:** The ability of a robot to consistently return to the same position.
- **Significance:** Critical for tasks requiring high precision, such as assembly or machining.
- **Units:** Millimeters or inches

Precision

- **Definition:** The robot's ability to move to a specific point within a narrow tolerance.
- **Significance:** Similar to repeatability, precision is important for tasks requiring accuracy.
- **Units:** Millimeters or inches

Accuracy

- **Definition:** The ability of a robot to move to a target position that is within a specified distance of the desired location.
- **Significance:** A measure of overall positioning accuracy, considering both repeatability and absolute positioning errors.
- **Units:** Millimeters or inches

Classification of Robots Based on Drive Technologies

- Robots can be classified based on the primary technology used to drive their movements.

Electrically Driven Robots:

- **DC Motors:** Used for linear and rotational movements.
- **Stepper Motors:** Provide precise angular positioning.
- **Servo Motors:** Offer precise rotational control with feedback.

Pneumatically Driven Robots:

- Utilize compressed air to generate linear or rotational motion.
- Suitable for applications requiring high speed and force, such as assembly and material handling.

Classification of Robots Based on Drive Technologies

Hydraulically Driven Robots:

- Use hydraulic fluid under pressure for powerful linear or rotational movements.
- Ideal for heavy-duty applications, such as construction and material handling.

Hybrid Robots:

- Combine multiple drive technologies to achieve a balance of speed, force, and precision.

Biomimetic Robots:

- Inspired by biological systems, such as muscles or tendons, for unique and adaptable movements.

Classification of Robots Based on Work Envelope Geometry

- Robots can be classified based on the shape of the workspace or work envelope they can reach.

Cartesian Robots:

- **Work envelope:** Rectangular prism.
- **Common applications:** Assembly lines, machine tending, and pick-and-place operations.

Cylindrical Robots:

- **Work envelope:** Cylinder.
- **Common applications:** Material handling, welding, and machine tending.

Classification of Robots Based on Work Envelope Geometry

Spherical Robots:

- **Work envelope:** Sphere.
- **Common applications:** Material handling, painting, and spray coating.

Articulated Arm Robots:

- **Work envelope:** Complex, often resembling a human arm.
- **Common applications:** Assembly, welding, and material handling.

Parallel Robots:

- **Work envelope:** Varies depending on the specific configuration.
- **Common applications:** High-speed applications, such as flight simulators and surgical robotics.

Classification of Robots Based on Motion Control Methods

- Robots can be classified based on the methods used to control their movements.

Open-Loop Control:

- **Definition:** Commands are sent to actuators without feedback from sensors.
- **Advantages:** Simple to implement and cost-effective.
- **Disadvantages:** Less precise and susceptible to disturbances.
- **Common applications:** Simple tasks that do not require high accuracy, such as basic material handling.

Classification of Robots Based on Motion Control Methods

Closed-Loop Control:

- **Definition:** Feedback from sensors is used to adjust commands, ensuring accurate and precise control.
- **Advantages:** More precise, robust to disturbances, and suitable for complex tasks.
- **Disadvantages:** More complex to implement and may require additional hardware.
- **Common applications:** Assembly, welding, and precision machining.

Classification of Robots Based on Motion Control Methods

Hybrid Control:

- **Definition:** Combines open-loop and closed-loop control for a balance of simplicity and precision.
- **Advantages:** Can be more efficient and cost-effective than pure closed-loop control.
- **Disadvantages:** May require careful tuning of control parameters.
- **Common applications:** Tasks that require a combination of speed and accuracy, such as packaging and pick-and-place operations.

Classification of Robots Based on Motion Control Methods

Adaptive Control:

- **Definition:** Adjusts control parameters based on changing conditions or disturbances.
- **Advantages:** More robust to uncertainties and variations in the environment.
- **Disadvantages:** More complex to implement and may require significant computational resources.
- **Common applications:** Tasks that involve unpredictable environments or changing conditions, such as autonomous vehicles or robotic surgery.

Safety Measures in Robotics

- Ensuring the safety of both humans and robots is paramount in any robotic application.

1. Physical Barriers and Enclosures:

- **Safety cages:** Enclose robots to prevent accidental contact with humans.
- **Light curtains:** Use light beams to detect human intrusion and stop robot operations.
- **Pressure-sensitive mats:** Detect human presence and halt robot movements.

Safety Measures in Robotics

2. Emergency Stop Systems:

- **Emergency stop buttons:** Easily accessible buttons that immediately halt robot operations.
- **Emergency stop circuits:** Ensure rapid and reliable stopping.

Safety Measures in Robotics

3. Robot Design and Programming:

- **Collision avoidance algorithms:** Program robots to detect and avoid obstacles, including humans.
- **Force-limited actuators:** Limit the force a robot can exert, preventing injuries.
- **Redundant safety systems:** Implement multiple safety features for added reliability.

Safety Measures in Robotics

4. Operator Training:

- **Proper training:** Ensure operators are knowledgeable about robot safety procedures and emergency response.
- **Regular training:** Conduct periodic training to keep operators updated on safety practices.

Safety Measures in Robotics

5. Risk Assessment:

- **Identify hazards:** Conduct a thorough risk assessment to identify potential hazards and risks.
- **Implement measures:** Develop and implement safety measures to mitigate identified risks.

Safety Measures in Robotics

6. Maintenance and Inspection:

- **Regular maintenance:** Conduct routine maintenance to ensure robots are operating safely and correctly.
- **Safety inspections:** Regularly inspect robots and safety equipment for any defects or damage.

7. Compliance with Standards:

- **Adhere to standards:** Ensure robots comply with relevant safety standards, such as ISO 10218.

Safety Measures in Robotics

8. Ethical Considerations:

- **Responsible development:** Consider ethical implications when designing and deploying robots.
- **Avoid harmful applications:** Ensure robots are not used for harmful or dangerous purposes.