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UNIT-6-Al in Robotics

Robotic Perception –

Robotic perception is the ability of a robot to understand and interpret its surroundings using various sensors and intelligent algorithms. It enables robots to **see**, **hear**, **touch**, and **analyze** the environment so that they can make informed decisions and act accordingly.

□ Key Components of Robotic Perception

1. Sensors (Input)

Robotic perception starts with sensors that gather data from the environment.

Sensor Type	Function	Examples
Camera (RGB, Stereo, Depth)	Vision	Object detection, face recognition
LiDAR (Light Detection and Ranging)	3D mapping	Self-driving cars, drones
Ultrasonic Sensors	Distance measurement	Obstacle avoidance
Infrared Sensors	Heat or proximity detection	Night vision, object tracking
Microphones	Audio input	Speech recognition
Touch Sensors (Tactile)	Physical interaction	Grasping objects, pressure sensing
IMU (Inertial Measurement Unit)	Movement tracking	Orientation, acceleration, rotation

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2. Perception Algorithms

These algorithms process the raw sensor data and convert it into meaningful information.

Examples:

- **Image processing** – e.g., edge detection, color segmentation
- **Object recognition** – identifies and classifies objects
- **SLAM (Simultaneous Localization and Mapping)** – maps the environment while tracking the robot's position
- **Sensor fusion** – combines data from multiple sensors for better accuracy

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3. Understanding the Environment

Once data is processed, the robot forms a **model of the environment**:

- **2D/3D Maps**
- **Obstacle identification**
- **Object positions and movements**
- **Semantic understanding** (e.g., identifying "this is a chair")

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4. Decision Making and Action

Based on perception, the robot can:

- Plan a path (navigation)
- Avoid obstacles
- Pick and place objects
- Interact with humans
- Adapt to changes in the environment

□ Applications of Robotic Perception

Field	Use Case
Self-driving cars	Detect traffic signs, other vehicles, pedestrians
Drones	Avoid obstacles, map terrains
Industrial robots	Recognize and handle different objects on an assembly line
Healthcare	Guide surgical robots or assistive robots in hospitals
Agriculture	Detect crop conditions, navigate through fields

Field	Use Case
Home robots	Recognize people, clean efficiently, follow commands

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□ AI in Robotic Perception

Artificial Intelligence (especially **Machine Learning** and **Deep Learning**) plays a major role in robotic perception by enabling:

- Object detection and classification
- Scene understanding
- Human-robot interaction
- Gesture and emotion recognition

Localization:

□ What is Localization in Robotics?

Localization is the process by which a robot determines its **position** and **orientation** (i.e., where it is and which way it's facing) within a given environment.

Think of it like this: Just as a person uses landmarks and GPS to figure out where they are in a city, **robots use sensors and maps to locate themselves** in a known or unknown environment.

□ Why is Localization Important?

Without knowing **where** it is, a robot **cannot navigate**, **make decisions**, or **interact effectively** with its surroundings. Localization is **critical for autonomy**, especially in:

- Self-driving cars
- Delivery robots
- Warehouse automation
- Drones

□ Key Concepts of Localization

1. Pose

- **Pose = Position (x, y, z) + Orientation (θ / rotation)**
- Example: A robot at coordinate (2.0, 3.5) facing 45° north-east.

2. Map

- Can be:
  - **Known** (pre-built map)
  - **Unknown** (robot creates a map while localizing – see SLAM)
- Used for comparing sensor data and estimating the current location.

3. Sensors Used

Sensor	Function
LiDAR	Measures distances to objects around the robot
Camera	Captures visual data (used in visual SLAM)
IMU	Tracks motion and orientation
GPS	Used in outdoor localization
Odometry (wheel encoders)	Measures how far the robot has traveled

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□ Types of Localization

1. Global Localization

- The robot **does not know** where it is initially.
- It uses sensor data to estimate its **starting position** on a map.

2. Local Localization (Tracking)

- The robot has a **rough idea** of its location and updates it as it moves.

3. Kidnapped Robot Problem

- When the robot is suddenly moved to a new place, it must **re-localize**.

□ How Does It Work? (Methods & Algorithms)

□ 1. Dead Reckoning

- Uses odometry (wheel movement) to estimate position.
- Problem: Errors accumulate over time.

□ 2. Kalman Filter

- Combines noisy sensor data (e.g., from IMU, GPS) to estimate position.
- Works well in linear, Gaussian systems.

□ 3. Particle Filter (Monte Carlo Localization - MCL)

- Maintains many "guesses" (particles) about where the robot might be.
- Updates them based on sensor inputs and probabilities.

□ 4. SLAM (Simultaneous Localization and Mapping)

- Robot **localizes itself and builds a map** at the same time.
- Used when no prior map is available.

□ Example Scenario

A warehouse robot needs to pick up a box:

1. Uses **LiDAR** and **odometry** to estimate position.
2. Refers to a **known warehouse map**.
3. Calculates current location: (x=5.2, y=7.1, heading=90°)
4. Plans path to the box based on this localization.

Mapping: Configuring Space:

□ What is Mapping in Robotics?

Mapping refers to the process by which a robot **creates a representation of its environment** so it can understand and interact with it effectively.

In simple terms:

Mapping = Teaching a robot what its world looks like.

This "world" could be:

- A room
- A house
- A warehouse
- A city block (for self-driving cars)

□ Why is Mapping Important?

- Allows **navigation**: The robot can plan a route from Point A to B.
- Enables **obstacle avoidance**: It knows where walls, furniture, or humans are.
- Supports **task execution**: e.g., vacuuming only the living room.
- Essential for **autonomous behavior**.

□ Mapping = Configuring Space

Mapping is about **converting physical space into a digital format** the robot can understand. This configuration involves:

1. Identifying Structures

Walls, doors, corridors, furniture, etc.

2. Positioning Objects

Where are the obstacles? What’s the layout?

3. Creating Boundaries and Paths

Where the robot can or cannot go.

□ Types of Maps in Robotics

Type	Description	Example
Metric Map	Precise, uses coordinates	2D grid map or 3D point cloud
Topological Map	Graph-based, focuses on connectivity	Rooms connected by paths
Semantic Map	Adds meaning to spaces	"This is a kitchen", "This is a charging station"
Occupancy Grid Map	A grid where each cell is marked as occupied, free, or unknown	Used in indoor robots like vacuum cleaners

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□ Tools for Mapping (Sensors)

Sensor	Role in Mapping
LiDAR	Measures distances in 360° to create 2D/3D maps
Camera (RGB or Depth)	Captures visual layout and depth
Ultrasonic/IR Sensors	Detect nearby objects
IMU	Provides motion/orientation data
Wheel Encoders	Measure how far the robot has moved

□ Mapping Algorithms

1. SLAM (Simultaneous Localization and Mapping)

- The robot **builds the map** and **figures out its location** at the same time.
- Useful when the environment is unknown.
- Two main types:
  - **Visual SLAM** (uses camera)
  - **LiDAR-based SLAM**

2. Grid Mapping (Occupancy Grids)

- Divides space into small square "cells"
- Each cell is:
  - Free = 0
  - Occupied = 1
  - Unknown = -1

□ Example: Configuring Space in a Room

1. Robot enters an unknown room.
2. Uses LiDAR to detect walls.
3. Divides floor into grid cells.
4. Labels each cell as:
   - Occupied (by chair, wall)
   - Free (open space)
   - Unknown (not yet explored)
5. Updates the map in real-time as it moves.

Planning Uncertain Movements:

□ Planning Under Uncertainty in Robotics

Planning uncertain movements refers to how a robot makes decisions and plans paths when it is **not fully sure** about its environment, location, or the results of its actions.

□ What Does "Uncertainty" Mean?

In real-world environments, robots often face **incomplete**, **inaccurate**, or **noisy data** due to:

- Imperfect sensors (camera, LiDAR, GPS)
- Slippery surfaces or wheel slippage
- Dynamic obstacles (humans, other robots)
- Changing environments (e.g., moved furniture)

So, **uncertainty = lack of full knowledge** about the current state or outcome.

□ Goal: Make the Best Decision Despite Uncertainty

The robot needs to:

- **Predict possible outcomes** of actions
- **Choose a plan** that works well even if things don’t go as expected
- **Adjust plans** as it gathers new information

□ Types of Uncertainties

Type	Description	Example
Sensor uncertainty	Inaccurate or noisy readings	GPS shows you’re 5m away from your actual spot
Actuation uncertainty	Movements may not go exactly as planned	Robot turns 89° instead of 90°
Environment uncertainty	Environment might change or be unknown	A closed door the robot thought was open
Map uncertainty	The map might be outdated or incomplete	Furniture moved after mapping

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□ Techniques to Plan Under Uncertainty

1. Probabilistic Planning

- Uses **probabilities** to model all possible outcomes.
- Represent the robot’s **belief** about the world as a probability distribution.

□ Example: Belief Space

- Instead of one exact location, the robot keeps track of a **belief** over possible positions.

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2. Markov Decision Process (MDP)

- A framework where:
  - States = positions or situations
  - Actions = movements (e.g., move forward, turn left)
  - Transition probabilities = chance of going from one state to another
  - Rewards = goal achievement or collision avoidance

□ MDPs help robots choose actions that **maximize expected rewards** over time.

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3. Partially Observable MDP (POMDP)

- Extends MDP to handle **incomplete or noisy observations**.
- Robot doesn't know exactly which state it's in, but uses **beliefs**.

Example:

A robot may not know if it's in room A or room B, but assigns 70% probability to A and 30% to B based on sensors.

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4. Motion Planning with Uncertainty

- Plan for **worst-case scenarios** or use **risk-aware** paths.
- Techniques include:
  - **Probabilistic Roadmaps (PRM)**
  - **Rapidly-Exploring Random Trees (RRT)**
  - **Belief Space Planning** (planning in a space of probability distributions)

□ Real-Life Example: Robot Delivery in a Building

1. Robot must deliver a package across a building.
2. Sensors are noisy; it's unsure about its exact location.
3. Some hallways may be blocked.
4. It uses **belief-based planning** and **updates its plan dynamically**.
5. Chooses a path with **higher success probability**, even if it's longer.

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□ Dynamics and Control of Movement in Robotics

In robotics, **dynamics and control** are key concepts that determine **how a robot physically moves in the real world** — not just planning the motion, but **actually executing it safely, smoothly, and accurately**.

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1. What is Dynamics?

Dynamics refers to the study of forces and motion — how **forces cause a robot to move**.

□ Key Idea:

Robots are physical systems. You can't just tell a robot to "move" — you must consider:

- Its **mass**
- **Forces and torques** acting on it
- How its **joints, motors, wheels, and arms** react

□ Two Types of Dynamics:

Type	Description	Example
Forward Dynamics	Calculates how the robot moves given forces	If I apply 10N to the wheel, how far will it go?
Inverse Dynamics	Calculates what forces are needed for desired motion	To move the arm to position X, what torque is needed?

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2. What is Control?

Control refers to the **methods and algorithms** used to make a robot follow a desired motion or behavior accurately.

□ Closed-Loop Control:

- Uses **feedback** from sensors (e.g., encoders, IMU) to **correct movement errors**.

- Example: If a robot is drifting off path, control adjusts motor speeds to bring it back.

□ Components of Movement Control

Component	Function
Actuators	Convert electrical signals to motion (e.g., motors, servos)
Sensors	Measure current position, velocity, etc. (e.g., encoders, gyros)
Controllers	Algorithms that compute the required control signals (e.g., PID)

□ Common Control Techniques

1. PID Control (Proportional-Integral-Derivative)

Most widely used for simple robot control.

- **P**: How far you are from the goal
- **I**: Sum of past errors
- **D**: How fast the error is changing

□ Keeps robot on path, reduces overshoot, and smooths the motion.

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2. Model Predictive Control (MPC)

Advanced method that uses a model of the robot’s dynamics to:

- Predict future behavior
- Optimize control actions over a time horizon
- Handle constraints (like max speed or torque limits)

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3. Impedance & Admittance Control

Used in **collaborative or soft robots**:

- Adjust motion **based on contact with the environment**
- Makes robots feel “softer” or more human-like

□ Example: Controlling a Robotic Arm

Let’s say you want a robotic arm to pick up a cup:

1. **Kinematics** plans the joint angles needed to reach the cup.
2. **Dynamics** calculates the torques needed to move each joint.
3. **Control** (e.g., PID) applies those torques via motors.
4. **Sensors** check if the arm is on track — and correct if needed.

□ Example: Mobile Robot Driving in a Hallway

1. Desired path is a straight line.
2. Wheels slip a bit; robot drifts.
3. IMU and wheel encoders detect deviation.
4. PID controller adjusts wheel speeds to get back on course.

Ethics and risks of artificial intelligence in robotics:

□ Ethics and Risks of Artificial Intelligence in Robotics

As Artificial Intelligence (AI) becomes increasingly integrated into **robotic systems**, it raises **serious ethical questions and potential risks**. These systems are no longer just mechanical devices; they are **decision-makers**, influencing lives, economies, safety, and privacy.

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1. Why Ethics in Robotics & AI Matters

Ethics ensures that **robots behave responsibly**, especially as they:

- Work **closely with humans** (e.g., in healthcare or homes)
- Make **independent decisions**
- Are used in **high-stakes domains** (e.g., defense, policing, surgery)

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Without ethical design, AI-driven robots can unintentionally cause harm, reinforce bias, or invade privacy.

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2. Major Risks in AI-Enabled Robotics

Risk Area	Description	Example
□ **Autonomous Weapons**	Robots making kill decisions without human input	Military drones attacking targets based on algorithm
□ **Bias & Discrimination**	AI learns biased patterns from data	A robot assistant prioritizing one group over another in service
□ **Privacy Invasion**	Robots collecting sensitive data	Home robots recording conversations or habits
□ **Job Displacement**	Replacing human labor	Robots automating factory, warehouse, or delivery jobs
□ **Safety Hazards**	Physical harm due to malfunctions or poor decision-making	Self-driving robot hits a pedestrian
□ **Lack of Accountability**	Unclear who is responsible for robot actions	Who’s to blame if a robot misdiagnoses a patient?
□ **Overdependence**	Humans relying too much on robots	Medical staff trusting a robot’s decision without verification

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3. Ethical Principles in AI & Robotics

Principle	Meaning	Impact
□ **Beneficence**	Robots should **benefit** humans	Assist the elderly or disabled
□ **Non-maleficence**	Robots should **not cause harm**	Avoid accidents, false arrests, or misdiagnoses
□ **Autonomy**	Respect human decision-making	Don't override human choices unnecessarily
□ **Transparency**	Be open about how decisions are made	Clear explanations for robot actions

Principle	Meaning	Impact
□ **Privacy**	Protect user data	No unauthorized recording or data sharing
□ **Accountability**	Designers and users should be responsible	Traceable logs and ethical design practices

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4. Real-World Ethical Dilemmas

□ **Self-driving Cars:**

- If a crash is inevitable, should the car **protect the driver or pedestrians**?
- How is the decision made? Can the user override it?

□ **Medical Robots:**

- Can an AI-powered surgical robot **override a doctor's judgment**?
- If it makes a mistake, who is **legally responsible**?

□ **Surveillance Drones:**

- If a robot patrols public spaces, how is data stored?
- Can it be misused by governments for **mass surveillance**?

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5. Steps to Address the Risks

1. **Ethical Design Frameworks**
   - Integrate ethics into **early stages** of robot development.
2. **Human-in-the-loop Systems**
   - Ensure a **human decision-maker** is always present in critical tasks.
3. **Explainable AI (XAI)**
   - Make AI behavior **transparent** and **understandable**.
4. **Data Governance**
   - Use **unbiased, diverse datasets** and follow **privacy laws** (like GDPR).
5. **International Policies & Regulations**
   - Global guidelines on weaponization, privacy, and safety (e.g., EU AI Act).

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