Lecture 03

1. Autonomous Robots

- **Definition**: Robots that *sense, compute, communicate, and act* on their own! �→💻→🤝→⚡
- **Key Abilities**:
  - **Locomotion**: Moving *themselves* (e.g., drones flying 🚁, robots walking 🦿).
  - **Manipulation**: Moving *objects* (e.g., robot arms picking items 🏋️).

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2. Locomotion

- **Types**: Rolling (wheels 🛞), walking (humanoid robots 🦿), sliding (snake robots 🐍), jumping (hopper bots 🦘), climbing (spider bots 🕷️).
- **Key Idea**: Different locomotion = different design challenges (e.g., balance for bipedal robots!).

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3. Pose

- **What**: Position + Orientation 📍 + 🧭.
  - *Example*: A drone's pose = where it is (GPS coordinates 🌐) + which way it's facing (yaw/pitch/roll ✈️).
- **Relative Pose**: Always measured *relative to a reference frame* (e.g., "the cup is 2m *in front* of the robot").

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4. Coordinate Frames

- **What**: A 3D "map" with X, Y, Z axes 🗺️.
- **Example**:
  - **World Frame** {W}: Fixed to the room (e.g., origin = corner of the lab 🧪).
  - **Robot Frame** {R}: Fixed to the robot (e.g., origin = its center 🤖).
- **Key Takeaway**: All poses are *relative*! There's no "absolute" pose.

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5. Orientation Representations

Euler Angles

- **Roll, Pitch, Yaw** (like an airplane ✈️):
  - **Roll**: Tilting side-to-side (🤸).
  - **Pitch**: Nose up/down (📈).
  - **Yaw**: Turning left/right (🔄).
- **Pros**: Intuitive!
- **Cons**: Discontinuous (small changes → big jumps in angles).

Axis-Angle

- **What**: A single rotation around a custom axis (e.g., spinning a pen 🖊️ around your finger).
- **Formula**: Orientation = [*axis vector*, *rotation angle*].

Rotation Matrices

- **What**: 3x3 matrix that rotates points in space 🔄.
- **Pros**: Mathematically powerful (combine rotations, apply to points).
- **Cons**: Redundant (9 numbers for 3 DOF).

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6. Relative Pose & Transformations

- **Rigid-Body Transformation**: Moving an object *without changing its shape* (e.g., sliding a book on a table 📖→📖).
- **Example**:
  - **Teapot Pose**: Relative to camera → camera pose relative to robot → robot pose in room.
  - **Chain of Frames**: Pose A → B → C = Multiply transformations!

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7. Key Takeaways

- **Autonomous Robots** = Sense + Actuate (locomotion/manipulation).
- **Pose** = Where + How oriented (relative to a frame).
- **Euler Angles** = Roll-Pitch-Yaw (easy but jumpy).
- **Rotation Matrices** = Math-friendly but redundant.

Cheat Sheet

Term	Definition	Example
Locomotion	Robot moves *itself*	Drone flying 🚁
Manipulation	Robot moves *objects*	Arm picking a box 📦
Euler Angles	Roll, pitch, yaw	Airplane maneuvering ✈️
Axis-Angle	Rotation around a custom axis	Spinning a globe 🌐
Rotation Matrix	3x3 matrix for rotations	Rotating a 3D model 🖥️

إِنَّ اللَّهَ وَمَلَائِكَتَهُ يُصَلُّونَ عَلَى النَّبِيِّ ۚ يَا أَيُّهَا الَّذِينَ آمَنُوا صَلُّوا عَلَيْهِ وَسَلِّمُوا تَسْلِيمًا (56)

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1. 3D Rotation Matrices

- **Purpose**: Represent orientations in 3D space using 3×3 matrices.
- **Key Rotations**:
  - **X-axis**: $R_x(\theta) = \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos\theta & -\sin\theta \\ 0 & \sin\theta & \cos\theta \end{bmatrix}$
  - **Y-axis**: $R_y(\theta) = \begin{bmatrix} \cos\theta & 0 & \sin\theta \\ 0 & 1 & 0 \\ -\sin\theta & 0 & \cos\theta \end{bmatrix}$
  - **Z-axis**: $R_z(\theta) = \begin{bmatrix} \cos\theta & -\sin\theta & 0 \\ \sin\theta & \cos\theta & 0 \\ 0 & 0 & 1 \end{bmatrix}$
- **Use Case**: Combine rotations (e.g., robot arm joints) by multiplying matrices.

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2. Configuration Space (C-space)

- **Definition**: All possible robot configurations defined by **generalized coordinates** (e.g., joint angles for a robot arm).
- **Holonomic vs. Non-Holonomic**:
  - **Holonomic**: Full control over all DOF (e.g., drone 🚀).
  - **Non-Holonomic**: Fewer controllable DOF than total DOF (e.g., car 🚗 can't move sideways).
- **Example**: A car's C-space includes (x, y, θ), but motion is constrained by steering.

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3. Workspace vs. Task Space

- **Workspace**: Physical area a robot can reach (e.g., robot arm's reachable volume 🤖).
- **Task Space**: Poses required for a task, even if unachievable (e.g., inserting a peg into a hole requires precise orientation 🕳️).

4. Robotic Components

- **Effectors**: Limbs for movement (arms, legs, wheels).
- **Perception**: Sensors (cameras 👁️, LiDAR, touch).
- **Control**: "Brain" algorithms (planning, decision-making 🧠).
- **Power**: Energy source (batteries 🔋).
- **Communication**: Data transfer (Wi-Fi, Bluetooth 📡).

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5. Intelligent Robots & AI

- **Agent**: Perceives environment, acts to maximize success (e.g., self-driving car 🚗).
- **AI Areas**: Planning, learning, vision, NLP (e.g., robot learns to avoid obstacles 🧠).

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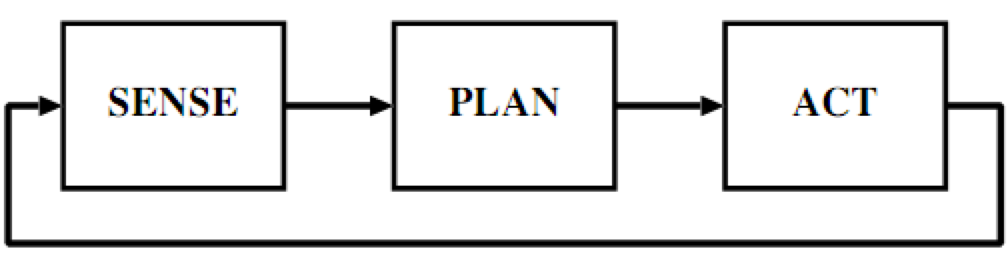
6. Robot Paradigms

Paradigm	Structure	Pros	Cons
Hierarchical	SENSE→PLAN→ACT	Structured, global planning	Slow (planning bottleneck 🐌)
Reactive	SENSE→ACT	Fast, real-time responses ⚡	No long-term planning 🤷‍♂️
Hybrid	PLAN→(SENSE→ACT)	Balances planning + reactivity	Complex integration 🧩



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7. Behaviors

- **Definition**: Sensor → Action mappings (e.g., "avoid obstacle" when near a wall 🚧).
- **Releaser**: Trigger (e.g., detecting light 🌞 activates "seek light" behavior).
- **Guide**: Sensor data directs action (e.g., proximity sensors steer around obstacles 🔴).

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8. Degrees of Freedom (DOF)

- **DOF**: Independent movements (e.g., 6 DOF arm: x, y, z + roll, pitch, yaw 🦾).
- **Redundant Robots**: More DOF than needed (e.g., human arm with 7 DOF 👐).

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9. Key Examples

- **Holonomic Robot**: Omnidirectional drone (moves freely in 3D 🚁).
- **Non-Holonomic Robot**: Car (steering limits motion 🚗).
- **Hybrid Paradigm**: Delivery robot plans route (mission planning) + reacts to obstacles (reactive behavior 📦).

Cheat Sheet

Term	Key Idea
Rotation Matrices	Math for 3D rotations (combine with multiplication 🔄).

Term	Key Idea
C-space	All possible robot configurations (joint angles, poses 🗺️).
Reactive Paradigm	Fast, no planning (e.g., Roomba avoiding furniture 🧹).
Behavior	"If sensor X, do action Y" (e.g., follow light 💡).

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