AI in Robotics: Delivery Robots and Drones

1. Introduction: AI in Robotics

Artificial Intelligence (AI) is transforming robots from rigid, pre-programmed tools into adaptive, autonomous agents. In this lecture, we explored how AI is powering delivery robots and drones, enabling them to perform complex tasks like navigation, object avoidance, environment mapping, and even collaborative learning.

1.1 Perception and Sensing

- Robots are equipped with cameras, LiDAR, radar, GPS, and ultrasonic sensors.
- **AI models (e.g., CNNs)** process camera feeds to detect objects, people, traffic signs, or landmarks.
- **Sensor fusion algorithms** combine data from multiple sources to create a coherent, real-time understanding of the robot's surroundings.

1.2 AI for Decision Making

- Traditional robotics used hand-coded rules.
- AI enables learning from interaction via **Reinforcement Learning (RL)**.
- Robots use trial-and-error to learn optimal behavior in dynamic environments, handling unpredictable scenarios gracefully.

1.3 SLAM and Navigation

- Simultaneous Localization and Mapping (SLAM) is essential for robots that operate in unfamiliar or unmapped areas.
- **AI-enhanced SLAM** uses deep neural networks to improve feature extraction, loop closure detection, and map accuracy in challenging environments (e.g., poor lighting, dynamic obstacles).

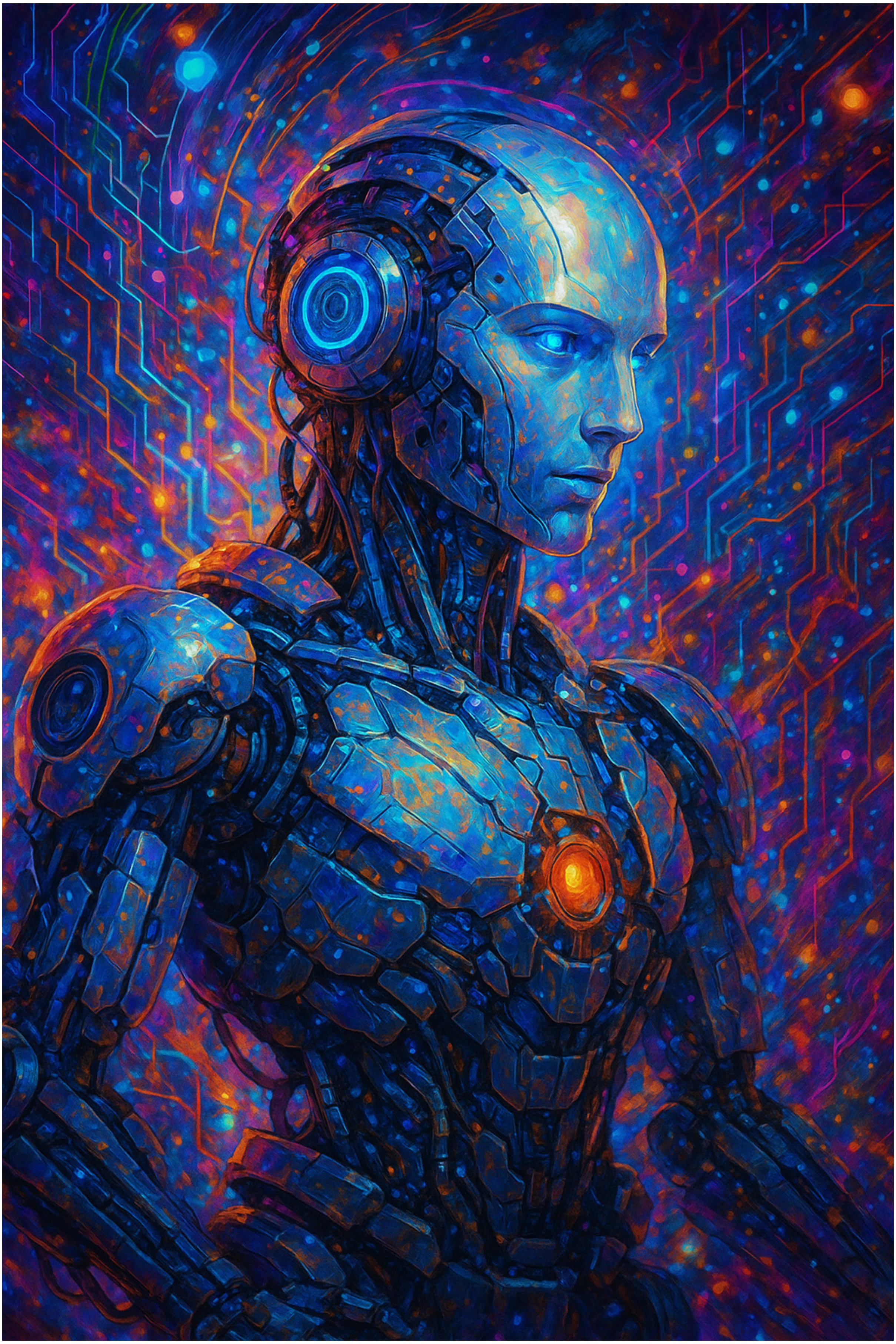

Figure 1: AI in Robotics

1.4 Motion Planning and Control

- AI enables **adaptive control** systems that adjust based on terrain, payload, and real-time sensor feedback.
- Algorithms like **LSTM, DDPG, and PPO** help robots learn how to move, balance, and respond to disturbances (e.g., wheel slip, wind).

1.5 Autonomous Collaboration

- AI allows teams of robots or drones to coordinate using shared policies and objectives.
- Approaches like **swarm intelligence and federated learning** allow agents to learn together or share experiences without centralized data storage.

2. Path Planning and Object Avoidance

2.1 What is Path Planning?

Path planning refers to computing an optimal route from a start point to a goal while avoiding obstacles. Key objectives:

- Safety: Avoid people, vehicles, and environmental hazards.
- Efficiency: Minimize distance, time, or energy use.
- Adaptability: Update the path in real time when conditions change.

2.2 AI-Based Planning Techniques

- **DQN (Deep Q-Network):** Learns discrete action sequences through rewards.
- **PPO (Proximal Policy Optimization)** and **A3C (Asynchronous Advantage Actor-Critic)** support continuous actions and faster learning in uncertain environments.
- These models outperform classical path planners (e.g., A*) in dynamic, partially observable settings like crowded sidewalks or airspace.

2.3 Object Avoidance in Dynamic Environments

- AI predicts the future movement of dynamic objects (e.g., humans, pets, vehicles).
- **LSTM networks** help by modeling time-series data to anticipate movement patterns.
- Example: A sidewalk robot slows down when it detects a dog approaching based on its trajectory.

3. Simultaneous Localization and Mapping (SLAM)

3.1 SLAM Overview

- SLAM allows a robot to map an unknown environment while keeping track of its own location.
- Key challenge: The robot starts without a map and without knowing where it is.

3.2 AI in SLAM

- **Feature Extraction:** AI uses CNNs or SuperPoint to identify robust landmarks across lighting and viewpoint variations.
- **Loop Closure:** Detecting when the robot revisits a known location. Deep learning models like NetVLAD and DeepLoop increase accuracy and reduce false positives.

3.3 Applications

- Used in drones, autonomous vehicles, AR/VR, and service robots for navigation and positioning.

4. AI-Based Real-Time Control

4.1 Sensor Fusion

- Combines IMU, LiDAR, GPS, and vision data to produce a coherent model of the robot's state.
- Reduces drift and corrects for sensor errors (e.g., GPS outage or wheel slip).

4.2 Control Algorithms

- **LSTM:** Recognizes temporal dependencies for smoother control.
- **DDPG:** Suitable for fine-grained control in continuous spaces (e.g., drone thrust).
- **PPO:** Balances performance and stability, ideal for legged robots and UAVs.

4.3 Visual Servoing

- CNNs interpret camera input to generate control commands.
- Used in:
  - Drone landing on moving targets.

- Robotic arms grasping irregular objects.
- AGVs adjusting position in warehouses.

5. Case Study: Amazon Scout

5.1 System Overview

Amazon Scout is a sidewalk delivery robot designed for autonomous last-mile delivery in urban/suburban areas.

5.2 Technology Stack

- **Perception:** 360° view using cameras, LiDAR, and ultrasonic sensors.
- **SLAM + GPS:** Localizes itself and builds dynamic maps.
- **Path Planning:** Recomputes routes if sidewalks are blocked.
- **Obstacle Avoidance:** Detects humans, pets, poles.
- **Object Recognition:** Identifies delivery zones and crosswalks.
- **Edge AI:** Uses embedded compute (e.g., NVIDIA Jetson) for on-device inference.

5.3 Impact

- Tested in U.S. states like Washington and California.
- Reduces delivery time and carbon emissions.
- Opens only for verified users via mobile app.

6. Case Study: Swiggy Drones

6.1 Purpose

Autonomous drones delivering food in congested cities or remote areas where road delivery is slow or infeasible.

6.2 AI Capabilities

- **Route Planning:** Uses AI to navigate via GPS, avoiding no-fly zones.
- **Obstacle Avoidance:** Uses cameras, ultrasonic sensors, and LiDAR.
- **Payload Control:** Adjusts thrust based on meal weight and weather conditions.
- **Fleet Management:** Central AI system coordinates multiple drones.

6.3 System Architecture

- **Flight Controller:** PX4 or ArduPilot autopilot boards.
- **Navigation:** RTK-GPS for centimeter-level accuracy.
- **Edge AI:** Jetson Nano/Xavier for real-time vision.
- **Delivery:** Winch or box-drop system.

6.4 Indian Context

- Pilot programs in Hyderabad, Bangalore, Gurugram.
- Approved by India's Ministry of Civil Aviation under Drone Rules 2021.

7. Case Study: Wing by Google (Alphabet)

7.1 Mission

Deliver small packages like groceries or medical items using autonomous UAVs.

7.2 AI Systems

- **Route Optimization:** AI selects flight paths based on traffic, weather, and demand.
- **Collision Avoidance:** Avoids birds, buildings, and other drones using deep learning.
- **Weather Awareness:** Adjusts altitude and path in real-time.
- **Payload Delivery:** Winch system stabilized by visual feedback.

7.3 Deployment

- **Australia:** Logan (groceries, meals).
- **USA:** Christiansburg (medicines).
- **Finland:** Helsinki (general e-commerce).
- Delivery in under 6 minutes, fully autonomous.