Cost-Effective Ferromagnetic Pipe Climbing Robot using ESP32-CAM

- **Problem Statement:**
  - Industrial pipelines, tanks, and marine vessels are built from ferromagnetic materials and need frequent inspection.
  - Manual inspections are dangerous and costly.
  - Existing robotic systems are expensive and often use Raspberry Pi, increasing weight and power consumption.
  - Goal: Develop a compact, 3-wheel magnetic adhesion robot using ESP32-CAM for live video streaming and remote control.
- **Aim**
  - Enable remote inspection in hazardous areas.
  - Reduce human intervention while improving safety.
  - Provide a low-cost, lightweight, and power-efficient robot for industrial use.
  - Achieve autonomous/semi-autonomous navigation on ferromagnetic pipes.
  - Ensure magnetic adhesion with 3-wheel stability.
  - Integrate sensors for obstacle detection and predictive maintenance.
- **Solution Approach**
  - ESP32-CAM acts as controller + camera, streams video, processes basic sensor data, and communicates via Wi-Fi.
  - 3 BO motors (6V, 60–150 RPM) provide motion:
  - 2 × Rubber wheels for drive,
  - 1 × Omni wheel for balance/steering.
  - Motor driver (L298N / L293D) controls motors from ESP32-CAM signals.
  - Neodymium magnets provide strong adhesion to ferromagnetic surfaces.
  - Sensors:
  - HC-SR04 → obstacle detection,
  - MPU6050 → orientation sensing,
  - IR sensors → edge/proximity.

Component List

- ESP32-CAM (AI-Thinker + OV2640)
- Motor Driver (L298N / L293D)
- BO DC Gear Motors (6V, ~60–150 RPM)
- Omni Wheel (65 mm)
- Normal Rubber Wheels (65 mm)
- Chassis Plate (Acrylic / 3D-printed base)
- Strong Neodymium Magnets
- Ultrasonic Sensor (HC-SR04)
- MPU6050 (Accelerometer + Gyro)
- Li-ion Battery Pack (7.4V, 2200 mAh) + Charger
- Buck Regulator (7.4V → 5V)
- Jumper wires, connectors, misc. hardware

Logic Flow

- Power ON & Initialization → ESP32-CAM, motor driver, and sensors start.
- Wi-Fi Setup → ESP32-CAM creates server, Flutter app connects.
- Live Video Streaming → Camera feed sent to app.
- User Commands (Forward, Backward, Left, Right, Stop) sent from app → ESP32-CAM → motor driver → motors.
- Sensor Feedback (Ultrasonic, MPU6050, IR) read by ESP32-CAM and displayed in app.
- Safety Logic → If obstacle/edge detected, robot stops or adjusts.
- Shutdown → Robot stops safely when commanded.

Advantages

- Cheaper than 4-wheel version.
- Simpler mechanical design (3 motors only).
- Lighter weight → easier climbing with magnets.
- Mobile app control with live video feed.
- Low power consumption vs. Raspberry Pi solution.

Disadvantages

- Less stable than 4-wheel design on rough pipes.
- Motors are BO type → lower torque (limited for heavy loads).

- ESP32-CAM camera quality lower than Pi camera.

Flutter App Features

- Live Video Feed (MJPEG stream from ESP32-CAM).
- Navigation Control Buttons: Forward, Backward, Left, Right, Stop.
- Sensor Dashboard: Display obstacle distance, tilt angle, IR proximity alerts.

Future Scope Section

- AI-based defect detection (cloud/PC processing).
- Thermal/gas sensors for industrial safety.
- Upgrading BO motors to high-torque gear motors for heavier loads.