**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.