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Project Title: Autonomous Robot for WRO Future Engineers 2025
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1. Introduction

Our project is an autonomous robot developed for the WRO Future Engineers 2025 challenge. The goal of the robot is to navigate the competition field, detect and classify colored blocks, and return to the start position with maximum precision and reliability.

We approached the design with three main principles:

1. **Accuracy in navigation** (moving straight, turning correctly, staying centered).
2. **Reliability in detection** (block colors and zones).
3. **Flexibility for improvement** (modular design to upgrade sensors).

The current version of our robot combines **3D-printed mechanical parts**, **Arduino-based control electronics**, and a mix of sensors (ultrasonics, gyroscope, HuskyLens). We are also working on a **next generation version** integrating a **Slamtec A1 LiDAR with Raspberry Pi**, which will provide higher precision mapping and path planning.

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2. Mechanical Design

- The chassis is fully **3D printed**, allowing us to customize dimensions and weight balance.
- A **servo motor** is mounted at the front to steer the robot with a rack-and-pinion style linkage.
- A single **DC motor with an L298N driver** powers the rear wheels.
- Components are arranged to keep the center of gravity low, which reduces vibration for sensors.

Why 3D Printing?

- Rapid prototyping: We redesigned steering brackets 3 times until the servo angle matched.
- Lightweight: PLA parts reduced unnecessary strain on the DC motor.
- Customizability: The ultrasonic sensor holders are angled at exactly 90° to improve field centering.

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3. Electronics and Sensors

Our electronics follow a modular design, making it easier to test and replace components.

- **Ultrasonic Sensors (HC-SR04):**
  - Front sensor: ensures the robot keeps a safe distance from walls/blocks and helps in detecting the return point.
  - Left & Right sensors: measure distances to the side walls to center the robot automatically in the lane.
- **MPU6050 Gyroscope:**
  - Used for detecting yaw angle (rotation).
  - Helps in keeping the robot moving straight, as wheel drift can otherwise cause deviation.
  - Enables accurate 90°/180° turns.
- **Servo Motor (Steering):**
  - Controlled via PWM from Arduino.
  - Allows us to define “left,” “right,” and “center” positions precisely.
  - We tested multiple servo angle values and recorded them until movement matched the geometry of the wheels.
- **DC Motor + L298N Motor Driver:**
  - Provides forward/backward movement.
  - Speed is controlled by PWM to maintain consistent performance.
- **HuskyLens Camera:**
  - Detects color IDs of blocks and identifies the colored area.
  - Determines if the robot is near its target or needs to adjust course.
  - Acts as the "eye" of the robot, while the gyroscope and ultrasonics act as the "ears."
- **Future Upgrade: Slamtec A1 LiDAR with Raspberry Pi 5:**
  - We purchased a Slamtec A1 LiDAR to replace the ultrasonics in the future.
  - The plan: integrate it with ROS2 on Raspberry Pi for real-time mapping and localization.
  - This will allow our robot to:
    - Build a **map of the field** dynamically.
    - Rely less on wall-based ultrasonic centering.
    - Achieve **cm-level precision** in positioning.

    - During testing, we noticed that ultrasonic sensors sometimes misread distances due to block reflections. That's when we decided to invest in LiDAR, inspired by professional self-driving robots. This upgrade represents our commitment to precision and innovation.

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4. Software and Programming

We programmed the robot using **Arduino IDE** for low-level control and plan to integrate **Python + ROS2** for the LiDAR version.

Current Control (Arduino):

- **Loop cycle:**
    1. Read sensors (ultrasonics + gyroscope + HuskyLens).
    2. Correct steering angle to keep robot centered.
    3. Adjust motor speed.
    4. Act if HuskyLens detects target color ID.
- **Gyro filtering:**
    - We applied a complementary filter to reduce drift from the MPU6050.
- **Safe distance algorithm:**
    - Robot slows down if front ultrasonic detects < 20 cm.
    - Stops if < 10 cm.
- **Return to Start:**
    - Gyroscope angle tracking allows the robot to retrace its path.
    - Front ultrasonic confirms the robot is aligned at the start point.

Planned LiDAR Software (Raspberry Pi):

- ROS2 node to publish `/scan` topic from Slamtec A1.
- Path planning using obstacle avoidance.
- Record path in the first lap, replay path in later laps for maximum accuracy.

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5. Testing and Results

- **Servo testing:** we tested multiple angle values with delay loops until we found the correct center, left, and right turning points.
- **Ultrasonic centering:** when distances from left and right differ by > 3 cm, the servo automatically corrects steering.
- **Gyroscope accuracy:** robot can move straight for ~1.5 meters with < 5 cm deviation.
- **HuskyLens detection:** correctly identified block colors in 9/10 trials under competition lighting.

6. Challenges and Improvements

- Ultrasonics sometimes gave **false echoes** when blocks were angled.
- Gyroscope drifted slightly during long runs.
- Servo required fine-tuning due to plastic flexibility in the 3D print.

Planned Improvements

- Replace ultrasonics with **LiDAR mapping**.
- Add **PID control** for steering using gyroscope feedback.
- Use **computer vision (OpenCV)** on Raspberry Pi to enhance HuskyLens detection.

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7. Sustainability and Design Choices

- 3D printing allowed us to reuse and recycle plastic parts by re-melting failed prints.
- We designed the robot to be **modular**: sensors can be unplugged and replaced quickly.
- By upgrading to LiDAR, the same robot can be used for **research beyond WRO**, e.g., indoor delivery robots.

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8. Future Work

- Full LiDAR-based navigation.
- Integration with **SLAM algorithms** to build maps.
- Adding multi-block detection and optimized route planning.

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9. Conclusion

Our robot combines traditional ultrasonic navigation with modern AI vision (HuskyLens) and precise gyro control. The addition of LiDAR marks the transition toward professional-grade navigation. Through continuous improvement and modular design, we built not just a competition robot, but a platform for learning about autonomous driving technologies.