Alphaslack

WRO 2025 Future Engineers

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Jonathan Yeo Tze Ho
Aung Swan Oo
Xu Yunhe

Introduction

This report presents the design and development of our autonomous vehicle for the WRO 2025 Future Engineers category. The project integrates mechanical construction, electronics, and control software into a system capable of autonomous navigation.

The purpose of this document is to:

- Provide an overview of the vehicle's architecture and functions.
- Explain the reasoning behind major design choices.
- Outline the role of each subsystem (mobility, power, sensing, computation, and obstacle management).
- Serve as a reference for ongoing improvements and as a record of our participation in the competition

1. Mobility

The vehicle uses a **two-motor configuration**: one DC motor for propulsion and one DC motor for steering. The propulsion motor drives the vehicle forward and backward, while the steering motor adjusts the wheel angle, forming an **Ackermann-style steering system**. Both motors operate through **L298N motor drivers**, with speed and position regulated by **PWM signals** from the Raspberry Pi 5.

A **PID control loop** regulates both propulsion and steering. For the drive motor, PID maintains constant speed despite load changes or battery voltage drops. For the steering motor, PID ensures the wheel angle is reached quickly and held steadily without overshoot or oscillation.

The main trade-off in this configuration lies between **stability and maneuverability**. Ackermann steering provides smooth, predictable motion and precise path tracking, but it requires a larger turning radius compared to differential drive. This reduces the ability to perform tight rotations but increases consistency during forward motion and cornering.

2. Power

We use a **dual power strategy** to isolate loads:

- **Raspberry Pi 5 + sensors** powered by a **30W, 10,000 mAh USB-C power bank**.
- **Drive and steering motors** powered by a **Li-Po battery** through the L298N drivers.

Protective components are included:

- **Resistors** for GPIO protection.
- **Voltage regulators** to ensure safe levels for the Pi's inputs.
- **Inline fuses** and the Li-Po's **BMS** to guard against shorts or over-discharge.

This separation ensures stable performance preventing motor surges from resetting the Raspberry Pi.

3. Sensing

The sensing system integrates multiple devices for navigation:

- **Logitech USB** webcam provides vision input for line tracking, color recognition, and higher-level obstacle perception.
- **HC-SR04 ultrasonic sensor** detects obstacles directly ahead, giving short-range measurements and protection from hitting the obstacle.
- **MPU6050 IMU** measures orientation and angular changes, used for tracking turns and stabilizing steering behavior.

4. Obstacle Management

Obstacle detection uses **two layers**:

- **Ultrasonic sensing** to provide fast stop/slow responses when an object is detected within a threshold distance.
- **Vision (camera)** to detect markers, blocks and course boundaries.

The avoidance strategy is **steer-around maneuvering**. When an obstacle is detected, the system reduces speed, adjusts steering to bypass the obstacle, and then re-centers to continue forward. For the WRO FE challenge, this is sufficient, though extensions can be added for more advanced versions. Current logic is rule-based for reliability, but ML-based decision-making is being tested.

5. Control and Computation

The **Raspberry Pi 5 (8GB)** serves as the central controller. It handles:

- **Vision processing** using the USB webcam.
- **Sensor fusion** from IMU and ultrasonic inputs.
- **Control** of the drive and steering motors via L298N motor drivers.

Connections:

- **USB**: Webcam.
- **I2C**: MPU6050.
- **GPIO**: Ultrasonic trigger/echo.
- **PWM GPIO**: Motor control signals to the L298N.

The Pi runs tasks in parallel to guarantee responsive obstacle detection while processing camera input.

6. Motivation

The design choices are based on reliability, simplicity, and effective use of available parts. LEGO is used for the frame and motors because it provides a sturdy yet modular structure that can be quickly assembled and modified. Using LEGO motors also ensures mechanical compatibility with the frame while keeping the design lightweight and easy to adjust.

The Ackermann-style steering system was selected because it matches the layout of the LEGO chassis and provides smooth directional control through a dedicated steering motor. A separate drive motor handles propulsion, which keeps the control system straightforward compared to multi-motor differential arrangements.

Power is split between a Li-Po battery for the motors and a USB power bank for the Raspberry Pi 5. This prevents voltage fluctuations from the motors from affecting the controller. L298N motor drivers were chosen because they integrate easily with both DC motors and Raspberry Pi GPIO.

The sensing setup of a Logitech webcam, HC-SR04 ultrasonic sensor, and MPU6050 IMU was selected to give a balance of vision, distance measurement, and orientation feedback. Each sensor plays a distinct role, and together they provide reliable navigation and obstacle detection.

These decisions result in a system that combines the modularity of LEGO mechanics with the flexibility of external electronics, while remaining simple, robust, and open to further improvement.

Summary

This project presents the design of an autonomous vehicle developed for the WRO 2025 Future Engineers category. The system integrates a two-motor Ackermann steering configuration, dual power domains for stability, and a sensing suite combining vision, ultrasonic, and inertial data. Obstacle management is handled through layered detection and rule-based avoidance, with scope for machine learning integration. Using LEGO for the frame and motors together with external electronics provides a modular and adaptable platform. The overall design emphasizes simplicity, robustness, and expandability, offering a solid foundation for both competition tasks and future enhancements.