Princess Sumaya University for Technology

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Embedded Systems (22442)

Project

Autonomous Mobile Robot Challenge

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Abstract

This project presents the design and implementation of an autonomous mobile robot developed for a multi-stage challenge. The robot is required to perform several tasks, including line following, tunnel detection, obstacle navigation, bump traversal, and parking. The system integrates mechanical design, electrical hardware, and software logic to enable autonomous operation across different zones of the course. This report discusses the design, control logic, and challenges encountered during the project.

The robot's control system is based on a PIC16F877A microcontroller, and the robot behavior is implemented using a finite-state machine approach. Multiple flow charts are used to describe the overall system logic. The robot is built on a two-wheel differential-drive chassis with a passive caster wheel to provide stability and maneuverability. A variety of sensors are used to perceive the environment, including IR sensors for line tracking and wall detection, ultrasonic sensors for obstacle and wall detection, and an LDR sensor for tunnel detection.

During development, several practical challenges were encountered, such as motor power imbalance, unreliable IR-based obstacle detection, and battery charging issues. These issues were handled by implementing multi-conditional control logic, adjusting PWM values for motor balance, and using a 3S Battery Management System (BMS) for safe battery charging.

This project demonstrates the importance of testing, calibration, and practical problem-solving in developing reliable autonomous robotic systems. This report discusses the design, control logic, and challenges encountered during the project.

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Introduction

The field of robotics comes hand in hand with the embedded systems field, the advancement of embedded systems over the years enabled machines to perceive and navigate complex environments with minimal interventions from humans, from automation to self-driving cars, for the robot to be able to switch between different moving styles like follow a line, then notice that it is in a tunnel then move freely without a line, this in itself is a significant requirement for modern autonomous systems.

Project objectives

This project focuses on designing an Autonomous Mobile Robot, developed in way that enables it to participate in a multi-stage navigational challenge, the primary features that are in this robot are to deal with the following challenges:

1) Line following: tracking of a predefined path using infrared sensing.
2) Tunnel navigation: perform specific actions upon recognizing that the robot is in the tunnel, using an LDR sensor.
3) Obstacle Avoidance: to avoid the obstacle and navigate to the designated parking spot.
4) Parking: to park in the parking area and raise a flag.

System architecture overview

To tackle these challenges, our team designed an integrated system that focuses on mechanical stability, electrical efficiency, and intelligent software logic, our approach utilizes the PIC 16F877A microcontroller as the central processing unit, interfacing with a number of sensors and drivers.

The software approach was to build a finite-state machine, so the robot can switch between these states after detecting specific environmental triggers, this report showcases the engineering decisions, hardware integration, and algorithmic logic that define our robot’s performance in the competition.

Our Design

Mechanical Design

Design Approach

While designing the autonomous mobile robot the structural simplicity was our first priority, we focused on component integration and compatibility with the physical constraints of the environment. Things like dimensional clearance or inclined surfaces, and reliable sensor readings in specific sections of the map.

Base Chassis Description

The robot is built on the given two-wheel mobile robot chassis that contains an acrylic base plate, two DC geared motors with rear-mounted wheels, and a passive caster wheel. One of the advantages of this chassis is that it is a lightweight yet rigid platform capable of supporting the required components and sensors.

Locomotion and Support System

Drive Mechanism

The robot employs a differential-drive configuration where the turning of the car depends on controlling the speed and direction of the fixed wheels meaning there is no steering wheel, it does that using two independently driven DC motors, they are place on the right and left side of the chassis symmetrically. This configuration allows the robot to move easily in narrow spaces and follow curved paths without using a steering mechanism.

Passive Support Wheel

A passive caster (free-rotating) wheel is placed at the lower rear section of the chassis to provide a third point of ground contact. The free-wheel supports chassis stability and allows smooth movement without driving the robot.

Structural Integration and Component Placement

Battery Pack Placement

The battery pack is placed on the lower section of the chassis, providing a compact and accessible power source. This placement was primarily chosen to free the upper chassis area for breadboard placement and electronic connections.

Breadboard and Electronics Placing

Breadboards and electronic modules are placed on the upper section of the chassis, where there is enough space. This placement allows easy access for wiring, testing, and any modification we might do during development while ensuring that electronic components do not interfere with the wheels, or the motor operation, or sensor placement.

Sensor Placing

Line-Following Sensors

Line-following IR sensors are placed close to the ground to ensure it detects the line. Their position minimizes sensitivity to light variations in the surrounding environment and it maintains a consistent sensing distance from the ground.

Ultrasonic Distance Sensor

Two ultrasonic distance sensors are used on the robot. One sensor is positioned at the front of the robot for forward obstacle detection, while a second sensor is positioned on the right side of the chassis to detect the presence of a wall after exiting the tunnel. The placing height and direction ensure that the sensor operates effectively in narrow and confined sections of the given map.

Light Sensor

A light-dependent resistor (LDR) is positioned on the upper portion of the robot to detect changes in ambient light conditions. This allows accurate detection of reduced lighting environments such as the enclosed tunnel.

Mechanical Constraints and Compliance

The mechanical design complies with all relevant dimensional and clearance constraints of the operating environment. The overall height of the robot remains within allowable limits, ensuring safe passage through low-clearance sections. All components are mounted within the chassis footprint to prevent mechanical interference during navigation.

Limitations and Future Improvements

While the current mechanical design satisfies the project requirements, potential improvements include adjustable sensor mounts for fine alignment, modular mounting solutions for easier component replacement, and enhanced mechanical protection for exposed wiring.

Electrical Design

The electrical design acts as the nervous system of the robot, it performs power regulation, signal processing, and motor control. In our design, we prioritized power efficiency to ensure the robot work in a way that's reliable throughout the competition, the three main categories to cover in this section are: the control unit, the sensors integration, power distribution system.

Control and actuation

At the core of the robot is the PIC16F877A microcontroller. Which processes inputs from the different sensors to execute specific instructions, to drive the DC motors, we used the L298N H-bridge module. This allows us to control the motors using PWM signals from the microcontroller unit, enabling the robot to adjust its speed during the navigation between different zones and make precise turns during the obstacle avoidance zone.

Sensor integration

What makes the robot able to perceive its surroundings is a collection of different sensors that include:

- Line tracking: Two IR reflective sensors are used to detect the contrast between the line and the floor.
- Distance Sensing: Two HC-SR04 ultrasonic sensors are used to detect walls and obstacles.
- Light intensity: one LDR sensor is used to detect the robot entrance into the tunnel.

Power Management

To prevent brownouts (microcontroller resetting due to the motor current spikes), the design uses a dual trail power supply. Three 3.7 Volts batteries providing the main power, which is then regulated. To sum up, a high power of 12 volts is directly connected from the batteries to the motor driver, a small regulated 5 volts from the MB102 breadboard power supply module to the microcontroller and sensors.

Software Design

General Flow Chart

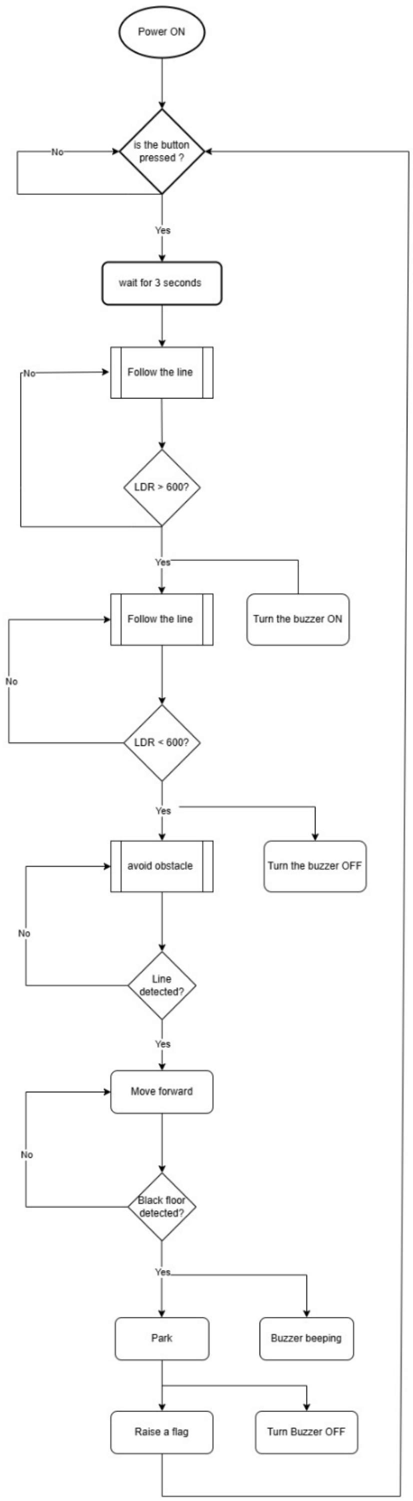

Figure 1: General Flow Chart

Line Follower Flow Chart

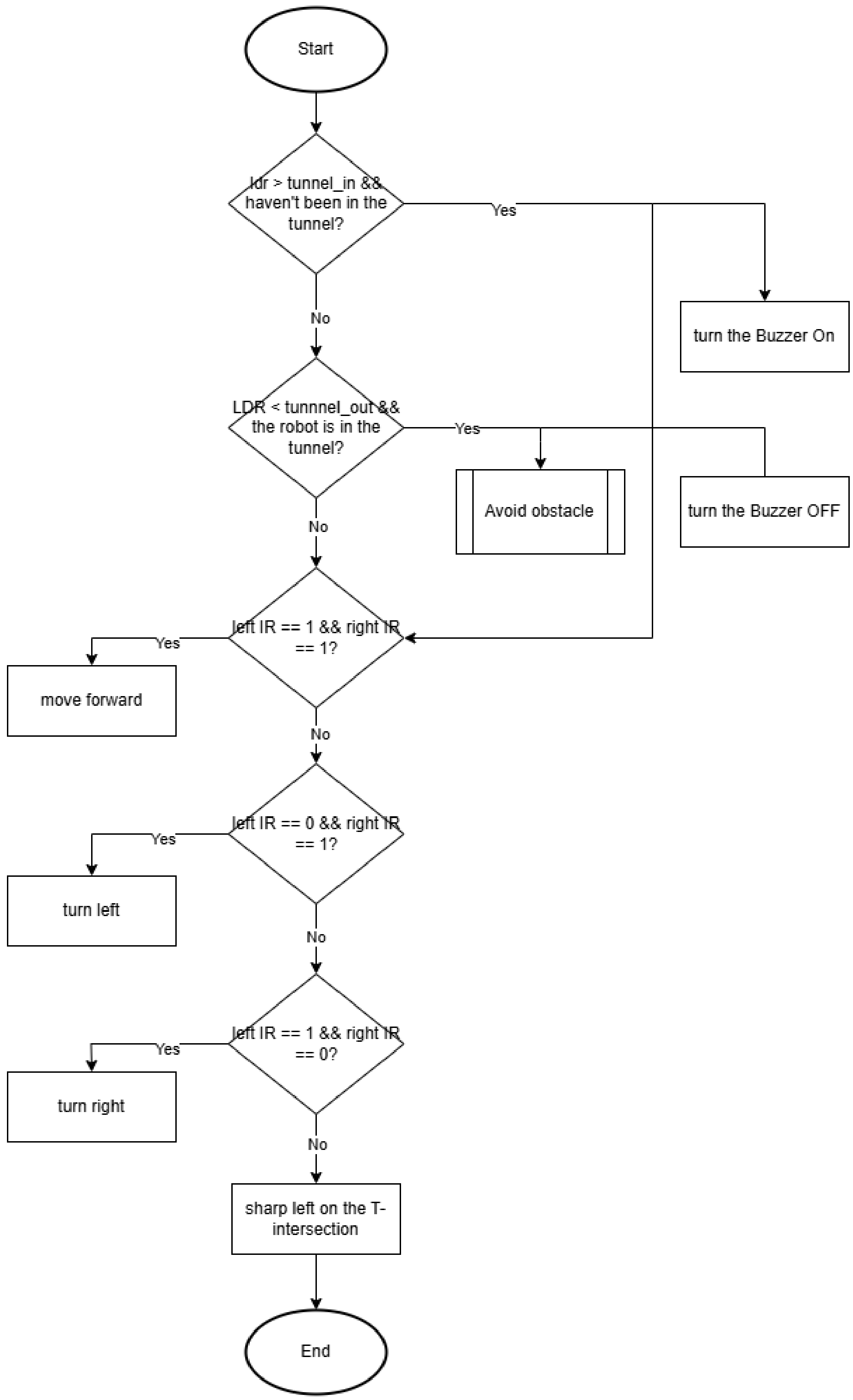

Figure 2: Line Follower Flow Chart

Obstacle Avoidance Flow Chart

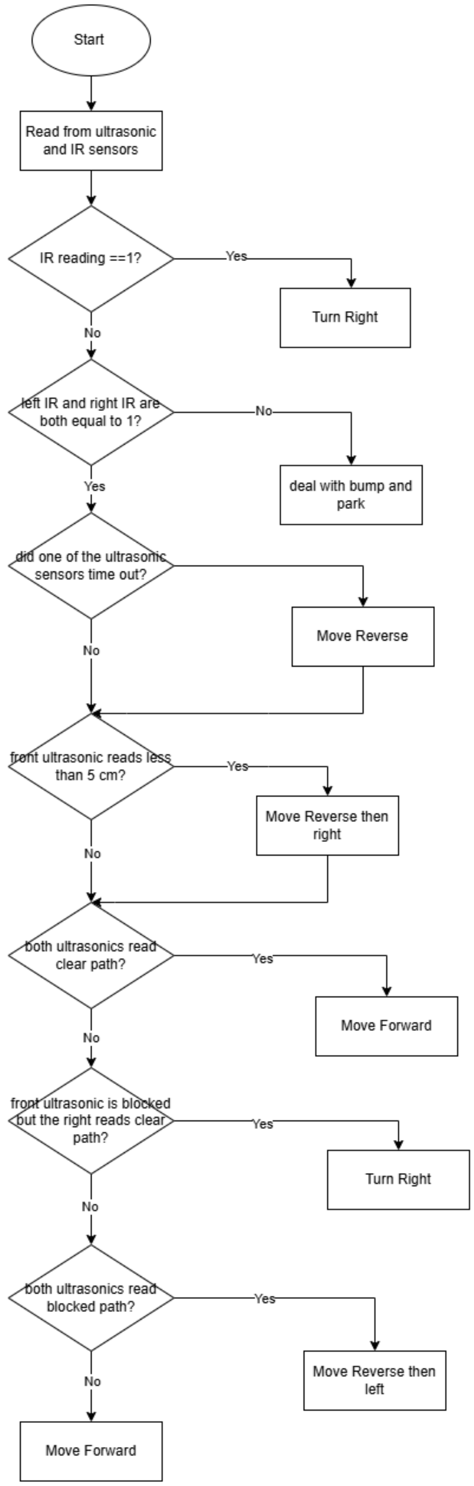

Figure 3: Obstacle Avoidance Flow Chart

Problems and recommendations

Microcontroller Pin Issues

During testing, the PIC microcontroller pins and legs were easily damaged. Frequently changing the wiring and configurations, caused some pins to bend and break. We tried fixing the pins by heating and straightening them, but this did not work properly. As a result, we had to buy multiple microcontrollers, since the two originally available were not enough to complete the project.

Motor Power Difference and Straight Motion Problem

One of the main problems we faced was that the two motors did not have the same power. Even when both motors were set to the same PWM value, the robot did not move straight and instead curved to one side.

In the line-tracking zone, this issue was less noticeable because the IR sensors continuously corrected the robot's movement while following the line. However, when the robot exited the tunnel and needed to move straight without line guidance, the imbalance became clear.

During testing, one motor stopped responding to the control code entirely. At first, we suspected an issue with the motor driver or H-bridge, but after further testing, it became clear that the motor itself was damaged. The motor was then replaced.

After installing the new motor, the robot still did not move straight when both motors were given the same PWM value, as the motors were not perfectly matched. Through trial and error, we found that the robot moved in a straight line only when there was a difference of approximately 11 PWM values between the two motors (for example, one motor at 65 and the other at 55).

When the robot was set to maximum speed during line tracking, the IR sensors could not detect the T-intersection fast enough. This caused delayed responses and incorrect behavior.

We reduced the speed to a medium level, which allowed the robot to detect the line and intersection reliably. In future designs, the robot speed could be adjusted automatically depending on the section of the track.

Obstacle Detection Problems

With the front ultrasonic sensor, we tried using IR sensors on the sides to detect obstacles in the obstacle zone. However, the IR sensors were unreliable because they were sensitive to surface color, especially when detecting black and white obstacles, as well as reflections from nearby surfaces. This made it difficult to set a stable detection threshold, and the sensor readings were inconsistent.

We tested several configurations to solve this issue; we tried reducing the number of IR sensors and placing them at the back of the robot. We also tried adjusting the sensitivity using the resistor on the IR sensor, but this was not enough to fix the problem. The IR sensors continued to give unstable readings, which affected the robot's ability to navigate the obstacle zone.

To solve this problem, we changed our approach and replaced the IR sensor on the right side with an additional ultrasonic sensor placed at the same location. This side ultrasonic sensor works with the front ultrasonic sensor to provide more consistent and reliable distance measurements.

Using two ultrasonic sensors allowed us to implement a wall-following strategy instead of relying with the help of on IR on the left of the robot. The front ultrasonic sensor detects obstacles ahead, while the right ultrasonic sensor detects the wall after exiting the tunnel, the left IR detects if the wall was too close from the left, This approach proved to be more reliable and allowed the robot to navigate through the obstacle zone successfully.

Battery Charging Issues

Charging the batteries was difficult because the available charger was not working properly. This caused delays and limited testing time. To solve this, we used a 3S Battery Management System (BMS) to safely charge and protect the batteries.

This project showed that hardware problems such as motor differences, sensor instability, and component damage are common in real systems. Testing, calibration, and trial-and-error were essential to understanding and improving the robot's performance.

Conclusions

The autonomous mobile robot challenge successfully demonstrated the integration of mechanical design, electrical engineering, and software logic to navigate a complex, multi-stage environment. Using the PIC16F877A microcontroller and a finite-state approach, the robot was able to transition between different operational modes, including line following, tunnel navigation, and obstacle avoidance.

Through constant testing and troubleshooting, we uncovered key insights that shaped the entire project:

- Hardware Calibration: physical inconsistencies required effort to overcome, like the power imbalance between DC motors, which needed a specific PWM offset to achieve straight line motion.
- Sensor optimization: through our trials, we noticed that the IR sensors were not reliable, they were prone to errors caused by surface color and ambient reflections, so we relied on ultrasonic sensors, it provided far more reliable distance measurements for wall-following and obstacle avoidance.
- System Resilience: challenges about the fragile nature of the microcontroller pins and battery management were addressed by using a 3S Battery Management System and more careful hardware handling.

Ultimately, the project illustrated that while theoretical design is foundational, real-world calibration and trial-and-error are essential for building a reliable autonomous system capable of perceiving and reacting to its environment.

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