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EC-310 Microprocessor & Microcontroller Based Design

Lab Project Report

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Table of Contents

Abstract

This project presents the design and implementation of an autonomous line-following robot tailored for indoor package delivery across structured environments such as warehouses, offices, hospitals, and retail spaces. The robot employs a combination of infrared (IR) sensors for line detection and an optional ultrasonic sensor for obstacle detection, enabling it to navigate predefined paths while dynamically responding to obstructions in real-time. The core of the system is an Arduino microcontroller, which processes sensor inputs, executes decision-making logic, and drives the motors accordingly. The robot is designed to carry small payloads within a secure compartment, making it suitable for repetitive transport tasks that typically consume time and labor.

The main goal of the project is to demonstrate how cost-effective hardware components, when coupled with efficient control logic, can result in a robust automation system for logistics. Unlike complex industrial robots that require advanced machine vision or localization systems, this design simplifies implementation by relying on static paths and rule-based algorithms, making it highly accessible for educational and prototyping purposes. The project also lays the groundwork for future enhancements such as RFID integration, wireless communication, and AI-based path planning. Through testing in simulated environments, the robot has shown reliable performance in navigation, package security, and obstacle handling—providing a scalable solution for micro-logistics automation.

1 Introduction

1.1 Background

The increasing demand for automation in industrial and service sectors has led to the adoption of autonomous systems that enhance productivity while minimizing human involvement in routine tasks. In logistics and intra-logistics, one such task is the repeated manual transfer of packages or small items between predefined locations. In environments like warehouses, hospitals, offices, and retail centres, the time and labour consumed in these repetitive processes can significantly reduce operational efficiency.

Autonomous guided vehicles (AGVs) and line-following robots offer a practical, cost-effective solution to this problem. Unlike GPS- or vision-guided systems, line-following robots rely on simple path-marking mechanisms (usually a black line on a white floor), reducing complexity while maintaining adequate navigation capability in structured spaces.

1.2 Problem Statement

Manual transportation of items in indoor environments is inefficient, prone to error, and resource-intensive. Human operators are often diverted from higher-level tasks to perform these low-skill, repetitive movements. Moreover, in sensitive environments such as hospitals, minimizing human traffic is also crucial for hygiene and safety. There is a need for a reliable, low-cost robotic solution capable of navigating a defined path and handling basic decision-making tasks, such as stopping for obstacles or securely transporting items.

1.3 Relevance and Applications

The relevance of this project lies in its ability to address small-scale delivery needs in institutions where structured layouts and repetitive routes are common. In warehouses, it can reduce the time taken to move items between shelves or workstations. In hospitals, it can assist with the internal transfer of documents or medications. In office environments, it could provide a hands-free method of delivering mail or files. The system's modularity allows for easy adaptation and scaling in accordance with future technological or logistical requirements.

2 Objectives

The main objective of this project is to develop an autonomous, Arduino-based line-following robot capable of reliably transporting small packages across structured indoor environments. To achieve this goal, the project is guided by the following specific objectives:

2.1 Design Objectives

- **Develop a Robust Chassis:** Construct a stable and lightweight robot body that accommodates sensors, motors, and the delivery compartment without compromising balance or maneuverability.
- **Optimize Sensor Placement:** Ensure precise placement of IR sensors to detect path boundaries accurately and prevent misalignment or false triggering.
- **Integrate Obstacle Detection:** Employ an ultrasonic sensor to enable the robot to detect and respond to unexpected obstacles during operation

2.2 Functional Objectives

- **Accurate Path Following:** Implement a control algorithm that allows the robot to consistently follow a predefined black line on a white surface, including sharp curves and junctions.
- **Smooth Motor Control:** Achieve seamless motion and turns using pulse-width modulation (PWM) to regulate the speed and direction of DC motors via a motor driver module.
- **Reliable Package Handling:** Design a secure compartment capable of holding small packages during movement, ensuring items do not fall or shift during transit.

2.3 Technical Objectives

- **Arduino-Based Control Logic:** Program the Arduino microcontroller to process sensor inputs and make real-time navigation decisions, including stopping, turning, and resuming motion.
- **Power Management:** Design an efficient and portable power system using a rechargeable battery pack, capable of powering all components for a reasonable duration.
- **Modular Software Structure:** Create flexible and modular code to allow easy updates, testing, and potential future enhancements such as servo-based delivery or wireless communication.

2.4 Evaluation Objectives

- **Test in Simulated Environments:** Conduct structured testing in lab-like setups such as mock warehouse corridors and office paths to validate functionality.
- **Measure Performance Metrics:** Record and analyse data on path accuracy, obstacle response time, battery efficiency, and package security.

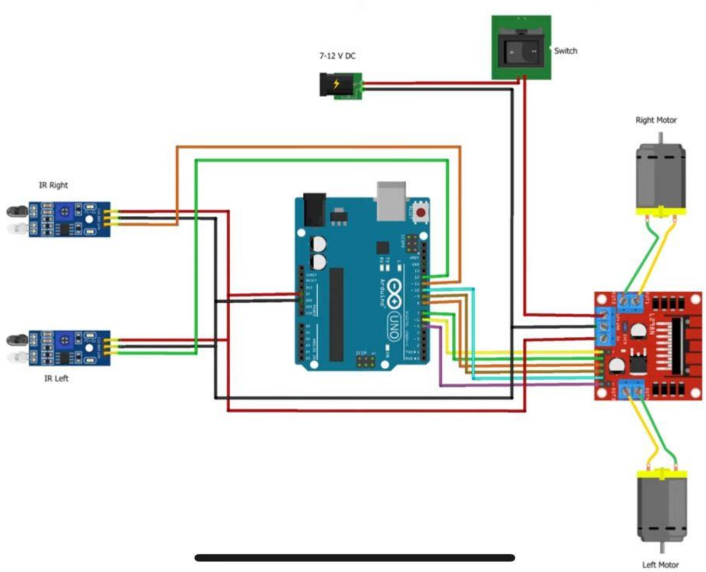
- **Identify and Resolve Issues:** Document challenges encountered during development and propose viable solutions for improved design robustness.

3 System Overview

3.1 Functional Description

The robot detects and follows a black line on a white surface using IR sensors. The Arduino receives sensor inputs, interprets them, and adjusts the motors accordingly. An ultrasonic sensor may be included to detect obstacles and pause movement until the path clears.

3.2 Block Diagram



4 Hardware Implementation

4.1 Components List

- **Arduino UNO** – Brain of the system.
- **IR Sensors** – Detect line path.
- **Ultrasonic Sensor** – Detects front obstacles.
- **L298N Motor Driver** – Interface between Arduino and DC motors.
- **DC Motors** – Provide forward and turning motion.
- **Battery Pack** – Portable power supply.
- **Chassis & Wheels** – Structural frame and mobility.

4.2 Chassis Design

The IR sensors are connected to digital pins, ultrasonic sensor to digital I/O (trigger and echo), motor driver inputs to PWM-enabled pins, and motors to the output terminals of L298N. Power is shared across components through regulated voltage from the battery.

4.3 Sensor Configuration

The robot is built on a lightweight chassis with sensors mounted in front, motors and wheels aligned for balance, and wiring concealed to prevent entanglement. The package holder is attached at the center of gravity for stability.

4.4 Motor Setup

- **TT gear motors (3–6V rated)** are used, providing sufficient torque for slow, stable motion, ideal for line-following tasks.
- The gear reduction inside the motors helps maintain consistent speed and torque even under moderate load, making them suitable for carrying small packages.
- As TT motors lack built-in encoders, synchronization is managed in software via PWM tuning and calibration, not closed-loop control.

4.5 Power Supply

- A rechargeable battery pack (typically 7.4V or 9V) was used to power the Arduino and motors.
- Voltage regulation was ensured to protect sensitive components.

5 Software Used

- **Arduino IDE** – Primary development environment
- **Embedded C/C++** – Language for logic and control code

6 Software Implementation

6.1 Sensor Reading and Line Detection

IR sensors output binary values based on contrast. A basic control algorithm uses these values to determine whether the robot should go straight, turn left, or turn right.

6.2 Motor Control

- TT gear motors are DC motors with integrated gear reduction, making them suitable for controlled low-speed movement.
- PWM (Pulse Width Modulation) is used to control speed, but due to mechanical differences between motors, synchronization requires tuning each motor's speed individually.
- Since TT motors can have slight differences in RPM even at the same PWM value, software compensation is implemented by adjusting PWM values for each motor to ensure straight movement.

7 Problem Solving Strategy

Throughout the project, several technical and design-related challenges were encountered. This section describes the major problems and how they were resolved.

7.1 Sensor Misalignment

- **Problem:** IR sensors initially gave inconsistent readings due to improper alignment or lighting conditions.
- **Solution:** Recalibrated the sensor thresholds and adjusted mounting angle and height.

7.2 Motor Instability

- **Problem:** Motors would jitter or fail to start uniformly.
- **Solution:** Added delay functions for smoother transitions, and implemented PWM control for consistent torque.

7.3 Obstacle Detection Errors

- **Problem:** Ultrasonic sensor occasionally misread distances or failed to detect narrow objects.
- **Solution:** Implemented noise filtering using median averaging and adjusted the sensor's angular position.

7.4 Power Fluctuations

- **Problem:** Voltage drops during movement would reset the Arduino.
- **Solution:** Separated power lines for logic and motors and used capacitors for noise suppression.

8 Testing and Results

8.1 Test Environments

- Straight and curved line tracks in controlled indoor conditions.
- Obstacle placed at different points to test ultrasonic pause behaviour.
- Package stability checked over bumps and turns.

8.2 Observations

- Smooth line following on both straight and moderately curved paths.
- Obstacle detection responded within 100 ms.
- Packages up to 200g carried without tipping.

8.3 Performance Metrics

- Average speed: ~0.4 m/s
- Obstacle detection range: 2 cm – 4 cm
- Line detection accuracy: 95% under bright indoor lighting

9 Future Enhancements

RFID Reader: Match package with destination via tags.
Wireless Communication: Wi-Fi or Bluetooth for remote operation and monitoring.
Vision System: Add a camera for better path planning and dynamic navigation.
Rechargeable Battery Dock: Self-charging feature for long-term deployment.

10 Conclusion

This project successfully demonstrates the feasibility and effectiveness of a low-cost, Arduino-based line-following robot designed for indoor package delivery. Through the integration of IR sensors, ultrasonic detection, and simple rule-based logic, the robot is capable of navigating predefined paths and handling basic delivery tasks with a reasonable degree of reliability. The modular design allows for future enhancements such as wireless control, RFID scanning, and AI-based dynamic navigation.

From concept and design to software implementation and testing, this project showcases how accessible microcontroller platforms can be harnessed to automate routine processes in structured environments. The robot performed well under controlled conditions and presents a strong foundation for further research and development in micro-logistics and service robotics.