Chair of High-Power Converter Systems
TUM School of Engineering and Design
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Cyber Physical System

Autonomous Line-Following and Obstacle-Avoiding Robot

Autonomous Mobile robot project

Objective: Design and implement a robot to follow a line and avoid obstacles

Platform: Arduino Uno

Sensors: IR (line tracking), Ultrasonic (obstacle detection)

Control: State-based logic for smooth navigation

Focus: Architecture, challenges, future improvements

Introduction

Autonomous mobile robots streamline logistics and automation, from warehouses to delivery. They follow predefined paths while avoiding obstacles, demonstrating the core principles of cyber-physical systems. This project develops a small-scale prototype to showcase these capabilities.

Our Project Objectives

1. Construct a robot to follow a white line on a black surface (variable can be set in the code)
2. Integrate an ultrasonic sensor for real-time obstacle detection
3. Implement Arduino control logic for smooth mode switching
4. Document the full design process from concept to prototype

Methodology (Part 1)

Requirements Analysis

Defined goals: line following & obstacle avoidance

Component Selection

Arduino Uno as controller

L293D motor shield + IR & ultrasonic sensors

Hardware Assembly

Chassis + electronics wired as per circuit design

Methodology (Part 2)

Custom Fabrication

3D-printed mount for ultrasonic sensor

Software Implementation

Arduino IDE code integrates sensor data & controls motors

Testing & Iteration

Track tests with adjustments to thresholds, speeds & wiring

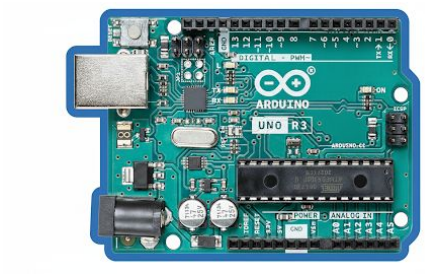
System Architecture

Control Unit
Arduino Uno as main processor
Runs control logic, reads sensors, commands motor driver

Sensing Unit
Two IR sensors for line detection
Ultrasonic sensor on servo for obstacle scanning

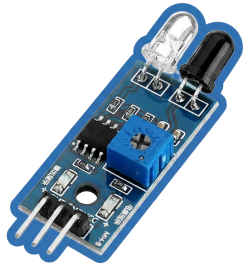
Motion Unit
Four DC motors via L293D shield for movement
Servo pans ultrasonic sensor for wider field of view

Hardware Components



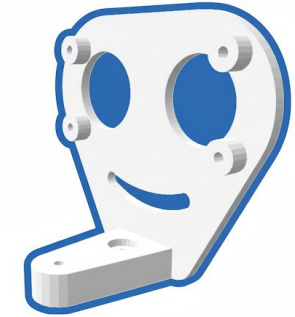
Arduino UNO

L293D Motor Shield



2x IR Sensor

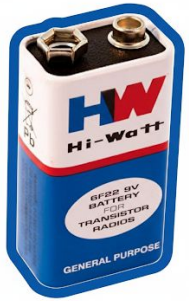
HC-SR04 Ultrasonic



Custom 3D Printed Mount

4x DC Motor

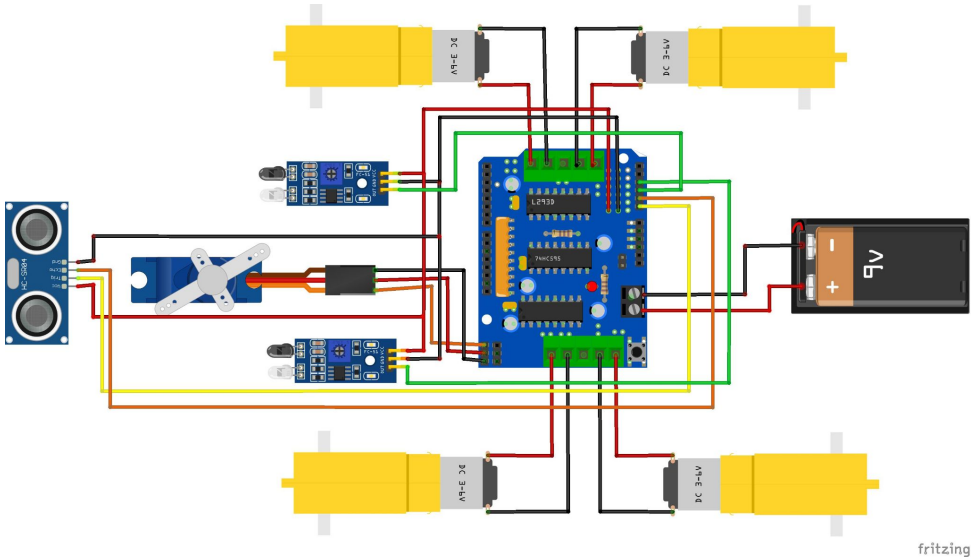
SG90 Servo Motor



9V Battery

Simplified Circuit Wiring

- **Left motors on M1, right motors on M3** → ensures synchronization
- **Ultrasonic sensor on servo** → enables scanning left/right
- **IR sensors at the front** → line detection
- **Power supply**: initially 9V battery → later replaced with 2 × 3.7V Li-ion



Software Architecture

Line Following

- State-based system in Arduino (C++)
- **IR sensors** guide movement:
  - Both on white → forward
  - Right on line → turn right
  - Left on line → turn left

Obstacle Avoidance State

- Triggered when obstacle < 20 cm
- Robot stops & scans with **servo + ultrasonic sensor**
- Picks clearest path → turns → moves → tries to reacquire line

Design Iteration and Refinements

Sensor Stability

- Initial mount vibrated → inaccurate ultrasonic readings
- Fixed with **custom 3D-printed mount** → stable & reliable data

Motor Synchronization

- Four motors hard to keep balanced
- Solution: paired left motors + paired right motors → **smoother, predictable motion**

The custom 3D-printed mount for the HC-SR04 sensor.

Problems Faced

- **IR Sensor Calibration**
  - Sensitive to ambient light → frequent threshold adjustments
- **Power Source Failure**
  - 9V battery overheated & failed → replaced with **2 × 3.7V Li-ion**
- **Traction & Turning**
  - Uneven motor speeds + wheel slip → difficult smooth turns

Limitations And Constraints

- **Surface Dependency**
  - Needs strong black/white contrast
- **Basic Avoidance Algorithm**
  - Struggles in cluttered/complex environments
- **Open-Loop Control**
  - No feedback sensors (e.g., encoders) → less precise speed/distance control

Future Improvements

- **PID Control** → smoother, more accurate line following
- **Better Power Source** → rechargeable LiPo + regulator
- **Sensor Fusion** → add IMU (gyroscope/accelerometer) for improved navigation

Conclusion

- Built a **line-following robot** with **obstacle avoidance**
- Successfully integrated **sensors, control, and actuation**
- Achieved a **robust working prototype**
- Gained valuable **hands-on CPS experience**