Interim Design Report

Micromouse Sensing Subsystem

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Chapter 1

Introduction

1.1 Problem Description

This project aims to design a micromouse robot, which is an autonomous robot specifically designed to navigate and solve maze challenges. Within the broader context of this project, the specific challenge is to design and manufacture the Sensor Module for the Sensing subsystem. This module serves as the "eyes" of the robot, detecting obstacles and providing critical information to the processor for effective maze navigation.

1.2 Scope and Limitations

Project Scope:

This project focuses on the implementation and design of a sensor module for a micromouse robot. The module includes features for object detection, a power-saving mechanism, and compatibility with the provided motherboard. The design of the power module, motherboard, processor, as well as software/firmware development, are beyond the scope of this project. Although minor software components are needed for sensor testing/interfacing, the primary emphasis remains on hardware design.

Limitations:

The system must be designed within a total budget of R600, equivalent to $30. Of this amount, $13.5 is allocated for manufacturing the PCBs, leaving $16.5 for components for two assembled PCBs. Component selection was limited to basic parts such as common SMD components to manage the budget, with a few selected extended parts. To address the limitation of component testing, equivalent components from White Lab were chosen and tested to confirm potential final component selection.

The module must also be designed to minimize power consumption to avoid prematurely depleting the provided LiPo 800mAh 3.7V battery and to ensure compatibility with the provided motherboard and STM32 processor. Another constraint was the size of the PCB, ensuring it fits within maze constraints and allows for optimal rotational motion. The maze includes dead ends and multiple paths, with each pixel representing a 200mm square that the robot must navigate. Finally time constraints were needed to be met for PCB manufacturing deadlines.

1.3 GitHub Link

The GitHub link for the project can be found here: Link

Chapter 2

Requirements Analysis

This section identifies and outlines the project requirements. From these requirements, specifications were developed. A feasibility analysis was performed on the derived specifications.

2.1 Requirements

The requirements for a micromouse sensing module are described in Table 2.1.

Table 2.1: Requirements of the Sensing subsystem.

Requirement ID	Description
UR01	Subsystem must detect obstacles in front of and to the sides of the robot
UR02	Subsystem PCB must be size appropriate for Maze Constraints
FR01	Subsystem must have power saving management
FR02	Subsystem must be designed for reliability to prove the system works
FR03	Subsystem must fit onto the pin headers on the motherboard
FR04	Subsystem must minimize power and current usage to prevent premature battery drain
FR05	Subsystem must use JLCPCB Basic Parts for budget constraints where possible

2.2 Specifications

The specifications, refined from the requirements in Table 2.1, for the micromouse sensing module are described in Table 2.2.

Table 2.2: Specifications of the Sensing subsystem derived from the requirements in Table 2.1.

Specification ID	Description
SP01	Obstacle Detection in Front and Sides
SP02	Size Appropriate for Maze Constraints
SP03	Power-saving Mechanism
SP04	Reliability Design
SP05	Motherboard Pin Header Compatibility
SP06	Power and Current Management
SP07	Use JLCPCB Basic Parts

2.3 Testing Procedures

A summary of the testing procedures detailed in chapter 4 is given in Table 2.3.

Table 2.3: Acceptance Test Procedures Summary

Acceptance Test ID	Description
AT01	Powers on: Confirm +BATT is supplied to designated jumpers and pads.
AT02	Shorts to GND: Check for shorts between traces and ground using a multimeter.
AT03	LED voltage at test points: Measure voltage across LED test points.
AT04	Photodiode voltage at test points: Measure voltage across photodiode test points.
AT05	Op-amp output: Measure output voltage of op-amps at specified jumpers.
AT06	PCB Size Check: Verify that PCB dimensions match the specified size requirements.
AT07	Component Check: Inspect and verify the presence and correct placement of required components on the PCB.

2.4 Traceability Analysis

The show how the requirements, specifications and testing procedures all link, Table 2.4 is provided.

Table 2.4: Requirements Traceability Matrix

#	Requirements	Specifications	Acceptance Test
1	UR01	SP01	AT01, AT06
2	UR02	SP02	AT06
3	FR01	SP03	AT01, AT03, AT04
4	FR02	SP04	AT04, AT06, AT07
5	FR03	SP05	AT06, AT07
6	FR04	SP06	AT02, AT03, AT04, AT05
7	FR05	SP07	AT07

2.4.1 Traceability Analysis 1

Requirement UR01 necessitates the subsystem's ability to detect obstacles in front of and to the sides of the robot, leading to Specification SP01. To ensure this functionality, AT01 is suggested to verify that the subsystem powers on and supplies the necessary power to designated jumpers and pads which in turn powers the IR LEDs and photodiodes. While AT06 is in addition suggested to visually confirm if IR LEDs are obstructed or not based on PCB dimensions.

2.4.2 Traceability Analysis 2

Requirement UR02 specifies the need for the subsystem PCB to be size-appropriate for maze constraints, leading to Specification SP02. To ensure the PCB's size appropriateness, AT06 is suggested to verify that PCB dimensions match the specified size requirements.

2.4.3 Traceability Analysis 3

Requirement FR01 demands the implementation of a power-saving mechanism, leading to Specification SP03. To validate this mechanism, AT01 is suggested to ensure that the subsystem powers on and supplies the necessary power. While AT03 & AT04 is further suggested to ensure correct voltages and in appropriate range for power-saving.

2.4.4 Traceability Analysis 4

Requirement FR02 necessitates a reliability design for the subsystem, leading to Specification SP04. This reliability design can be validated through AT04, which measures the photodiode voltage at test points, ensuring proper functionality. While visual inspection through AT06 & AT07 determines whether a reliability design has been implemented.

2.4.5 Traceability Analysis 5

Requirement FR03 requires compatibility with the motherboard's pin headers, leading to Specification SP05. This compatibility can be tested through AT06 & AT07, which visually inspects and would determine compatibility with the motherboard's pin headers.

2.4.6 Traceability Analysis 6

Requirement FR04 necessitates the minimization of power and current consumption, thereby leading to Specification SP06. To validate this design requirement, a series of tests including AT02, AT03, AT04, and AT05 are recommended. These tests aim to verify several aspects, such as checking for shorts between traces and the ground, ensuring that voltages from IR LEDs, photodiodes, and op-amps fall within appropriate ranges, and confirming the absence of run-away voltages, all contributing to the goal of achieving minimal power and current usage.

2.4.7 Traceability Analysis 7

Requirement FR05 mandates the use of JLCPCB Basic Parts for budget constraints, leading to Specification SP07. This can be tested through AT07, which visually inspects components, ensuring the use of the specified parts.

Chapter 3

Subsystem Design

3.1 Design Decisions:

3.1.1 Final Design

The subsystem design for the Micromouse incorporates infrared (IR) sensors to detect walls and obstacles in its surroundings. An IR sensor consists of two primary components:

1. **IR Emitter LED**: This component produces infrared light. When the IR emitter emits light, it reflects off nearby objects.
2. **IR Receiver (Photodiode)**: The IR receiver, which is a photodiode, detects the reflected IR light. The photodiode generates varying electrical values based on the distance to the reflecting object.

These values are then processed by a voltage comparator and its output is sent to the microcontroller. Additionally, a potentiometer is used to calibrate the sensor output to meet specific requirements.

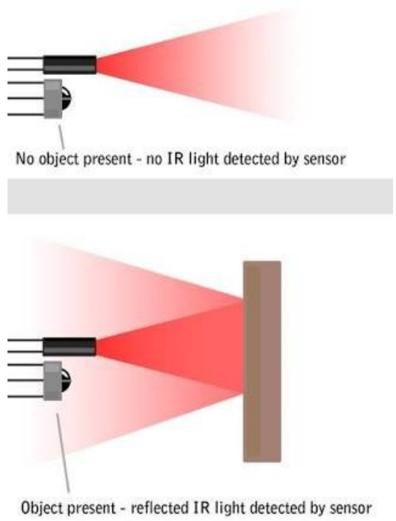


Figure 3.1: Depiction of the operation of an IR Sensor

3.2 Sensor Type Decision:

While alternatives to IR sensors exist, such as sonar or ultrasonic sensors that use sound waves to measure distance, IR sensors are superior in detecting the presence of objects, like walls. Although ultrasonic sensors offer greater distance-measuring accuracy, IR sensors are significantly faster, making them more suitable for micromouse applications. Moreover, Time of Flight (ToF) sensors surpass both ultrasonic and IR sensors in accuracy. However, they communicate using the I2C protocol, which is not available with the micromouse motherboard. Plus they are expensive and would be out of budget.

When selecting the appropriate sensing design, additional factors such as detection speed, communication protocol, ease of implementation, and cost must be considered as well. The choice of sensor also impacts the speed, which is crucial for minimizing power consumption. To conserve power, the device should emit, receive, and turn off as quickly as possible while still being affordable. Overall, IR sensors effectively meet all these requirements, making them the ideal choice for the Micromouse when compared to ultrasonic and ToF sensors. A comparison table of the 3 sensing designs are shown in table 3.1.

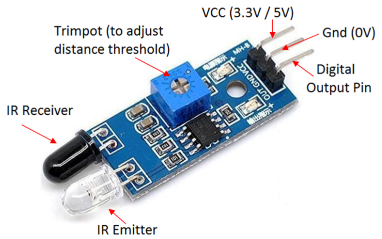


Figure 3.2: China-Made IR Sensor

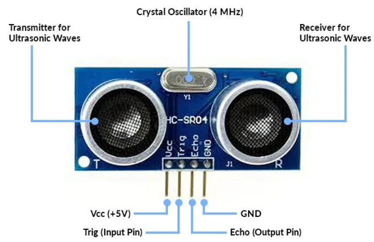


Figure 3.3: Ultrasonic Sensor

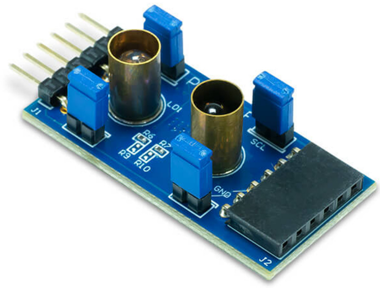


Figure 3.4: Digilent PmodTOF Sensor

Table 3.1: Comparison of Sensing Designs

Parameter	**IR Sensor**	**Ultrasonic Sensor**	**ToF Sensor**
Detection Speed	Faster	Slower	Fastest
Communication Protocol	Analog	Analog/Digital	I2C
Distance Measuring Accuracy	Moderate	High	Highest
Object Detection	Excellent	Moderate	Excellent
Ease of Implementation	Easy	Moderate	Moderate
Cost	Low	Moderate	High
Power Consumption	Low	Moderate	Moderate

Using IR sensors for the Micromouse has its Pros & Cons, table 3.2. However, most of the disadvantages are mitigated through calibration and programming.

Table 3.2: Pros & Cons

Pros	**Cons**
Easy to Implement	Affected by Ambient Light
Non-Contact Functionality	Requires Calibration
Output Analog Values	Sensor Variations
Fast Sensing	Non Linear Scaling of Distances

3.3 Component Selection:

Infrared Light Emitting Diodes (IR LEDs) form the foundational components of IR sensors. The selection of an appropriate IR LED for the Micromouse is a critical task, given the extensive range available in the JLCPCB parts library. To facilitate this selection process, multiple options were systematically evaluated and are presented in the comparison table below. The table provides an analysis based on key parameters, including the 1/2 angle, radiant intensity (mW/Sr), current (I) in milliamperes (mA), wavelength (nm), and spot size. The spot size is defined as the diameter of the 50% power circle at a distance of 100 mm, as indicated in each respective datasheet, see appendix A for full calculations.

Part Number	1/2 Angle (deg)	Radiant Intensity (mW/Sr)	Current (I) (mA)	Wavelength (nm)	Spot Size (mm)
SFH 4544	10	550	100	940	17.5
IR333-A	10	85	100	940	17.5
TSAL6200	17	40	100	940	30.3
TSAL6400	25	50	100	940	44.5

Table 3.3: Comparison of IR LED Options for the Micromouse

From this comparison [3.3], the obvious choice of IR LED was the SFH 4544 from Osram. It is bright and has a good spot size for a suitable receiver. The calculated resistor to drive the LED is 51Ohms. The calculation is provided in Appendix A.

3.4 PCB Shape and LED Positioning:

In the process of determining the optimal PCB shape and LED positioning for the sensor board, several shapes were evaluated, including a semicircle, a rectangle, and ultimately, a hybrid shape consisting of an arc attached to a rectangle. Each design consideration took into account the placement and size of the wheels, as well as the necessity for a smooth center of rotation. After careful analysis, it was determined that the hybrid shape provided the best balance of maneuverability and structural integrity.

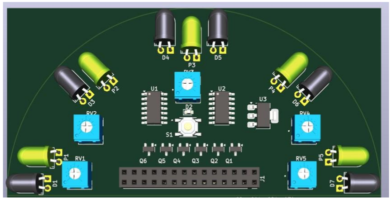


Figure 3.5: Size & Initial Position Concept

Regarding LED positioning, various options were explored to enable the micromouse to effectively perceive its surroundings. Initially considering IR LEDs directly facing left and right, it was found that these positions would be obstructed by the micromouse's wheels. Consequently, two IR LEDs were angled slightly forward on each side to ensure unobstructed visibility. Furthermore, two IR LEDs positioned at the top were angled to provide comprehensive coverage along the left and right sides of the maze walls. This strategic arrangement of LEDs, coupled with the PCB shape, enables the micromouse to navigate the maze with precision and efficiency.

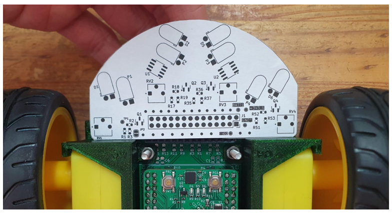


Figure 3.6: Final PCB Shape with IR LED Positions

3.5 Failure Management

To address PCB manufacturing and design calculation errors, the following failure management has been considered, as illustrated in Table 3.4.

3.6 System Integration and Interfacing

To integrate the subsystem into the larger system, certain parts of the system need to be physically connected as outlined in Table ??. The following diagram [3.9] elucidates the integration process:

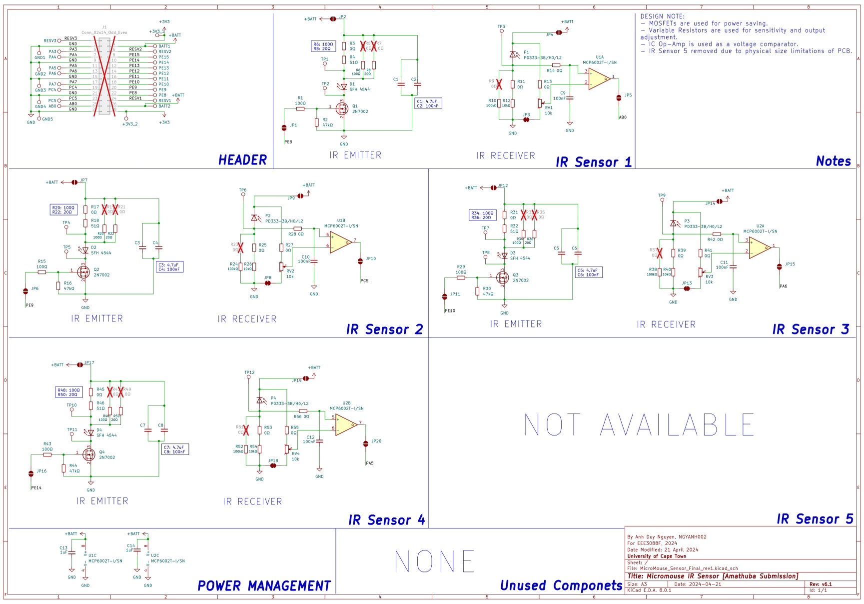
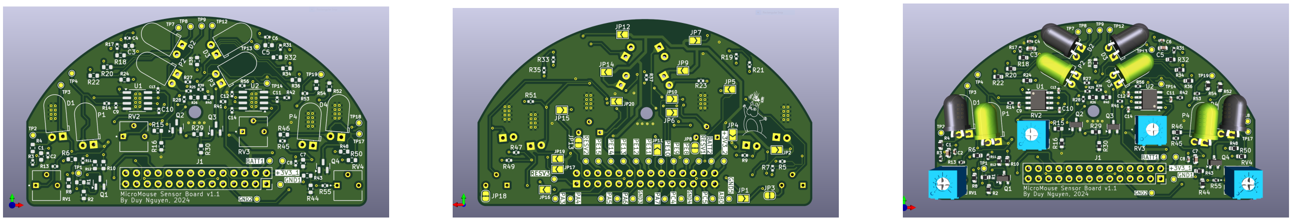


Figure 3.7: Schematic



(a) Front PCB (b) Back PCB (c) 3D PCB

Figure 3.8: PCB

Name	**Description**
Center Hole	Allows for ‘hotwiring’ to test pads beneath the board by connecting them to other pins or testing externally.
Redundant Resistors	Provides backup resistors that can be connected via jumpers or blank $0\,\Omega$ pads in case of incorrect resistor values or resistor failure.
Jumpers	Allows for the disconnection or connection of failed or needed circuits/components by bridging or bypassing them with solder connections.
$0\,\Omega$ Resistors	Functions similarly to jumpers, allowing for the selection or bypassing of circuit paths by replacing or removal of $0\,\Omega$ resistors.

Table 3.4: Failure Management Techniques

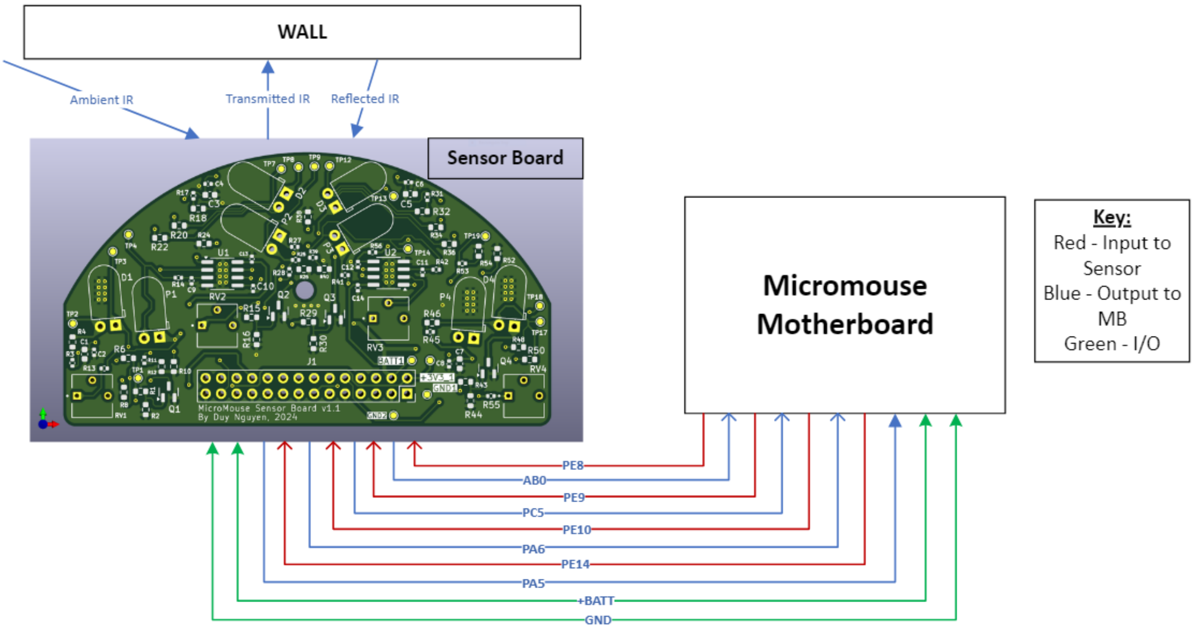


Figure 3.9: Interface Diagram

Interface	Description	Pins/Output
I001	Sensor Board to Micromouse Motherboard for data transfer (Analog)	• Analog: Pin 22 to STM PE8 • Analog: Pin 20 to STM PE9 • Analog: Pin 18 to STM PE10 • Analog: Pin 10 to STM PE14 • Power: Pin 1 & 26 to STM BATT+ • GND: Breakout GND* to STM GND
I002	Micromouse Motherboard to Sensor Board for IR LED control (PWM)	• PWM: STM Pin AB0 to Pin 25 • PWM: STM Pin PC5 to Pin 23 • PWM: STM Pin PA6 to Pin 13 • PWM: STM Pin PA5 to Pin 11

Table 3.5: Interfacing specifications

Chapter 4

Acceptance Testing

4.1 Tests

This table 4.1 outlines the Acceptance Test Protocols (ATPs) specifically designed to verify that each component and functionality of the PCB operates as expected. Unlike the Failure Management section, which addresses measures to prevent failures, this section focuses on validating that the board meets the established requirements and specifications.

It's noted that multiple ATPs may be associated with each requirement or specification, ensuring comprehensive testing coverage.

Table 4.1: Acceptance Test Protocols used to determine that the subsystem works to specification

Test ID	Description	Testing Procedure	Pass/Fail Criteria
AT01	Powers on	• Confirm +BATT is supplied to JP2, JP4, JP7, JP9, JP12, JP14, JP17, JP19, Pin 4 & 26 • Confirm JP Pads soldered	Voltage present at all pins
AT02	Shorts to GND	• Check for any shorts between traces and ground plane using a multimeter in continuity mode	No continuity between any trace and ground
AT03	LED voltage at test points	• Measure voltage across LED test points	Voltage within specified range (1.2V-1.6V)
AT04	Photodiode voltage at test points	• Measure voltage across photodiode test points	Voltage within specified range (0V - 5V)
AT05	Op-amp output	• Measure output voltage of op-amps at JP5, JP10, JP15, JP20	Voltage within specified range (0V - 3.6V)
AT06	PCB Size Check	• Verify that PCB dimensions match the specified size requirements	PCB size within specified dimensions
AT07	Component Check	• Inspect and verify the presence and correct placement of required components on the PCB	All required components present and correctly placed

4.2 Critical Analysis of Testing

This will only be completed for the final report.

Chapter 5

Conclusion

This will only be completed for the final report.

5.1 Recommendations

This will only be completed for the final report.

Appendix A

Reference Calculations

Calculation of IR LED Spot Size

To calculate the spot size of an IR LED at a distance of $s = 100$ mm, you can use the formula:

$$d = 2s \tan\left(\frac{\theta}{2}\right)$$

where:

- d is the spot size,
- s is the distance from the LED, and
- θ is the divergence angle.

Resistor Calculations:

For the IR LEDs (SFH 4544), the resistor values in the circuit were calculated using Ohm's Law to achieve optimal voltage levels for reliable performance. Chose to run IR LED at 1/3 of amperage. Given:

$$I_F = 33.3\,\text{mA}, \quad V_F = 1.6\,\text{V}, \quad V_{cc} = 3.3\,\text{V}$$

The resistance R is calculated using Ohm's law:

$$R = \frac{V_{cc} - V_F}{I_F}$$

$$R = \frac{3.3\,\text{V} - 1.6\,\text{V}}{33.3\,\text{mA}}$$

$$R = \frac{1.7\,\text{V}}{33.3\,\text{mA}} = 51\,\Omega$$

Therefore, the calculated resistance is $51\,\Omega$. Appropriate sized capacitors and photo-diode resistors were chosen for filtration and low current from breadboard assignment.