Interim Design Report

Micromouse Sensing Subsystem

Prepared by:
Zuhayr Halday

Prepared for:
EEE3088F
Department of Electrical Engineering
University of Cape Town

April 21, 2024

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Chapter 1

Introduction

1.1 Problem Description

The problem the entire project deals with is to design, build, and test a fully-functioning MicroMouse robot. Akin to the mice in the famous Kerplunk Experiments, a MicroMouse robot should be able to solve a maze using the shortest and fastest route possible.

While the greater problem of building a MicroMouse may seem simple, it is quite a complex task which must be broken down into many smaller and more manageable sub-tasks. To do so, a fundamental question must be asked: 'What does a robot (or any entity) require in order to solve a maze?' The four basic necessities to addressing the greater project are found by answering this question, that being: the ability to move, to detect obstacles such as maze walls, the logical capability or 'brain' to decide how the robot moves based on what it detects, and the ability to power itself while solving the maze. By applying the philosophy of Systems Engineering and principle of modular design, these smaller problems can be addressed by assigning each to different subsystems: Power, Sensing, and the Motherboard.

The Motherboard not only houses all other subsystems, but addresses the movement and 'brain' aspects of the project, as the two wheels and motors of the MicroMouse are attached to the main Motherboard PCB, and in order to deal with its input and output logic capabilities, an STM32L476 microcontroller is also mounted onto the Motherboard, with pin headers to facilitate connection and interfacing between other subsystems.

The Power subsystem is in charge of directing power from a battery to all subsystems and motors of the MicroMouse, and conversely, charging said battery when the robot is plugged into an external power source.

The third and final subsystem, Sensing, will be the part of the MicroMouse that is able to detect the presence and distance from the walls of the maze and send the information it detects to the microcontroller, in order to determine the direction in and speed at which the robot should traverse the maze. This report specifically focuses on the problem of designing, building and testing the Sensing subsystem.

1.2 Scope and Limitations

The scope of this specific project only concerns the Sensing subsystem described above, its interactions with the environment around it, and its ability to interface with other subsystems. Intricate details of other subsystems are not included in this scope.

The biggest limitations of this project are the size of the Sensing PCB, and the components from which it is able to made up of. Firstly, in order to not obstruct the turning radius of the wheels of the robot, the Sensing PCB is limited to a width and length of roughly 85mm and 30mm respectively. Secondly, the components of said PCB must include a 2x14, 2.54mm pin pitch socket in order to connect to the Motherboard subsystem. These components are only able to be comprised of available parts from JLCPCB, and must have a total manufacturing cost of $15 for a single board.

1.3 GitHub Link

The GitHub repo for this project is available here.

Chapter 2

Requirements Analysis

2.1 Requirements

The requirements for the micromouse sensing subsystem are described in Table 2.1.

Requirement ID	Description
REQ01	Each subsystem sensor is able to detect a wall or reflective object
REQ02	Subsystem has sensors on the left, right, and front sides of the micromouse
REQ03	Subsystem has pin sockets to interface with the motherboard and processor
REQ04	Subsystem is able to be powered by a battery
REQ05	Outputs of each sensor are repeatable and continuous
REQ06	Subsystem PCB size must not obstruct wheels and must fit on the motherboard
REQ07	Output of each sensor is in the form of an analogue voltage signal
REQ08	Subsystem only uses JLCPCB components
REQ09	Manufacturing cost of PCB's are within budget

Table 2.1: Requirements of the sensing subsystem.

2.2 Specifications

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

Specification ID	Description
SP01	Each subsystem sensor makes use of infrared (IR) LED's and photodiodes to detect obstacles
SP02	Sensors should only detect obstacles that are 6-10 cm away, and should have distinguishable outputs within that distance range
SP03	PCB includes a 2x14, 2.54mm pin pitch socket to connect to the motherboard
SP04	Subsystem is able to be powered by a 3.7V 1S1P 18650 battery
SP05	Outputs of each sensor are reliable and not affected by external light
SP06	Subsystem PCB should have a width and length of no greater than 85mm and 30mm respectively
SP07	Output signal of each sensor should be within 0.8-1.5V, so as to not drain the battery
SP08	Subsystem makes use of mostly basic components, avoiding extended components where possible
SP09	Manufacturing cost of a single PCB is $15 or lower

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

2.3 Testing Procedures

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

Test ID	**Description**
AT01	IR LEDs Power on
AT02	IR Photodiodes Power on
AT03	Subsystem output changes at the left, right, and front of the board
AT04	Connects to motherboard
AT05	Powers on
AT06	Accepted by JLCPCB

Table 2.3: Acceptance Testing Summary for Subsystem

2.4 Traceability Analysis

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

#	Requirements	Specifications	Acceptance Test
1	REQ01	SP01	AT01, AT02
2	REQ02	SP02	AT03
3	REQ03	SP03	AT04
4	REQ04	SP04	AT01, AT02, AT05
5	REQ05	SP05	AT03
6	REQ06	SP06	AT04
7	REQ07	SP07	AT03
8	REQ08	SP08	AT06
9	REQ09	SP09	AT06

Table 2.4: Requirements Traceability Matrix

2.4.1 Traceability Analysis 1

SP01 was derived from REQ01, as IR proximity detection circuits are popular for object detection robotics. AT01 and AT02 test if these IR components function as intended to satisfy REQ01 and SP01.

2.4.2 Traceability Analysis 2

SP02 was derived from REQ02, since the micromouse should be able to see walls in all forward directions, but should not be hesitant to move when detecting a wall from far away. AT03 was made to test each side's sensor only produces an output signal when 6-10cm away from an obstacle/wall.

2.4.3 Traceability Analysis 3

SP03 was derived from REQ03, as this is the connector needed to mount the subsystem to the motherboard, allowing the microcontroller to interface with the subsystem. AT04 will test this, as if the PCB does not fit onto and connect to the microcontroller, the micromouse will not function.

2.4.4 Traceability Analysis 4

SP04 was derived from REQ04, as the battery specified to be used to power the micromouse was given. AT01, AT02, and AT05 test this, as this will indicate whether or not components are being powered, and whether the power drain is too much for the battery to handle.

2.4.5 Traceability Analysis 5

SP05 was derived from REQ05, as outputs should consistently detect obstacles in real time, and should not falsely detect obstacles due to external light. AT03 tests this as it monitors the output signal of the subsystem when obstacles and external light is present.

2.4.6 Traceability Analysis 6

SP06 was derived from REQ06, as this is the space allocated to the sensing subsystem on the motherboard PCB. AT04 will test this, as the subsystem will not connect to the motherboard if it does not fit, or obstructs the wheels of the micromouse.

2.4.7 Traceability Analysis 7

SP07 was derived from REQ07, as the output signal is generated by the photodiode drawing current from the battery, and should not drain the battery too fast. AT03 tests this by monitoring the current draw and voltages of each output signal to make sure it is within a suitable range.

2.4.8 Traceability Analysis 8

SP08 was derived from REQ08, because there is a high chance of the subsystem cost going over-budget when using many extended components from JLCPCB. AT06 tests this, as one is able to see the total cost of manufacturing when submitting a PCB to JLCPCB.

2.4.9 Traceability Analysis 9

SP09 was derived from REQ09, as this was the budget allocated to the sensing subsystem. AT06 tests this, as one is able to see the total cost of manufacturing when submitting a PCB to JLCPCB.

Chapter 3

Subsystem Design

3.1 Design Decisions

While the initial circuit layout remained the same throughout all versions of the design, component choices differed greatly, especially when taking into account component stock and pricing from JLCPCB. All IR components demanded extended component fees, which greatly scaled down the size of the subsystem. On top of this, many ideal components were out of stock. Compromises had to be made when making design decisions, but were done while still keeping all specifications and requirements in mind.

3.1.1 IR LED Emitter Circuit

In accordance with SP01 in section 2.2, an IR LED circuit needed to be part of the design, and in accordance with REQ02, these LEDs needed to have directionality. Immediately, this elminated the consideration of using any surface-mounted IR LEDs, as there would be absolutely no way to manipulate the surface of the PCB to face the left, right, and front of the micromouse. Therefore, only through-hole LEDs were considered.

Expanding on the property of directionality, radial LEDs were ideal, as the angle of half-intensity for side-emitting was much smaller than those of radial LEDs. Outputs of the sensor circuit are greatly dependent on the intensity of light emitted by the IR LEDs, so in order to take SP05 and SP07 (section 2.2) into account, only radial through-hole IR LEDs were considered.

Due to limited stock and budget constraints, this narrowed the selection down to just two IR LEDs: the **TSAL6200** and the **TSAL4400**. The pros and cons of each component were then weighed against each other, as seen in Table 3.1: While there were not many differences between these IR LEDs, the

TSAL6200		TSAL4400	
Pros	Cons	Pros	Cons
Cheaper	Smaller half-intensity angle	Larger half-intensity angle	More Expensive
Higher radiant intensity			Lower radiant intensity

Table 3.1: TSAL6200 vs TSAL4400

differences that mattered the most were cost effectiveness, and radiant intensity, and the TSAL6200 was the better choice in both of these categories. Therefore, the **TSAL6200** was used in the IR LED Emitter Circuit. (**Note:** Two TSAL6200 LED's will be used per side of the PCB to ensure adequate light intensity)

Calculations

As this in an LED, a current-limiting resistor is required to safely power the LED. Due to the maximum current rating of 100mA for the TSAL6200, calculations are needed in order to find a resistance value which will safely limit the current under the maximum rating:

$$R_{LED} = \frac{(V_S - V_F)}{I_{max}}$$

Using the known source voltage of 3.7V (1S1P 18650 battery), and the maximum forward voltage drop and maximum current, as listed in the TSAL6200 datasheet:

$$R_{LED} = \frac{(3.7 - 1.6)}{100 * 10^{-3}} = 21\Omega$$

Therefore, any resistor larger than 21Ω will suffice. For this circuit, 39Ω was used as the current-limiting resistor for each LED, resulting in $I_{LED} = 60mA$.

3.1.2 IR Photodiode Sensor Circuit

In order to generate some sort of output signal from merely an IR LED, an IR photodiode was necessary. As IR light reflects off of obstacles, a reverse-biased IR photodiode is able to detect the reflected IR light, and generate a current dependent on the intensity of the reflected light. Three IR photodiodes were used in the subsystem, one for the left, right, and front of the PCB.

Unlike the IR LEDs, the photodiode should have as small of a viewing angle as possible, so as not to detect IR light from any direction other than the one it faces. The photodiode should ideally have a daylight blocking filter as well, in order to reduce the disturbance from external light.

Based on all of the above factors, the 'SFH' line of photodiodes from Osram are ideal, as all of these photodiodes have a roughly >90% spectral sensitivity to light of wavelength 940nm, which is the wavelength of light emitted by our chosen IR LEDs. On top of having its built-in daylight blocker, this sensitivity is also very low for lower wavelengths of light, further reducing the impact of external light to the sensor. After considering the entire line of available SFH photodiodes, the **SFH213FA** was selected, due to it being one of the only photodiodes from this line still in stock, while having the lowest viewing angle out of all of the in-stock options.

Calculations

Using the Radiant Power curve of the TSAL6200 from its datasheet, we can see that a forward current of 60mA results in the LED emitting light with power $P_{radiant} = 25mW$. The Light Intensity formula can now be applied:

$$I_N = \frac{P_{radiant}}{4\pi r^2}$$

Calculating the radial light intensity 60mm (close distance) away from the LED:

$$\therefore I_N = \frac{25 * 10^3}{4\pi(6cm)^2} = 552.6\mu W/cm^2$$

This light intensity will be used in order to determine the photocurrent of the SFH213FA, when receiving IR light from the TSAL6200. Using the Photocurrent Curve of the SFH213FA from the datasheet, it can be determined that a light intensity of $552.6\mu W/cm^2$ corresponds to a photocurrent of:$I_P \approx 22\mu A$

With this current value, we can determine the voltage drop across a load resistor R_L connected in series with the SFH213FA. This is a simple calculation, and choosing an E12 resistance value of $47k\Omega$ gives an output voltage:

$$V_{out} = I * R = (22 * 10^{-6})(47000) = 1.03V$$

Therefore, when the sensor fully reflects all light from the IR LED from 6cm away, the system should have an output of 1.03V at maximum, when taking into account materials that allow IR to pass through or other external factors.

According to the Light Intensity equation, $P_{radiant}$ will decrease as distance increases, meaning less light intensity, and hence less photocurrent as the sensor moves further away from the reflective obstacle. This means that the selected photodiode is perfect for meeting the SP07 specification for the output signal of the sensor.

3.1.3 Transistor Switch Circuit

While not making a large difference to how the subsystem sensors will function, the design choice to use an NPN BJT as a switch for the IR LEDs is important in reducing the power consumption of the subsystem, allowing for longer battery life. The emitter of the NPN will be connected to the end of the IR LED Emitter circuit, and its base will be connected to one of the PWM pins of the microcontroller. This is done so that the LEDs will pulse rapidly, conserving battery life whenever it is turned off, but still pulsing fast enough to be detected by the photodiode sensors. The TSAL6200 selected previously is also very suitable for high-pulse operation, and will not be damaged.

The **2222A** NPN BJT was selected as the transistor, since its maximum current rating is able to handle the current from up to five TSAL6200s operating at 60mA simultaneously. This is also a very versatile and cheap transistor, and does not disagree with any specifications or requirements. A base resistor of $1k\Omega$ will be used with the 2222A, and the PWM pin from the microcontroller will then control the base voltage of the 2222A, rapidly pulsing the IR LEDs.

3.1.4 Final Design

The final design for the Sensing subsystem is comprised of the three aforementioned circuits. All components are suitable for use with one another and within the circuit. All absolute maximum and minimum ratings were checked and all selected components have suitable ranges for operation within the subsystem. The final design schematic and PCB can be seen below. (**Note:** All datasheets mentioned above can be accessed from the GitHub repo under *Sensing Subsystem/Datasheets*)

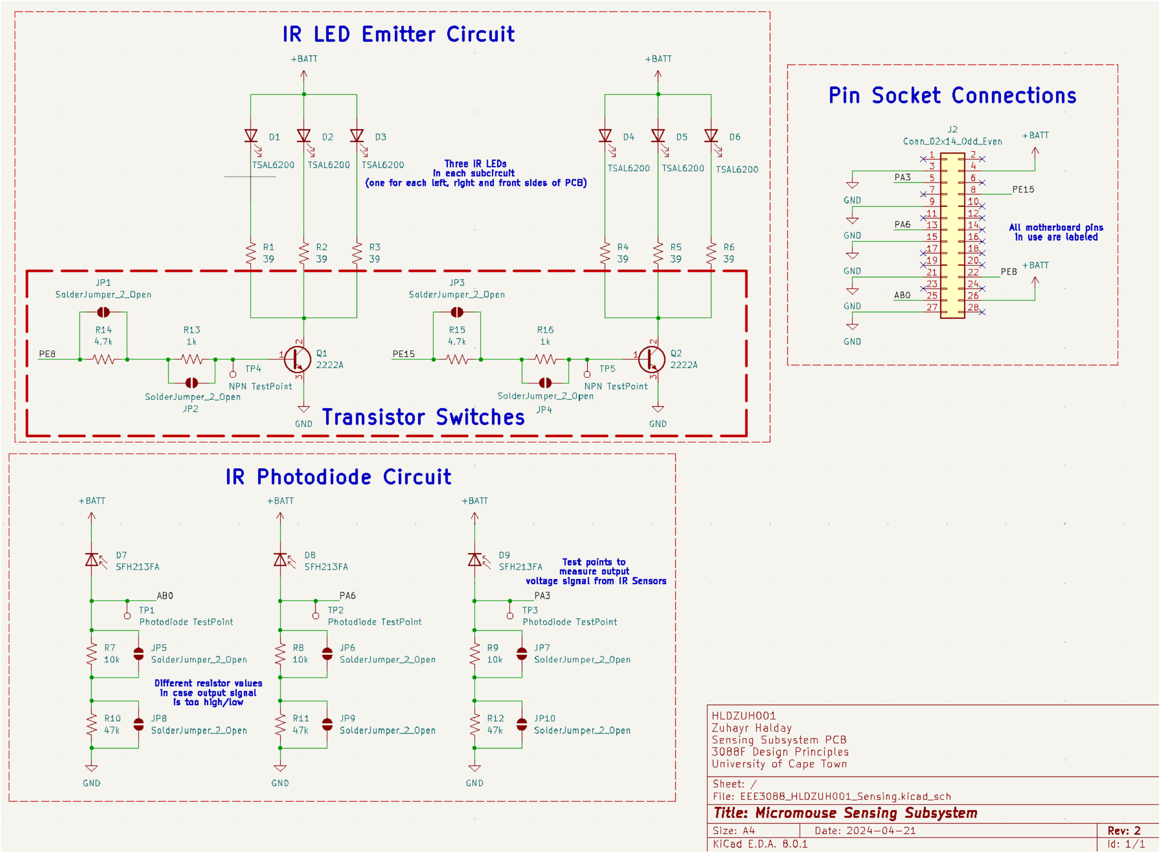
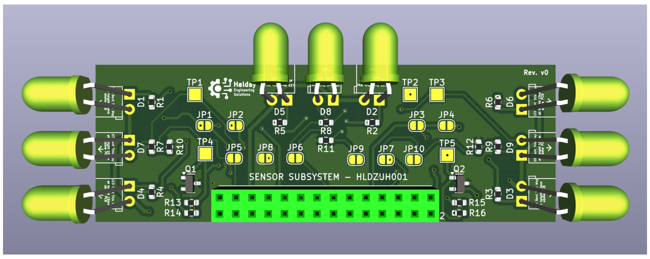
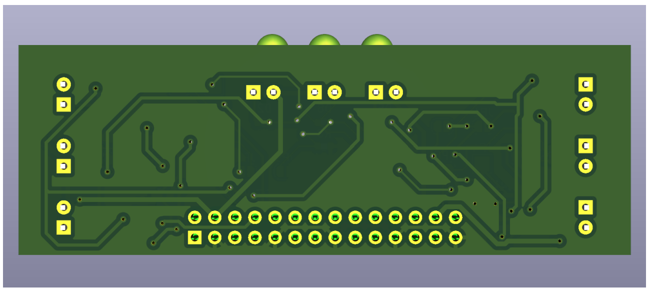


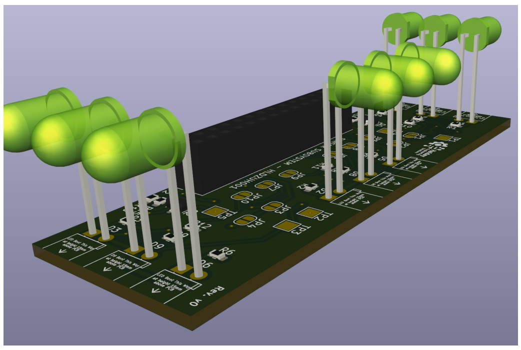
Figure 3.1: Schematic



(a) Front PCB



(b) Back PCB



(c) 3D PCB

Figure 3.2: PCB

Name	Description
Modular IR LED Circuits	Six IR LEDs have been split up into two separate circuits of three each (one for each side of the board). This is done so that if one circuit fails, there will still be at least one functioning IR LED and photodiode on each side of the board.
PCB Thermal Management	The width of all PCB tracks vary depending on how much current is expected to travel through each track. Wider tracks correspond to higher current, ensuring the PCB stays safe from thermal impacts.
Redundant Resistors	In the cases where exact resistor values were not able to be calculated, multiple different resistors were added to the PCB, with solder jumpers connecting each to the circuit, so that different resistor values can be experimented with.
Test Points	Test points were added to parts of the subsystem in order to measure voltage or current during testing, to avoid any unexpected mishaps and monitor the expected subsystem performance.

Table 3.2: Failure Management for the Sensing Subsystem

3.2 Failure Management

3.3 System Integration and Interfacing

To integrate the subsystem with the rest of the system ....

Interface	Description	Pins/Output
I001	IR LED and Photodiode Circuits to Motherboard +BATT and GND for power	• +BATT: IR LEDs to Motherboard Pin4 • +BATT: IR Photodiode to Motherboard Pin26 • GND: All circuits to Motherboard Pin3, Pin9, Pin15, Pin21, Pin27
I002	Motherboard PWM to Transistor Switch Circuits	• Motherboard PE8 to Transistor Q1 • Motherboard PE15 to Transistor Q2
I003	IR Photodiode Circuit Output to Motherboard ADC Pins	• IR Photodiodes to Motherboard PA3, PA6, AB0

Table 3.3: Interfacing specifications

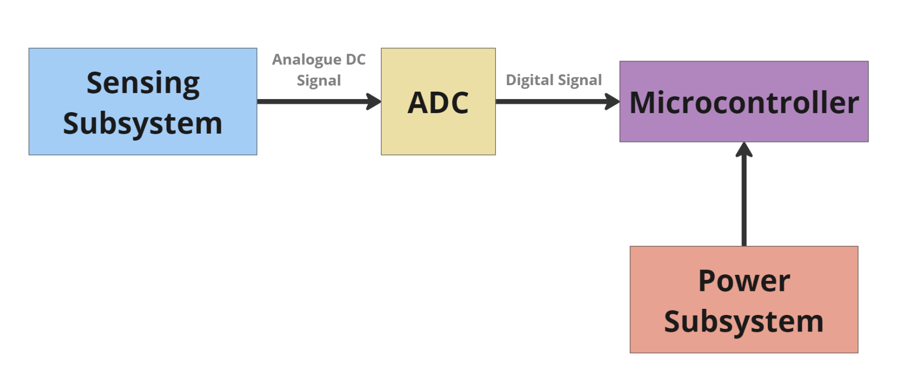


Figure 3.3: System Interfacing Diagram

Chapter 4

Acceptance Testing

4.1 Tests

Test ID	Description	Testing Procedure	Pass/Fail Criteria
AT01	IR LEDs Power on	• Connect subsystem to the motherboard • Measure currents and voltages at test points	IR Light not visible
AT02	IR Photodiodes Power on	• Connect subsystem to the motherboard • Measure currents and voltages at test points	No output signal while IR LEDs are on
AT03	Subsystem output changes at the left, right, and front of the board	• Place a reflective surface in front of each sensor • Vary surface between 6-10cm from each sensor	• Output does not vary with distance to obstacle • No output signal when obstacle is in front of each sensor
AT04	Connects to motherboard	Connect subsystem to motherboard	Does not connect to/fit on motherboard
AT05	Powers on	• Connect subsystem to the motherboard • Measure currents and voltages at test points	• Subsystem does not power on • Voltage/current exceeds maximum component ratings
AT06	Accepted by JLCPCB	Submit PCB design and BOM files to JLCPCB shopping cart	• PCB not accepted by JLCPCB • Manufacturing cost exceeds $15 per board

Table 4.1: Subsystem acceptance tests

4.2 Critical Analysis of Testing

Table 4.2: Subsystem acceptance test results

Test ID	Description	Result
AT01	Powers on	

4.2.1 AT01

This worked, this did not work. I suspect that is because of x y and z.