Interim Design Report

Micromouse Sensing Subsystem

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April 21, 2024

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Chapter 1

Introduction

1.1 Problem Description

1.1.1 Design Problem Statement

Design and develop a sensing PCB responsible for detecting obstructions(walls) nearby and providing the processor with that data.

1.1.2 Context

A micro-mouse is a battery powered robot whose goal is to navigate through a maze. This report is written on the sensing subsystem within the context of the UCT EEE3088F Micro-mouse project. The project focuses on the design of the micro-mouse's hardware. The sensing subsystem is one of four subsystems in this project, namely: the motherboard, the processor, power and sensing.

The motherboard connects all the subsystems. It acts as a baseboard that the sensing subsystem slots onto to connect to the processor subsystem. The power subsystem supplies the motherboard with power. The sensing subsystem is connected to the battery and 3.3V supply via the processor. The processor also supplies a logic input to the sensing subsystem. The sensing subsystem interacts with the environment to detect walls in the way of the micro-mouse. The sensing subsystem sends this data to the processor to be interpreted. This is summarised in Figure 1.1 adjacent. The power subsystem has been added for completeness but can be ignored.

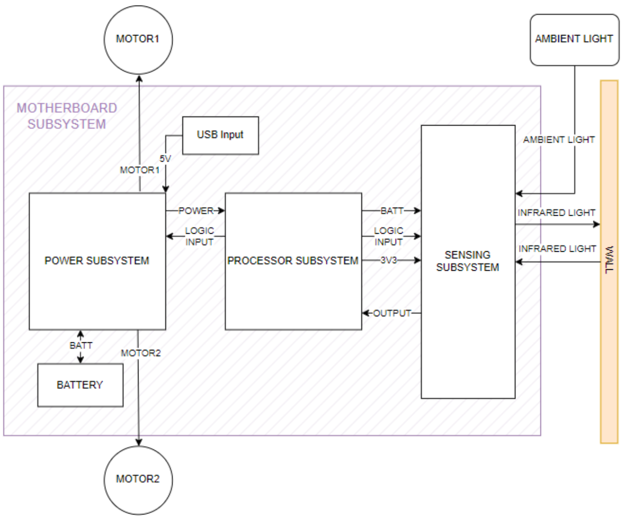


Figure 1.1: Context Diagram

1.2 Scope and Limitations

The scope includes the design of the sensing PCB but the manufacturing of the PCB is external. It must detect walls, however, it does not have to interpret any data. The data is sent to the processor to be interpreted. It has design limitations: it must fit onto the pin headers on the motherboard, it must be an appropriate size for the micro-mouse and the components must be available on JLCPCB. Additionally, it has financial limitations: must not exceed $16.5 for two boards. Finally, it has a time limitation: must be completed by May 17th 2024.

1.3 GitHub Link

https://github.com/Luke-VDW/micromouse

Chapter 2

Requirements Analysis

2.1 Requirements

The requirements for a micro-mouse sensing module are described in Table 2.1.

Table 2.1: Requirements of the Sensing Subsystem.

Requirement ID	Description
R01	It must be externally powered.
R02	It must not exceed the power and current limitations.
R03	It must detect walls.
R04	It must prove it can detect walls
R05	It must fit onto the pin headers on the motherboard.
R06	It must be an appropriate size for the micro-mouse.
R07	It must adhere to the budget.
R08	All components must come from JLCPCB .

2.2 Specifications

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

Table 2.2: Specifications of the Sensing Subsystem

Specification ID	Description
S01	The IR emitter circuitry voltage will be supplied by the Battery LiPo 800mAh 3.7V.
S02	The IR sensor circuitry voltage will be supplied by the 3.3V supply from the processor.
S03	The maximum draw of 400mA from the battery results in a discharge time from full to fully discharged of 2 hours.
S04	It must detect walls at the front, left and right sides of the PCB.
S05	A simple code must be written to interpret the sensing subsystem's output voltage that is sent to the processor.
S06	The output voltage should be significantly greater than the minimum voltage output to indicate detection. The sensor detects ambient light and therefore the output voltage will have a non-zero minimum voltage output.
S07	It must have a pin pitch less than or equal to 2.54mm.
S08	The PCB's size must not exceed an 80mm square.
S09	The PCB component cost must not exceed $16.5 for 2 boards.
S10	JLCPCB must have more than 1000 units available of the component.

2.3 Testing Procedures

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

Table 2.3: Summary of Testing Procedures

Acceptance Test ID	Description
AT01	Measure voltage across IR emitter circuitry.
AT02	Measure voltage across IR sensor circuitry.
AT03	Measure the current through the IR emitter circuit.
AT04	Measure the current through the IR sensor circuit.
AT05	Check there is IR emitter circuitry and IR sensor circuitry for the front, left and right sides of the PCB.
AT06	The processor board has three LEDs. Observe LED1, LED2 and LED3 which indicate a wall is sensed on the left, front and right, respectively, by turning on. If no wall is sensed, then no LEDs will be on.
AT07	Measure the output voltage of the IR sensor circuitry.
AT08	Measure the pin pitch on the sensing PCB.
AT09	Measure the PCB's length and width.
AT10	Check PCB cost is within budget.
AT11	Check the manufacturing bill of materials.

2.4 Traceability Analysis

Table 2.4 shows how the requirements, specifications and testing procedures all link.

Table 2.4: Requirements Traceability Matrix

#	Requirements	Specifications	Acceptance Tests
1	R01	S01 S02	AT01 AT02
2	R02	S03	AT03 AT04
3	R03	S04	AT05
4	R04	S05 S06	AT06 AT07
5	R05	S06	AT08
6	R06	S07	AT09
7	R07	S08	AT10
8	R08	S09	AT11

2.4.1 Traceability Analysis 1

The sensing subsystem must be externally powered (R01). The voltage across the IR emitter circuitry (S01) will be measured (AT01) to test whether the voltage is within the battery's range. Therefore, indicating whether it is successfully powered by the battery. The voltage across the IR sensor circuitry (S02) will be measured (AT02) to test whether the voltage is approximately 3.3V. Therefore, indicating whether it is successfully powered by the processor output.

2.4.2 Traceability Analysis 2

The sensing subsystem must not exceed the power and current limitations(R02). The current through the IR emitter circuitry (AT03) and the IR sensing circuitry (AT04) will be measured to test whether they exceed the 400mA total current limit (S03).

2.4.3 Traceability Analysis 3

The sensing subsystem must detect walls (R03) at the front, left and right sides of the PCB (S04). Therefore, a check for IR emitter circuitry and IR sensor circuitry for the front, left and right sides of the PCB (AT05) is performed.

2.4.4 Traceability Analysis 4

The sensing subsystem must be able to prove it can detect walls (R04). A simple code must be written to interpret the sensing subsystem's output voltage that is sent to the processor (S05) which has three LEDs. Observing whether LED1, LED2 and LED3 are on or off (AT06) is effective in proving detection. The detection can also be determined directly by measuring the output voltage of the IR sensor circuitry (AT07). The output voltage should be significantly greater than the minimum voltage output, due to ambient light, to indicate detection (S06).

2.4.5 Traceability Analysis 5

The sensing PCB must fit onto the pin headers on the motherboard (R05). Measure the pin pitch on the sensing PCB (AT08) to determine whether they exceed the 2.54mm maximum pin pitch limit (S07).

2.4.6 Traceability Analysis 6

The sensing PCB must be proportional to the micro-mouse (R06). The length and width of the PCB must be measured (AT09) to determine whether they are less than 80mm (S08). Thus indicating correct or incorrect proportionality.

2.4.7 Traceability Analysis 7

The sensing PCBs must adhere to the budget (R07). The budget for 2 boards is $16.5 (S09). This will be checked (AT10) to ensure the PCBs cost has not exceeded the budget.

2.4.8 Traceability Analysis 8

Components are limited to availability at JLCPCB (R08). To ensure the component is added to the PCB, JLC must have more than 1000 units available of the component (S10). This will be checked (AT11) to ensure the PCB will be populated with the components ordered.

Chapter 3

Subsystem Design

3.1 Design Decisions

The sensing subsystem has four major design elements. The IR emitter and IR sensor circuitry, the power supply, the logic addition and The PCB shape. The design options are evaluated and compared in Table 3.1, Table 3.2, Table 3.4 and Table 3.3, respectively. Finally, a design decision is made and the other designs are discarded.

3.1.1 IR Emitter and IR Sensor Circuitry

Table 3.1: IR Emitter and IR Sensor Circuitry Options

	Option	Pro	Con
1	The IR emitting diode and the photo-transistor are mounted side by side as one component.	The photo-transistor only detects the emitted IR light after it has been reflected. It does not detect the IR light directly because there is a divider between the emitting diode and the photo-transistor.	Only one IR emitting diode per photo-transistor limits the proximity at which the photo-transistor can detect walls.
2	The IR emitting diode and the photo-transistor individual components.	Many IR emitting diodes per photo-transistor which increases the proximity at which the photo-transistor can detect walls.	The photo-transistor detects IR light emitted directly from the diode because there is no divider between the emitting diode and the photo-transistor. The photo-transistor detects the reflected IR light and the direct IR light. The photo-transistor will therefore have inaccurate proximity sensing.

Design decision: Option 2
Three photo-transistors will be used at the left, front and right sides of the PCB. Each photo-transistor will have two IR emitting diodes on either side which will increase the proximity at which the photo-transistor can detect walls. To combat the direct IR light detected by the photo-transistor, a divider (black insulation tape) can be inserted between the IR emitting diodes and photo-transistors after the PCB has been manufactured and delivered.

Note discarded design:
Option 1 could be chosen. To combat the issue of having only one IR emitting diode per photo-transistor, additional individual IR emitting diodes can be added. However, the addition of another extended components will cause budget issues. Additionally, the availability of the integrated photo-transistor and IR emitting diode components are limited. This would have caused issues during component selection subsection 3.1.5.

3.1.2 Power Supply

Table 3.2: Power Supply Options

	Option	Pro	Con
1	Battery LiPo 800mAh 3.7V	A maximum of 400mA current can be drawn. A large amount of current through the diodes cause the diodes to emit a large amount of IR light. This increases the proximity at which the photo-transistor can detect walls.	The battery voltage is unstable. This causes unpredictable voltage outputs from the senor circuitry to the processor. The processor cannot accurately interpret the data.
2	STM32L476 3V3 Output	3V3 voltage is stable. Therefore, there is predictable voltage outputs from the senor circuitry to the processor. The processor accurately interpret the data.	A maximum of 100mA current can be drawn from the I/O pins. A small amount of current through the diodes cause the diodes to emit a small amount of IR light. This decreases the proximity at which the photo-transistor can detect walls.

Design decision: Option 1 and Option 2

The Battery LiPo 800mAh 3.7V powers the IR emitter circuitry. This ensures enough current is supplied to the diodes to increase IR emitted light which increases the proximity at which the photo-transistor can detect walls. The STM32L476 3V3 Output powers the IR sensor circuitry. This ensures the voltage supply is stable and therefore there is predictable voltage outputs from the senor circuitry to the processor.

Note discarded design:

Powering the sensing subsystem with only the Battery LiPo 800mAh 3.7V or only the STM32L476 3V3 Output will have either current or voltage issues. Both issues cause serious operational defects as discussed in Table 3.2.

3.1.3 PCB Shape

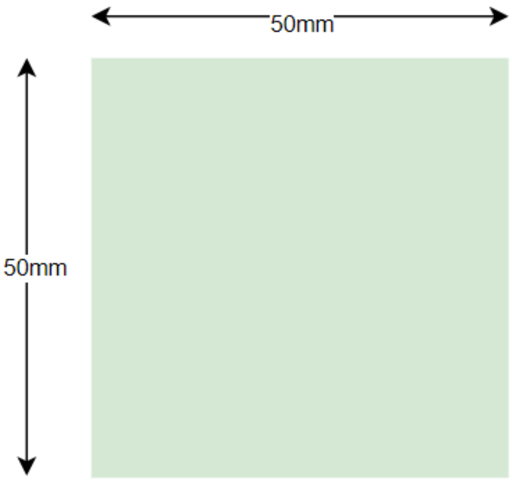


Figure 3.1: PCB Shape Small

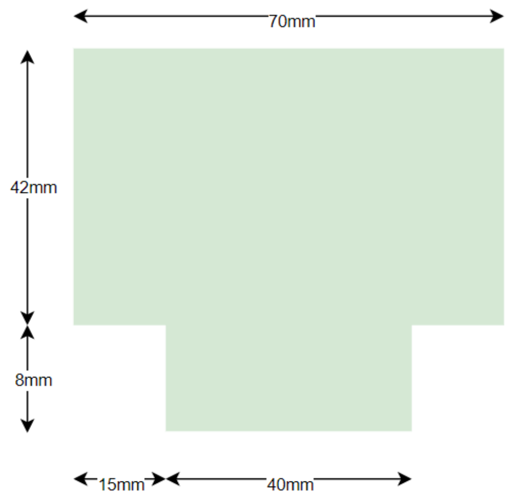


Figure 3.2: PCB Shape Wide

Table 3.3: PCB Shape Options

	Option	Pro	Con
1	A small square 50mmx50mm PCB seen in Figure 3.1.	The micro-mouse will have a smaller turning circle for ease of navigation through the maze.	The maze is 200mm wide. The IR emitting diodes will be approximately 75mm from the left and right side walls of the maze. The walls may be out of the photo-transistor's range.
2	A wide 'T' shape 50mmx70mm PCB seen in Figure 3.2.	The maze is 200mm wide. The IR emitting diodes will be approximately 65mm from the left and right side walls of the maze. The walls will be within the photo-transistor's range.	The micro-mouse's larger turning circle will impede its ability to navigate through the maze efficiently.

Design decision: Option 2

The walls must be within range of the photo-transistor for the sensing subsystem to meet it's requirements. The turning circle will hinder the micro-mouses ability to efficiently navigate the maze but it will still be functional. It is less than a 80mm square to meet the specification.

Note discarded design:

Option 1 could have been chosen. It is less than a 80mm square to meet the specification. The micro-mouse would be able to efficiently solve the maze provided the photo-transistor can detect the walls. However, if the photo-transistor cannot detect the walls, it will not be functional.

3.1.4 Logic Addition

Table 3.4: Logic Addition Options

	Option	Pro	Con
1	A transistor is added to the IR emitter circuits. The PWM signal from the processor will supply the base with power. This causes the transistor and therefore the IR emitting diodes to repeatedly switch on and off. While the IR emitting diodes are off, they do not draw power from the battery.	The Battery LiPo 800mAh has power limitations. The power dissipated by the IR emitting diodes over a period of time is halve the initial power dissipated. Therefore, double the current can be drawn and achieve the same initial power dissipated over a period of time.	The photo-transistor can only detect a wall when the IR emitting diodes are on i.e. there are periods of time when the photo-transisitor cannot detect a wall within range.
2	No logic addition	The photo-transistor is continuously sensing whether there is a wall or not because the IR emitting diodes are always on.	The Battery LiPo 800mAh has power limitations. The current cannot be doubled without increasing the power drawn from the battery.

Design decision: Option 1

In this design the IR emitting diodes can draw double the current without exceed the battery limitations. Double current through the diodes cause the diodes to emit a large amount of IR light. This increases the proximity at which the photo-transistor can detect walls. This is implemented for each IR emitter circuit. This is important to allow adequate time and space for the micro-mouse to avoid the wall. The photo-transistor will only be able to detect a wall when the IR emitting diode is on. However, this is not detrimental to the design. The micro-mouse will be relatively slow and the periods of no detection ability will be extremely small in comparison. Therefore, the micro-mouse will still have adequate time and space to avoid the wall despite the small delay in detection.

Note discarded design:

Option 2 could be chosen. The diodes would still emit enough IR light for the photo-transistor to detect walls. However, it will need to be closer to the wall to detect it, thus, leaving little room to avoid the wall. This will increase the time taken to avoid the wall and, ultimately, the time taken to navigate through a maze.

3.1.5 Component Selection

The design designs chosen in the IR Emitter and Circuitry subsection 3.1.1, the Power Supply subsection 3.1.2, the PCB Shape subsection 3.1.3 and Logic Addition subsection 3.1.4 require the following components: IR emitter, photo-transistor and transistor. E12 resistors and capacitors will be used, their values will be calculated in the calculations subsection 3.1.6.

Table 3.5: IR Emitting Diode Options

IR Emitting Diode	Radiant Power at Maximum Current	Rise/Fall Time	Total Cost	Stock
TSAL6200	40mW	9ns	$4.3028	1047
SFH 7016	11mW	15ns	$43.1	41

Table 3.6: Photo-transistor Options

Photo-transistor	Peak Sensitivity	Extra Feature	Total Cost	Stock
DY-PT204-6C	940nm		$3.1778	4963
QSD123	880nm	Daylight filter	$6.65	2
SFH 309 FA	900nm		$4.4876	1631

Table 3.7: Transistor Options

Transistor	Rise Time	Fall Time	Total Cost	Stock
MMBT3904	35nS	50nS	$0.0582	1097041
PN2222ATA	20nS	60nS	$3.4634	9
2N2222A	25nS	60nS	$2.9972	23386

As per Table 3.5, IR Emitting Diode **TSAL6200** is chosen due to it's superior radiant power, short rise/fall time and low cost.

As per, Table 3.6, Photo-transistor **SHF 309 FA** is chosen due to its peak sensitivity aligning with IR Emitting Diode TSAL6200.

As per Table 3.7, Transistor **MMBT3904** is chosen due to its short rise/fall time and low total cost.

The stock of all components is greater than 1000 as per the specification to ensure the component will be available during maufacturing.

3.1.6 Calculations

The resistor values must be calculated to bias the components chosen in subsection 3.1.5 with the correct voltage and current for operation in the Emitter Circuit Figure 3.3 and Sensor Circuit Figure 3.4. The capacitor value must be chosen to effectively reduce noise in the Sensor Circuit Figure 3.4.

Emitter Circuit

Determine R_B:
Set: $PWM = 3.3V$
Known: $V_{BE} = 0.95V$
KVL: $PWM - I_B R_B - V_{BE} = 0$
$R_B = 270\Omega$ where $I_B = 8.7mA$

Determine R_1:
Known: $BATT = \pm 3.7V$
Known: $V_{CE} = 1V$
KVL: $BATT - I_{C1} R_1 - V_f - V_{CE} = 0$
$R_1 = 10\Omega$ where $I_C 1 = \pm 110mA$

Similarly, $R_2 = 10\Omega$

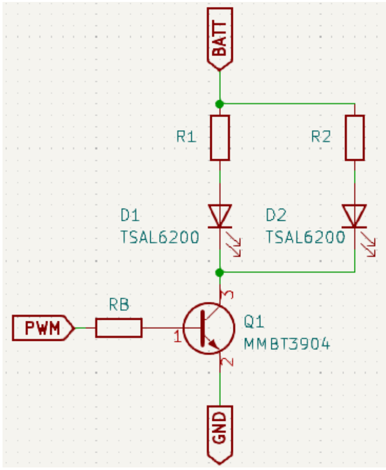


Figure 3.3: Emitter Circuit

Sensor Circuit

Determine R_S:
Known: $3V3$ Input
Known: I_S and V_{CE} varies depending on the amount of IR light the photo-transistor detects.
KVL: $3V3 - V_{CE} - I_S R_S = 0$
$R_S = 10k\Omega$
A large value for R_S was chosen to increase the output voltage, *Analog*, which is sent to the processor for interpretation.

Determine C:
Set: Output voltage, *Analog*, threshold is $2V$.
The processor will indicate a wall when $Analog > 2V$.
A decoupling capacitor will reduce noise from the *Analog* output voltage. The capacitor value must fall within the range $10nF - 1uF$.
$C = 100nF$

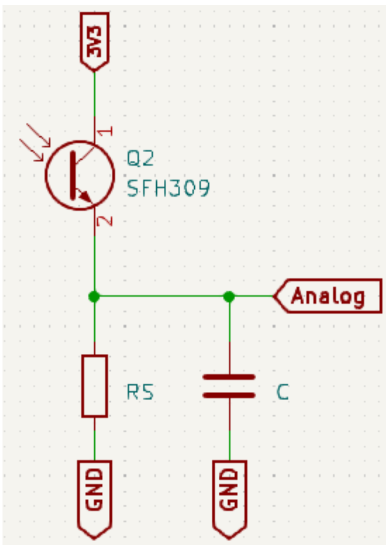


Figure 3.4: Sensor Circuit

3.1.7 Final Design

The design consists of three Infrared Emitter circuits and three Infrared Proximity Sensor circuits for the left, centre and right sides of the PCB. The Infrared Emitter circuits emit IR light on the walls. The IR emitting diodes repeatedly switch on and off to save the battery's power. The Infrared Proximity Sensor circuits detect the reflected IR light and outputs a corresponding analog voltage to the processor. If the output voltage is above the voltage threshold, 2V, the processor indicates a wall has been detected. A further analysis is seen in Figure 3.5 below. The design, component, resister and capacitor decisions were motivated in the previous subsections.

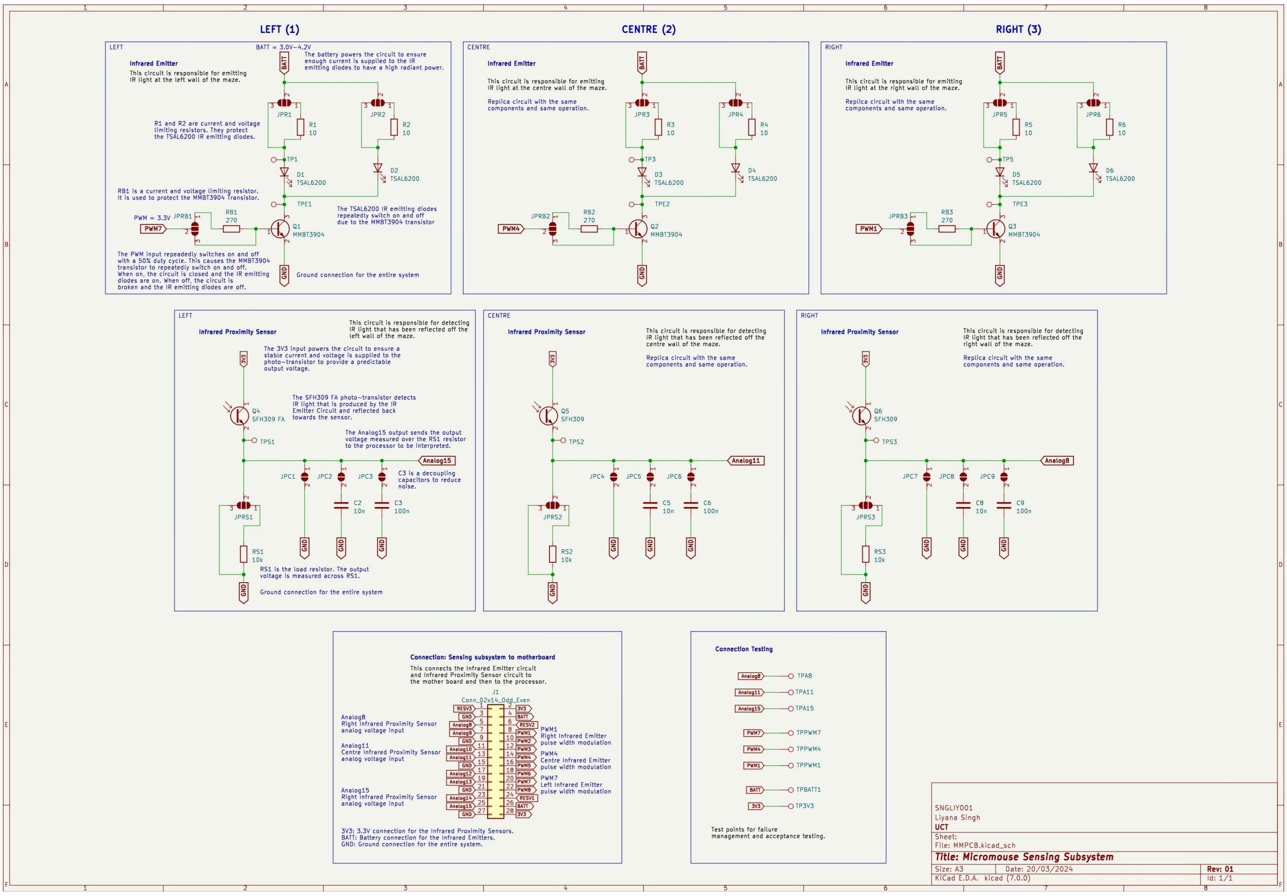
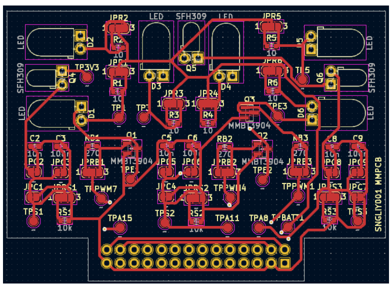
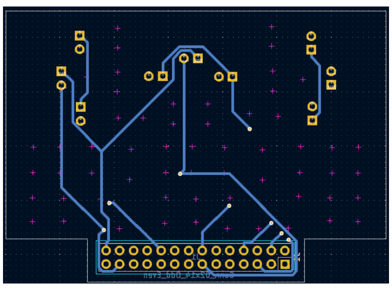


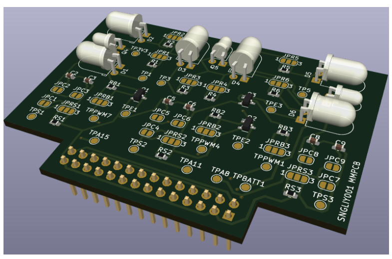
Figure 3.5: Schematic



(a) Front PCB



(b) Back PCB



(c) 3D PCB

Figure 3.6: PCB

3.2 Failure Management

Please refer to the Schematic Figure 3.5 for the jumper and test point positions.

Table 3.8: Failure Management

Name	Description
Resistor Jumpers	Every resistor in the schematic has a three pad jumper. The jumper can be used to connect the current resistor to the circuit as calculated. However, if there is a calculation error, a second resistor can be added to the circuit in place of the incorrect resistor.
Capacitor Jumpers and Additional Capacitors	The capacitor has a two pad jumper. The capacitor $C3 = C6 = C9 = 100nF$ as calculated can be connected. However, the additional capacitor $C2 = C5 = C8 = 10nF$ can be connected instead. If neither are correct, a third capacitor $C1 = C4 = C7$ can be chosen and connected to replace the other two.
Tractability Infrared Emitter Circuit	Test points TP1, TP2 and TP3 in conjunction with TPE1, TPE2 and TPE3 are used to measure voltage at significant points in the circuit. The voltage over the IR emitting diodes and the collector emitter voltage of the transistors can be tested.
Tractability Infrared Proximity Circuit	The test points TPS1, TPS2 and TPS3 in conjunction with TPA15, TPA11 and TPA8 are used to measure voltage at significant points in the circuit. The voltage over the load resistor and the output voltage sent to the processor.

3.3 System Integration and Interfacing

Table 3.9: Interfacing Specifications

ID	Interface	Description	Pins/Output
I1	J1	Power supplied from processor subsystem (STM32L476) to sensing subsystem	• 3V0-4V2: STM BATT to PIN04 • 3V3: STM 3V3 to PIN02
I2	J1	PWM signals from processor subsystem (STM32L476) to sensing subsystem	• PWM1: STM PE15 to PIN08 • PWM4: STM PE12 to PIN14 • PWM7: STM PE9 to PIN20
I3	J1	Analog output voltage from sensing subsystem to processor subsystem (STM32L476)	• Analog8: PIN05 to STM PA3 • Analog11: PIN13 to STM PA6 • Analog15: PIN25 to STM AB0
I4	J1	Sensing subsystem ground to processor subsystem (STM32L476) ground	• GND: PIN21 to STM GND

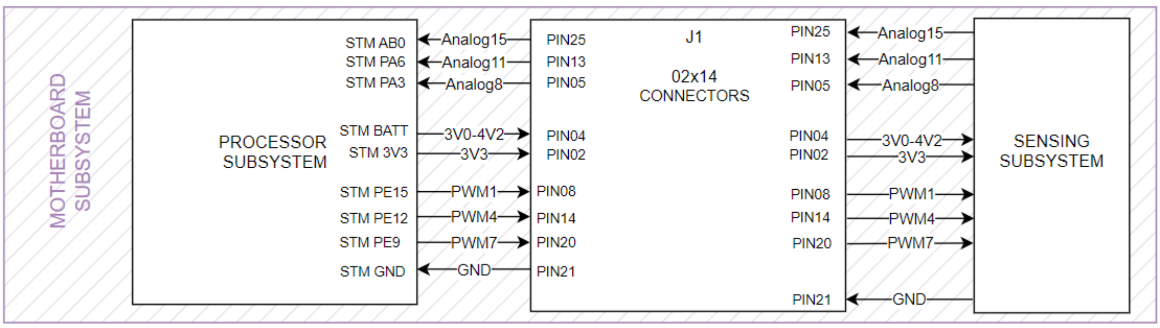


Figure 3.7: Interfacing Diagram

Chapter 4

Acceptance Testing

4.1 Tests

Table 4.1: Acceptance Tests

Test ID	Description	Testing Procedure	Pass/Fail Criteria
AT01	Measure voltage across IR emitter circuitry.	• Use a multi-meter to measure across the test point TPBATT1 and GND.	• Voltage is 3V3-4V2.
AT02	Measure voltage across IR sensor circuitry.	• Use a multi-meter to measure across the test point TP3V3 and GND.	• Voltage is 3V3. • Voltage is stable.
AT03	Measure the current through the IR emitter circuit.	• Assume AT01 passed. • Use an oscilloscope to measure across pad1 and pad2 of jumper JPR1, JPR2 and JPR3. • Add the average currents together.	• Current is below 360mA.
AT04	Measure the current through the IR sensor circuit.	• Assume AT02 passed. • Use an oscilloscope to measure across pad1 and pad2 of jumper JPRS1, JPRS2 and JPRS3. • Add the currents together.	• Current is below 40mA.
AT05	Check there is IR emitter circuitry and IR sensor circuitry for the front, left and right sides of the PCB.	• Observe the PCB.	• Two front facing, right facing and left facing TSAL6200 IR emitting diodes. • One front facing, right facing and left facing SFH 309 FA phototransistor.
AT06	The processor board has three LEDs. Observe LED1, LED2 and LED3 which indicate a wall is sensed on the left, front and right, respectively, by turning on. If no wall is sensed, then no LEDs will be on.	• Assume AT01, AT02, AT03, AT04 and AT05 have passed. • Observe the three LEDs. • Bring a section of the maze wall to the left of the PCB • Bring a section of the maze wall to the front of the PCB • Bring a section of the maze wall to the right of the PCB	• Initially no LEDs are on. • Then LED1 turns on. • Then LED2 turns on. • Then LED3 turns on.

Test ID	Description	Testing Procedure	Pass/Fail Criteria
AT07	Measure the output voltage of the IR sensor circuitry.	• Assume AT01, AT02, AT03, AT04 and AT05 have passed. • Use a multi-meter to measure the output voltage on TPA8, TPA11 and TPA15. • Bring a section of the maze wall to the left of the PCB. Measure the voltage at TPA8. • Bring a section of the maze wall to the front of the PCB. Measure the voltage at TPA11. • Bring a section of the maze wall to the right of the PCB. Measure the voltage at TPA15.	• Initially the voltage at TPA8, TPA11 and TPA15 are 0V. • Then TPA8 is >2V. • Then TPA11 is >2V. • Then TPA15 is >2V.
AT08	Measure the pin pitch on the sensing PCB.	• Use a caliper to measure the diameter of the pin pitch holes.	• The pin pitch is <=2.54mm
AT09	Measure the PCB's length and width.	• Use a PCB ruler to measure the length of the PCB. • Use a PCB ruler to measure the width of the PCB.	• The length of the PCB <=80mm. • The width of the PCB <=80mm.
AT10	Check PCB cost is within budget.	• Review the JLCPCB website order.	• The total order for two PCBs is <=30$
AT11	Check component availability.	• Check the JLCPCB manufacturing bill of materials.	• All components appear on the manufacturing bill of materials.