Project Design Report

Micromouse Sensor Subsystem

Prepared by:
Nicholas Tucker (TCKNIC006)

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

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Chapter 1

Introduction

1.1 Problem Description

The project is focused on the development of the hardware for a micromouse, which is a small robotic vehicle designed to navigate and solve a maze autonomously. In order for the mouse to be successful, it needs to reach the finishing area within the maze. The project has been compartmentalised into four modules: the processor (which has a STM32L476 microcontroller), motherboard, sensing subsystem and power subsystem. The processor and motherboard modules have been designed prior. The third year engineering students have been tasked with designing the sensing subsystem and power subsystem in pairs. This design report will focus on the sensing subsystem, which is responsible for detecting objects and allowing the micromouse to traverse through the maze with proper alignment in the centre of a pathway. This project will not deal with the software of the sensor subsystem.

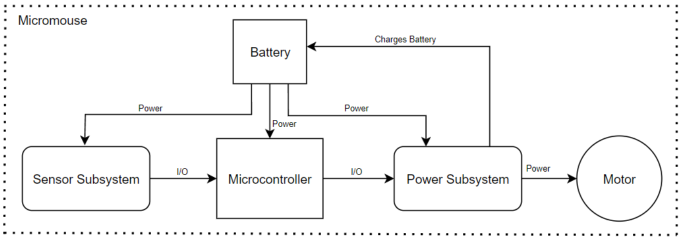


Figure 1.1: Simplified Context Diagram

1.2 Scope and Limitations

Scope of the report:

- Describe the specific objectives and goals of the sensing subsystem within the context of the overall project.
- Identify the requirements and specifications of the sensing subsystem.
- Explain how these requirements and specifications will be tested for.
- Discuss the decisions involving component selection, evaluating possible solutions and providing calculations used to design the sensing subsystem.
- Discuss how the PCB is designed to mitigate failure in the sensing-subsystem circuit design.
- Show how the sensing subsystem fits into the larger system.

Limitations of the report:

- A budget may have restricted the selection of components, potentially affecting the overall quality or performance of the system.
- The short timeframe (less than a semester) may have limited the depth of research, design iterations, and testing procedures, thereby impacting the comprehensiveness and robustness of the design.
- Although access to a lab with oscilloscopes and multimeters was available, other specialized equipment or facilities may have been lacking, limiting the range and quality of tests that could be implemented.

1.3 GitHub Link

Link to the shared repository on GitHub: https://github.com/NichTucker/Micromouse

Chapter 2

Requirements Analysis

2.1 Requirements

The requirements for the micromouse sensor module are described in Table 2.1.

Table 2.1: Requirements of the sensing subsystem.

Requirement ID	Description
R01	System shall sense when an object is in front and by the sides of the micromouse.
R02	Output of the system shall be consistent at different distances from an object.
R03	Outputs of system shall be suitable for microcontroller.
R04	Subsystem shall be power efficient when in operation and have mitigation means on the effects of ambient light on the system.
R05	Components on PCB shall be accessible to be tested.
R06	Total cost of PCB shall be within the budget.
R07	Power shall be supplied by a battery.
R08	PCB shall be small enough and be shaped such that the micromouse can fit in the pathway and turn through corners of the maze.
R09	PCB shall not be too heavy.

2.2 Specifications

The specifications, refined from the requirements in Table 2.1, for the micromouse sensor 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	Peak voltage at output increases when sensor is brought closer to an object.
SP02	Peak voltage when sensor is 8 cms away from an object shall be greater than 2.5V with a range/consistency less than $\pm$0.2V at the output.
SP03	Peak voltage when sensor is 16 cms away from an object shall be within 0.9V and 1.7V with a range/consistency less than $\pm$0.2V at the output.
SP04	When no object is sensed, the voltage at the output shall be less than 0.5V with a range/consistency less than $\pm$0.2V and output waveform shall have an amplitude of less than 0.1V.
SP05	Output of sensor shall never be more than 3.3V.
SP06	Emitter/sender of sensor shall be pulsed at a particular pulse width and duty cycle.
SP07	Test points shall be placed across key components in order to measure their voltage w.r.t. ground.
SP08	Total cost of two PCB boards shall be no more than 30 USD. This includes the PCB manufacture, the PCB assembly and the remaining budget for components.
SP09	A Polymer Lithium Ion battery rated at 3.7V and 800mAh from Micro Robotics shall supply power to the system.
SP010	The pathways in the maze are 200mm wide. Maximum length and width of PCB shall be smaller than 60mm, thereby leaving leeway for microcontroller to turn through corners.
SP11	Mass of PCB shall not be more than 300g.

2.3 Testing Procedures

A summary of the testing procedures detailed in Chapter 4 is given below:

Acceptance Test ID	Description
AT01	Voltage at output will be tested when sensor is moved closer to an object.
AT02	Output voltage when sensor is 8 cms away from an object shall be measured.
AT03	Output voltage when sensor is 16cm away from an object shall be measured.
AT04	Output Voltage when no object is sensed shall be measured.
AT05	Voltage regulator's output voltages shall be measured w.r.t. ground.
AT06	Pulse length and duty cycle of emitter and receiver shall be measured.
AT07	Each test point on PCB shall be tested to ensure they are working correctly.
AT08	Total cost of two PCB boards shall be calculated.
AT09	Voltage across battery shall be measured.
AT10	The dimensions of the PCB shall be measured.
AT11	Mass of PCB shall be measured.

2.4 Traceability Analysis

Table 2.3 shows how the requirements, specifications and testing procedures all link:

Table 2.3: Requirements Traceability Matrix

#	Requirements	Specifications	Acceptance Test
1	R01	SP01	AT01
2	R02	SP02, SP03, SP04	AT02, AT03, AT04
3	R03	SP05	AT05
4	R04	SP06	AT06
5	R05	SP07	AT07
6	R06	SP08	AT08
7	R07	SP09	AT09
8	R08	SP10	AT10
9	R09	SP11	AT11

2.4.1 Traceability Analysis 1

R01 states that the system shall sense when an object is in front and by the sides of the micromouse. From this SP01 is derived: the peak voltage at output increases when the sensor is brought closer to an object. To test this AT01, which is to test the voltage at the output when the sensor is moved closer to an object, is suggested because if the acceptance test is passed, R01 is complete and the system does 'sense'/respond to when an object is in front and by the sides of the micromouse.

2.4.2 Traceability Analysis 2

From R02, which is that the output of the system shall be consistent at different distances from an object, SP02, SP03 and SP04 can be derived. SP02 specifies that the peak output voltage when the sensor is 8 cm away from an object shall be greater than 2.5V with a range/consistency less than 0.2V. SP03 states that the peak output voltage when the sensor is 16 cm away from an object shall be within 0.9V and 1.7V with a range/consistency less than 0.2V. SP04 states that when no object is sensed, the voltage at the output shall be less than 0.5V with a range/consistency less than 0.2V and the output trace shall have an amplitude less than 0.1V. These specifications can be tested through AT02, AT03 and AT04: measuring the output voltages when the sensor is 8 cms, 16cm and appropriately far away from an object, respectively. If all these tests are passed, the output of the system shall be deemed consistent at different distances from an object.

2.4.3 Traceability Analysis 3

R03 is that the outputs of system shall be suitable for the microcontroller. From this SP05 is derived: the output of the sensors shall never be more than 3.3V. To complete this, AT04 is conducted to measure the voltage regulator's output voltages w.r.t. ground. This is because the sensors cannot output more than their input voltage, which should be equal to 3.3V.

2.4.4 Traceability Analysis 4

R04 states that the system shall be power efficient when in operation and have mitigation means on the effects of ambient light on the system. This results in SP06: which is that the emitter/sender of sensor shall be pulsed at a particular pulse width and duty cycle. This can be tested through AT06, which is by measuring the pulse length and duty cycle, ensuring that the emitter/sender is pulsed, thereby saving power when in operation.

2.4.5 Traceability Analysis 5

From R05, being that the components on the PCB shall be accessible to be tested, SP07 can be derived: test points shall be placed across key components in order to measure their voltage w.r.t. ground, because this allows the components to be tested. This can be approved through AT07 in that each test point on PCB shall be tested to ensure that they are working correctly.

2.4.6 Traceability Analysis 6

R06 states that the total cost of PCB shall be within the budget. This results in SP08 stating that the total cost of two PCB boards shall be no more than 30 USD. This can be evaluated through AT08, which is by calculating or determining the price of two boards.

2.4.7 Traceability Analysis 7

R07 is the power shall be supplied by a battery from which SP09 can be derived: a polymer lithium ion battery rated at 3.7V and 800mAh. To test this AT09 is suggested, which is to measure the voltage across the battery, ensuring that the battery is operating as expected.

2.4.8 Traceability Analysis 8

R08 states that the PCB shall be small enough and be shaped such that the micromouse can fit in the pathways and turn through corners of the maze. This leads to SP10, which specifies that the maximum length and width of the PCB shall be smaller than 60mm because a PCB smaller this shall fit in the pathways and turn through corners of the maze. This can be tested through AT09: measuring the dimensions of the PCB.

2.4.9 Traceability Analysis 9

From R10, PCB shall not be too heavy, SP12 can be derived. This is that the mass of the PCB shall not be more than 300g as this will cause the centre of mass of the micromouse to change dramatically making it difficult for it to turn and could cause the micromouse to topple. SP12 can be evaluated through AT12, where the mass of PCB is measured.

Chapter 3

Subsystem Design

3.1 Design Decisions

The battery that is supplying power to the micromouse is a Polymer Lithium Ion battery rated at 3.7V and 800mAh. It provides a voltage that ranges from 3.75V to 4.2V. This difference would cause a change in the output of the system at the same distance at two different instances in time, hence reducing the consistency. A voltage regulator is needed so that a fixed voltage is supplied irrespective of the change of the batteries voltage. The voltage regulator shall output 3.3V to the sensor subsystem and be a basic component supplied by the PCB manufacture as it reduces the cost of the component significantly. Three voltage regulators were considered:

Table 3.1: Voltage regulators

Voltage Regulator	**Price ($)**	**Accuracy** (±%)	**Quiescent Current (mA)**	**I_out_max (mA)**
HT7533-1	0.097	3	0.0025	100
XC6206P332MR	0.092	2	0.001	200
AMS1117-3.3	0.127	3	5	1000

The parameters considered in determining the correct voltage regulator were the price, accuracy, quiescent current and the maximum output current of the voltage regulator. The quiescent current indicates the power consumption, and ideally, this value should be as low as possible. Herewith, the XC6206P332MR is chosen as it has the greatest accuracy, the lowest price and the lowest quiescent current (power-consumption) of the three voltage regulators. Its maximum output current is also the most suitable as the current draw of the sensor subsystem will be lower than 200mA.

Due to the limitation of a strict budget and size, simplicity should be a central goal of the sensor subsystem. The complexity and sophistication of the sensor should be relevant only to the amount of information that needs to be received or transmitted. Adding too many sensors or using too complicated of sensors will not necessarily improve the performance or functionality of the micromouse. Therefore, the minimum of three sensors would be placed in the front and sides of the sensor board to detect objects and barriers on the sides and in front of the micromouse aligning with SP01. Multiple sensor systems were also considered. A touch sensor acts operates like a switch when touched or pressed against an object. A sonar sensor emits ultrasonic waves and converts the reflected waves from the object into a signal, thereby indicating the distance the object is from the sensor. An infrared sensor emits a specific frequency of infrared radiation (IR) to an object, and uses the amount of reflected IR to generate a signal, thereby also determining distance. Table 3.2 below shows the pros and cons of these sensors.

Table 3.2: Pro's and con's of various sensor systems

Sensor System	**Pros**	**Cons**
Sonar	• Not affected by colour or reflectiveness of object • Not affected by ambient light • Most accurate • Generates an analogue signal	• Material reflect and absorb sound differently • Not good at defining the edges of a corner • Expensive
Touch	• Output signal is most accurate • Cost-effective • Power and energy-effective	• Only two logic outputs: one when it has touched the wall and one when it has not • Not time-efficient as bumping into walls will increase time taken to finish the maze • Requires that the microcontroller not move too fast through the maze as to not damage any of its components when it bumps into a wall

Sensor System	Pros	Cons
Infrared	• Cost-effective • Power and energy-effective • Generates an analogue signal	• Sensitive to ambient light

The infrared sensor is the most logical choice as it provides a cost and power-effective solution whilst meeting the requirements of the sensor subsystem. One major con of the infrared sensor is that it is sensitive to ambient light. However, if the IR emitter is pulsed, the affects of ambient light can be mitigated by comparing the IR receiver output when the emitter is on and when it is off. Pulsing the emitter also saves power, which is needed to keep the battery from dying for longer.

The IR receiver must have a fast response time to perform cohesively with the pulsing of the IR emitter. Therefore, the phototransistor is a better choice for the receiver as it has a faster response time than that of a photodiode.

To narrow down the selection for the IR emitter and receiver, the pair shall operate at the same peak wave length and be 5mm radially sized (as they can be bent to face horizontally and generally fit well on the board). The IR emitter shall have a high radiant intensity, a low forward voltage and be suitable for high pulse current operation. The following IR emitters are the most appropriate in terms of the above parameters from their respective manufacturers and have stocks above 1000 on the PCB manufacturer.

Table 3.3: IR emitters

Emitter	Price ($)	Forward Voltage (V)	Peak Wavelength (nm)	Radiant Intensity	Viewing Angle (°)
IR204/H60	0.055	1.4	940	35mW/sr@100mA	50
TSAL6400	0.164	1.35	940	50mW/sr@100mA	25
MHL512IR059CRT	0.083	1.35	940	3mW/sr@20mA	70
DY-FIR333C/H34-A5	0.054	1.3	940	85mW/sr@100mA	10

Initially, the DY-FIR333C/H34-A5 seems to be the most favourable pick. However, its viewing angle, 10° is too small (and the IR204/H60 and the MHL512IR059CRT is far too big) . If the emitter were to be moved in any way, it may cause the sensor to underperform. Therefore to be conservative, the TSAL6400 is chosen with a viewing angle of 25°. Although the TSAL6400 is the most expensive, the budget is somewhat disregarded as the sensor is the most crucial part of the subsystem.

For the phototransistor, the parameters considered are the saturated collector-emitter voltage and the photo sensitivity. The following phototransistors in Table 3.4 are the most appropriate in terms of the above parameters from their respective manufacturers, have stocks above 1000 on the PCB manufacturer and have a peak wavelength of 940nm. PT333-3B is chosen as it provides the greatest difference in collector current for a change in irradiance, meaning it is

Table 3.4: Phototransistors

Receiver	Price ($)	$V_{CE_{\mathrm{sat}}}$ (V)	On State Collector Current (mA) @ $E_e = 1mW/cm^2$	On State Collector Current (mA) @ $E_e = 0.5mW/cm^2$
MHL524PT03BRT	0.089	0.4	1.4	0.5
PT204-6B-27	0.064	0.4	1.9	0.9
PT333-3B	0.048	0.4	6.4	1.0
TEFT4300	0.209	0.3	3.2	1.2

the most light-sensitive. It is also the cheapest option. The saturated collector-emitter voltage is ignored as all of the phototransistors have a similar value.

The final design of the sensor-subsystem integrates the above chosen components along with passive components to ensure that an appropriate balance of performance, efficiency, and cost-effectiveness is achived. Power supplied by the battery is regulated by the XC6206P332MR voltage regulator to provide a constant 3.3V output for the sensor circuits which is necessary for the consistency of the sensor-subsystem. The sensor subsystem uses three infrared sensors made up of the TSAL6400 IR emitters paired with PT333-3B phototransistors to detect obstacles and navigate the maze efficiently. The shape of the PCB is rounded at the front to house the emitters and phototransistor pairs. The front sensor is placed in the front and middle of the PCB, and the left and right sensors are placed on the left and right of the front of the PCB respectively, facing slightly forward to anticipate turns in the maze. To reduce the effects of the IR sensors to ambient light and to extend battery life, the IR emitter circuit is designed such that the IR emitters are pulsed. Thereupon, the receiver circuit is designed in such a way as to integrate cohesively with the pulsing of the emitters. The emitter circuit includes a MOSFET to control the pulsing of the IR emitter, providing fast switching capabilities and low power consumption.

3.2 Calculations

3.2.1 Emitter Circuit

R_3 limits the current through the IR emitter. The desired current running through the emitter is 20mA.

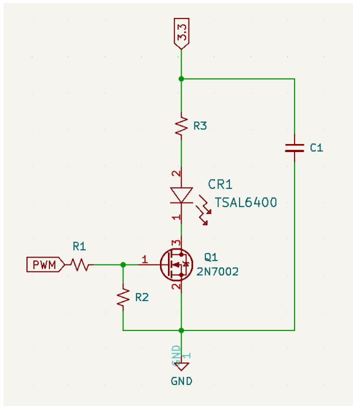


Figure 3.1: Emitter Circuit

$$V_{drop} = 3.3V - V_{CE_{\text{sat}}} = 3.3V - 1.35V = 1.95V$$

$R_{DS_{\text{On}}}$ of MOSFET is small and can therefore be neglected.

$$\therefore R_3 = 1.95V/20mA = 97.5\Omega \approx 100\Omega$$

R_1 limits current flow from the microcontroller to the mosfet gate.

$$R_1 = 100\Omega$$

R_2 is a pull-down resistor. It pulls the MOSFET gate low, thereby keeping the emitter off when the microcontroller pin is floating or disconnected. It is a high resistance to not draw too much current.

$$R_2 = 47k\Omega$$

C_1 stabilizes the supply voltage from the switching noise and also reduces the turn on time for the IR emitter.

C_1 is a 4.7uF and a 0.1uF capacitor in parallel.

The 4.7uF capacitor smooths out the voltage whereas the 0.1uF capacitor will act as a high frequency noise filter.
**The 2N7002 is chosen for the MOSFET as it is the only basic MOSFET suited for low-voltage, low-current application with fast-switching speeds that is supplied by the manufacturer.*

3.2.2 Receiver Circuit

The more light that is received from the emitter by the phototransistor, the more current that flows through the phototransistor.

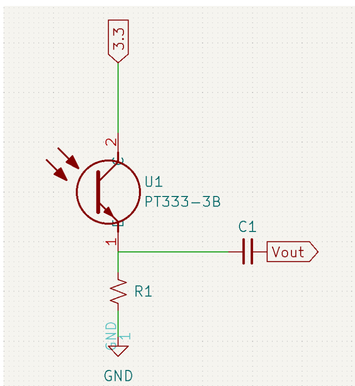


Figure 3.2: Receiver Circuit

Since the input of the analogue pins of the microcontroller have high impedance, resistor R_1 creates a voltage divider. The output voltage is across R_1. R_1 must be chosen such as to maximise the resolution of the sensor and to also limit the current through the circuit. Increasing the resistance causes more voltage to drop across the output for the same changes in current.

$$V_{out} = R_1 * I$$

Therefore, increasing the resistance makes the output more sensitive to light. Because it is difficult to know how much light will be exposed to the phototransistor, R_1 has been chosen to be a fixed resistor in series with a variable resistor.

$$R_1 = R_{pot} + R_{fixed}$$

The minimum resistance of R_1 will be equal to R_{fixed}, whilst the variable resistor can increase from this to a maximum of $R_1 = R_{pot_{\max}} + R_{fixed}$.
Let the maximum current $I_{max} = 3mA$. Using KVL:

$$3.3V - V_{CE_{sat}} - I_{max} * R_{fixed} = 0$$

$$R_{fixed} * 3mA = 3.3V - 0.4V$$

$$\therefore R_{fixed} = 966.67 \approx 1000k\Omega$$

R_{pot} is chosen to have a value of 2kΩ.

Therefore, R_1 can have a value from 1000 to 3000 Ohms. C_1 acts as a coupling capacitor. It ensures that only the AC signal generated by the pulsing emitter is transmitted to the microcontroller, while blocking any DC bias that may be present. This, in turn, helps to protect the microcontroller and also ensures the accurate detection of the signal. Let:

$$C_1 = 0.1uF$$

3.3 Final Design

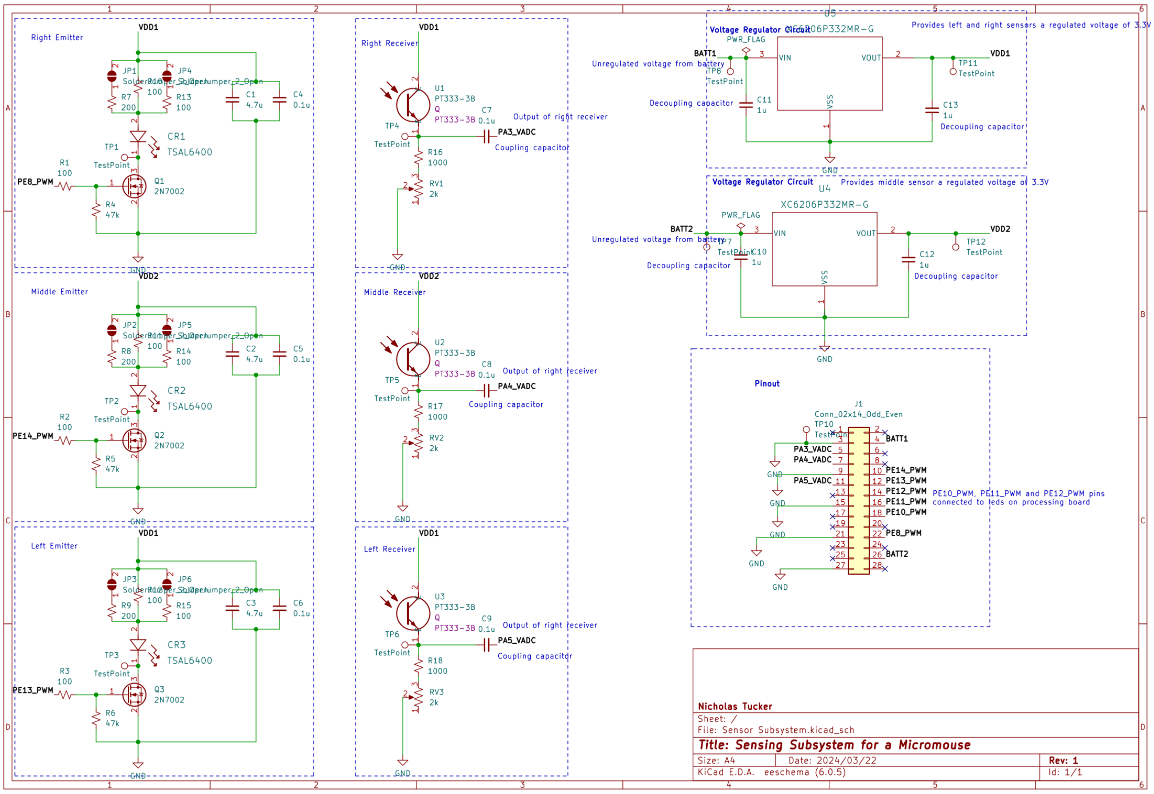
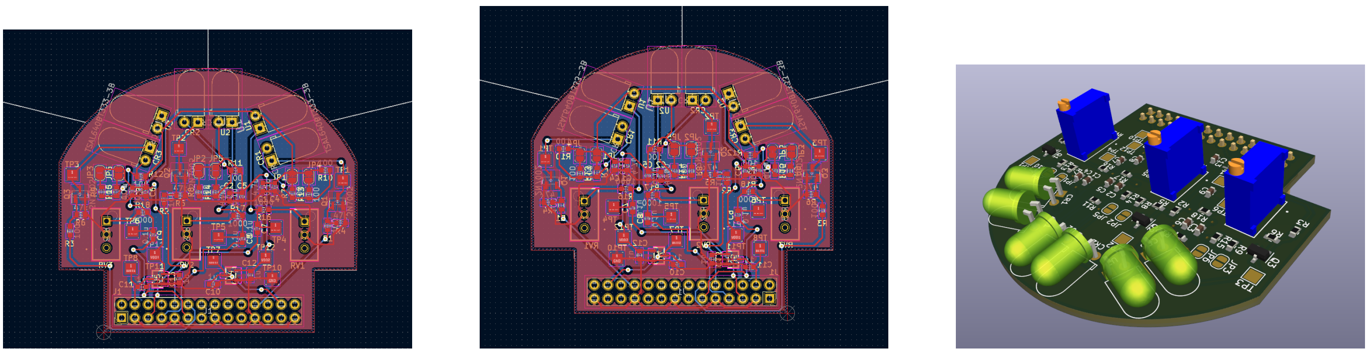


Figure 3.3: Schematic



(a) Front PCB

(b) Back PCB

(c) 3D PCB

Figure 3.4: PCB

3.4 Failure Management

Table 3.5 shows the failure management processes in regards to the PCB design and why they are implimented:

Table 3.5: The failure management processes taken

Name	Description
Solder jumpers placed in parallel with resistor that is in series with IR emitter of the emitter circuit.	If too little current is flowing into the IR emitter such that the radiant intensity of the emitter under performs, the jumper can be soldered to bridge the gap. This, thereby, reduces the equivalent resistance of the branch causing more current to flow and increasing the radiant intensity of the IR emitter. The equivalent resistance can therefore have values of 100, 67, 50 or 40 Ohms.
Potentiometer placed in series with resistor across phototransistor of receiver circuit.	The potentiometer is connected as a variable resistor. Its resistance can range from 0 to 2000 Ohms. Because a 1k Ohm resistor is placed in series with it, the combined resistance can range from 1k to 3k Ohms. Increasing the resistance causes more voltage to drop across the output for the same changes in current. Therefore, increasing the resistance of the potentiometer makes the output more sensitive to light. If there is too little change in the output when an object is sensed, the resistance of the potentiometer can be increased to counteract this.
Jumper test points placed before or after key components.	The voltage before or after (depending on where the test point is placed) can be measured w.r.t. ground. Hence, if a problem were too occur within the subsystem circuitry, the problem can be isolated with much greater precision than if no test points were placed. The problem can then be identified and solved for.

3.5 System Integration and Interfacing

Table 3.6 shows which pins connect to and interact with other parts of the system:

Table 3.6: Interfacing specifications

Interface	Description	Pins/Output
I01	Sensor outputs to STM for data transfer	• Output of right receiver to analogue input STM PA3 • Output of middle receiver to analogue input STM PA4 • Output of left receiver to analogue input STM PA5 • GND: right, middle and left emitter and receiver GNDs to STM GND
I02	STM to sensor subsystem to pulse IR emitters of sensor subsystem	• STM PE8 (PWM) to gate resistor of 2N7002 mosfet of right emitter • STM PE14 (PWM) to gate resistor of 2N7002 mosfet of middle emitter • STM PE15 (PWM) to gate resistor of 2N7002 mosfet of left emitter
I03	Battery supply to sensor subsystem	• BATT1 (BATT) to input of voltage regulator U5 • BATT2 (BATT) to input of voltage regulator U4
IO4	STM (PWM) to LEDS on processor board	• STM PE10 to right LED • STM PE11 to middle LED • STM PE12 to left LED

Figure 3.5 shows a high level block diagram showing how the sensing subsystem fits into the larger system:

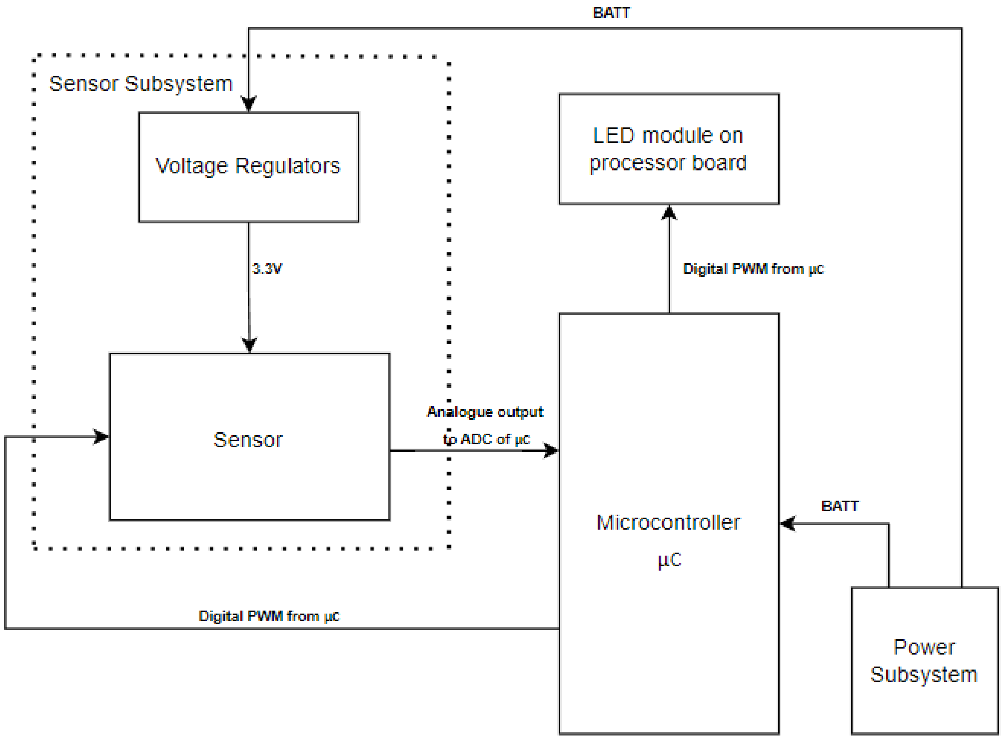


Figure 3.5: Interface diagram

Chapter 4

Acceptance Testing

4.1 Tests

**Assume when sensors are tested, power is supplied to the sensor subsystem, specifically to BATT1 and BATT2, which connect to the input of the voltage regulators U5 and U4 respectively. The emitters are also pulsed using PWM provided by the microcontroller to the gate resistors of the mosfets of the emitter circuits. Assume also that each sensor (right, left and middle) are tested independently. These are test points TP4, TP5 and TP6, which are the test points at the output of the right, left and middle receiver respectively.*

Table 4.1: Sensor subsystem acceptance tests

Test ID	Description	Testing Procedure	Pass/Fail Criteria
AT01	Voltage at output shall be tested when sensor is moved closer to an object.	• Oscilloscope is connected to the test point at the output of the receiver and to the ground test point TP10. • The sensor is placed a distance away from a barrier and slowly brought closer (perpendicular) to the barrier until it is approximately 5cm away. • Whilst the sensor is moved, the waveform of the output voltage on the oscilloscope is observed.	PASS: the peak voltage increases and the minimum/low voltage remains the same with an acceptable range of ±0.03V as the sensor moves towards the barrier. FAIL: the peak voltage stays the same or decreases as the sensor moves towards the barrier.
AT02	Output voltage when sensor is 8 cms away from an object shall be measured.	• Oscilloscope is connected to the test point at the output of the receiver and to the ground test point TP10. • Using a ruler or tape-measure, the sensor is placed 8cm perpendicular to a barrier. • The peak voltage is measured using the oscilloscope. • The test is repeated at least five times with the sensor being turned off for at least 10 seconds and then turned on, then moving the sensor back and forwards to the 8cm mark each time and each peak voltage measurement is recorded.	PASS: the average of the peak output voltages is greater than 2.5V and the range is less than ±0.2V. If the range of these voltages is less than ±0.2V but average less than 2.5V, the radiant intensity of the emitters must be adjusted until the voltages average greater than 2.5V. FAIL: the voltages are inconsistent. The peak voltage range is greater than ±0.2V. The radiant intensity of the emitter cannot be adjusted such that the voltages are greater than 2.5V.

Test ID	Description	Testing Procedure	Pass/Fail Criteria
AT03	Output voltage when sensor is 16cm away from an object shall be measured.	• Oscilloscope is connected to the test point at the output of the receiver and to the ground test point TP10. • Using a ruler or tape-measure, the sensor is placed 16cm perpendicular to a barrier. • The peak voltage is measured using the oscilloscope. • The test is repeated at least five times with the sensor being turned off for at least 10 seconds and then turned on, then moving the sensor back and forwards to the 16cm mark each time and each peak voltage measurement is recorded.	PASS: the average of the peak output voltages is between 0.9V and 1.7V and has a range/consistency less than ±0.2V. FAIL: The average of the peak voltage is outside of 0.9V and 1.7V or the range of the peak voltages is greater than ±0.2V.
AT04	Output voltage when no object is sensed shall be measured.	• Oscilloscope is connected to the test point at the output of the receiver and to the ground test point TP10. • Ensure that no barrier/object is within 3m to the front of the sensor. • The voltage is measured using the oscilloscope. • The test is repeated at least five times with the sensor switched off for at least 10 seconds and on each time and each voltage measurement is recorded.	PASS: The voltages lie within a range of ±0.2V and average less than 0.5V. The waveform of the output voltage must also be flat with a maximum amplitude of 0.1V. FAIL: Voltages lie outside a range of ±0.2V or the average of the voltage measurements is greater than 0.5V. FAIL: Amplitude of output voltage trace is greater than 0.1V
AT05	Voltage regulator's output voltages shall be measured w.r.t. ground.	• Oscilloscope is connected to the output of each voltage regulator, TP11 and TP12, and to the ground test point TP10.	PASS: Voltage is equal to (3.3±0.02)V FAIL: Voltage is not equal to (3.3±0.02)V
AT06	Pulse length and duty cycle of emitter and receiver shall be measured.	• Oscilloscope is connected to the test point at the drain of the MOSFET (TP1, TP2 and TP3) and to the ground test point TP10. Measure the pulse length and calculate the duty cycle using the oscilloscope. • Using a ruler or tape measure, position the sensor 1cm away from a barrier and connect the oscilloscope to the test point at the output of the receiver and to the ground test point TP10. Measure the pulse length and calculate the duty cycle using the oscilloscope.	PASS: the measured pulse length and duty cycle of both the receiver and emitter match the input pulse signal, with a maximum deviation of 5% for each. FAIL: The measured pulse length or duty cycle of either the receiver or emitter deviates from the input pulse signal by more than 5%.
AT07	Each test point on PCB shall be tested to ensure they are working correctly.	• Ensure power is supplied normally to the sensor subsystem, with emitters being pulsed. • Multimeter is set on the continuity test mode • Multimeter is then systematically connected to every test point that is not the ground test point and the ground test point.	PASS: Every test point passes the continuity test. FAIL: At least one test point fails the continuity test.
AT08	Total cost of PCB shall be calculated.	• Price of PCB can be found on quote from PCB manufacturer.	PASS: Cost of 2 PCB's is less than 30 USD FAIL: Cost of 2 PCB's is more than 30 USD

Test ID	Description	Testing Procedure	Pass/Fail Criteria
AT09	Voltage across battery shall be measured.	• Using a multimeter, connect one probe to TP8, which is connected to the BATT1 pin, and connect the other probe to the ground test point, TP10. • Using a multimeter, connect one probe to TP7, which is connected to the BATT12 pin, and connect the other probe to the ground test point, TP10.	PASS: both voltages measured lie within the range 3.75 to 4.2V. FAIL: at least one of the voltages lie outside of this range.
AT10	The dimensions of the PCB shall be measured.	• Using a ruler or tape measure, the maximum width and length of the PCB is measured.	PASS: the maximum length and width are both smaller than 60mm. FAIL: the maximum length or width is greater than 60mm.
AT11	Mass of PCB shall be measured.	• Using a scale, mass of PCB is measured. The manufacturer may also provide a calculated mass.	PASS: the mass is less than 300 grams. FAIL: mass is equal to or greater than 300 grams.

4.2 Critical Analysis of Testing

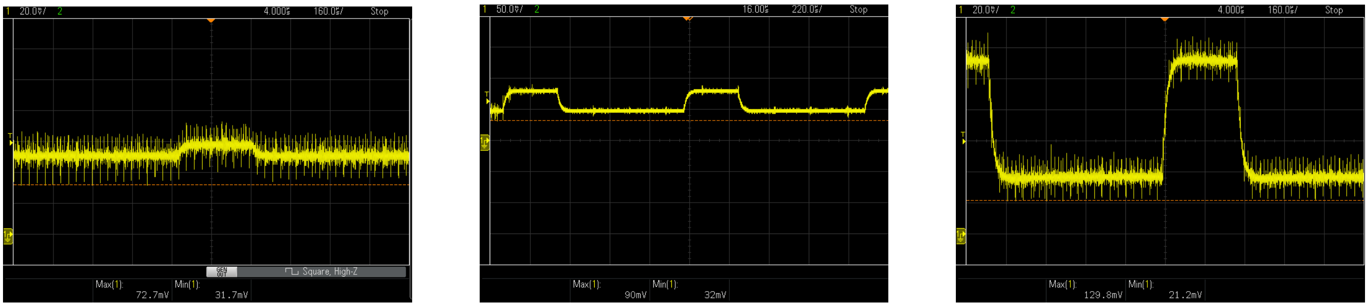
Table 4.2: Subsystem acceptance test results

Test ID	Description	Result
AT01	Voltage at output shall be tested when sensor is moved closer to an object.	PASS
AT02	Output voltage when sensor is 8 cms away from an object shall be measured.	FAIL
AT03	Output voltage when sensor is 16cm away from an object shall be measured.	FAIL
AT04	Output Voltage when no object is sensed shall be measured.	PASS
AT05	Voltage regulator's output voltages shall be measured w.r.t. ground.	PASS
AT06	Pulse length and duty cycle of emitter and receiver shall be measured.	PASS
AT07	Each test point on PCB shall be tested to ensure they are working correctly.	PASS
AT08	Total cost of PCB shall be calculated.	PASS
AT09	Voltage across battery shall be measured.	PASS
AT10	The dimensions of the PCB shall be measured.	PASS
AT11	Mass of PCB shall be measured.	PASS

The five most significant ATPs are discussed and assessed below:

4.2.1 AT01

Figure 4.1 below show the outputs of the front sensor when the PCB is slowly brought closer (perpendicular) to the barrier at three different instances:



(a) Far (b) Medium (c) Near

Figure 4.1

The peak voltage clearly increases from left to right, where the maximum voltage is equal to 72.7mV when the PCB is far from the wall, 90mV when the PCB is at a medium distance from the wall and 129.8mV when the PCB is placed flush against the wall. The minimum/low voltage levels are equal to 31.7mV when the PCB is far from the wall, 32mV when the PCB is at a medium distance from the wall and 21.2mV when the PCB is placed flush against the wall. The left and right sensor outputted essentially identical results and thus for the brevity of this section, only outputs from the middle sensor are shown. Nonetheless, a considerable amount of noise can be observed in the waveforms on the oscilloscope. Because of this, these measurements are not necessarily precise and accurate and may affect the quality of information transferred to the microcontroller. However, the test only considers how the peak voltage changes as the PCB is moved relative to a barrier and the amount the minimum/low voltage changes. Since the peak voltage increases as the sensor moves towards the barrier and the most the minimum/low voltage changes is less than 0.03V, AT01 is passed.

4.2.2 AT02

In order for ATP02 to be passed the peak output voltage must be greater than 2.5V and the range less than ±0.2V. If the range of these voltages is less than ±0.2V but average less than 2.5V, the radiant intensity of the emitters must be adjusted until the voltages average greater than 2.5V. Initially, the peak voltages were indistinguishable, and no pulses could be seen in the output of the sensor. To solve this, failure management processes are used: the solder jumpers placed in parallel with resistor that is in series with IR emitter of the emitter circuit were soldered to increase the radiant intensity of the emitters. The resistance of the potentiometer of the receiver circuit was also maximised, such that the receiver circuit was the most sensitive to light it could be, and create larger voltage changes in the pulses of the output of the sensor. Figure 4.2 below shows the output of the middle sensor when the PCB is placed 8 cm perpendicular to a barrier with the failure management processes taken:

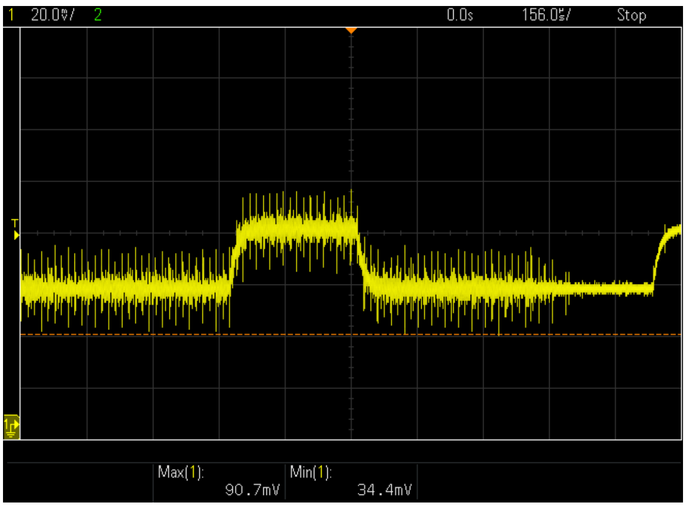


Figure 4.2: Output voltage when sensor is 8 cms away from wall

The peak voltage of the sensor is equal to 90.7mV and the minimum voltage (the voltage when the IR emitters are off when pulsing) is equal to 34.4mV. However, the peak voltage of the sensor remains consistent, and keeps within a range of ±20mV when turned on and off multiple times and moved around. Thus, the consistency condition of AT02 is satisfied. However, ultimately since the peak output voltages were much less than 2.5V, AT02 is failed.

Since the test is failed so substantially, and all failure management processes have already been taken as to meet the pass conditions for the acceptance test, the potentiometer (RV1, RV2 and RV3) is removed. Through a process of trial-and-error, a 1MΩ is chosen to replace the potentiometer. This is done because even when the resistance of the potentiometer is set at its maximum value and the resistance in series with the phototransistor is then 3kΩ. The resistance is still far too small to draw a significant voltage difference between when the emitters are pulsed off and then on. Figure 4.3 shows the output of the middle sensor when the PCB is placed 8 cm perpendicular to a barrier and the potentiometer is replaced by a 1MΩ resistor. The left and right sensor display essentially the same result:

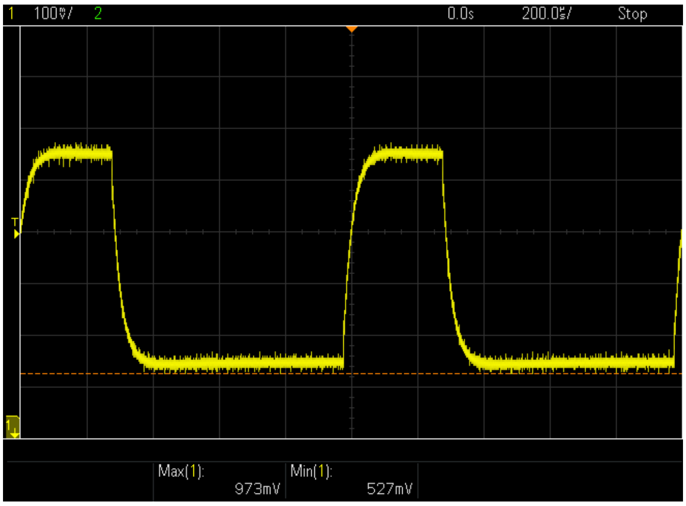


Figure 4.3: Output voltage when sensor is 8 cms away from wall and potentiometer is replaced by a 1MΩ resistor

The peak voltage of the sensor is now higher with a value of 973mV, which is more than ten times the peak voltage of the sensor before. Comparing the two waveforms, the noise also reduces considerably. Again the peak voltage of the sensor remains consistent, and keeps within a range of ±20mV when turned on and off multiple times and moved around, and thereby still satisfies the consistency condition of AT02. Nonetheless, since the peak output voltage is still less than 2.5V, AT02 is failed. However, a significant improvement to the design is made. The reason why the peak output voltage is still too low is because the 0.1uF capacitor (C7, C8, and C9) connecting the output of the sensor to the microcontroller may be causing a significant voltage drop to the output voltage. Therefore, to fix this problem, a larger capacitor can be used such as 0.5uF, or the frequency of the input PWM to the emitter circuit can be increased. If neither of these options work, the capacitors (C7, C8, and C9) can be short-circuited.

4.2.3 AT04

In order for AT04 to be passed, when no barrier is placed in front of the sensor, the output voltage must lie within a range of ±0.2V and average less than 0.5V. The trace of the output voltage must also be flat with a maximum amplitude of 0.1V. Figure 4.4 shows the output of the middle sensor under the testing conditions. The left and right sensor display very similar results. The potentiometer is set at is maximum resistance and the emitters operating at their full radiant intensity:

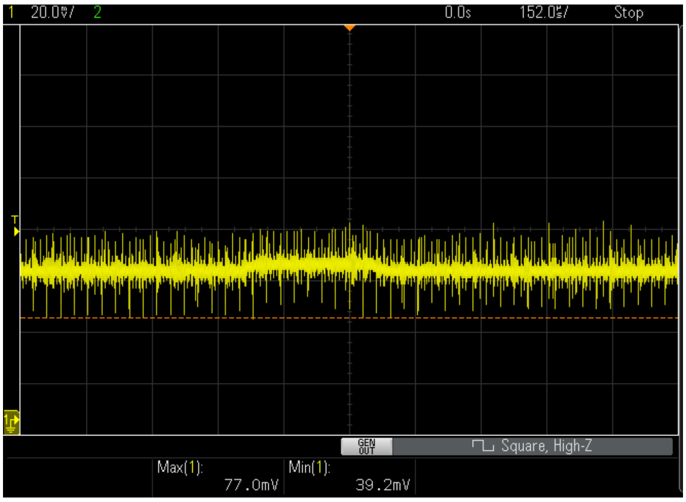


Figure 4.4: Output voltage when no barrier is placed in front of the sensor

The output lies far below 0.5V and the waveform is flat with an amplitude of approximately 40mV. The output voltage also stays within a range of ±0.1V when the sensor is turned on and off and moved around. Therefore, AT04 is passed as it passes all the conditions. Observing the waveform of figure 4.4, a lot of noise is present. This reduces the quality of the information passed on to the microcontroller. The noise is a result of the resistance in series with the phototransistor of the receiver being too low, causing the output voltage to be lower and thus being more susceptible to noise. Figure 4.5 below shows the output of the middle sensor when no barrier is placed in front of it, and the potentiometer is replaced by a 1MΩ resistor. Once again, the left and right sensor display essentially the same results:

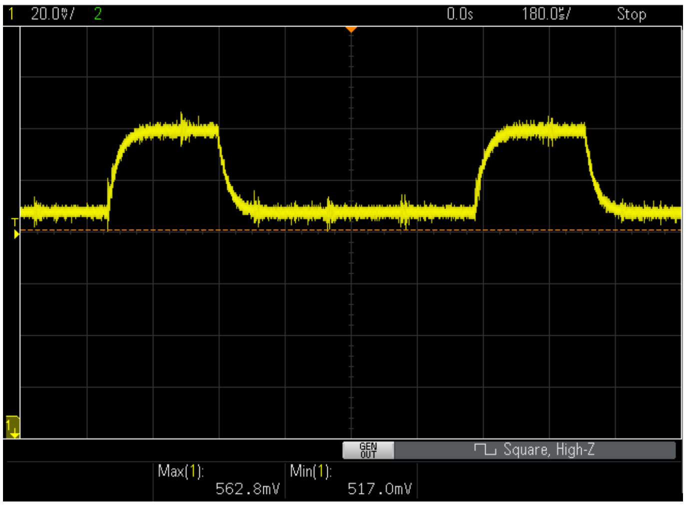


Figure 4.5: Output voltage when no barrier is placed in front of the sensor and potentiometer is replaced by a 1MΩ resistor

Although the output voltage still stays within a range of ±0.1V when the sensor is turned on and off and moved around, the output lies just above 0.5V and the waveform is no longer flat. Therefore, AT04 fails. However, replacing the potentiometer with a 1MΩ resistor is imperative to use the resolution of the ADC more effectively, thereby creating a more functional sensor subsystem. The effect of noise is also reduced as a result. The reasoning behind pulses being observed in the output voltage even though no barrier is placed in front of the sensor is because the receiver is slightly detecting the pulses of the emitter adjacent to it (due to the IR of the emitter being detectable in the viewing angle of the phototransistor). Hence, to fix this, insulating tape can be wrapped around the phototransistor leaving only the front of it exposed, thereby reducing the viewing angle, causing the waveform to be more flatter.

4.2.4 AT05

Voltage regulator's (U5 and U4) output voltages (VDD1 and VDD2) is measured w.r.t. ground. Figure 4.6 below shows the measurement for both voltage regulators measured using a multimeter:

(a) Vout of U5 (Vdd1)

(b) Vout of U4 (Vdd2)

Figure 4.6: Measurement for both voltage regulators using a multimeter

The output of both voltage regulators is within the range of (3.3±0.02)V. Therefore, AT05 is passed. This ensures that the voltage at the output of the sensors will hence never be larger than 3.3V thereby protecting the internal circuitry of the microcontroller and ensuring that the change in the output of the system at the same distance at two different instances in time is constant.

4.2.5 AT06

Pulse length and duty cycle of emitter and receiver is measured. The input PWM signal has a frequency of 1kHz and a duty cycle of 30%. Therefore, the pulse length for the input PWM signal is 0.3ms. The measured signal at the front emitter matches the input pulse signal with a pulse length of exactly 0.3ms and 30% duty cycle. Figure 4.7 shows the output of the middle sensor when it is 1cm away from a barrier. The potentiometer is set at is maximum resistance and the emitters operating at their full radiant intensity. The left and right sensor display the same results.

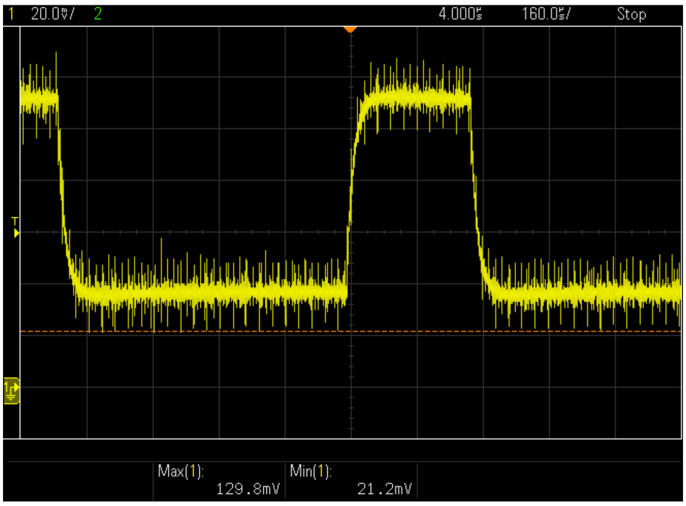


Figure 4.7: The output of the middle sensor when it is 1cm away from a barrier

The pulse length is measured to be 0.32ms and the period is measured to be 1.04ms. Therefore, the duty cycle is calculated to be 31%. AT06 is passed as the measured pulse length and duty cycle of both the receiver and emitter match the input pulse signal, with a maximum deviation of within 5% for each.

Figure 4.8 below shows the output of the middle sensor when it is 1cm away from a barrier, and the potentiometer is replaced by a 1MΩ resistor. Once again, the left and right sensor display essentially the same results:

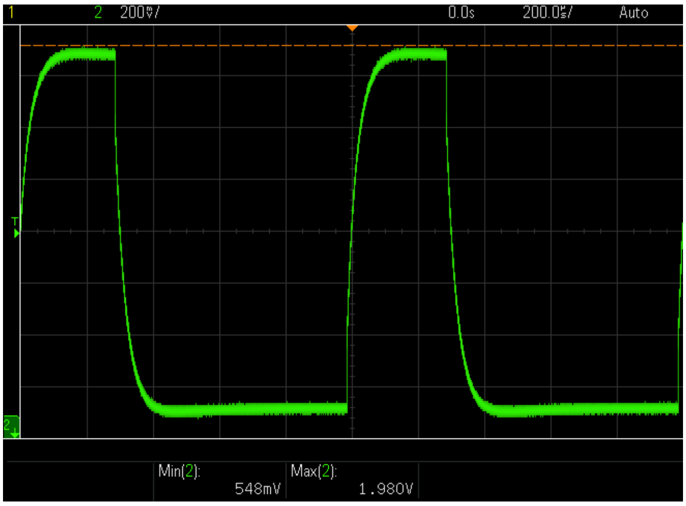


Figure 4.8: The output of the middle sensor when it is 1cm away from a barrier and the potentiometer is replaced by a 1MΩ resistor

The pulse length is measured to be 3ms and the period is measured to be 1ms. Therefore, the duty cycle is calculated to be 30% and thus AT06 is passed.

Chapter 5

Conclusion

This report is aimed to design, develop and test the hardware for the sensor subsystem of a micromouse. The sensing subsystem uses and integrates with the already designed processor, motherboard, and power subsystem in order for the micromouse to successfully traverse through a maze. The sensor subsystem ensures that the micromouse can detect obstacles and maintain proper alignment within the pathways of the maze. The report outlines the specific objectives and goals of the sensing subsystem. It identifies the requirements and specifications for the subsystem, discusses the decisions involving component selection, evaluates possible solutions and provides calculations used to design the sensing subsystem. It also details the testing procedures used to evaluate if the specification of the subsystem are met. Additionally, it addresses design considerations for mitigating failure in the sensing subsystem circuit design and demonstrates how the subsystem fits into the larger micromouse system.

To summarize some of the significant acceptance tests, the output voltages of the voltage regulators are within the acceptable range, thereby protecting the internal circuitry of the microcontroller and keeping the output of the system at the same distance, at two different instances in time, constant (AT05). The measured pulse length and duty cycle of both the emitter and receiver also matched the input pulse signal within a maximum deviation of 5%, confirming the switching capabilities of the emitter circuit and the receiver circuit. However, though most of the acceptance tests, AT01, AT04, and AT05 to AT11 were passed, there are some problems with the final design of the sensor subsystem. Through the critical analysis of the acceptance tests where the output of the sensors were directly assessed (AT01 to AT04), a major problem is that the peak output voltage increases to a much smaller than accepted degree when the sensor moves closer to a barrier (not sensitive enough to changes in proximity of the sensor to the barrier). This is why tests AT02 and AT03 were failed. Therefore, the output of the sensor is not fully maximized for the ADC of the microcontroller. However, suggestions were made to resolve this problem. These include replacing the potentiometer with a 1MΩ resistor, which significantly improved the sensitivity (and reduced noise present in the output waveform) of the receiver circuit. Suggestions such as increasing the frequency of the PWM signal to the emitter circuit or increasing the capacitance of the coupling capacitors that connect the output of the sensor to the microcontroller were also suggested but were not tested. Nontheless, the peak output voltage increased enough as to provide the microcontroller with enough information as to tell if a barrier was placed, to the left, right and front of it, thereby making it capable for the micromouse to successfully traverse through the maze with proper alignment within the pathways of the maze.

The project faced several challenges, including a limited budget and time frame, which restricted component selection and the depth of design iterations and testing. Despite having access to basic lab equipment, the lack of specialized facilities may have constrained the range and quality of tests conducted. Therefore, the design of the sensor-subsystem is by no means perfected and recommendations can be made.

5.1 Recommendations

The 1kΩ resistor in series with the 2kΩ potentiometer in each receiver circuit should be replaced by a much larger resistance, such as a 500kΩ resistor in series with a 1MΩ potentiometer. This increases the sensitivity of the reciever circuit drastically while also being able to control it. The coupling capacitors that connect the sensors outputs to the microcontroller can also be replaced by a larger capacitance, such as 0.5uF capacitors. The effects of the frequency of the PWM on the output of the sensor should also be fully understood to achieve the most efficient match. Filters such as band pass filters could also be placed where output of the sensor connects to the analogue pins of the microcontroller to reduce noise in the sensor output, thereby improving the sensor's accuracy. Insulating tape should also be placed around each phototransistor of the receiving circuits to reduce the viewing angle of the sensor. This helps to prevent the sensor from detecting the infrared (IR) pulses emitted by the adjacent emitters. If all these changes are implimented, a significant improvement to the design can be achieved.

Chapter 6

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