Interim Design Report

Micromouse Sensor Subsystem

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Contents

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.

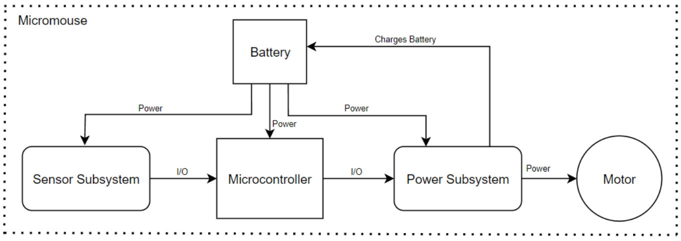


Figure 1.1: Simplified Context Diagram

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	System shall have switching means to save power when not in operation.
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	Components used shall be well-stocked from PCB manufacturer.
R10	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 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 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 0.2V and output trace shall have an amplitude less than 0.1V.
SP05	Output of sensor shall never be more than 3.3V.
SP06	Sub-system shall be power efficient when in operation.
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	Components used shall have more than 1000 in stock from PCB manfacturer.
SP12	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 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	Stock of each component shall be determined.
AT12	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
10	R10	SP12	AT12

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. 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

R09 is that the components used shall be well-stocked from the PCB manufacturer. From this SP11 is derived which is that components that are used shall have more than 1000 in stock from PCB manufacturer. This can be evaluated through AT11 where the stock of each component shall be determined.

2.4.10 Traceability Analysis 10

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 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. The table 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**
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
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
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 Wave-length (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 overlooked 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 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

Table 3.4: Phototransistors

Receiver	**Price ($)**	$V_{CE_{\mathbf{sat}}}$ **(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

is chosen as it provides the greatest difference in collector current for a change in irradiance, meaning it is 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.

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.

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

$R_{DS_{On}}$ 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.

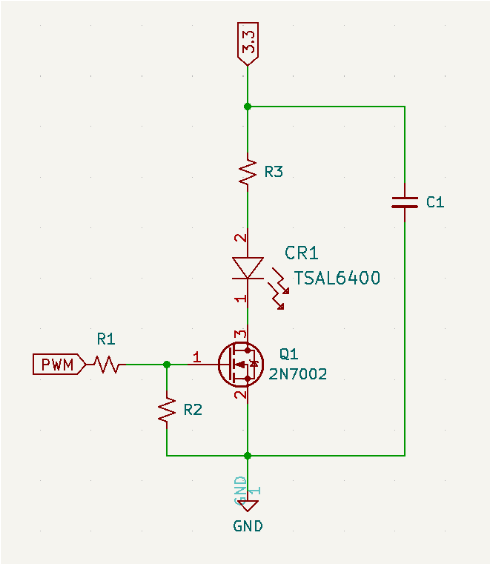


Figure 3.1: Emitter Circuit

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.
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 bee 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:

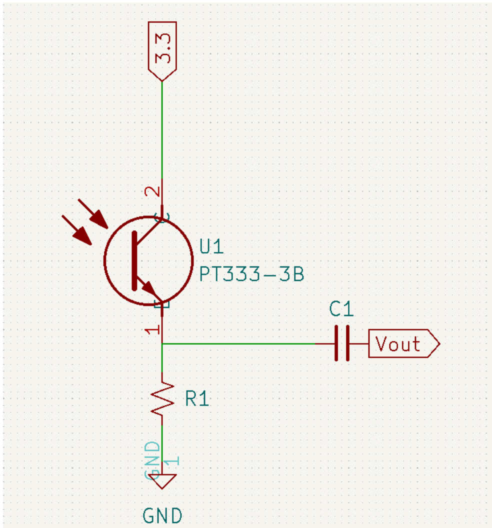


Figure 3.2: Receiver Circuit

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

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

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

R_{pot} is chosen to have a value of 2kΩ. Therefore, R_1 can have a value from 1000 to 4000 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

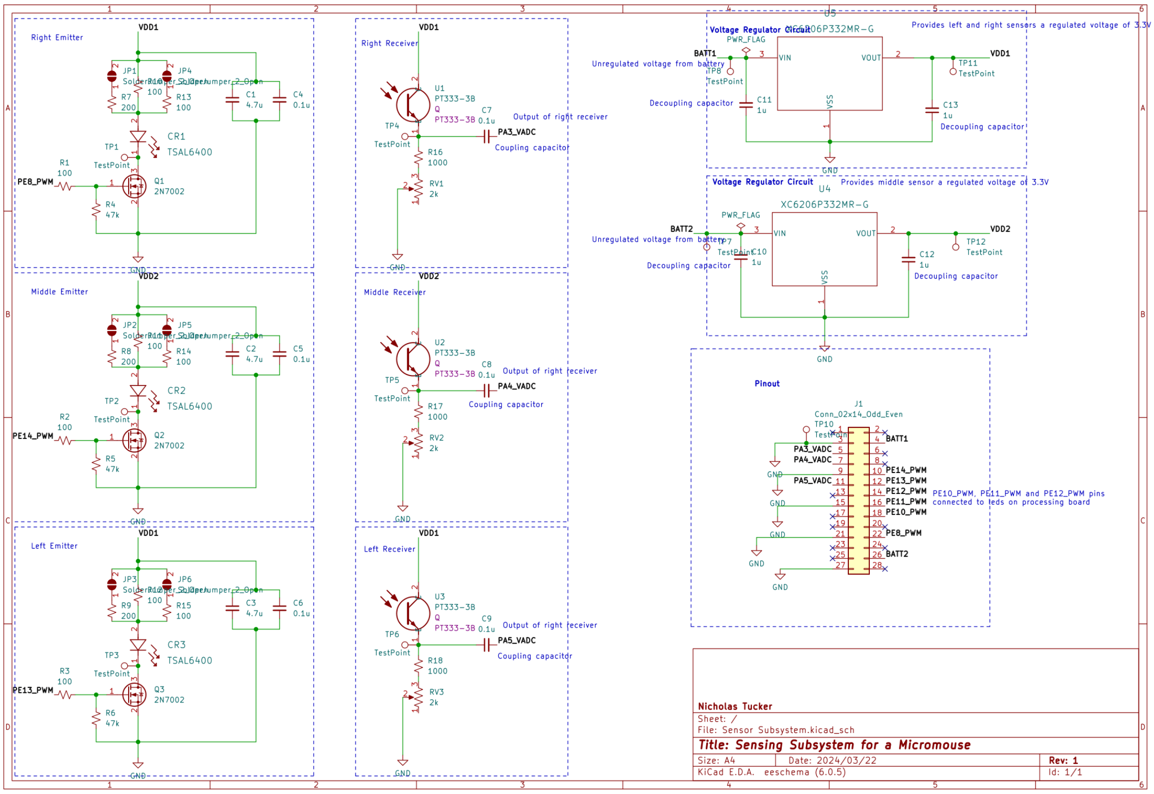
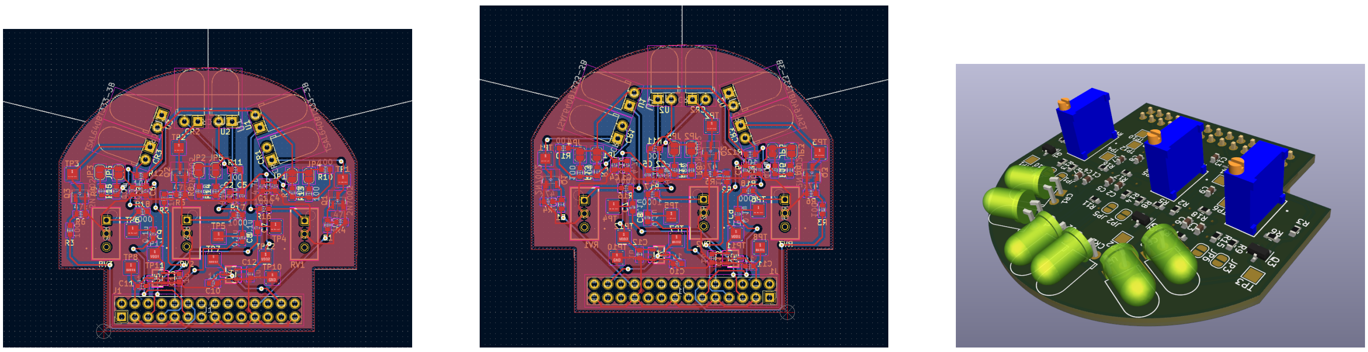


Figure 3.3: Schematic



(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 to input of voltage regulator U5 • BATT2 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:

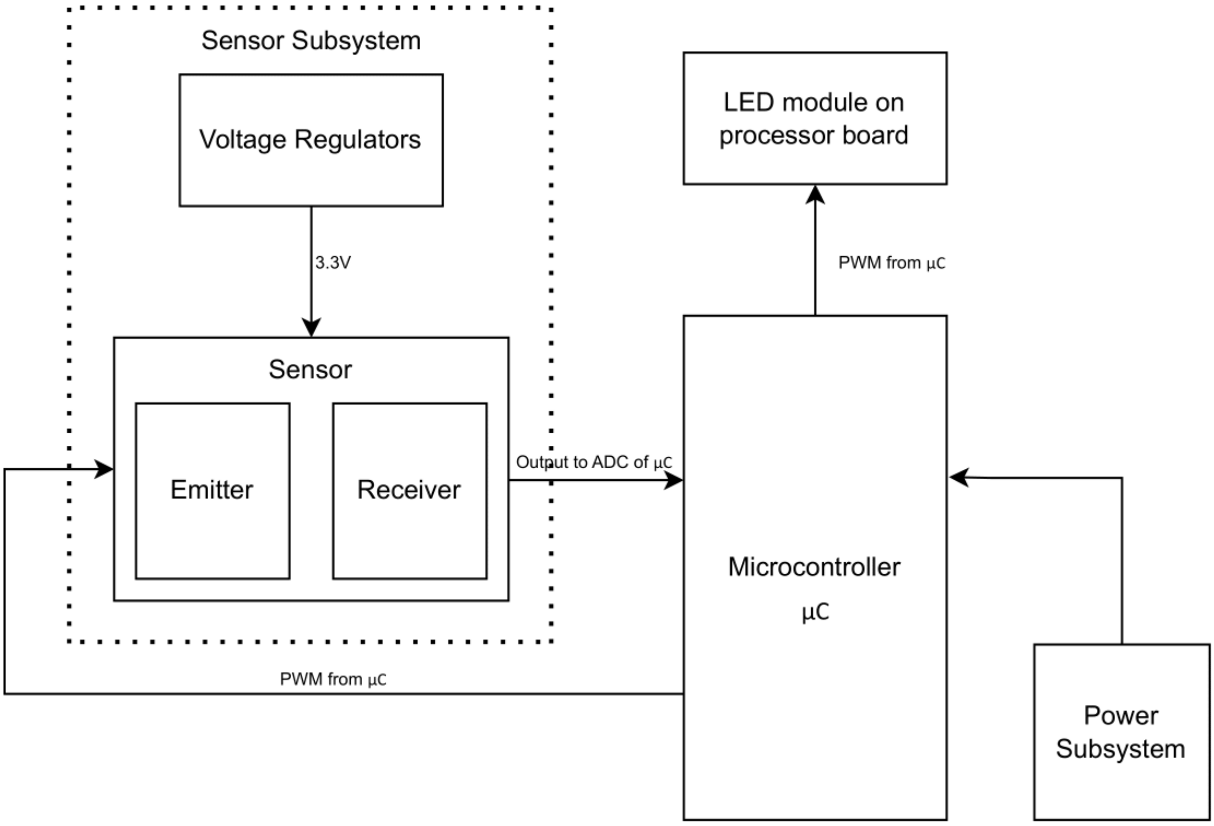


Figure 3.5: Interface diagram

Chapter 4

Acceptance Testing

4.1 Tests

**Assume when sensors are tested, power is supplied normally to the sensor subsystem, with emitters being pulsed. 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 trace of the output voltage on the oscilloscope is observed.	PASS: the peak voltage increases 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 moved 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.
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 moved back and forwards to the 16cm mark each time and each peak voltage measurement is recorded.	PASS: the peak output voltages have an average between 0.9V and 1.7V and have a range less than 0.2V. FAIL: The peak voltage average is outside of 0.9V and 1.7V or the peak voltage range is greater than 0.2V.

Test ID	Description	Testing Procedure	Pass/Fail Criteria
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 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 trace 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 3.3V FAIL: Voltage is not equal to 3.3V
AT06	Pulse length and duty cycle 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.	PASS: the measured pulse length and duty cycle is the same as the input pulse signal. FAIL: the measured pulse length or duty cycle is not the same as the input pulse signal.
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. 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
AT09	Voltage across battery shall be measured.	• Using a multimeter, the voltage across the battery is measured.	PASS: the voltage measured lies within the range 3.75 to 4.2V. FAIL: the voltage lies 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	Stock of each component used.	• Stock of each component used on the PCB board can be seen on the PCB manufacturer component list.	PASS: Every component used has stock above or equal to 1000 at the time of manufacture. FAIL: At least one component has stock less than 1000 at the time of manufacture.
AT12	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.

Chapter 5

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