Final Design Report

Micromouse: Sensing Subsystem

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Chapter 1

Introduction

1.1 Problem Description

This project is a task in which a sensing subsystem is to be designed and manufactured to be fitted on a fully functioning micro-mouse.

The greater project is a micro-mouse. A micro-mouse is in essence, a fully autonomous maze-solving robot. Historically these robots were made to solve a 16x16 grid of cells by finding a way from an initial starting point to the centre of a maize, unaided. The focus of this course is to design, test and implement either the Power Subsystem or Sensing Subsystem of the micro-mouse. The focus of this project is on the hardware backing the robot. There are four aspects of the hardware to be taken into account when designing the specific subsystem solution - in this case the sensing subsystem -; the processor, the motherboard, sensing and power. The motherboard will be responsible for connecting all four PCBs and is the base that all other modules will connect to. The processor board - which makes use of an STM32L476 - will be the control module of the robot which will involve a small software aspect in order to see its functioning correctly. The power module powers all aspects of the robot and lastly, the sensing subsystem - around which this project report will be based - is responsible for the detection of the surroundings of the robot.

In keeping with the goal of the project, this specific subsystem (sensing) is to detect the presence of an obstacle (in the most likely case, a maze wall) in front of and to either side of the functioning micro-mouse. In addition, this subsystem should have the means to save power when not in operation while abiding by all the set-out requirements and specifications within the scope of work.

1.2 Scope and Limitations

The scope of this project is to design and manufacture a sensing subsystem that will provide information to the processor on whether there is an obstruction in the way of the micro-mouse. The processor and motherboard will be provided and the group partner is designing the power subsystem. Of the objectives of this subsystem, detection sits are the forefront. Detection needs to be in front of and on either side of the robot. In addition, the following objectives are also to be implemented:

- Designing for reliability.
- Taking into account power draw in order to ensure that the micro-mouse is able to solve the maze without the battery being drained completely.
- A small software aspect in order to properly integrate this subsystem with the micro-controller and visibly indicate its functionality.

There are several limitations that need to be considered:

- Design Limitation: The subsystem PCB should be a suitable size for the robot and compatible with the motherboard pin headers.
- Time Limitation: The final complete and working PCB is to be demonstrated on 13/05/2024.
- Cost Limitation: There is a cost restriction of $16.50 for both boards ($8.25 per board).

1.3 GitHub Link

Group 62 GitHub link.

Chapter 2

Requirements Analysis

2.1 Requirements

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

Table 2.1: Requirements[R] of the sensing subsystem design.

Requirement ID	Description
R01	The PCB design should be an appropriate size for easy maneuvering.
R02	The PCB design must cost within the specified budget.
R03	The design must detect obstacles in front of and to either side of the subsystem.
R04	The design PCB must be compatible with the motherboard.
R05	The design must be powered externally.
R06	The design must have a power-saving functionality.
R07	The design must be able to mitigate the effects of ambient light for whole system.
R08	The design components must all be sourced from the manufacturer.
R09	The design must be manufactured by a specific company and all components must be specified.

2.2 Specifications

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

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

Specification ID	Description
SP01	The PCB design must not exceed the bounds of an $85mm^2$ square.
SP02	The design must not exceed \$8.25 per board (\$30 Grand Total).
SP03	The design must use a different LED to indicate detection - in the front, left or right - of the three available LEDs.
SP04	The design PCB must be compatible with a 2x14 (2.4mm pin pitch) pin header.
SP05-1	The design must be powered by 3.5V to 3.7V.
SP05-2	The design must have a current draw of no more than 400mA.
SP06	The design PWM supply must be pulse width modulated with a duty cycle of 50%.
SP07	An ambient light reference output must be set against the sensor output.
SP08	All components must be sourced from JLCPCB with a stock quantity greater than 1000.
SP09	The manufacturing must be with JLCPCB and all components must be specified on the production files.

2.3 Testing Procedures

A summary of the acceptance testing [AT] procedures detailed in chapter 4 is given below in Table 2.3.
Reference Key:
'AT' - Acceptance Testing; 'UT' - Unit Testing; 'UAT' - User Acceptance Testing; 'BAT' - Business Acceptance Testing.

Table 2.3: Acceptance Testing [AT] descriptions derived from the table of requirements in Table 2.1.

AT ID	**AT Type**	**Description**
AT01	UAT	Measure the manufactured PCB or ensure the dimensions of the PCB enclosed in the production files are adequate.
AT02	BAT	Review the manufacturing order cost.
AT03-1	UT	Observe a different LED turn on for detection in front of and on either side of the robot and no LED turning on when no detection.
AT03-2	UT	Measuring the voltage across the emitters of the sensing circuit.
AT03-3	UT	Measuring the output voltage of the sensing circuit.
AT04	UT	Using a calliper to measure pin header through-hole connections.
AT05-1	UT	Measuring the input voltage of the sensing circuit.
AT05-2	UT	Measuring the input current of the sensing circuit.
AT06	UT	Ensuring the micro-controller has been set to provide an output signal that has a duty cycle of 50%.
AT07	UT	Ensuring that a calibration reference has been encoded to mitigate ambient light.
AT08	BAT	Review the manufacturing bill of materials and ensure quantity is over 1000.
AT09	BAT	Review the manufacturing bill and ensure it is from JLCPCB and that all components are specified

2.4 Traceability Analysis

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

Table 2.4: Requirements Traceability Matrix

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

2.4.1 Traceability Analysis 1

R01 - the appropriate size requirement in order to allow for the robot to have adequate mobility within the maze is from which SP01, the specification that dictates the size of the PCB should be no greater than the bounds of an 85mm x 85mm square, can be derived. In order to 'test' that this requirement is satisfied - AT01 is suggested, which is to measure the manufactured PCB or ensure the dimensions on the production files are sufficient.

2.4.2 Traceability Analysis 2

R02, requiring the cost of the PCB manufacturing to be within a certain budget, SP02 - dictating that the design should not cost more than $8.25 per board ($30 Grand Total) - can be derived. These can be verified through AT02 which entails reviewing the manufacturing order cost to ensure that it is below the specified limit.

2.4.3 Traceability Analysis 3

R03 - requires the system to detect obstacles and indicate its location gives rise to the specification SP03 which is that the design must use a different LED to indicate detection in the front, left and right of the robot. To test for this, we can use AT03-1, AT03-2 and AT03-3. AT03-1 indicates that to test for this, we should observe a different LED turn on for detection at each location and no LED being on when there is no detection. AT03-2 suggests measuring the voltage across the emitters in order to ensure that they are functioning and AT03-3 suggests measuring the voltage output of each of the three sensing circuits to observe that a higher output is at the location of the obstacle.

2.4.4 Traceability Analysis 4

R04 - is the requirement that indicates that the design must provide a real time input to the micro-controller and to do this the design PCB must be compatible with the motherboard pin headers (R04) leads to SP04 which specifies that the design PCB must be compatible with a 2x14 (2.4mm pin pitch) pin header. In order to validate this requirement, AT04 suggests using a calliper to measure the pin header through hole connections present in the design.

2.4.5 Traceability Analysis 5

R05 - the requirements that dictate the power of the system should be external which requires observing power and current restrictions brings forth the specification which says that the design should be powered by 3.5V to 3.7V (SP05-1) while having a current draw of no more than 400mA (SP05-2). In order to validate this AT05-1 suggests measuring the input voltage of the sensing circuit to observe its adherence to the specification SP05-1 and AT05-2 suggests measuring the input current to observe its adherence to the specification SP05-2.

2.4.6 Traceability Analysis 6

R06 indicates that the design input supply must have a power-saving functionality and that is accomplished by having an input supply from a PWM port. This gives rise to specification SP06 which indicates that the pulse width modulation must be set to 50% and AT06 suggests a way to validate this is to observe that the micro-controller port output has been set to the desired duty cycle.

2.4.7 Traceability Analysis 7

R07 - the requirement that indicates a need for the mitigation of ambient light gives rise to SP07 which requires that the sensors measure of ambient light be used a reference to ensure it does not affect the output. AT07 indicates that to ensure the above is met, it needs to be confirmed that a calibration reference has been encoded in the micro-controller.

2.4.8 Traceability Analysis 8

R08 - the requirement that indicates that all components should be sourced from the PCB manufacturer. From the above, we can see how SP08 came about which specifies that all components must be from JLCPCB with them being in stock in excess of 1000 units. AT08 suggests that to validate this the manufacturing bill of materials must be reviewed.

2.4.9 Traceability Analysis 9

R09 requires that the design must be manufactured by a specific company and all components need to be declared. This gives rise to SP09 which indicates that all manufacturing needs to be done through JLCPCB and all components must be declared on the production files. AT09 suggests that to ensure the above crtieron have been fulfilled, the maufacturing bill needs to be reviewed.

Chapter 3

Subsystem Design

3.1 Design Decisions

In this section, two of the most crucial aspects of the design process are going to be explored - Circuit Component Selection and PCB Design Selection. From which, many design decisions are to be made.

3.1.1 Circuit Component Selection

- Infrared Sensor:

Three different infrared sensors were considered for the sensing circuit of the subsystem - the QRD1114, SFH309FA and SFH205. This is to ensure that the sensing capabilities of the subsystem, are in keeping with the requirements and specifications.

Table 3.1: Pros and Cons of the considered infrared sensors.

	QRD1114	SFH309FA	SFH205
Pro	-Detection at up to 200mm. -Both an IR emitter and IR receiver.	-Sensitivity: 730-1120nm. -Size: 0.45mmx0.45mm. -Quantity in stock: 1632 -Cost: \$0.2696	-Sensitivity: 800-1100nm. -Size: 2.65mmx2.65mm. -Cost: \$0.5940
Con	-Quantity in stock: 5. -Cost: \$1.57 -Part Type: Extended	-Simply an IR receiver. -Part Type: Extended	-Quantity in stock: 0 - Simply an IR receiver. - Part Type: Extended

Selected Infrared Sensor Design Decision:

SFH309FA - based on the spectral sensitivity, small component size, large in stock quantity and low cost. This sensor is able to provide all the sensing abilities of the other two, with the added stock and cost benefits.

Discarded Infrared Sensor Design Decision:

QRD1114 - based on the low in stock quantity and high cost, this option was not feasible. SFH205 - due to the part not being in stock, it was immediately removed from consideration.

- Infrared Emitter:

Three different infrared emitters were considered for the emitter circuit of the subsystem, the QRD1114, TSAL6100 and TSAL6200.This is to ensure that the emitting capabilities of the subsystem, are in keeping with the requirements, specifications and selected sensor (above).

Table 3.2: Pros and Cons of the considered infrared emitters.

	TSAL6200	TSAL6100	QRD1114
Pro	-Peak emission: 940nm -Cost: \$0.1194 -Quantity in Stock: 1476	Peak emission: 940nm -Cost: \$0.1205 -Half intensity angle: 10 deg	-Peak emission: 940nm. -Both an IR emitter and IR receiver.
Con	-Part Type: Extended -Half intensity angle: 17 deg	-Quantity in stock: 0 -Part Type: Extended	-Quantity in stock: 5. -Cost: \$1.57 -Part Type: Extended

Selected Infrared Emitter Design Decision:

TSAL6200 - based off of the peak emission, large in stock quantity and low cost. This sensor is able to provide all the emitting abilities of the other two, with the added stock and cost benefits.

Discarded Infrared Emitter Design Decision:

QRD1114 - based on the low in stock quantity and high cost, this option was not feasible. TSAL6100 - due to the part not being in stock, it was immediately removed from consideration - however was initially considered due to low cost and good angle of half intensity.

- Emitter Circuit Transistor:

Two bipolar junction transistors were considered for use as a switch in the emitter circuit of this sensing subsystem, the MMBT3904 and MMBT3904-G.

Table 3.3: Pros and Cons of the considered bipolar junction transistors.

	MMBT3904	MMBT3904-G
Pro	-Cost: \$0.0097 -Quantity in stock: 1096136 -Part Type: Basic	-Cost: \$0.0063 -Quantity in stock: 369248
Con	-Ic(max) is 200mA. -Power Dissipation: 200mW	-Part Type: Extended -Power Dissipation: 225mW

Selected BJT Design Decision:

MMBT3904 - based off of the lower power dissipation, high in stock quantity and basic part classification.

Discarded BJT Design Decision:

MMBT3904-G - based off of the greater power dissipation and extended part classification.

- E24 Component Values:

The use of E24 values was considered for the capacitors and resistors in this subsystem, however, since most resistors and capacitors are available in E12 values, basic components were easy to source in large quantities and low cost. In discarding the idea of E24 values, certain E12 values were selected to ensure that calculated component values were the same, if not extremely close. Some of the benefits of using the E24 series are the wider range of values as well as lesser associated tolerance.

3.1.2 PCB Design Selection

- Component Quantities/Configurations:

Table 3.4: Pros and Cons of the considered component quantities and configurations.

	Dual Emitter/Sensor Component	Single Sensor and Emitter	Single Sensor and Dual Emitter
Pro	-Single component allowing for PCB modularity.	-Cost: \$0.38 per pair, so \$1.167 per board. -Emission: sufficient IR light emission to be detected after reflection.	-Cost: \$0.50 per set, so \$1.52 per board. -Emission: excellent IR light emission to be detected after reflection.
Con	-Cost: \$1.57 per unit, so \$4.71 per board to allow for all direction detection. -Emission: Combination component has a poor emittance and so additional emitters will be required.	-Coverage: Detection of IR light from source in addition to reflected light. -Reflection Loss:A single emitter results in a portion of IR light lost due to the angle at which the emitter and sensor are placed.	-Coverage: Detection of IR light from the source in addition to reflected light.

Selected Component Quantity Design Decision:

The single sensor and dual emitter design was selected due to the enhanced infrared emittance to ensure better detection for the required locations and distances. While the single sensor and emitter

design was acceptable, the single sensor and dual emitter was within the confines of the budget and enhanced.
Discarded Component Quantity Design Decision:
The dual component design was discarded due to the cost implications and poor performance - relative to the other two designs. The single sensor and emitter was discarded for the enhanced ability of the dual emitter option.

- PCB Shape and Size:

Table 3.5: Pros and Cons of the considered PCB shape and size.

	Square	Rectangle	T-shape
Pro	-Does not jut out of the robot allowing for good mobility.	-The large PCB coverage allows for sufficient room for all necessary circuitry.	-Sufficient room for all the necessary circuitry without protruding from the robot allowing for range of motion.
Con	-Inadequate visibility (created by extension) to allow for complete obstacle detection on the left and right of the robot.	-Protruding from the robot, disabling a complete range of motion within the confines of the maze.	-Minimal protruding which will reduce the motion of the robot in the maze.

Selected PCB Shape and Size Design Decision:
The chosen shape and size design decision is the T-shape. This is as a result of the minimal protruding, while still extending enough to allow for the IR sensor to adequately detect obstacles from a distance point of view as well allowing visibility - in that the sensors visibility will not be hindered by parts of the robot.
Discarded PCB Shape and Size Design Decision:
The square and rectangle designs were discarded. The square - due to the dimensions allowing for the sensors visibility to be hindered by parts of the robot and the rectangle due to its size disabling a wide range of motion for the robot within the walls of the maze (200x200mm).

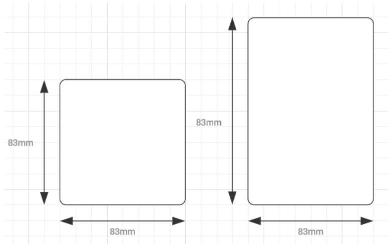


Figure 3.1: Square/Rect Shape

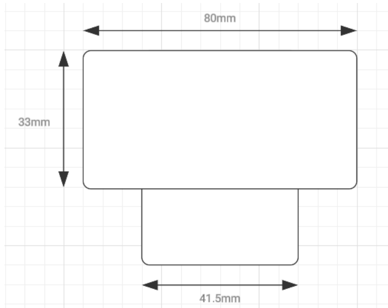


Figure 3.2: T Shape

- Sensor Placement and Angle:
Selected Sensor Placement and Angle Design Decision:
The chosen angle and placement was at 90 degrees with a wall to the left and right of the robot. This is in order to ensure maximum reflected IR light returning and not having to take into consideration IR reflected light lost due to the angle and distance at which the sensor is in relation to an obstacle on either side of the robot.
Discarded Sensor Placement and Angle Design Decision:
The 45 degree angle placement was discarded due to the poor detection ability of the sensors due to the distance at which the obstacle would be should the sensor be angled in this manner.

Table 3.6: Pros and Cons of the considered sensor placement and angle.

	45 degrees	90 degrees
Pro	-Allows for better placed circuitry on the manufactured PCB.	-Maximum detection ability due to proximity to reflective surface and orthogonal nature of reflection.
Con	-Poor detection ability due to distance from the reflected surface/obstacle.	-PCB needs to be protruding in order to circumvent the sensors being obstructed by parts of the robot.

3.1.3 Final Design

The following design was selected based off of the above six unique design decisions. A sensing module is going to consist of a single SFH309FA infrared sensor accompanied by two TSAL6200 infrared emitters on either side. This is going to allow for adequate infrared light to be reflected and so detected by the SFH309FA. There are going to be three of these sensing modules that comprise the full sensing subsystem, one facing forward, one facing ninety degrees to the left and one facing ninety degrees to the right. So as to ensure the obstacle is within sensing range. These are all going to be mounted on a T-shaped PCB which allows for an adequate range of motion for the robot without compromising the visibility of the sensing module.

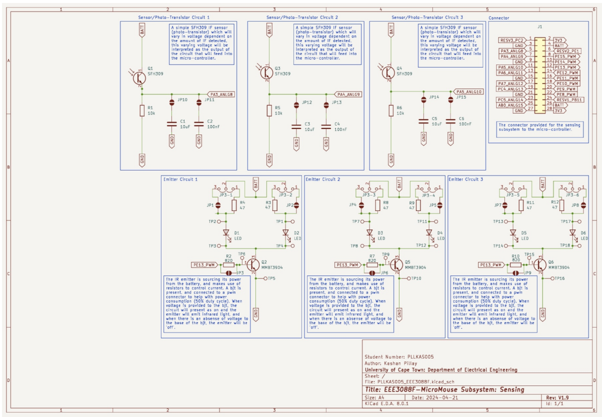


Figure 3.3: Final Design Schematic

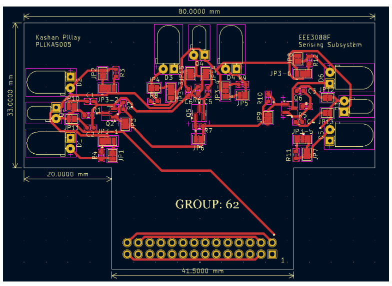
CALCULATIONS: (Emitter Circuit 1)

Source Voltage = 3.3V, Current Draw = 0.1A, Forward Voltage = 1.2V (TSAL6200)

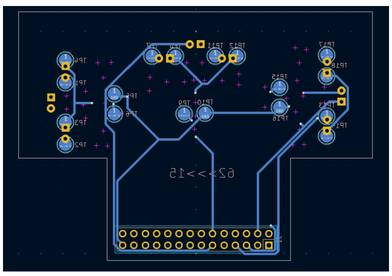
R4=(3.3V-1.2V)/0.05A=42Ohms. E12: R4 = 47Ohms. Similarly R3=R8=R9=R11=R12= 47Ohms

PWM Voltage = 3.3V, Vce = 0.7V and Ib = 3.33mA (for Ic = 100mA) (MMBT3904)

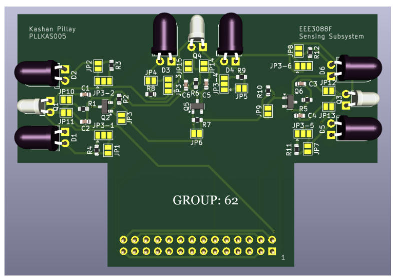
KVL:3v3-Vce=I(R2). R2=(3.3V-0.7V)/0.0033A=787Ohms. E12: R2=820Ohms. Similarly R7=R10=820Ohms.



(a) Front PCB



(b) Back PCB



(c) 3D PCB

Figure 3.4: PCB

3.2 Failure Management

Below, Table 3.7 summarises the precautions taken to account for design errors/flaws.

Table 3.7: Failure Management Measures

Measure	Description
3-Point Jumpers (open)	i. These jumpers have been used at the voltage input of both branches of each emitter circuit. This jumper allows for the use of solder to connect the input voltage to a branch of choice in order to connect a different resistor, should there be a calculation error.
Test Points	i. These have been used to provide the voltage drop across the infrared emitter in order to ascertain the functional status of this component. ii. These have been used to provide the voltage drop across the base-emitter junction of the bipolar junction transistor (emitter circuit) in order to ensure that the transistor is operating in the desired (linear) region.
Pad-Jumper (open)	i. These have been used in the additional branch of the input voltage to each emitter circuit. This allows the addition of a different valued resistor or to completely short the branch. ii. These have been used across the resistor in the base of the bjt in order to all for the decrease of resistance by the addition of a resistor in parallel. iii. These have been used as connectors to two different capacitors at the output of each infrared sensor circuit in order to allow for selection between the two different valued components.
Additional Capacitors	i. These are connected to the circuit using open solder pad jumpers in order to allow for error catching in the integration with the ADC.

3.3 System Integration and Interfacing

Below, Table 3.8 and Figure 3.5 summarise the integral integration and interfacing aspects.

Table 3.8: System Interfacing Table

Interface	Description	Pins/Output
I001	Sensing-subsystem to Processor-subsystem (housing the STM32L476) in order for the micro-controller (ADC) to receive the output of the sensor circuit (obstacle detection) of the sensing subsystem.	• ANLG8: PIN5 to STM PA3 • ANLG9: PIN7 to STM PA4 • ANLG10: PIN11 to STM PA5
I002	Processor-subsystem (housing the STM32L476) to Sensing-subsystem in order for there to be power from the source to the emitter circuit of the sensing subsystem.	• STM BATT (3V3-4V2) to PIN26
I003	Sensing-subsystem to Processor-subsystem (housing the STM32L476) in order to have ground as a reference.	• PIN21 to STM GND
I004	Processor-subsystem (housing the STM32L476) to the Sensing-subsystem in order to reduce power consumption a PWM signal is supplied to the base of the emitter circuit, control the bjt which is acting as a switch.	• PWM: STM PE13 (3V3) to PIN12

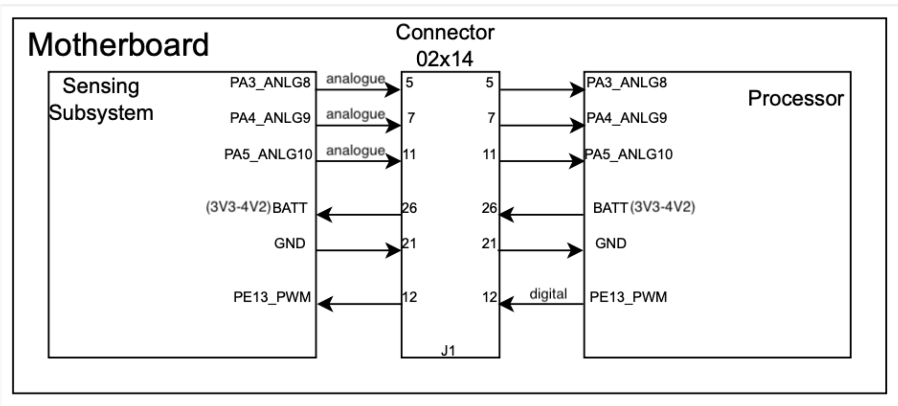


Figure 3.5: System Interfacing Diagram

Chapter 4

Acceptance Testing

4.1 Tests

Table 4.1: Subsystem Acceptance Tests

AT ID	Description	Testing Procedure	Pass/Fail Criteria
AT01	(User Acceptance Testing) Measure the manufactured PCB.	Measure the length and breadth of the manufactured PCB with a PCB ruler or caliper.	PASS: A length and breadth both less than 85mm, so as to not exceed the bounds of an $85mm^2$ square. FAIL: a length or breadth greater than 85mm.
AT02	(Business Acceptance Testing) Review the manufacturing order cost.	By looking at the confirmation of receipt or order receipt the cost can be confirmed.	PASS: The total cost being less than \$30. FAIL: The total cost exceeding \$30.
AT03-1	(Unit Testing) Observe a different LED turn on for detection in the front of and on either side of the robot and no LED turning on when no detection.	i. Place an obstacle in front of the powered micro-mouse ii. Place an obstacle to the left of the micro-mouse. iii. Place an obstacle to the right of the micro-mouse. iiii. Have no obstacles in the surroundings of the robot.	i. PASS: LED 1 (PB6) turns on. FAIL: LED 1 (PB6) stays off. ii. PASS: LED 2 (PB7) turns on. FAIL: LED 2 (PB7) stays off. iii. PASS: LED 3 (PB5) turns on. FAIL: LED 3 (PB5) stays off. iiii. PASS: ALL LEDs stay off. FAIL: Any LEDs turn on.
AT03-2	(Unit Testing) Measuring the voltage across the emitters of the sensing circuit.	Using a voltmeter, measure the voltage across the emitters using the placed testing points as per the schematic (Figure 3.3).	PASS: Measured voltage is in the range of 1.2-1.6V. FAIL: Measured voltage is greater than or less than 1.2-1.6V.
AT03-3	(Unit Testing) Measuring the output voltage of the sensing circuit.	Using an oscilloscope, measure the output voltage across the placed test points as per the schematic (Figure 3.3).	PASS: The voltage being in the range of 0.5-3.3V. FAIL: The output voltage being less than 0.5V.

AT ID	Description	Testing Procedure	Pass Criteria
AT04	(Unit Testing) Measuring the pin header through-hole connections.	Using a caliper, measure the through-hole connections.	PASS: The measurement being in the range of 2.4mm. FAIL: The measurement being greater than 2.4mm.
AT05-1	(Unit Testing) Measuring the input voltage of the sensing circuit.	Using a voltmeter, measure the input voltage (STM BATT to PIN26) with respect to ground.	PASS: The input voltage should be in the range of 3.3V. FAIL: The input voltage not being +/-3.3V.
AT05-2	(Unit Testing) Measuring the input current of the sensing circuit.	Using an ammeter, measure the input current (STM BATT to PIN26) of the circuit.	PASS: The current being less than 100mA. FAIL: The current being greater than 100mA.
AT06	(Unit Testing) Ensuring the micro-controller has been set to provide an output signal that has a duty cycle of 50%.	Using the suggested interfacing software (STM32CubeMX and VSCode), encode the required duty cycle by creating a delay.	PASS: The duty cycle should be less than 100% to ensure any sort of power saving. FAIL: The duty cycle being greater than 100%.
AT07	(Unit Testing) Ensure that a calibration reference has been encoded to mitigate ambient light.	Using the suggested interfacing software (STM32CubeMX and VSCode), encode a measure of ambient lighting to be used as a reference when programming the micro-controller.	PASS: Ambient light measurement is able to be recorded, and utilised. FAIL: Ambient light interferes with sensing circuitry.
AT08	(Business Acceptance Testing) Review the manufacturing bill of materials.	By looking at the confirmation of receipt or order receipt the component quantity can be confirmed.	PASS: Components must have a quantity of greater than 1000. FAIL: Components having a quantity less than 1000.
AT09	(Business Acceptance Testing) Review the manufacturing confirmation and bill of materials.	By looking at the manufacturing bill, the component selection and manufacturing company can be confirmed.	PASS: Manufacturing company JLCPCB and all components specified. FAIL: Manufacturing company is not JLCPCB and some components missing from declaration.

4.2 Critical Analysis of Testing

4.2.1 AT01

Objective
This user acceptance testing procedure was to measure the length and breadth of the PCB.
Equipment
Grip GV937 Vernier Caliper
Procedure
Measure the length and breadth of the manufactured PCB, ensuring the caliper has been calibrated.
Analysis
This ATP follows R01 - 'The PCB design should be an appropriate size' and SP01 - 'The PCB design must not exceed the bounds of an $85mm^2$ square'. In order to pass this test, the length and breadth had to both be less than 85mm. By observing these dimensions, mobility within the specified maze cell can be guaranteed. Ensuring the aforementioned mobility is why this ATP is seen as significant. As seen in Figure 4.1 and Figure 4.2 the dimensions of the designed and manufactured PCB is within the bounds of an $85mm^2$ square with a length = 80mm and a breadth of 55mm. No deviations were observed beyond the instruments accuracy limits. This is as a result of the submitted Ki-CAD design obeying all the necessary DRC and ERC confinements and the use of JLCPCB which was able to provide almost precise measurements due to their use of a complex mechanical manufacturing process.

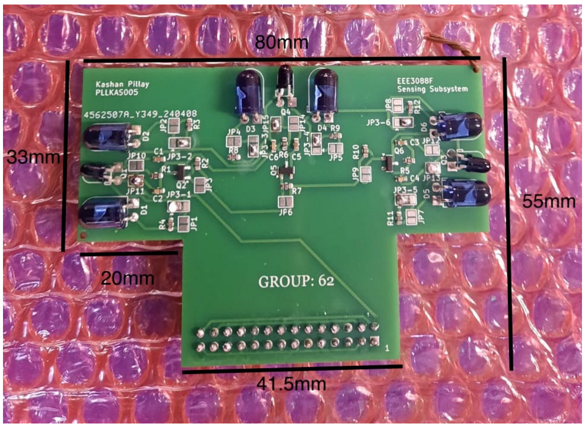


Figure 4.1: Dimensions - Showing Front

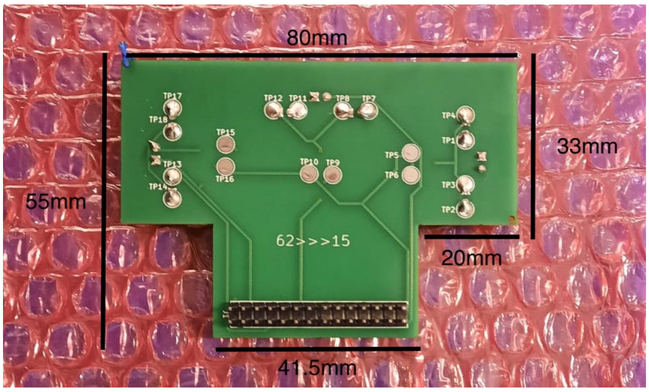


Figure 4.2: Dimensions - Showing Rear

4.2.2 AT02

Objective
This business acceptance testing procedure was to review the manufacturing order cost.
Procedure
By reviewing the confirmation of order receipt, the cost can be confirmed.
Analysis

This ATP follows R02 - 'The PCB design must cost within the specified budget.' and SP02 - 'The design must not cost more than \$8.25 per board (\$30 Grand Total)'. In order to pass this test, the grand total cost must be less than \$30. Should this not be enforced, the PCB will fail to be ordered and for this reason this ATP is highlighted as significant. As is evident by Figure 4.3, this test was passed as the grand total cost was \$19.26. The cost for the PCB design can be broken down in to a Manufacturing Cost, Assembly Cost and Component Cost. Due to JLCPCB having a minimum of 5 units (unpopulated) per order, there is a set Manufacturing Cost of $4. It is required that 2 units be populated and so the associated Assembly Cost is $9.50. That leaves us with a maximum $8.25 per board for components. This ATP was passed due to the selection of component types. Extended Parts were kept to a minimum and used purely out of necessity in order to avoid the additional cost. As per Figure 4.3, there are additional 'hand soldering fees' and 'manual assembly' fees that are present as a result of Extended Parts and Through Hole Components that are unable to be soldered with the machine.

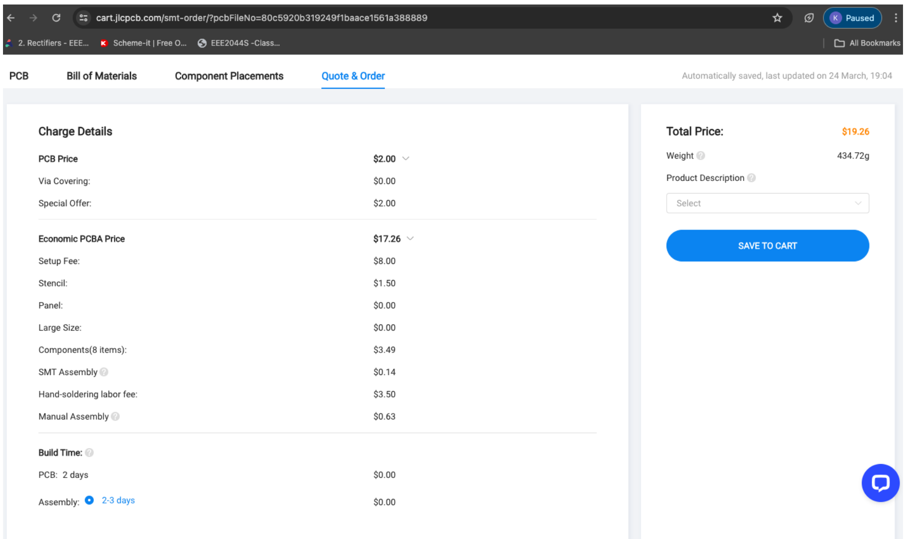


Figure 4.3: Confirmation of Order

4.2.3 AT03-1

Objective

This unit testing acceptance testing procedure was observe a different LED turn on for detection in front of and on either side of the robot and no LED turning on when no detection.

Equipment

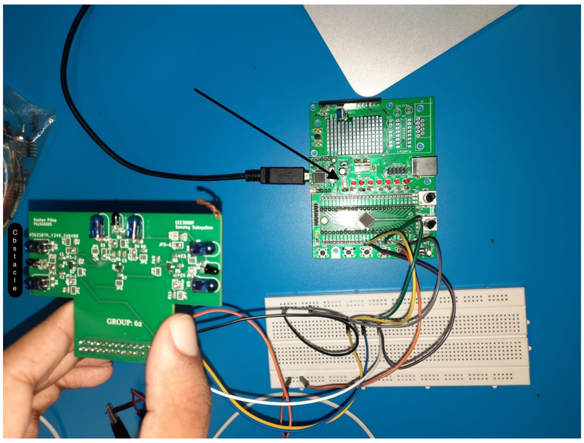
Second year STM32F0 Devkit using a combination of STM32CubeMX and VSCode and a DC Power Supply.

Procedure

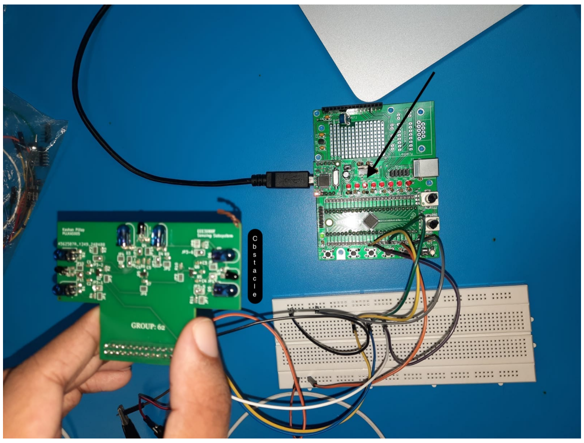
Place an object in front of, to the left, to the right and then have no obstacles surrounding the powered STM32F0 connected to the PCB.

Analysis

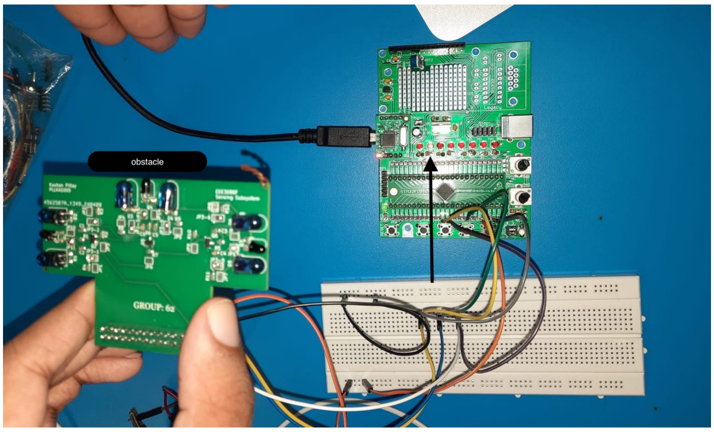
This ATP follows R03 - 'The design must detect obstacles in front of and to either side of the subsystem.' and SP03 - 'The design must use a different LED to indicate detection - in the front, left or right - of the three available LEDs.'. In order to pass this ATP LED 1 (PB6) must turn on for detecting an obstacle in front of the subsystem, LED2 (PB7) must turn on for detecting an obstacle to the left of the subsystem and LED3 (PB5) must turn on for detecting an obstacle to the right of the subsystem. As seen in Figure 4.4, this ATP was passed. In addition, when no objects were placed around the subsystem, no LED came on. In order to test this functionality, the second year STM32F0 Devkit was used to provide a PWM signal to the PCB as well as receive an analogue signal from the PCB. Using a combination of STM32CubeMX and VSCode (with STM32 for VSCode Extention), code was written and flashed to the STM32F0 to turn on either PB5, PB6 or PB7 based off of the analogue input status. A delay was encoded to conform with the selected compensating capacitor value. Once all of the above was configured, a 3V3 DC Supply was used to mimic the external battery supply. A continuity test was performed to ensure that all power sources were not shorted to ground and a diode test was performed to ensure the polarity of each of the IR emitters were connected properly. Before any of the results were captured, the LEDs were initialised to mitigate the effects of ambient light.



(a) Sensing To The Left



(b) Sensing To The Right



(c) Sensing In The Front

Figure 4.4: Sensing In All Directions

4.2.4 AT03-2

Objective
This unit testing acceptance testing procedure was to measure the voltage of the emitters of the sensing circuit.
Equipment
DC Power Supply, Function Generator, Multimeter
Procedure
Using a voltmeter, measure the voltage across the emitters using the placed testing points as per the schematic.
Analysis
This ATP follows R03 - 'The design must detect obstacles in front of and to either side of the subsystem.' and SP03 - 'The design must use a different LED to indicate detection - in the front, left or right - of the three available LEDs.'. Seeing as though without a properly functioning emitter, the subsystem will be obsolete, this is why this ATP is classified as significant. In order to pass this ATP, the measured

voltage across each emitter should be between 1.2-1.6V. As evident in Figure 4.5, this ATP has been passed. In order to measure these voltages, there are various test points on the PCB that can be utilised. The test points utilised are: D1 - TP2/TP3, D2 - TP1/T44 which is the left. D3 - TP7/TP8, D4 - TP11/TP12 which is the front. D5 - TP13/TP14, D6 - TP17/TP18 which is the right. An extremely slight fluctuation can be expected due to the fact that there is a transistor acting as a switch in this circuit which is powered by a PWM signal (a square wave (50% duty cycle) from the oscilloscope acts as a PWM in this case) in order to decrease the amount of power wasted from the emitting circuit.

(a) Left Emitter

(b) Right Emitter

(c) Front Emitter

Figure 4.5: Voltage Across The Emitter

4.2.5 AT03-3

Objective
This unit testing acceptance testing procedure was to measure the output voltage of the sensing circuit.
Equipment
DC Power Supply, Function Generator, Oscilloscope (and probes)
Procedure
Using an oscilloscope, measure the output voltage across the placed test points as per the schematic.
Analysis
This ATP follows R03 - 'The design must detect obstacles in front of and to either side of the subsystem.' and SP03 - 'The design must use a different LED to indicate detection - in the front, left or right - of the three available LEDs.'. This ATP was selected as significant due to its nature of testing not simply the IR sensing ability of the circuit, but also acting a way to ensure that the method for power saving is functioning as intended. To pass this ATP the voltage must be in the range of 0.5-3.3V as an AC signal. As is evident in Figure 4.6, this ATP has been passed. In order to perform this ATP, a sqaure wave (acting as a PWM) is taken from the function generator and a DC power supply is there to mimic the external battery. With these in place, using a probe, follow the schematic and measure the output from each of the circuits with respect to ground. This output is what will be fed to the ADC of the micro-controller. The AC signal is present as a result of the PWM powering the BJT in the emitter circuit. This enables pockets of IR light to be emitted and thus received by the sensor. This output also provides insight into how the power saving functionality will behave and is indicative that it is functioning as expected. The slight attenuation noticed is due to the capacitor present which acts as a safeguard to the ADC of the micro-controller - since high frequency components will be shorted.

(a) Left Output (b) Right Output (c) Front Output

Figure 4.6: Voltage Across The Emitter

Table 4.2: Subsystem Acceptance Test Results

AT ID	**Description**	**Result**
AT01	(User Acceptance Testing) Measure the manufactured PCB.	PASS
AT02	(Business Acceptance Testing) Review the manufacturing order cost.	PASS
AT03-1	(Unit Testing) Observe a different LED turn on for detection in the front of and on either side of the robot and no LED turning on when no detection.	PASS
AT03-2	(Unit Testing) Measuring the voltage across the emitters of the sensing circuit.	PASS
AT03-3	(Unit Testing) Measuring the output voltage of the sensing circuit.	PASS
AT04	(Unit Testing) Measuring the pin header through-hole connections.	PASS
AT05-1	(Unit Testing) Measuring the input voltage of the sensing circuit.	PASS
AT05-2	(Unit Testing) Measuring the input current of the sensing circuit.	PASS
AT06	(Unit Testing) Ensuring the micro-controller has been set to provide an output signal that has a duty cycle of 50%.	PASS
AT07	(Unit Testing) Ensure that a calibration reference has been encoded to mitigate ambient light.	PASS
AT08	(Business Acceptance Testing) Review the manufacturing bill of materials.	PASS
AT09	(Business Acceptance Testing) Review the manufacturing confirmation and bill of materials.	PASS

Chapter 5

Conclusion

This project is a task in which a sensing subsystem is to be designed and manufactured to be fitted on a fully functioning micro-mouse. This specific subsystem (sensing) is to detect the presence of an obstacle (in the most likely case, a maze wall) in front of and to either side of the functioning micro-mouse. This report highlights the process followed to design, test and implement the above mentioned project.The final design is a fully functioning sensing subsystem that makes use of three SFH309FA photo-transistors and six TSAL6200 infrared emitters as the primary components. They were selected due to their cost, availability and specifications which all followed the set out requirements. The 'T' shaped PCB design eloquently suited the micro-mouse, allowing excellent visibility for obstacle detection while not prohibiting a full range of movement within the confines of a maze. The emitter circuit has been fitted with a BJT, that is powered by a pulsed signal. This reduces the power consumed by the subsystem, enabling an increase in duration while being powered by the same external battery. Overall, the project requirements and specifications which ranged from a strict budget to limited time to dimensions and distances, were all successfully fulfilled and even optimised. Should this system be placed on a micro-mouse, it can fulfill the job of detecting obstacles and reducing power consumption excellently. Based off of the Critical Analysis of Testing (Chapter 4 - Section 4.2), the above outlined design has been implemented well. The PCB design expands a mere 80mm by 55mm, well below the threshold of 85mm by 85mm while still ensuring the sensors are positioned for optimal detection. The system is capable of detecting obstacles to the front and either side of the robot while simultaneously having a method to reduce power consumption. This can be seen in sub-section 4.2.3 in which the direction of the obstacle has been indicated by an LED. The strict ($30) budget was adhered to, having only spent $19.26. The emitters are functioning optimally with all having a voltage drop of between 1.21V-1.32V and finally the sensing circuit output can be seen to have not only a voltage greater than 0.5V at its peak - but can be seen to exhibit substantial power saving capabilities.

5.1 Recommendations

Throughout the design, testing and implementation processes required for this project, the following has been noted to implement as an improvement on the existing design:

- Ensuring that the CAD ERC (Electrical Rules Checker) and DRC (Design Rules Checker) tools are utilised to prevent design errors.
- Having only a single emitter can drastically reduce power consumption without compromising on sensing capabilities.
- Ensuring that test points for through hole components do not overlap with the through hole connection. A design or electrical error could result in failure of the subsystem.
- Properly planning the use of time in the laboratory can greatly assist in in-efficient testing and debugging.
- Properly analysing the manufactured board to ensure that there have been no errors in manufacturing can reduce potential damage to delicate components.
- Simultaneously writing up report sections as the design and testing procedures commence can ensure that all the required information can be retrieved for future use.