Interim 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 for fitment in a fully functioning micro-mouse.

The greater project is a micro-mouse. A micro-mouse is in essence, a maze-solving robot. 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.

Requirement ID	Description
UR01	The design must maneuver within the confines of the maze.
FR01	The design PCB should be an appropriate size.
FR02	The design PCB must cost within the specified budget.
UR03	The design must detect obstacles
FR03	The design must be able to indicate location/detection ability.
UR04	The design must provide real-time input to the micro-controller.
FR04	The design PCB must be compatible with the motherboard.
UR05	The design must be powered externally.
FR05	The design must adhere to power and current restrictions.
UR06	The design must have a power-saving functionality.
FR06	The design input supply must be pulse width modulated.
UR07	The design components must all be sourced from the manufacturer.
FR07	The design must be manufactured by a specific company and all components must be specified.

Table 2.1: User[UR] and Functional[FR] requirements of the sensing subsystem design.

2.2 Specifications

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

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 ($16.50 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 pulse width modulation must be set to 50%.
SP07	The manufacturing must be with JLCPCB and all components must be specified on the production files with a stock of more than 1000.

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

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.

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	BAT	Review the manufacturing bill of materials.

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

2.4 Traceability Analysis

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

	Requirements	Specifications	Acceptance Test
1	UR01,FR01	SP01	AT01
2	FR02	SP02	AT02
3	UR03, FR03	SP03	AT03-1, AT03-2, AT03-3
4	UR04, FR04	SP04	AT04
5	UR05, FR05	SP05-1, SP05-2	AT05-1, AT05-2
6	UR06, FR06	SP06	AT06
7	UR07, FR07	SP07	AT07

Table 2.4: Requirements Traceability Matrix

2.4.1 Traceability Analysis 1

UR01 and so FR01 - 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

From FR02, 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 ($16.50 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

UR03 and so FR03 - the aspect that 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 successful application of requirements, 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 as required and AT03-3 suggests measuring the voltage output of each of the three sensing circuits to observe that a high output is at the circuit of the location in which there is an obstacle.

2.4.4 Traceability Analysis 4

UR04 and FR04 - is the requirement that indicates that the design must provide a real time input to the micro-controller (UR04) and to do this the design PCB must be compatible with the motherboard pin headers (FR04) 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

UR05 and FR05 - 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

UR06 indicates that the design input supply must have a power-saving functionality and that is accomplished by FR06 which entails 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 the micro-controller port output has been set to the desired duty cycle.

2.4.7 Traceability Analysis 7

UR07 - the requirement that indicates that all components should be sourced from the PCB manufacturer can be accomplished by FR07 which states that the design must be manufactured by a specific company and all required components must be comprised within the BOM that will sent to them. From the above, we can see how SP07 came about which specifies that all manufacturing must be with JLCPCB with components being in stock in excess of 1000 units. AT07 suggests a way in which we can validate this which is to review the manufacturing bill of materials (BOM) in order to confirm that all required components were requested.

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 these two aspects, various design decisions are going to be made.

3.1.1 Circuit Component Selection

- Infrared Sensor:

Three different infrared sensors were considered when designing this sensing subsystem the QRD1114, SFH309FA and SFH205.

	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

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

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 when designing this sensing subsystem the QRD1114, TSAL6100 and TSAL6200.

	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

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

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.

	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

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

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:

	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.

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

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:

	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.

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

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).

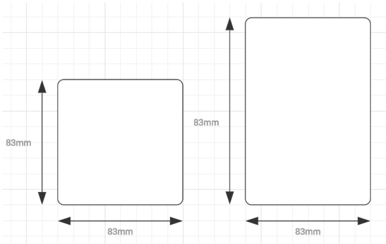


Figure 3.1: Square/Rect Shape

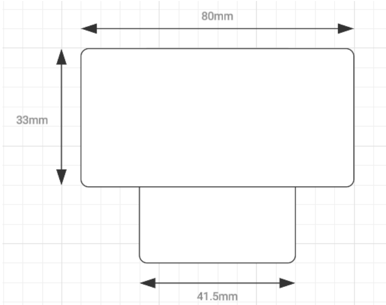


Figure 3.2: T Shape

- 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.

	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.

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

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.

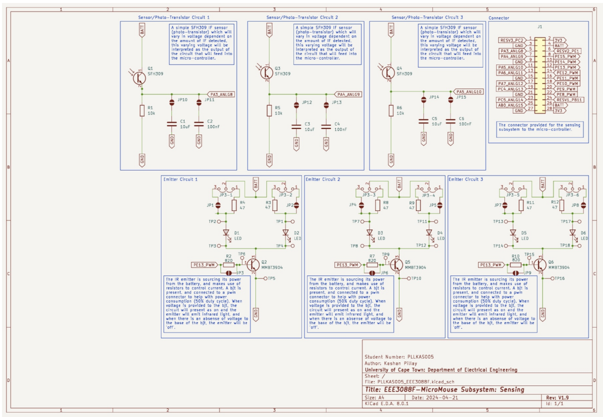


Figure 3.3: Final Design Schematic

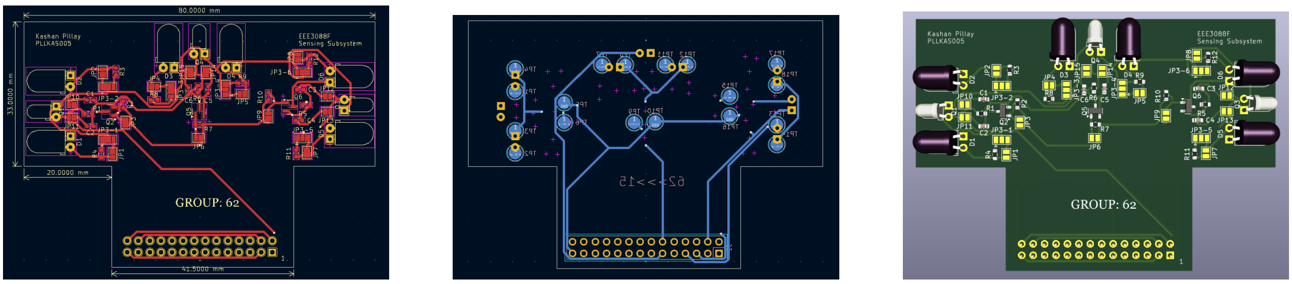
CALCULATIONS: (Emitter Circuit 1)

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.

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 resolve a calculation error for the resistor at this point.
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.

Table 3.7: Failure Management Measures

3.3 System Integration and Interfacing

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

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 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 to PIN12

Table 3.8: System Interfacing Table

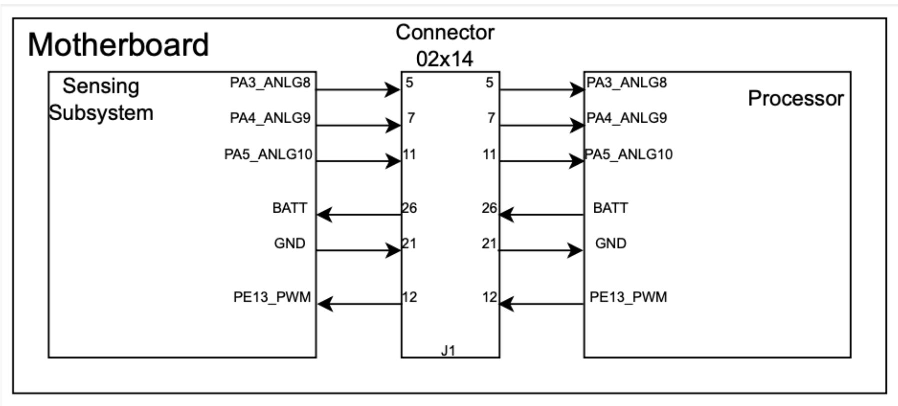


Figure 3.5: System Interfacing Diagram

Chapter 4

Acceptance Testing

4.1 Tests

AT ID	Description	Testing Procedure	Pass Criteria
AT01	(User Acceptance Testing) Measure the manufactured PCB or ensure the dimensions of the PCB enclosed in the production files are adequate.	i. Measure the length of the manufactured PCB with a PCB ruler. ii. Measure the breadth of the manufactured PCB with a PCB ruler.	i. Dimension of length less than 85mm. ii. Dimension of breadth less than 85mm.
AT02	(Business Acceptance Testing) Review the manufacturing order cost.	i. By looking at the confirmation of receipt or order receipt the cost can be confirmed.	i. The total cost being less than $16.50.
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. LED one lights up. ii. LED two lights up. iii. LED three lights up. iiii. None of the three LEDs turn on.
AT03-2	(Unit Testing) Measuring the voltage across the emitters of the sensing circuit.	i. Using a voltmeter, measure the voltage across the emitters using the placed testing points.	i. Voltage in the range of 1.2-1.6V.
AT03-3	(Unit Testing) Measuring the output voltage of the sensing circuit.	i.Using a voltmeter, measure the output voltage across the placed test points.	i. The voltage being in the range of 0.5-3.3V. (there should be an output voltage - due to ambient light)
AT04	(Unit Testing) Measuring the pin header through-hole connections.	i. Using a caliper, measure the through-hole connections.	i. The measurement being in the range of 2.4mm.

AT ID	Description	Testing Procedure	Pass Criteria
AT05-1	(Unit Testing) Measuring the input voltage of the sensing circuit.	i.Using a voltmeter, measure the input voltage with respect to ground.	i. The input voltage should be in the range of 3.3V.
AT05-2	(Unit Testing) Measuring the input current of the sensing circuit.	i.Using an ammeter, measure the input current of the circuit.	i. The current should be less than 100mA.
AT06	(Unit Testing) Ensuring the micro-controller has been set to provide an output signal that has a duty cycle of 50%.	i. Using the suggested interface software, encode the required duty cycle.	i.The duty cycle should be less than 100% to ensure any sort of power saving.
AT07	(Business Acceptance Testing) Review the manufacturing bill of materials.	i.By looking at the confirmation of receipt or order receipt the component selection can be confirmed.	i. Components should be populated on PCB and the order confirmed.

Table 4.1: Subsystem Acceptance Tests