Interim Design Report

Micro-mouse X Sensing Subsystem

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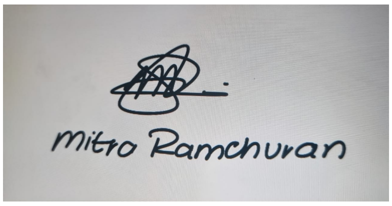

April 21, 2024

Name Surname

Date

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Introduction

0.1 Problem Description

The context of this report shows the design of a sensing PCB subsystem that takes in an input power signal to output a signal t at intervals. The output wave will send back an input Infra-red signal to indicate the presence of nearby objects in the testing rig developed. This signal will be sent to a processor to feedback instructions to avoid the nearby objects.

This sensing PCB subsystem will be connected to a motherboard along with a processor and power PCB subsystem that will function together as a simple maze-solving micro-mouse.

The sensing subsystem will be required to detect the walls of the maze as the micro-mouse navigates its way through. The sensing subsystem should detect the walls in-front of or to the sides and be able to navigate away from the maze walls towards the end point without turning into the walls of the maze or running out of battery.

0.2 Scope and Limitations

The project entails designing and manufacturing the sensor module for the micro-mouse using infra-red sensors. Coding is required to provide information to the processor of a detected obstruction and how to avoid the walls of a maze testing rig. A switching means is needed when the micro-mouse is not in operation.
The subsystem is limited to be an appropriate size to avoid collisions during rotation and to fit onto the pin-headers of the motherboard.[1] This project is developed by https://jlcpcb.com/ and is limited by a budget of 30 dollars. The board is developed soldered and therefore the project is limited to use available and well-stocked components of appropriate size, ordered from JLCPCB's website and does not entail previously used or elsewhere components.

This project does not entail the design and development of the motherboard, processor and power subsystems integrated in the greater project. It does not require the construction of the micro-mouse or the testing rig of the micro-mouse maze.

0.3 GitHub Link

GitHub Link: https://github.com/jameschloe810/EEE3088F.git

Requirements Analysis

0.4 Requirements

The requirements for a micro-mouse sensing module are described in Table 1.

Table 1: **Requirements of the sensing subsystem.**

Requirement ID	Description
R01	Take in Infrared light as input.
R02	Produce signal-based outputs.
R03	Little difference between small offset angle to the wall.
R04	System powered by a battery.
R05	Have switching means to save power when not in operation [?]
R06	Battery power can withstand time it takes to solve the maze.
R07	Project is within budget.
R08	Appropriate sensor PCB size.
R09	Provide data to the processor for navigation and obstacle avoidance.

0.5 Specifications

The specifications, refined from the requirements in Table 1, for the micro-mouse sensing module are described in Table 2.

Table 2: **Specifications of the sensing subsystem.**

Specification ID	Description
SP01	The subsystem must be powered by 3.3V power supply.
SP02	Output signal must be a signal between 0V and 2.5V
SP03	The sensor must not be sensitive to small changes in angle.
SP04	The output should show detection when there is a large change in angle.
SP05	The system should implement BJT's to allow for switching when not in system not in operation.
SP06	Little power and current should be used/drawn.
SP07	Project board has a total cost of 30 dollars between two boards.
SP08	Board must not interfere with maze walls during rotation and pin-headers of board must fit into sensor board.
SP09	Code must be written to inform processor during obstacle detection.

0.6 Testing Procedures

A summary of the testing procedures detailed in the Acceptance Testing Chapter (04) is given in Table 3.

Table 3: **Testing Procedures of the sensing subsystem**

Acceptance Test ID	**Description with brief explanation**
AT01	Power on. Tested by ensuring the power subsystem and measuring the power from battery is 3.3V
AT02	Output voltage test. Applying a test point to the output of the circuit to see if 0V-2.5V range is produced. As well as applying jumper points to allow different resistor values to be tested in order to produce the required output voltage.
AT03	Switching mechanism test. Applying a test points to the Bipolar Junction Transistor (BJT) within the circuit to test the voltage required for it to turn ON and switch OFF.
AT04	Current value test. Test points at photo-diodes to ensure little current is drawn to save battery power.
AT05	Budget test. JLCPB's Website provides budget breakdown for circuit board to ensure budget criteria is met.
AT06	Board measure test. Measured values of micro-mouse with wheels included to ensure appropriate size and placement of pin-headers.
AT07	Processor test. Writing code and testing that the necessary LED's light up during object detection.[2]

0.7 Traceability Analysis

Table 4: **Requirements Traceability Matrix**

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

Table 5: **Traceability Analysis**

Traceability Analysis	**Reasoning**
1	From R01, SP01 can be derived due to both highlighting on input signals. To test this, AT01 is suggested because the power supply generated from the power subsystem and battery will enable the necessary infrared output and reflected infrared input waveform strength to be produced/received. It is the basis voltage from which all other necessary voltages are needed for other input and output signals.
2	From R02, SP02 can be derived because this relates output signals. These can be tested through AT02 which tests the output voltage value to be within a certain range that will allow for the detection of obstructions in-front of and at the sides of the micro-mouse.
3	SP02,SP03 and SP04 can be derived from R03 due to the fact that in order for little difference to be detected in small angle changes, AT02 is required to test the output to not be interfered when the micro-mouse rotates slightly, the obstruction before rotation must still be recognised to be avoided. However when a large angle is detected, this means the micro-mouse has successfully rotated away from the obstruction.
4	SP01 can be derived from R04 with the test of AT01 because by testing the power subsystem, this will ensure the battery is charged and can be implemented as the power supply for the sensor subsystem.
5	SP01, SP05 can be derived from R05 and tested with AT03 due the the fact that the power supply will be the input to the switching system that is the Bipolar Junction Transistor (BJT) component of the circuit. A test point is required to ensure the BJT is in saturation to turn ON and operate the system.
6	R06 derives SP05 and SP06 an is tested with AT03, AT04. Using a BJT to act as a switch will avoid consistent operation of the micro-mouse and will in turn decrease battery usage. Current test points are used (AT04) to ensure little current is being drawn in order to avoid battery drainage.
7	From R07, SP07 can be specified with the test of AT05 which is using the JLCBCP's website to not only order the sensing PCB but to ensure that the required & 30 budget for two boards is met.
8	SP08 can be derived from R08 and tested with AT06. By measuring the micro-mouse upon which the sensing subsystem will be integrated into will avoid collisions during rotation and ensure precise component placement such as the pin-headers for the other PCB boards in the greater project environment.
9	From R09, SP09 can be derived with AT07. The Sensor board needs to integrate with the other boards for communication and data transfer.

Subsystem Design

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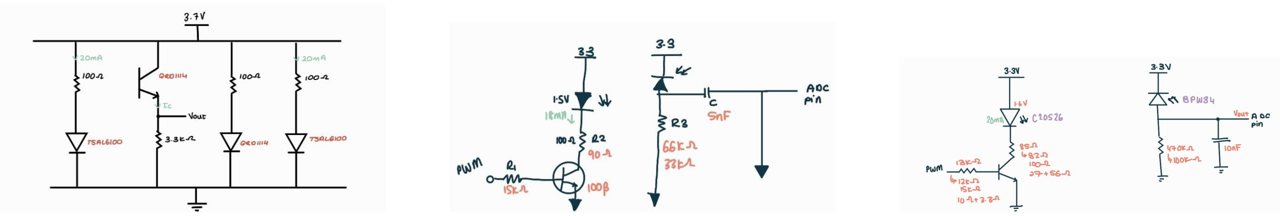
0.8 Design Decisions

Considered Design Decisions



(a) Design 1 (b) Design 2 (c) Design 3

Figure 1: Circuit Designs Considered

These figures show the circuit schematic for only one sensor. This circuit will be multiplied to have a total of three sensor circuits strategically places on the sensor board to detect obstructions in-front of and to the sides of the micro-mouse.

Table 6: **Design Decisions and Comparison**

Design	Description	Implementation Decision	Pros and Cons
1	This design builds on the previous project of the breadboard assignment adding a BJT to allow for switching operations.	This was not implemented as the final design due to the fact that a capacitor was not implemented for output voltage control which will provide for a more efficient circuit.	Pros: This circuit has been implemented before and verified in how it functions. Cons: Components used (QRD1114) are extended parts on JLCPCB and are too expensive.No capacitor is implemented to regulate voltage and noise at the output.
2	This design is more complex than design 1 and allows for cheaper components. A capacitor is now placed on the line of the output.	This circuit was not implemented as the final design because if the voltage at the capacitor is too high, the circuit does not work and will be limited to 1V.	Pros: This circuit is able to filter unwanted noise as the capacitor with the resistor in parallel creates a high pass filter and provides a stable output voltage. Photo-diode receiver is cheaper than Design 1. Cons: Output voltage is limited with capacitor at that position.

3	This design is more complex than design 1 and allows for cheaper components. A capacitor is now placed in parallel with the output voltage.	This design was implemented as the final design due to better efficiency and cheaper component costs.	Pros: The circuit is cheaper than Design 1 and Design 2. The circuit implements a more efficient way to filter out unwanted noise and get a stable output voltage due to the capacitor placement. Cons: resistor values are of E12 components and not exactly the calculated values therefore outputs can differ slightly but are still within requirements.

Calculations

Calculations for Design 1:

$$Voltage\ source\ - Vmax\ of\ TSAL6100\ = Voltage\ through\ R1, R2\ and\ R3$$

$$3.7 - 1.6 = 2.1V \tag{1}$$

$$R1, R2, R3 = \frac{V}{I} = \frac{2.1}{0.02} = 105\Omega \tag{2}$$

$$E12\ component = 100\Omega$$

R4 needs to be a very large value because the voltage across the resistor is directly proportional to the amount of Infrared waves on the photo-diode.

$$A\ 3.3k\Omega\ resistor\ is\ chosen.$$

$$I = \frac{V}{R} = \frac{3.7 - 1.7}{3300} = 0.6mA \tag{3}$$

$$This\ makes\ sense\ because\ the\ current\ in\ the\ emitter\ from\ the\ datasheet\ is\ 1mA.$$

$$Vout = I\ of\ photodiode \times R \tag{4}$$

Calculations for Design 2:

$$Voltage\ source\ - Vmax\ of\ TSAL6100\ = Voltage\ through\ R1, R2\ and\ R3$$

$$3.3 - 1.5 = 1.8V \tag{5}$$

$$R1, R2, R3 = \frac{V}{I} = \frac{1.8}{0.018} = 100\Omega \tag{6}$$

$$Ic = 18mA\ \beta = 100\ therefore\ I\beta = \frac{Ic}{\beta} = \frac{18mA}{100} = 0.18mA \tag{7}$$

Vbe is approx. 0.7V

$$Ratbaseoftransistor = \frac{(Vcc - Vbe)}{I\beta} = \frac{(3.3 - 0.7)}{0.18mA} = 14.44k\Omega \tag{8}$$

$$E12\ components\ allow\ for\ 15k\Omega\ or 12k\Omega.\ 15k\Omega\ chosen.$$

Looking at capacitor and resistor as high pass filter therefore low frequencies attenuated. A 5nF capacitor chosen with a 66k ohm resistor for the photo-diode receiver.

Calculations for Design 3:

$$Voltage\ source\ - Vmax\ of\ TSAL6100\ = Voltage\ through\ R1, R2\ and\ R3$$

$$3.3 - 1.6 = 1.7V \tag{9}$$

$$R1, R2, R3 = \frac{V}{I} = \frac{1.7}{0.02} = 85\Omega \tag{10}$$

E12 component 100 ohm was chosen.

$$Ic = 10mA\ \beta = 100\ therefore\ I\beta = \frac{Ic}{\beta} = \frac{10mA}{100} = 0.1mA \tag{11}$$

Vbe is approx. 0.7V

$$Ratbaseoftransistor = \frac{(Vcc - Vbe)}{I\beta} = \frac{(3.3 - 0.7)}{0.1mA} = 26k\Omega \tag{12}$$

$$E12\ components\ allow\ for\ 27k\Omega.$$

A capacitor of 10nF was chosen with a resistance of 100k ohms for the photo-diode receiver.

Component Selection

Table 7: **Components Considered**

Component	Suitability	Pros and Cons
TSAL6200	The parameters of the component looking at its data sheet is perfectly suited for the design requirements. Forward voltage of 1.6V and reverse current of 10 micro Amps.	Cons: Components with footprint was not available on JLCPCB therefore was unable to be used,
SFH205	The parameters of the component looking at its data sheet is perfectly suited for the design requirements.Dark current of 2 nano Amps and forward voltage of 1.3 V.	Cons: Component was not available on JLCPCB therefore was unable to be used.

BPW34	The parameters of the component looking at its data sheet is perfectly suited for the design requirements. Open circuit voltage of 320mV and reverse dark current of 30 nano Amps.	Pros: Available component when ordering from JLCPCB. Meets the requirements for the design.
MMBT3904	The parameters of the component looking at its data sheet is perfectly suited for the design requirements. collector current of 200mA, Vbe at 0.65V.	Pros: Available component when ordering from JLCPCB. Meets the requirements for the design.

E12 components were considered for this project only, by using E24 components this would effect the outcome of the considered designs as E12 components have a greater number of resistor values available, however it has a lower tolerance at 5%.

Final Design

The following design shows the final schematic of the sensing subsystem. This schematic integrates 3 sensing circuits that are strategically place around the arc of the PCB board to detect obstructions in-font of and to the side of the micro-mouse.

The schematic includes the use of a TSAL6200 photo-diode emitter, that will allow for the 3.3V current to be taken and produce a small current so as to not drain the battery. Three resistors are connected to the emitter with jumpers. This will enable testing to see which resistor value gives rise to the best results. A test point is also included to ensure the circuit is working as expected.

The photo-diode emitter configuration uses an MMBT3904 Bipolar Junction Transistor that will input a pulse width modulator enabling switching for the subsystem when not in operation and hence, will save battery power.

The schematic includes the use of a BPW34 photo-diode receiver configuration with jumpers used for the resistors to allow for correct testing of the output value. A capacitor of 10nF is connected to the configuration as well to get rid of potential noise and stabilise the output signal. The output will be sent to an analogue to digital converter, interfacing with the external environment of the micro-mouse.

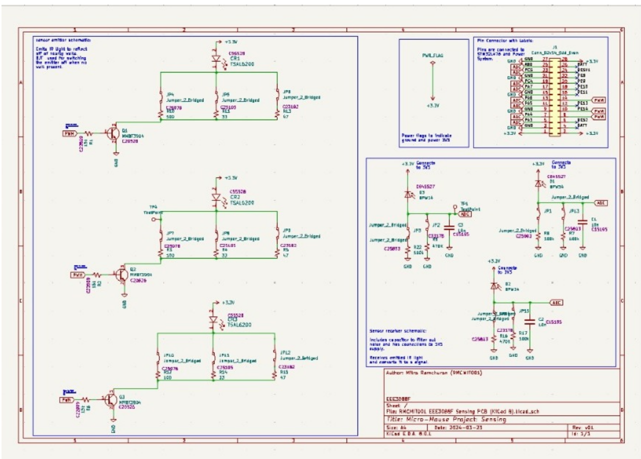
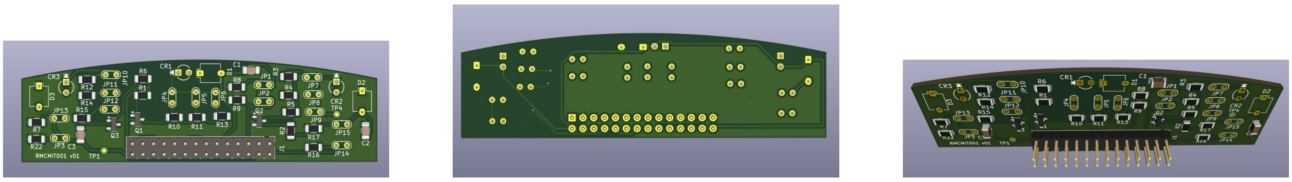


Figure 2: Schematic



(a) Front PCB (b) Back PCB (c) 3D PCB

Figure 3: PCB

0.9 Failure Management

Table 8: Failure Management Descriptions

Name	Description
Trace Issues	Trace issues were mitigated by applying vias to make traces on the backside of the board. Therefore, traces will not overlap and connections can be made where necessary. A Trace fast track software was also used to apply traces where necessary and this helped to make sure all components were connected properly [3] [4].
ERCs an DRCs	KiCad version 8 Software has Electrical Rule Checkers (ERC) as well as Design Rule Checkers (DRC) that were ran and warnings as well as errors were ran through to mitigate any potential electrical or design faults. In the design above, power flags were added, components were placed strategically to not get cut off the board and all traces were connected to their necessary components. Footprints were also assigned to each component so no component is left out of the board [3].

Components and Availability	Alternative JLCPCB components were considered if desired components were not in stock. Multiple different resistors were used with jumpers to test for best possible outputs.
Budget Issues	Budget issues were mitigated by avoiding the use of extended parts and using basic parts which are a lot cheaper and are not priced more due to extended parts needing to be outsourced. Alternative JLCPCB components were also considered if desired components were not in stock.
Errors in Circuit Design	The use of test points and jumpers were used in the circuit to test and ensure circuit functionality. If one part failed. the other could be used.

0.10 System Integration and Interfacing

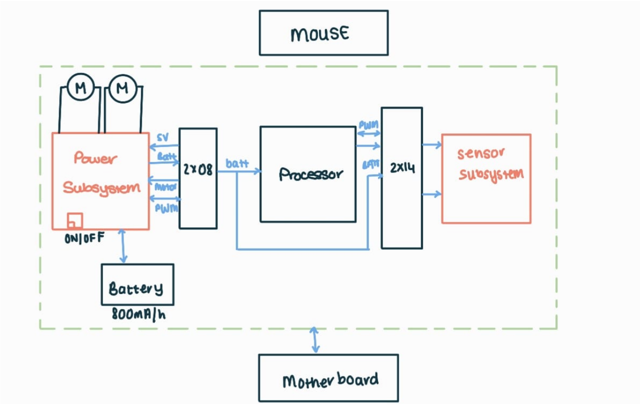


Figure 4: Interfacing Diagram

Table 9: Interfacing specifications

Interface	Description	Pins/Output
I001	Sensing system to STM for data transfer to computer	• PA3-PA7 Pins and Analogue Pin • PC4, PC5 Pins and Analog Pin • AB0 Pin and Analog Pin
I002	Reserve voltage Pins going from Processor to Power Subsystem and Sensing Subsystem	• RES3V3 Pin and PC2 Pin for sensor board. • RESV2 Pin and PE1 Pin for sensor board. • RESV1 Pin and PB11 Pin for sensor board. • PD7 Pin and RESV Pin for power board. • BATTERY CONN.
I003	Processor to computer for data transfer from STM	• Assuming the Processor is connected to a Micro B USB port, output via cable [1]
I004	Pulse Width Modulator Connection of Processor	• PE8-PE15 Pin and PWM Pin for sensor board. • PC6-9 Pin and PWM1-PWM4 Pin for power board.

Acceptance Testing

0.11 Tests

Table 10: **Subsystem acceptance tests**

Test ID	Description	Testing Procedure	Pass/Fail Criteria
AT01	Powers on	• Use a multi-meter to measure the voltage coming into the sensing subsystem. This is the voltage that is used in the power subsystem to charge the battery. • Use a multi-meter to measure at the test point at the input of the sensing subsystem to verify required voltage.	• Pass: The voltage measured at the test point or at the output of the power system is 3.3V. This is the voltage chosen to power the sensing subsystem. • Fail: The voltage is 0V, less than 3.2V or higher than 3.3V. This will give unwanted variations in output signals and the micro-mouse will not function as required.
AT02	Output voltage test	• Applying a test point to the output of the circuit to see if 0V-2.5V range is produced. • Applying jumpers in the PCB board to test certain resistor values for an accurate output signal	• Pass: Correct resistor value is found and output is within range of intended output signal that can be detected by the processor. • Fail: None of the resistor values are usable and give the correct output.
AT03	Switching mechanism test	• Applying a test-points to the Bipolar Junction Transistor (BJT) within the circuit to test the voltage required for it to turn ON and switch OFF.	• Pass: If the BJT is in saturation at 0.7V, the 'switch' will close and be on and the sensing sub-system will detect obstructions. If the BJT is 0V, the BJT is in cut-off and is an open 'switch' • Fail: incorrect BJT component was chosen that did not have the correct parameters for current and voltage values needed or voltage specifications mentioned were not met.

AT04	Current value test	• Test points at photodiodes to ensure little current is drawn to save battery power. • Current test points to ensure there are no breaks in the circuit and traces were made correctly.	• Pass: Current is extremely low (18mA) at emitter and therefore takes up less power and avoids battery drainage. • Fail: No current at all of large current that will drain the battery and or damage the circuit.
AT05	Budget test	• JLCPB's Website provides budget breakdown for circuit board to ensure budget criteria is met.	• Pass: Total price of two boards is below $30 . • Fail: The subsystem board is not ordered and cannot be further tested.
AT06	Board measure test	• Measurements take of micro-mouse to ensure appropriate size and placement of pin-headers.	• Pass: Micro-mouse is able to fit through maze during rotation and easily connected to pin-headers. • Fail: Pin placement incorrect an board cannot be used. The micro-mouse gets stuck and cannot move through maze.
AT07	Processor test	• Writing code and testing that the necessary LED's light up during object detection.	• Pass: Code can be understood by processor and detect obstruction at certain side of micro-mouse with an LED lighting up for indication purposes. • Fail: Code is not understood and obstruction cannot be avoided.

Bibliography

[1] U. of Cape Town, “Micr0mouse project brief,” 2024. [Online]. Available: https://amathuba.uct.ac.za/d2l/le/lessons/48483/topics/2299211

[2] Appendix below.

[3] DigiKey, “An intro to kicad – part 6: Place parts and define outline | digikey,” 2019. [Online]. Available: https://www.youtube.com/watch?v=dM5b_s2ysVk

[4] ——, “An intro to kicad – part 7: Board layout | digikey,” 2019. [Online]. Available: https://www.youtube.com/watch?v=jaQPr7PgImk

Appendix

```
# Pseudo-code for interfacing sensor with processor

# Define GPIO pins for sensor inputs
LEFT_SENSOR_PIN = 1
RIGHT_SENSOR_PIN = 2

# Initialize GPIO pins
initialize_gpio_pins()

# Function to read sensor data
def read_sensor(sensor_pin):
    # Read sensor value (1 for obstacle detected, 0 for no obstacle)
    return read_gpio_pin(sensor_pin)

# Main loop
while True:
    # Read sensor data
    left_obstacle = read_sensor(LEFT_SENSOR_PIN)
    right_obstacle = read_sensor(RIGHT_SENSOR_PIN)

    # Check if obstacles detected
    if left_obstacle:
        # Turn on left LED to indicate obstacle on the left
        turn_on_left_led()
    else:
        # Turn off left LED
        turn_off_left_led()

    if right_obstacle:
        # Turn on right LED to indicate obstacle on the right
        turn_on_right_led()
    else:
        # Turn off right LED
        turn_off_right_led()
```

Figure 5: Code