Interim Design Report

Micromouse X Subsystem

Prepared by:

Chloe James

Prepared for:

EEE3088F
Department of Electrical Engineering
University of Cape Town

May 17, 2024

Declaration

1. I know that plagiarism is wrong. Plagiarism is to use another's work and pretend that it is one's own.
2. I have used the IEEE convention for citation and referencing. Each contribution to, and quotation in, this report from the work(s) of other people has been attributed, and has been cited and referenced.
3. This report is my own work.
4. I have not allowed, and will not allow, anyone to copy my work with the intention of passing it off as their own work or part thereof.

May 17, 2024

Chloe James

Date

Contents

Chapter 1

Introduction

1.1 Problem Description

The project requires students to apply electrical engineering concepts to develop different subsystems for a micro-mouse maze-solving robot.
The greater project involves creating a fully functional micro-mouse robot that can autonomously navigate a maze. It is made up of multiple PCB boards, all integrated to create a micro-mouse. This requires two subsystems, power and sensing, as well as the processor board, and the motherboard which is the foundation for the other boards. The project aims to provide students with practical experience in complex design problems, as well as in working collaboratively.
The project involves designing and manufacturing the power subsystem PCB to power the micro-mouse. This subsystem must meet multiple specifications, such as operating two motors, providing an analog connection for the processor to sense the battery's state of charge(SoC), charging the battery from a 5V input, and including an ON/OFF switch with specific power draw characteristics. Additionally, the design must fit onto the motherboard and adhere to size constraints to minimize the robot's distance from the center of rotation. Successfully designing and implementing the power subsystem contributes to the overall functionality and performance of the micro-mouse robot, bringing the project closer to its goal of autonomously navigating a maze.

1.2 Scope and Limitations

The project consists of designing and manufacturing the power subsystem PCB for a micro-mouse maze-solving robot on Kicad and utilizing JLCPCB. This PCB will provide power to two motors, the processor board containing the STM32L476, and sensing subsystem. Additionally, the power board will be equiped with a charging circuit and the PCB will be an appropriate size to fit onto the micro-mouse. The project does not entail the design and manufacturing of other subsystems, such as the sensing subsystem or the motherboard. It also does not include the programming or integration of the subsystems into the final robot design. The limits of the project design include the need to meet strict performance requirements, which are shown in Table 2.1, within a constrained budget of $8.25 per board. Testing will be limited to the functionality and performance of the power subsystem. Development will be limited by the availability of components and the time available for designing and manufacturing the subsystem.

1.3 GitHub Link

Shared GitHub link

Chapter 2

Requirements Analysis

2.1 Requirements

The requirements for a micromouse power module are described in Table 2.1.

Table 2.1: Requirements of the power subsystem.

Requirement ID	Description
R01	Operate two motors.
R02	Provide power to the entire microcontroller and motors
R03	Provide an analog connection for the processor to sense the battery's voltage for determining the battery state of charge(SoC).
R04	Charge a single cell LiPo battery from a 5V input pin.
R05	Include an ON/OFF switch with specific power draw characteristics to switch the micro-mouse on and off.
R06	Adhere to size constraints to minimize the motherboard distance from the center of rotation.
R07	Adhere to a strict budget

2.2 Specifications

The specifications, refined from the requirements in Table 2.1, for the micro-mouse power 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	Each motor must be able to draw 200mA at the highest voltage(4.2V) of the battery.
S02	Use 2x8 JST(2.54mm pin pitch) pin header to connect the battery and the microcontroller pins.
SP03	The analog connection for the battery's voltage must be within 0-3.3V.
SP04	The battery charging circuit must be able to charge the battery from a 5V input.
SP05	The ON/OFF switch must have a power draw of less than 500uA in the OFF state and be able to supply the peak current in the ON state.
SP06	The board must be designed to fit onto the motherboard and to minimize the distance from the center of rotation so the micro-mouse will be able to move in the maze.
S07	The components must cost under $8.25 per board, including extended component fees.

2.3 Testing Procedures

A summary of the testing procedures detailed in chapter 4 is given in Table 2.3.

Table 2.3: Testing procedures of the power module subsystem.

Acceptance Test ID	**Description**
AT01	Check the continuity between power input and motor terminals.
AT02	Check the microcontroller and motors are receiving power.
AT03	Measure voltage at analog connection for battery voltage sensing.
AT04	Test charging functionality from 5V input pin.
AT05	Test if the circuit switches ON/OFF.
AT06	Measure the length and width of the PCB.

2.4 Traceability Analysis

The 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	R01	SP02	AT02
3	R03	SP03	AT03
4	R04	SP04	AT04
5	R05	SP05	AT05
6	R06	SP06	AT06

2.4.1 Traceability Analysis 1

Requirement R01 states that the power subsystem must operate two motors. Specification SP01 specifies that each motor must be able to draw 200mA at the highest voltage of a 1S1P battery. Testing procedure AT01 checks the continuity between the power input and motor output terminals, ensuring that the power subsystem can effectively drive the motors.

2.4.2 Traceability Analysis 2

R06 states that the power subsystem provides power to the motors and the microcontroller. SP06 can be derived from R06 as the pin headers are needed to correctly join the power subsystem with the other subsystems. AT06 ensures that the microcontroller and the motors are receiving power.

2.4.3 Traceability Analysis 3

Requirement R02 requires the power subsystem to provide an analog connection for the processor to sense the battery's voltage for determining the battery's state of charge. Specification SP02 specifies that the voltage at the analog connection must be within a specified range below 4.2V. Testing procedure AT02 measures the voltage at the analog connection to ensure it falls within the specified range, validating the functionality of the voltage sensing.

2.4.4 Traceability Analysis 4

Requirement R03 mandates that the power subsystem must charge the battery from a 5V input pin. Specification SP03 specifies that the battery charging circuit must be able to efficiently charge the battery from a 5V input. Testing procedure AT03 tests the charging functionality from the 5V input pin to ensure that the battery charges successfully, verifying the charging circuit's efficiency.

2.4.5 Traceability Analysis 5

Requirement R04 states that the power subsystem must include an ON/OFF switch with specific power draw characteristics. Specification SP04 specifies that the ON/OFF switch must have a power draw of less than 500uA in the OFF state and be able to supply the robot's peak current in the ON state. Testing procedure AT04 verifies the functionality of the ON/OFF switch, ensuring that it meets the specified power draw characteristics and can supply the required current to the robot.

2.4.6 Traceability Analysis 6

Requirement R05 mandates that the power subsystem PCB must adhere to size constraints to minimize the distance from the center of rotation. Specification SP05 measures the distance of the PCB from the center of rotation. Testing procedure AT05 verifies that the distance of the PCB from the center of rotation is within the specified limits, ensuring that the power subsystem design effectively minimizes the distance from the center of rotation.

Chapter 3

Subsystem Design

3.1 Design Decisions

3.1.1 Final Design

The final design is shown in Figure 3.2 below. It was chosen as this design was the most suitable and cost-effective solution to the design problem.
The power subsystem requirements shown in Table 2.1 of Chapter 1 were met by the use of an H-bridge for the motor drivers, an ADC voltage divider circuit, a switching circuit, and a battery charging circuit. In selecting components for each part of the subsystem, several factors were considered to ensure suitability for the project:

- Motor driver circuit:
  The DRV8837, a dual H-bridge motor driver IC (Integrated Circuit), was selected for the project. Its choice was based on several key features: the dual H-bridge configuration, which aligns with R01 requirements; it is used in 'low-voltage or battery-powered motion control applications'[1], meeting SP01 specifications; the inclusion of PWM control for motor speed regulation; built-in current limiting for motor protection; and its compact form factor, which is advantageous for meeting the design constraints, particularly R05.

- ADC voltage divider circuit:
  An ADC (Analog-to-Digital Converter) voltage divider circuit, in accordance to SP02, is used to scale down a higher voltage signal to a level that is within the input range of the ADC. This is necessary because the ADC has a limited input voltage range, and exceeding this range can damage the ADC or result in inaccurate readings.
  The voltage divider circuit consists of two chosen resistors of equal value connected in series, with the ADC input connected to the junction between the two resistors.
  Given that the battery is a LiPo 800mAh 3.7V, it means that when fully charged, the battery voltage can be around 4.2V. This voltage exceeds the typical operating range of the ADC, which is limited to 0V to 3.3V. Using 2 10kΩ in series creates a voltage divider.

- Switching circuit:
  The switching circuit controls the power subsystem, turning it ON or OFF. In the OFF state, the battery charges, while in the ON state, the battery powers the motors. A general-purpose low-voltage tactile switch, SW SPST, is used.

- Battery charging circuit:
  The TP4056 IC was chosen as the battery charging circuit.
  It has built-in features such as overcharge protection, thermal regulation, and over-discharge protection [2] which are essential for safe and efficient charging of lithium-ion batteries.
  Many of the component values are set according to the datasheet [2] to perform specific operations.
  But certian values need to be calculated as follows.
  The charging current (I_{charge}) is calculated using the formula:

$$I_{\text{charge}} = \frac{1.2\text{V}}{R_{\text{prog}}}$$

  The resistor needs to be set at 2.4Ω for the desired charge current (500mA) to be reached.
  The approximate charging time (t_{charge}) can be estimated as:

$$t_{\text{charge}} \approx \frac{1.5 \times \text{Battery Capacity (mAh)}}{\text{Charging Current (mA)}}$$

$$t_{\text{charge}} \approx \frac{1.5 \times 800\text{(mAh)}}{500\text{ (mA)}}$$

$$t_{\text{charge}} \approx\ 2.4s$$

  The LED resistor values are set to 10kΩ and the capacitors are set to 10uF as given in the datasheet [3].

- Size and shape of the board:
  The board needed to adhere to strict size constraints as it needed to fit onto the micro-mouse. The PCB had to have a 'proud' tab around a height of 18mm and a width of 35mm so the connectors from the power subsystem can be attached to the microcontroller.

3.1.2 Design options

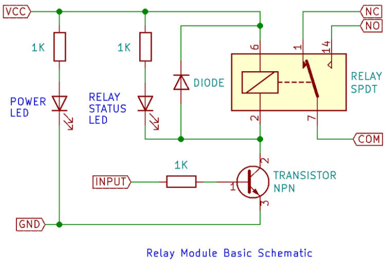
- Motor driver circuit:
  Alternative options such as the L293D [4] were considered but were not chosen due to higher power consumption, limited control, high supply voltage of 4.5 - 36 V [4], and protection features compared to the DRV8837.

- Switching circuit:
  An option of relays shown in Figure 3.1a was explored but the size and weight of the relays, high power consumption, high-voltage supply circuit [5] and the cost were not appropriate for this project as it is considered an extended part.

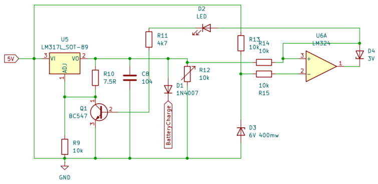
- Battery charging circuit:
  The option below, using a voltage regulator, BJT and an op-amp with some additional passive circuitry in Figure 3.1b was not chosen as there was limited current handling, no built-in battery management features, greater costs and the possibility of it not working was greater as it was many different components to create a battery charging circuit.

- ADC voltage divider:
  Other ADC ICs such as the MCP3008, shown in Figure 3.1c were considered but due to strict budget constraints, it could not be chosen as it is an extended part and an additional $3.10 would not fit the budget [6].

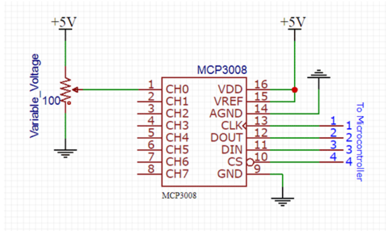
The following design...



(a) Relay switching circuit



(b) Charging circuit



(c) MCP3008 ADC circuit

Figure 3.1: Options

3.1.3 Final design diagrams

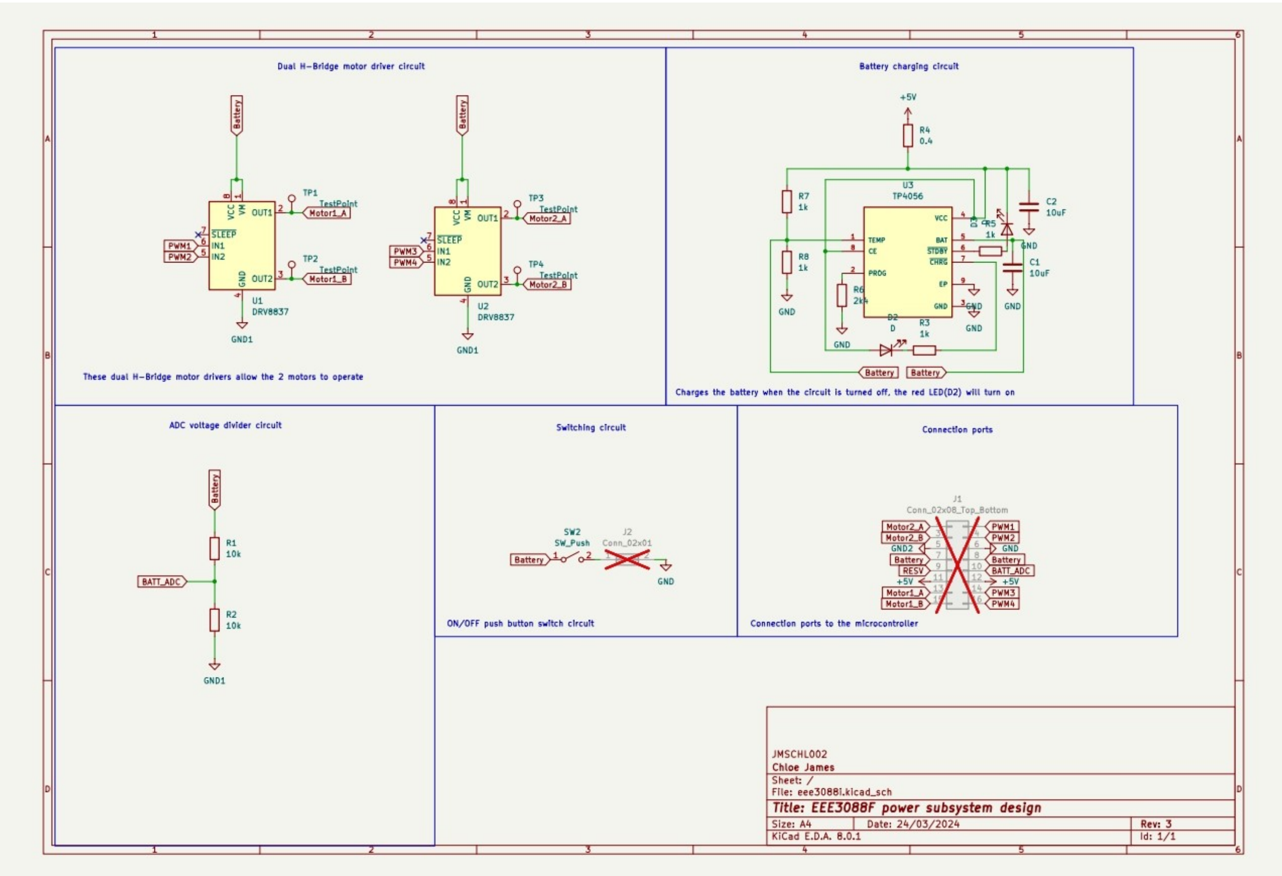
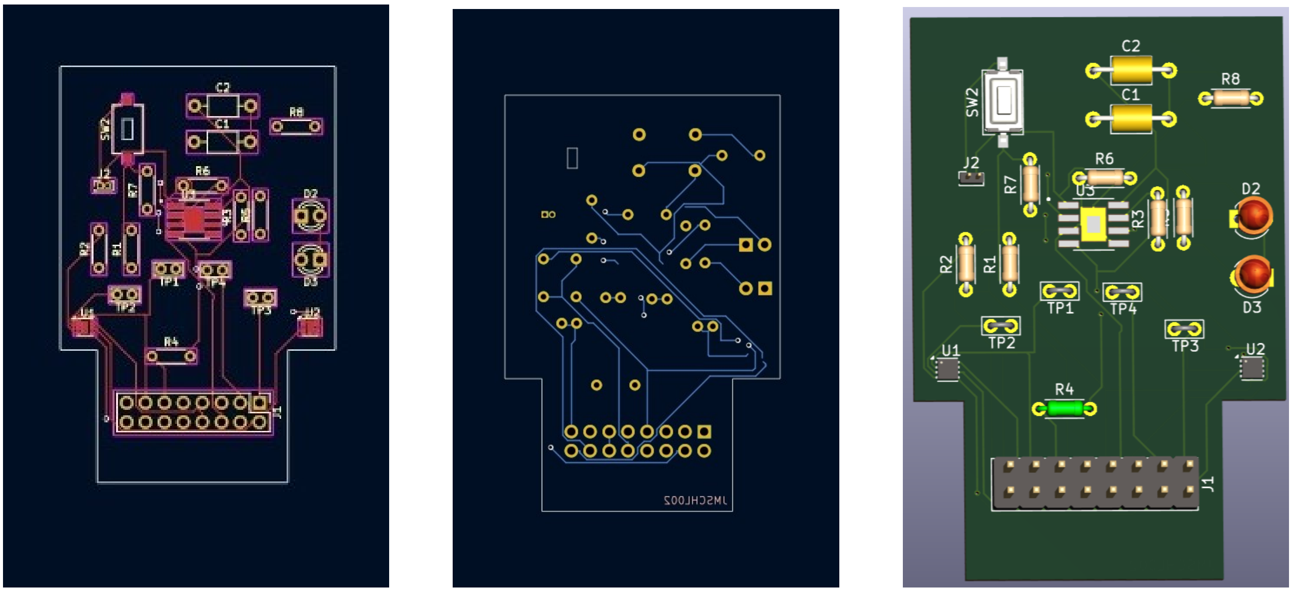


Figure 3.2: Schematic

The connectors in the schematic have been crossed out as they will not be populated on the PCB.



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

Figure 3.3: PCB

The use of ports was necessary in the design of the PCBs, as shown below in Figure 3.3b by the yellow circles, as multiple connections would overlap if ports were not used.
Test points, labled TP1, TP2, TP3, and TP4 were placed on the boards to allow for testing upon arrival.
The components are evenly distributed to ensure stability.

3.2 Failure Management

Table 3.1: Table showing the failure management of the power subsystem.

Name	**Description**
Component Redundancy	Incorporating duplicate components,within the budget, or backup circuits to provide redundancy in case of component failure.
The addition of circuitry	Addition of test points and jumpers to the circuit allows for physical testing upon the arrival of the boards.
Component Selection	Selecting through hole components where possible, with appropriate specifications to allow for them to be desoldered and new components to be soldered back onto the PCB in case of incorrect or faulty components.

3.3 System Integration and Interfacing

3.3.1 Interfacing table

The Pin Connectors allow the microcontroller, on the processor, and the motors, on the motherboard, to be powered through the power subsystem PCB. These connections are shown in Table 3.2 below.

Table 3.2: Interfacing specifications

Interface	Description	Pins/Output
I001	Motor Drivers	• Pin Connector: Pin 1 to Motor 2A • Pin Connector: Pin 3 to Motor 2B • Pin Connector: Pin 13 to Motor 1A • Pin Connector: Pin 15 to Motor 1B
I002	Microcontroller to power board(PWM)	• STM PC6(Pin 7) to Pin Connector: Pin 2 • STM PC7(Pin 5) to Pin Connector: Pin 4 • STM PC8(Pin 4) to Pin Connector: Pin 14 • STM PC9(Pin 3) to Pin Connector: Pin 16
I003	Microcontroller to power board(5V)	• STM 5V(Pin 10) to Pin Connector: Pin 12 • STM 5V(Pin10) to Pin Connector: Pin 11
I004	Power board to microcontroller(power)	• Pin Connector: Pin 7 to STM VBAT(Pin 2) • Pin Connector: Pin 8 to STM VBAT(Pin2)
I005	Power board to microcontroller (SoC)	• Pin Connector: Pin 10 to STM 3V3 ADC(Pin 48)

3.3.2 Interfacing Block Diagram

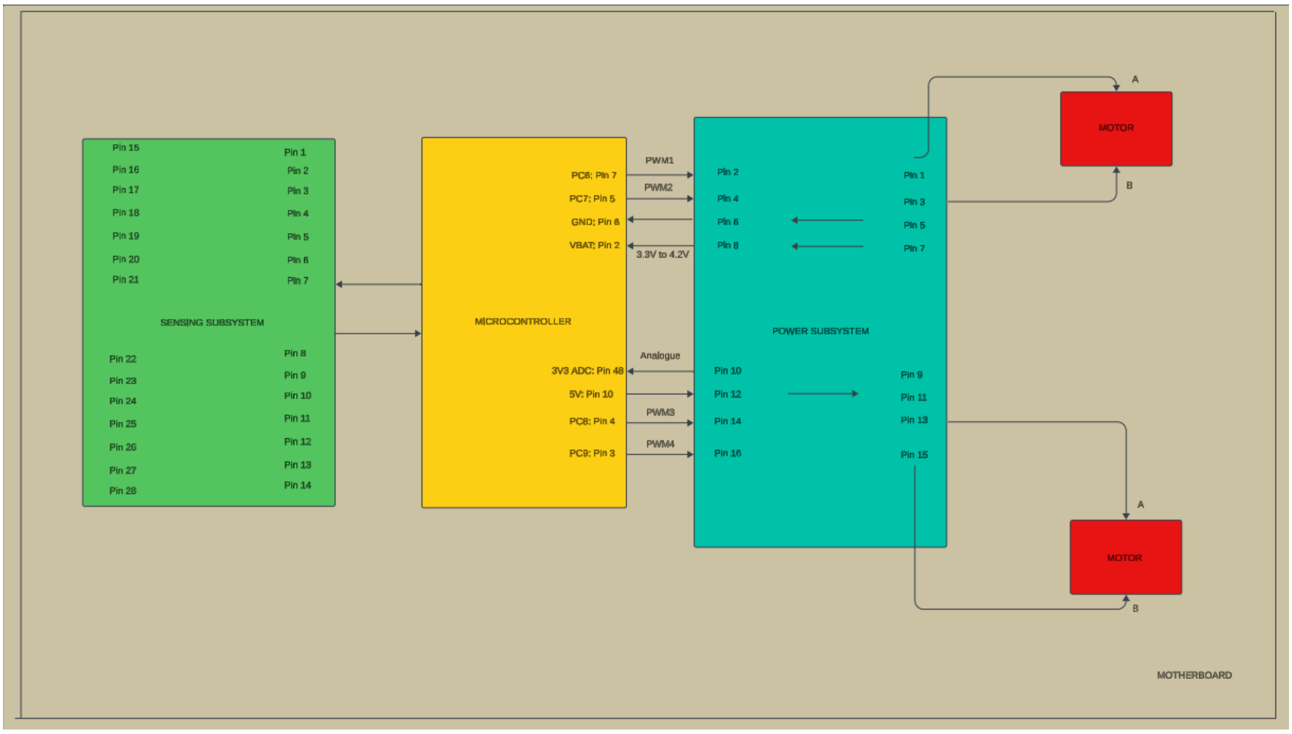


Figure 3.4: High-level interfacing diagram

The system which was designed for and created, the power subsystem, has been detailed with its connections to the processor and the motors. The interfacing diagram above shown in figure Figure 3.4 shows how the power subsystem fits into the system as a whole. All subsystems and the motors are connected to the motherboard which is the foundation of the entire project.

Chapter 4

Acceptance Testing

4.1 Tests

An outline of the structure of testing of the PCBs are detailed below in Table 4.1. These methods were used to test and verify functionality of the power subsystem.

Table 4.1: Subsystem acceptance tests

Test ID	Description	Testing Procedure	Pass/Fail Criteria
AT01	Check the motors are powered on	• Assume that the microcontroller is sending PWM signals to the motors and the entire system is ON. • Measure the voltage from Test point 1 and 2 WRT GND to check if there is a voltage going to Motor 1 A and B using a voltmeter. • Measure the voltage from Test Point 3 and 4 WRT GND to check if there is a voltage going through Motor 2 A and B with a voltmeter.	If the voltage measured at the Test Points goes high when the PWM signal is on for the respctive motor, the test is passed and the motor is being driven correctly.
AT02	Check the microcontroller receives power	• Measure the voltage at the microcontroller pin using a voltmeter • Check if the voltage matches the battery voltage	If the voltage matches, the test is passed.
AT03	Check the analog connection to the battery	• Measure the voltage from the BATT pin to the BATT ADC pin using the voltmeter to check if the ADC voltage divider circuit is working	The voltage of the BATT ADC measured should scale with the voltage of the battery but it should not increase over 3.3V. If the voltage increases beyond 3.3V the test fails.

Test ID	Description	Testing Procedure	Pass/Fail Criteria
AT04	Check if the battery charging circuit is working	• Use the multimeter to check for continuity between the 5V supply pin and the VCC pin of the TP4056 • Connect a capacitor which will act as the battery discharging device and draw power until the battery needs to be charged • Use the LEDs to monitor the SoC of the circuit	If the red LED is on, the battery is charging and if the white LED is on the battery is fully charged and the test passes. If no LEDs come on the circuit is not operating as expected, and the test fails
AT05	Check if the switch is working correctly	• Press the push button switch into the 'ON' position • Use a multimeter to perform a continuity test with one probe on VBATT and the other on the output of the switch	If there is continuity between the points tested, while in the 'ON' state, the multimeter will produce a short beeping sound, but if the button is let go and there is still continuity, the test has failed
AT06	Measure the dimensions of the PCB	• Use a ruler to measure the length and width of the entire board • Use a ruler to measure the length and width of the tab that was included on the PCB for connectors to be attached	If the length of the board is less than 100mm then the test is passed, if not then it is failed. The width of the tab should be 18mm or greater and the height of the tab should be 38mm. If the dimensions do not agree with the expected dimensions, the test fails

4.2 Critical Analysis of Testing

Testing was performed upon the arrival of the boards and modifications were made to better fit the problem description of the power subsystem. A final test was then performed, in which the PCB's were graded for their functionality. The outline of the results can be seen in Table 4.2 below. A more detailed description follows after the table as to why what worked and why what didn't work and solutions going foward.

Table 4.2: Subsystem acceptance test results

Test ID	Description	Result
AT01	The motors power on	Fail
AT02	The microcontroller receives power	Fail
AT03	The analog voltage connection to the battery works correctly	Pass
AT04	The battery charging circuit works	Fail
AT05	The switch works correctly	Pass
AT06	The dimensions of the board are correct	Pass

4.2.1 AT01

When tested according to the testing procedure stated in Table 4.1, the motors did not power on. Although a constant voltage supply passed through the driver IC(DRV3387) to the motor pins, it was mainly noise and it did not account for the pulse width modulation and thus did not drive the motors. The DRV3387 was meant to drive the motor as soon as the associated PWM signal went high and stop driving the motor as soon as the PWM of the respective motor went low.

Upon inspection, the connections to the motor drivers were not done correctly on the design of the PCB, causing the acceptance test to fail. The sleep pins of both motor drivers were not connected to VCC, and the PWM pins for motors 2A and 2B were not connected to the DRV8837 motor driver, which was only noticed upon the arrival of the PCBs.

Careful attempts were made to connect the pins to the DRV3387, but the IC was too small, which meant soldering was not possible. The driver was chosen as it is a small surface-mount IC and adhered to the size constraints of the board.

If vias had been placed in the correct positions, there would have been proper connections throughout the motor driver circuit, and it would have operated as expected. The connections to all the pins should have been thoroughly checked before the submission of the Gerber files, but due to time constraints, it was not possible. This would have allowed the main component of the power subsystem to work. Another possible solution was choosing an IC that was slightly bigger to allow for failure management and if connectors were not properly connected they would have been easier to integrate onto the PCB.

4.2.2 AT03

The analog voltage connection to the battery worked as designed for. Thus the test was passed.

The voltage of the BATT ADC pin scaled with the voltage of the battery and it was limited to 1.37V which is below the 3.3V maximum. It was needed to provide an analog connection that provides information on the battery's voltage for the processor to sense battery state of charge (SoC).

The circuit only worked correctly after modifications were done to the original circuit. An external voltage divider circuit had to be added onto the board as the originally designed one was not limiting the voltage to 3.3V but kept increasing as the voltage increased. This was most likely due to a faulty component but the problem was able to be rectified.

4.2.3 AT04

The battery charging circuit did not work as expected. The LEDs did not switch on when tested according to testing prcedures stated in **??**, which meant the circuit was not working, and the test failed.

The circuit was meant to charge the battery from the 5V pin. When the battery was charging, the red LED was supposed to switch on, and the white LED would switch on once it was fully charged. The continuity check using the multi-meter ensured that all the correct connection pins of the PCB were connected to the correct pins of the TP4056.

The circuit design was from the TP4056 datasheet which stated values that should be used for each component. This meant that the issue had to do with the overall connection of the circuit which could not be rectified as the TP4056 was also to small to manually handle and add or remove connections. The LEDs were replaced and both populated boards were tested but the circuit still did not perform as expected.

The TP4056 is temperature sensitive. It is suspected that the reason the circuit did not work was due to the circuit design and connections to components, which was unable to be changed as all the components were closely connected. The power through the resistor connected to the 5V input pin(R4) was to high causing the temperature of the entire circuit to rise and thus stop functioning. Although the resistor was replaced with different resistors, even in parallel combinations to increase the power rating, the resistors were not efficient and kept heating up. A power resistor was considered but the only ones avaliable were large through hole components and therefore unable to fit on the board given the size constraints the board had to adhere to.

The circuit design needed to be modified with the resistor of proper power rating as it did not perform as expected. Additionally better circuitry protection needed to be implemented so the PCB could have been more efficiently designed for failure.

4.2.4 AT05

The switch of the power subsystem did function correctly and the test was passed. The continuity between the points tested ensured a working ON and OFF state which was further justified by the voltage measurement across the battery and the switch when switched on and off.

The switch was expected to draw a maximum of 500uA when switched off and handle 1A of current.

The switch was able to handle 1A as it was rated for 1A maximum current and in the off state it drew less than 500uA. An opened circuit formed when the switch was opened, unpressed, and a closed circuit formed when the switch was closed, pressed. When in the OFF state the voltage across the switch was 0V whereas it increased to the battery supply voltage when the switch was pressed.

Although the switch worked as expected, it was not the most suitable type of switch chosen as it was a push-button switch. A better choice would have been the slide switch, which would ensure a definite ON and OFF state without having to hold the switch down.

4.2.5 AT06

The dimensions of the board fit the size constraints of fitting onto the micro-mouse and thus the test was passed.

The length of the board was 55mm (including the tab), and the tab had a width of 18mm and a length of 26mm. The dimensions of the PCB were in the range of the expected values, and therefore the board was able to fit onto the micro-mouse without interfering with other subsystems.

The size of the board was appropriate, as it was still big enough to test on and to add additional circuitry that was there in case of failure of the operation of components. The board was evenly distributed with components which allowed it to balance correctly when connected to the connection pins without causing the micro-mouse to topple over. This showed that the center of mass was in the center of the board and it would be able to move through a maze.

Chapter 5

Conclusion

5.1 Conclusion

The project aimed to design and develop the power subsystem for a micro-mouse robot, focusing on critical requirements such as operating two motors using two DRV3387, a dual H-Bridge motor driver, providing an analog connection for battery SoC sensing using an analog voltage divider circuit, incorporating a charging circuit from a 5V input using the TP4056, and a switching circuit. These requirements were explained further in chapter 2. Despite thorough planning and diligent execution, only parts of the subsystem met the intended performance criteria. The successful components, the ADC voltage divider circuit and the tactile switch functioned correctly and were validated through rigorous testing. However, the motor driver and battery charging circuit failed to meet the expected performance standards even after attempts to fix the issues stated in chapter 4, necessitating a re-evaluation of the design approach and component selection. Despite the setbacks, the project provided valuable insights and practical experience in subsystem design and testing, emphasizing the importance of iterative design, thorough testing, and flexibility in adapting to unforeseen challenges. This experience has been instrumental in developing practical skills and resilience, essential attributes for future engineering endeavors.

5.2 Recommendations

While the project did not fully achieve its objectives, it highlighted critical areas for improvement and reinforced the significance of robust design and testing methodologies. Addressing the failures in the motor driver and charging circuit will be essential for the complete realization of the micro-mouse power subsystem. Recommendations such as comprehensive testing, which includes testing and validating procedures to identify and rectify potential integration issues early in the design process. Another recommendation of an iterative design process could be implemented. It consists of prioritizing troubleshooting and redesigning the failed components to ensure all parts of the subsystem work harmoniously to meet the project's overall goals. Skill development also needs to be improved by continuously developing practical skills in circuit design through practice. Another main beneficial factor is time management. Enough time can thus be allowed for projects to be completed in advance so that troubleshooting can be done before moving on to the next stages.

Bibliography

[1] Texas Instruments, “DRV883x Low-Voltage H-Bridge Driver,” https://www.ti.com/lit/ds/symlink/drv8837.pdf?ts=1713427173464&ref_url=https%253A%252F%252Fwww.ti.com%252Fproduct%252FDRV8837, 2021.

[2] NanJing Top Power ASIC Corp. , “TP4056 1A Standalone Linear Li-lon Battery Charger with Thermal Regulation in SOP-8,” https://dlnmh9ip6v2uc.cloudfront.net/datasheets/Prototyping/TP4056.pdf.

[3] MicroChip, “TP4056 1A Standalone Linear Li-lon Battery Charger with Thermal Regulation in SOP-8,” https://cdn-shop.adafruit.com/datasheets/MCP3008.pdf, 2008.

[4] Micro Robotics, “L293D Driver IC - DIP,” https://www.robotics.org.za/L293D-DIP, 2024.

[5] OurPCB, “PCB Relay: Types, Design and Applications,” https://www.ourpcb.com/pcb-relay.html, 2024.

[6] Mouser, “MCP3008-I/P Microchip Technology,” https://www.mouser.co.za/ProductDetail/Microchip-Technology/MCP3008-I-P?qs=AF%252BffTaPb30XZ0OdV6HdVg%3D%3D, 2024.