Interim Design Report

Micromouse Power Subsystem

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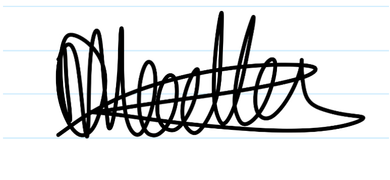


April 21, 2024

Name Surname

Date

Contents

Chapter 1

Introduction

1.1 Problem Description

The project's problem is to design and manufacture a power subsystem that is capable of powering an entire micro-mouse system.

The greater project comprises four subsystems that interface with one another, each of which has a related board. The motherboard carries two motors and is the foundation for the other boards: the processor board, sensor board, and power board (upon which the power subsystem will be implemented). The processor board contains the microcontroller and its related input/output pins which allow for operations to be dictated as required. The sensor subsystem can determine whether there is an obstruction in front and on either side of the robot and output that to the user as well as change its direction according to its findings. The power subsystem is responsible for powering each of the above-mentioned boards which, if they behave as intended, allow the robot to solve a maze correctly.

1.2 Scope and Limitations

The power subsystem will provide power to the two motors, the STM32L476 microcontroller on the processor board, and the sensors contained within the sensing subsystem. This ensures that all subsystems receive the required power to function as intended, and should it not behave correctly, the micro-mouse operation will be affected. Additionally, the power board will be fully equipped with a charging circuit to charge the battery. Without a functional charging circuit, the power provided to the above-mentioned subsystems will be limited to a single battery life. The power board containing the power subsystem will be an appropriate size as the micro-mouse in itself will be physically small and a large power board will affect the micro-mouse's center of mass and restrict the motion of the mouse in a maze.

There will be an ON/OFF switch with specific current limitations. Furthermore, there are specific connectors that must be catered for to allow for interfacing with the other subsystems. There is a financial limitation placed on the subsystem as the component cost budget for a single board is $ 8.25, which includes the fee for extended components. In addition, the time limitation states that the design must be completed by 24 March 2024 to allow for the manufacturing process to begin and the completed power board must be prepared for presentation on 8 May 2024.

1.3 GitHub Link

Click here to visit Group 62's GitHub

Chapter 2

Requirements Analysis

2.1 Requirements

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

Table 2.1: User and functional requirements of the power subsystem.

Requirement ID	Description
UR01	Provide power to the motors.
FR01	A motor driver circuit is used to provide the appropriate voltages to the motors.
UR02	Provide power to the microcontroller.
FR02	Have a connection from the microcontroller's battery pin to the battery.
UR03	Design must only include components from a PCB manufacturing company.
FR03	All components must be found on JCLPCB.
UR04	Fit onto the motherboard.
FR04	Must have a tab with the connectors on the power board.
UR05	Must be able to move within a maze.
FR05	Ensure the board's length does not interfere with the micromouse's center of rotation.
UR06	Adhere to a strict budget.
FR06	Select components whose sum does not exceed the budget.
UR07	Design must be able to be switched ON and OFF.
FR07	Have a physical ON/OFF switch that controls voltage to the other components.
UR08	Monitor the battery's state of charge.
FR08	Provide an analog connection with the voltage of the battery to the microcontroller.
UR09	Charge the battery.
FR09	Have a battery charging circuit that accounts for when the external voltage source is plugged in and when it is removed.

2.2 Specifications

The specifications, refined from the requirements in Table 2.1, for the micromouse power module, are described in Table 2.2.

Table 2.2: Specifications of the power subsystem derived from the requirements in Table 2.1.

Specification ID	Description
SP01	Motors have a maximum current draw of 200mA at 4.2V from the battery.
SP02	2x8 JST (2.54mm pin pitch) Pin Header joins the battery and microcontroller pins.
SP03	There must be a stock of over 500 on JCLPCB for each component.
SP04	The centered tab has a minimum height of 18mm and a maximum width of 35mm.
SP05	The board length must not exceed 100mm.
SP06	The components must cost under $ 8.25 per board, including extended part fees.
SP07	Use a switch to turn the power board ON/OFF and ensure it is labeled on the board.
SP08	Monitors and sends the battery's state of charge to the BATT-ADC pin.
SP09	Attach the battery to the power board using a two-pin 2mm JST pin header.
SP10	The max discharge must be at 0.5C for the 3.7V 800mAh Lithium-Polymer battery.

2.3 Testing Procedures

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

Table 2.3: A brief review of the testing procedures

Acceptance Test ID	**Description**
AT01	Check that motors receive power.
AT02	Check that the microcontroller is receiving power.
AT03	Check that all components are within acceptable stock limits on the JLCPCB website.
AT04	Measure the width and length of the tab.
AT05	Measure the width and length of the entire power board.
AT06	Calculate the total component cost and verify it on the JLCPCB website.
AT07	Check that the switch behaves correctly.
AT08	Code the microcontroller to display the state of charge from the ADC pin.
AT09	Check that the battery charging circuit is operational.

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	UR01, FR01	SP01	AT01
2	UR02, FR02	SP02	AT02
3	UR03, FR03	SP03	AT03
4	UR04, FR04	SPO4	AT04
5	UR05, FR05	SP05	AT05
6	UR06, FR06	SP06	AT06
7	UR07, FR07	SP07	AT07
8	UR08, FR08	SP08	AT08
9	UR09, FR09	SP09, SP10	AT09

2.4.1 Traceability Analysis 1

UR01 states that the motors must receive power from the power subsystem. In FR01 it is explained that a motor driver circuit must be used to do so, and SP01 states the maximum current through the output of that circuit. To test this AT01 is suggested because it verifies that power is being sent to the motors and that they are within the accepted current limits.

2.4.2 Traceability Analysis 2

From UR02, which says that the microcontroller is powered by the power subsystem, and FR02 which expands that a connection is required, SP02 can be derived because a specific pin header is needed to correctly interface with the other subsystems. AT02 ensures that the power is being correctly provided to the microcontroller.

2.4.3 Traceability Analysis 3

From UR03 and FR03, which state the requirement that all components must come from the same PCB manufacturing company- JLCPCB - SP03 can be derived as there needs to be adequate availability for a component to be populated on a board. These can be tested through AT03 which checks the quantity in stock for each component on the JLCPCB website.

2.4.4 Traceability Analysis 4

As seen in UR04 and FR03, the power board must have a tab with the specific dimensions titled in SP04 to ensure that it fits onto the motherboard comfortably. AT04 checks that these conditions are satisfied by measuring the dimensions and comparing them against the required values.

2.4.5 Traceability Analysis 5

UR05 and FR05 are concerned with the size of the power board as it will affect the movement of the micromouse as a whole, SP05 is a specification derived from the overall measurements of the micromouse and ensures that the power board does not extend too far past the end of the micromouse. This is tested through AT05 which measures the length of the power board.

2.4.6 Traceability Analysis 6

From UR06 and FR06, there is a strict financial requirement where the component cost cannot exceed $ 8.25 per board as specified in SP06, and AT06 verifies that the financial requirements are adhered.

2.4.7 Traceability Analysis 7

UR07 and FR07 state the need for a physical ON/OFF switch and SP07 details the necessary condition for a label on the board to ensure there is proper communication from the board to those using it. AT07 uses a continuity test on a multimeter to ensure that it is working as intended.

2.4.8 Traceability Analysis 8

UR08 and FR08 ensure that the battery's state of charge is monitored and sent to a specific pin in the microcontroller, specified in SP08 and verified by AT08 which uses the microcontroller to display the output of the BATT-ADC pin.

2.4.9 Traceability Analysis 9

The battery charging circuit, explained by UR09 AND FR09 with specifications from SP09 and SP10 outlines the need for a functional battery charging circuit that is effective when the battery is plugged into a voltage source and once it is removed. The output of the circuit is tested by AT09.

Chapter 3

Subsystem Design

3.1 Design Decisions

3.1.1 Component Selection

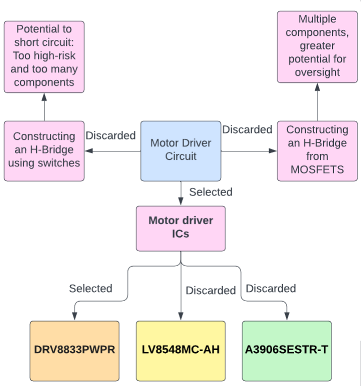
Motor Driver Circuit

For the motor driver circuit, multiple options were considered. An H-Bridge configuration is the most common solution as it allows for bidirectional control of the motor and speed control from Pulse-Width Modulation (PWM) signals from the microcontroller. Some H-Bridges can be constructed from scratch with MOSFETs or switches, and there are Integrated Circuits (ICs) that contain those components as internal circuitry. Ultimately, as the budget permitted it, an IC was chosen. This was a more promising route as there was less room for error than if the circuit was designed from scratch. In addition, a Dual H-Bridge IC will contain the functionality for both motors in a single component which saves space on the board and expenses if a suitable one is picked.

JLCPCB contains a multitude of Dual H-Bridge Motor Driver ICs, however, parts were filtered based on the following criteria:

- There must be stock
- The part cannot be unavailable
- There must be an English data sheet or an English version available online
- The supply voltage or PWM signal voltage must be in the range provided (3.7V and 3.3V, respectively)
- The IC must be able to handle a maximum of 400mA on the motor side
- It must be a dual H-Bridge Motor, therefore able to operate two DC motors as a single device • The IC must only require inputs from I/O Pins that are available to the power board

The first 3 viable options that fit all criteria are shown below in Figure 3.1:



	DRV8833PWPR	LV8548MC-AH	A3906SESTR-T
Price	$0.666	$0.834	$1.0995
Quantity In Stock	9436	4217	4336
Typical Application circuit	Yes, but just for one DC Brush Motor	Yes, with two DC Motors	Yes, but just for one DC Brush Motor
Characteristics	• Vcc: 2.7V to 10.8V • Vin : -0.3V to 5.75V • Iout(max) = 1.5A	• Vcc: 3V to 16V • Vin: 1.8V to 5.5V • Iout(max) = 1A	• Vcc: 2.5V to 9V • Vin: 2 to 5.5V • Iout(max) = 1A
Protection circuitry	• Overcurrent • Short circuit • Under-voltage lockout • Overtemperature • Low power sleep mode	• Low voltage • Thermal shutdown	• Crossover current protection • Undervoltage lockout • Thermal Shutdown Temperature
Size	5mm x 4.40mm	57mm x 57mm	4mmx4mm

Figure 3.1: Flow Chart with Motor Circuit options and Table comparing Motor Driver ICs

As seen in the figure above, the DRV8833PWPR is the cheapest option, has more protection circuitry, and is physically small so as not to take up too much space on the power board, it fulfills all the voltage and current requirements. Thus, the DRV8833PWPR whose data sheet can be found here was the final choice for the Motor Driver IC.

Battery Charging Circuit

For the battery to be charged, the appropriate circuit must be constructed. After a search on JLCPCB, it was found that there are three basic Battery Charging ICs that have the same functionality as building a battery charging circuit. The English data sheet for the TP4057 could not be found, so the selection was between the TP4054 and the TP4056. Both components are preset to 4.2V Charge Voltage and are adaptable to charging Single Cell Li-Ion Batteries directly from the USB Port. These are very similar components but their differences are recorded in the table below:

Table 3.1: Table comparing two Battery Charging ICs

	TP4054	**TP4056**
Price	$0.1289	$0.1724
Quantity in Stock	9468	107298
BAT Pin Current(max)	800mA	1200mA

Ultimately, the choice was made as the TP4056 contained an informative table on exactly which resistors to pick for specific desired battery currents while the TP4054 has many varying equations which resulted in various contradictory answers for the resistance. The price difference (among others) is minimal between the two ICs. The data sheet for the TP4056 can be found here.

Switch

There are only extended part switches that were considered for this project. A slide switch was considered the most appropriate as it has a definitive state of 'ON' and 'OFF'. After filtering out those that were not in stock, four hundred and twenty-five options were remaining.

Since the switch functionality is fairly simple, the first compatible switch on the list with the right specifications was selected. That was the SS-12D10G5 slide switch. The cost is $0.2618 and the average cost for slide switches varies from around $0.1 to $0.4 so this was an acceptable figure and there are 2362 in stock. Additionally, it is an adequate size to allow for easy switching but not too bulky for the final power board. The data sheet can be found here.

3.1.2 Calculations and Value Selection

To report the state of charge of the battery, a voltage divider consisting of two resistors and a capacitor is used. The value of the capacitance is 10uF to fit in with the E12 Series component values and its presence is needed to compensate for load capacitance. Since the microcontroller cannot handle an input of the full battery voltage (4.2V), the voltage divider scaled the voltage down by 50% as a precaution and, 2.1V is considered 'fully charged'. The values selected for the voltage divider are components that are part of the E12 Series and a simple combination that results in the desired scaling, as shown below.

Assume BattADC and BATT have volts as units:
BattADC = BATT * (R2/R1+R2) = BATT(1kOhm/2kOhm)= 1/2 BATT in Volts

The Motor Driver IC datasheet contained a typical application diagram, with exact capacitor values to ensure the motor driver circuit functions as intended. These values were verified as part of the E12 Series and included in the circuit as seen in the final schematic in the next subsection.

The resistors in the Battery Charging circuit were selected based on recommended values in the datasheet for the IC for charging a single-cell LI-Po battery.

3.1.3 Final Design

The following design contains all the selected components from the above subsection. This design was chosen as the switch needed to be in an accessible area for easy switching. The Test Points became quite cluttered when they were adjacent to their relative components but when aligned to one side the board appeared neater. The solder jumpers needed to be on the side of the board for easy access as it is simpler to solder onto the side instead of right in the middle of a board.

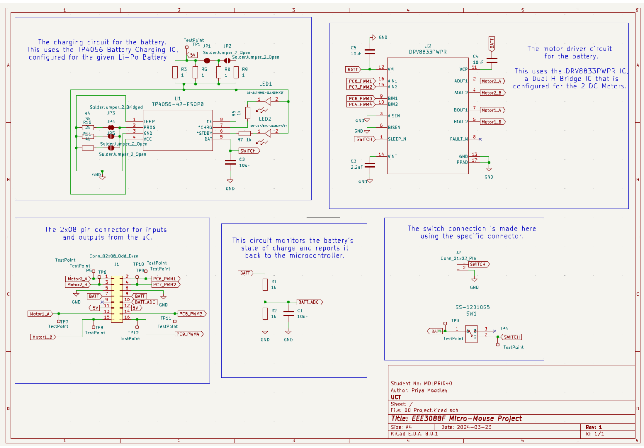
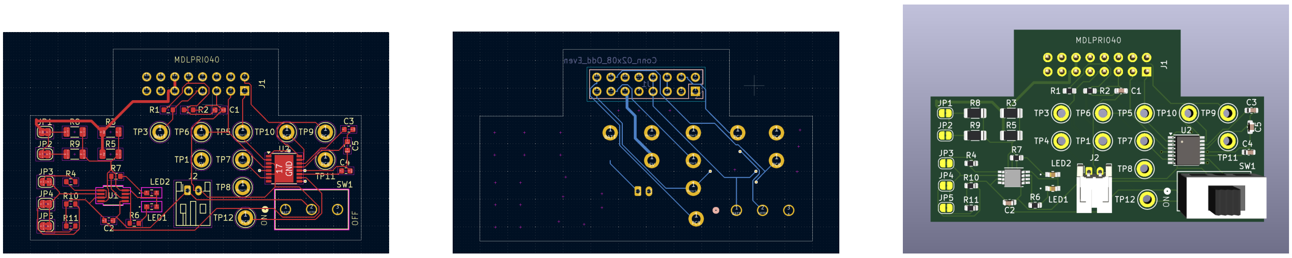


Figure 3.2: Schematic



(a) Front of the PCB (b) Back of the PCB (c) 3D version of the PCB

Figure 3.3: PCB

3.2 Failure Management

Since most of the components are ICs and have internal circuitry that cannot be modified, the replacement of components is difficult. The failure management for these components is essentially reliant on the testing to ensure that the components work as desired and if they do not, then understand exactly where the component failed. The table below outlines two instances where the resistor values were external to the IC and what other options are available should the initial choice not work.

Table 3.2: Table showing failure management methods

Name	**Description**
Resistor value 1 for Charging circuit.	The recommended resistance for the first resistor in the charging circuit with the IC is 0.25 Ohms. Since this is not available on JLCPCB, multiple 1 Ohm resistors have been placed in parallel to ensure a small enough resistance is achieved. They are added using solder-jumpers and will only be used if the initial resistors fail to work.
Resistor Value 2 for Charging circuit.	The resistor that sets the value for the current for the charging circuit. This value was selected based on the information given in the data sheet, however, multiple options are available and in the case that this value is incorrect and does not allow for charging, another one will be used.

3.3 System Integration and Interfacing

To integrate the power subsystem with the rest of the system, the main component used is the Pin Connector. This acts as a bus for connections with the microcontroller on the processor board as well as the motors on the motherboard. These connections are outlined in Table 3.3 and Figure 3.4 below.

Table 3.3: Interfacing specifications between the Power Board and the other subsystems

Interface	**Description**	**Pins Relations**
I001	Power Board Pin Connector to Motors for control of each motor.	• Pin Connector: Pin 1 to Motor 2: A • Pin Connector: Pin 3 to Motor 2: B • Pin Connector: Pin 13 to Motor 1: A • Pin Connector: Pin 15 to Motor 1: B
I002	STM32L476 to Power Board Pin Connector for PWM signals to control motors.	• STM PC6(Pin 6: PWM1) to Pin Connector: Pin 2 • STM PC7(Pin 7:PWM2) to Pin Connector: Pin 4 • STM PC8(Pin 4: PWM3) to Pin Connector: Pin 14 • STM PC6(Pin 3: PWM4) to Pin Connector: Pin 16
I003	STM32L476 to Power Board Pin Connector for access to the 5V voltage supply to charge the battery	• STM 5V USB(Pin 10) to Pin Connector: Pin 12. • STM 5V USB(Pin 10) to Pin Connector: Pin 11
I004	Power Board Pin Connector to STM32L476 to send the microcontroller information on the battery's state of charge.	• Pin Connector: Pin 10 to STM 3V3 ADC(Pin 48: Analogue)
I005	Power Board Pin Connector to STM32L476 to power the microcontroller.	• Pin Connector: Pin 7 to STM VBAT(Pin 2) • Pin Connector: Pin 8 to STM VBAT(Pin 2)

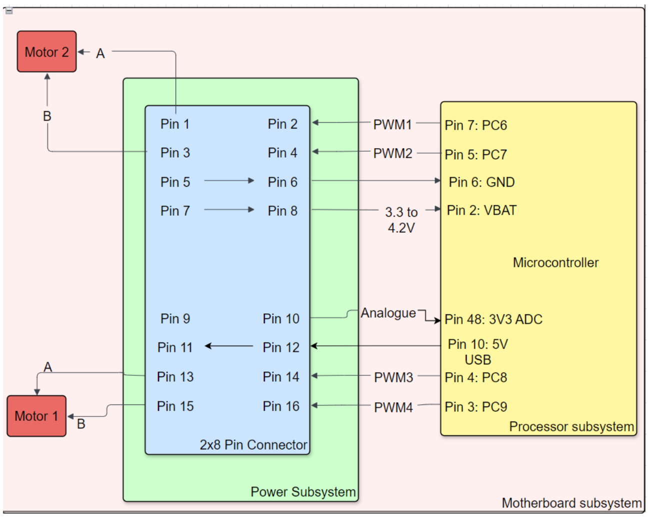


Figure 3.4: Interfacing Diagram of Power Subsystem with the other subsystems

Chapter 4

Acceptance Testing

4.1 Tests

Table 4.1: Power Subsystem acceptance tests

Test ID	Description	Testing Procedure	Pass/Fail Criteria
AT01	Check that motors receive power.	• Assume AT02 is passed and the microcontroller can send PWM signals to the motors. • Assume AT07 is passed and the switch works as intended. • Ensure that the switch is 'ON'. • Set code on the microcontroller to send PWM signals to the specific pins connected to each motor. • Measure the voltage from Test Points 7 and 8 to GND to check the voltage going to Motor 1 A and B respectively is enough to switch on the motor. • Measure the voltage from Test Point 11 and Test Point 12 to GND to check the voltage going to Motor 2 A and B respectively is enough to switch on the motor	If the voltage measured at the test points goes high when the respective PWM signal is on that pin then the motor is driven correctly and the test is passed.
AT02	Check that the microcontroller receives power.	• Assume AT07 is passed. • Measure the voltage at TP3 as this is connected to the microcontroller pin. • Check if the voltage matches the battery voltage.	If the voltage matches, the battery voltage is supplied to the microcontroller and the test is passed.
AT03	Check the bill of materials.	• Look at the bill of materials file generated by KiCAD and ensure each component matches its value and can be found and used on JLCPCB.	If all the desired components are there, the test is passed, else it is failed.
AT04	Measure the width and length of the tab.	• Use calipers to measure the width and length of the tab. • Compare the width to 35mm. • Compare the length to 18mm	if the width is less than 35mm and the length is greater than 18mm then the test is passed.

Test ID	Description	Testing Procedure	Pass/Fail Criteria
AT05	Measure the width and length of the entire power board.	• Use calipers to measure the length of the entire power board. • Compare the length against 100mm.	If the length is less than 100mm then the test is passed, otherwise it is failed.
AT06	Calculate the total component cost and verify on the JLCPCB website.	• Go to the online JLCPCB website and add all components to the cart. • Click on checkout and obtain a final sum for the component cost (excluding the board fees but including the extended part fee).	If the price for one board is less than $ 8.25 then the test is passed.
AT07	Check that the switch behaves correctly.	• Move the switch from 'OFF' to 'ON' position. • Using a multimeter, do a continuity test with one probe on TP3 and the other on TP4.	If the multimeter beeps when the switch is in the 'OFF' position, the test is failed. If there is a beep when it moves to the 'ON' position, the test is passed.
AT08	Code the microcontroller to display the state of charge from the ADC pin.	• Assume AT02 and AT07 have been passed. • Write code for the microcontroller's ADC pin to output the state of charge to an LCD Display or LEDs.	Verify the circuit works by reading the output of the LCD Display or monitoring the LED blinking.
AT09	Check that the battery charging circuit is operational.	• Use TP1 to verify that the input voltage is 5V as expected. • Use the LED indicators in the circuit to monitor the state of the battery.	If the red LED is on and the green is off: the battery is charging. If the red LED is off and the green LED is on: the battery has finished charging. If it is plugged in and both LEDs are off then the input voltage is too low or the temperature of the battery is out of the acceptable range or there is no battery connected and the test failed