Interim Design Report

Micromouse Power Subsystem

Prepared by:
Kavya Kaushik

Prepared for:
EEE3088F
Department of Electrical Engineering
University of Cape Town

April 21, 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.

Sign: 

Date: 21 April 2024

Contents

Chapter 1

Introduction

1.1 Problem Description

The project focuses on the development of an autonomous maze-solving robot, commonly known as a micro-mouse. the project aims to integrate power, sensing and control to operate this robot. This report is focused on the design of the power subsystem, with the goal of supplying uninterrupted regular current to the micro-mouse to ensure its safe and effective operation. The design involves considering specific design requirements and specifications while comprising of integration with the sensing and control subsystems while adhering to the specified limitations.

1.2 Scope and Limitations

Scope	**Limitations**
Component selection and sizing: Select appropriate components considering such as voltage, current ratings, energy capacity, sizing, efficiency and costs	Limited budget which impacts the cost and quality of components that can be used
Power distribution and regulation: Ensuring stable voltage supply to various subsystems and components of the robot, depending on specifications of the components and specifications of the rest of the system for integration	Constraints on the size of the components to ensure it fits onto the motherboard and along with the other subsystems
Implement a battery management system to control the charging and discharging for optimal battery performance	Limitations to the energy capacity of the system and discharge rates of the battery as per requirements
Ensure that the power subsystem can be integrated with the remaining system	Constraints about placement and connections of the other subsystems to ensure integration
Implement testing and fault tolerance mechanisms to ensure reliability of the circuit and to verify its functionality and performance during different conditions.	Limitations resources for sufficient testing and validation

Table 1.1: Scope and Limitations of the Power Subsystem

1.3 GitHub Link

Project GitHub repository: Github Link

Chapter 2

Requirements Analysis

2.1 Requirements

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

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

Requirement ID	Description
FR01	Supply power to the battery using voltage from a logic-based micro controller power supply to charge the battery
FR02	Regulate the charging and discharging of the battery to ensure overcharging, temperature monitoring and over-discharge protection by regulating the current drawn from the battery
FR03	Maximise battery life by allowing minimal power consumption
UR01	Supply regulated current to both motors to drive them
UR02	Provide an analogue signal that indicates the battery's state of charge from the battery voltage that can be sent to the ADC of the micro controller
UR03	Contains a switch to turn the power supply ON/OFF
FR04	The PCB board fits onto the pin headers of the motherboard
FR05	The PCB designed with an size suitable for the micro mouse robot
UR04	The PCB cost is within the budget specified
UR05	All components in stock with JLCPBCB
FR06	Battery has a maximum and minimum current draw in ON and OFF state

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 sensing subsystem derived from the requirements in Table 2.1.

Specification ID	Description
SP01	The battery used is a LiPo 800mAh 3.7V battery
SP02	The battery is charged is a 5V input pin from a microcontroller
SP03	The battery is kept at a max discharge rate of 0.5C(capacity) implying that a fully charged battery takes 2 hours to fully discharge
SP04	The maximum current drawn by the battery is 400mA
SP05	The circuit needs to supply current to two motors with a maximum current draw of 200 mA each

Specification ID	Description
SP06	The analog output needs to be within the range of to meet the STM32L476 microcontroller's ADC range
SP07	The battery can only draw less than 500uA when the switch is in the OFF state
SP08	The battery can draw the peak current of 400mA during the ON state of the switch
SP09	A JST PH 2mm pin pitch is used as the connector for the battery
SP10	A 2x8 (2.54mm pin pitch) pin header is for the power subsystem
SP11	The connector needs to be centered in a tab and have a maximum width of 35mm and a minimum height of 18mm
SP12	The circuit uses PWM integration with microcontroller
SP13	Both PCB boards need to be manufactured within $30

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 for Power Subsystem

Acceptance Test ID	Description
AT01	Battery Voltage supply check
AT02	Switching circuit ON state
AT03	Switching circuit OFF state
AT04	Input pin connection of 5V
AT05	Battery charging operation
AT06	Analog output supply of battery state of charge
AT07	Current output into motors test
AT08	Power supply of motors test
AT09	PCB dimensions test
AT10	Project budget test

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	FR01	SP01, SP02	AT01, AT04
2	FR02, FR03, FR06	SP03, SP04, SP07, SP08	AT02, AT03, AT05
3	UR01	SP05	AT07, AT08
4	UR02	SP06	AT06
5	FR04	SP10	AT09
6	UR04	SP13	AT10
7	FR05	SP11	AT09

Traceability Analysis 1 - FR01 is this from which SP01, SP02, can be derived. To test this AT01, AT04 is suggested to ensure successful operation of the battery

Traceability Analysis 2 - From FR02,FR03, FR04, SP03, SPO4, SP07 and SP08 can be derived to properly check the switching circuit and charging and discharging.

Traceability Analysis 3 - From UR01, SP05 can be derived to check the successful operation of motors which can be tested using AT07, AT08

Traceability analysis 4 - From UR02, SP06 can be derived and the output analoge signal which can be tested with AT06.

Traceability Analysis 5 - From FR04 SP10 can be derived and test AT09 can be conducted to test the implementation of pin header

Traceability analysis 6 - From UR04, SP13 can be derived to check the budgeting of PCB which can be tested using A10

Chapter 3

Subsystem Design

3.1 Design Decisions

3.1.1 Battery Management System

The battery used as per specification , and has a voltage range between 3.0V to 4.2V with a recommended Lithium Polymer charger[[reference]. The battery management system needs to consider the requirements such to ensure functionality and circuit protection, for which a battery management IC can be used.

Based on specification SP01, the battery management ICs that can support all functionality and are in stock are listed in Table 3.1.

Table 3.1: Component specifications for the battery management system

Item	Component	Voltage regulation	Charge current	Cost
1	MCP73831T-2ATI/OT	4.2V, 4.35, 4.40V, 4.50V	15mA to 500mA(prog*)	0.9945
2	BQ24295	4.55 V – 5.5 V	1792mA for V = 3.8V	0.7635
3	MCP73833/4	4.2V, 4.35V, 4.4V, 4.5V	1A (prog*)	1.5330
4	MCP73837/8	4.20V, 4.35V, 4.4V or 4.5V	15 mA – 1000 mA (prog*)	2.7900

*prog means the value is programmable

From Table 3.1, it can be seen that Component 3 draws a much larger current compared to the other three components, amongst which Component 1 is the cheapest. Therefore the MCP73831T component is finalised as the battery charging IC since it supports the voltage range of the battery which is 4.2V, it can handle the current drawn by the battery which is 400mA and it is the most cost-effective.

The datasheet is used to implement the circuit accoridng to specified resistors, LEDs and capacitors.

3.1.2 Motor Driver ICs

A motor driver IC is the most efficient way to power a motor driver, as it protects the microcontroller and battery power supply from getting damaged by the current drawn by the motors (https://www.wellpcb.com/what-is-motor-driver.html).

The implementation of an H-bridge can form a crucial component to drive the motors such that a voltage can be applied across the motor in either direction and the motors can be powered independently using control signals. (https://docs.onion.io/omega2-maker-kit/maker-kit-servo-h-bridge.html). A low voltage H-bridge can controol current flow, regulate current amplification and implement other protection features. Based on the specification SP05 and UR01 the Motor driver ICs considered are listed in Table 3.2.

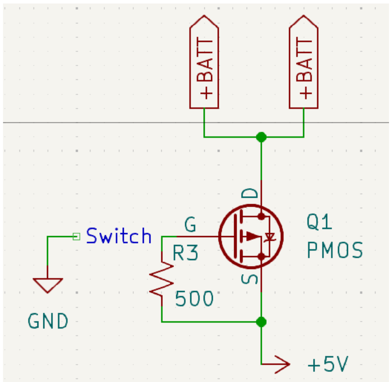
Table 3.2: Motor driver integrated chip specifications

Component	Drive Current	Driver type and output	Stock	Cost
DRV8834	1.5A	Dual bridge and can drive 2 DC motors	2419	0.9660
DRV8837DSGR	1.8A	H-Bridge and can drive 1 DC motor	67946	0.1235

To abide by costs and to ensure a high current capacity the DRV8837DSGR motor driver is chosen. The motor driver can only drive 1 motor hence two drivers are used in the circuit design. The drivers are powered by the battery and supply power to the motors for output.

3.1.3 Circuit Switch

The circuit switch needs to comply with requirements UR03 anD specifications SP07 and SP08. The circuit needs to ensure that the battery is completely disconnected in the ON state. The spec of two battery pins needs to be considered.

r0.4 

Design A - MOSFET Switch

A p-channel MOSFET can be used in enhancement mode to design high-current switches when configured as can be seen in subsection 3.1.3. When the switch is ON, current flows through the switch and into the battery pins and the circuit is is ON state. However, when the switch is disconnected, no current flows through the MOSFET and the circuit is in its OFF state.

The MOSFET used is SI2319CDS which can handle sufficient drain current to handle the battery current of 400mA. The switch used here is the surface mount SSAJ110100 which can carry a 10mA current at its gate.

Design B - A push/pull switch device

This circuit requires a switch that can handle the battery current and upon looking at available components on JLCPCB and avialable footprints on KiCad the SS-12D10L5 switch is chosen. Its specifications are given in Table 3.3

Based on Design A and Design B design A is chosen due to its simplicity, the use of fewer components reduces the risk of component failures and circuit costs. Design B also uses fewer connections thus avoiding the risk of faulty traces within the PCB.

Table 3.3: A single pole double throw switch specifications

Component	Current rating	Stock	Cost
SS-12D10L5	3A	41376	0.2847

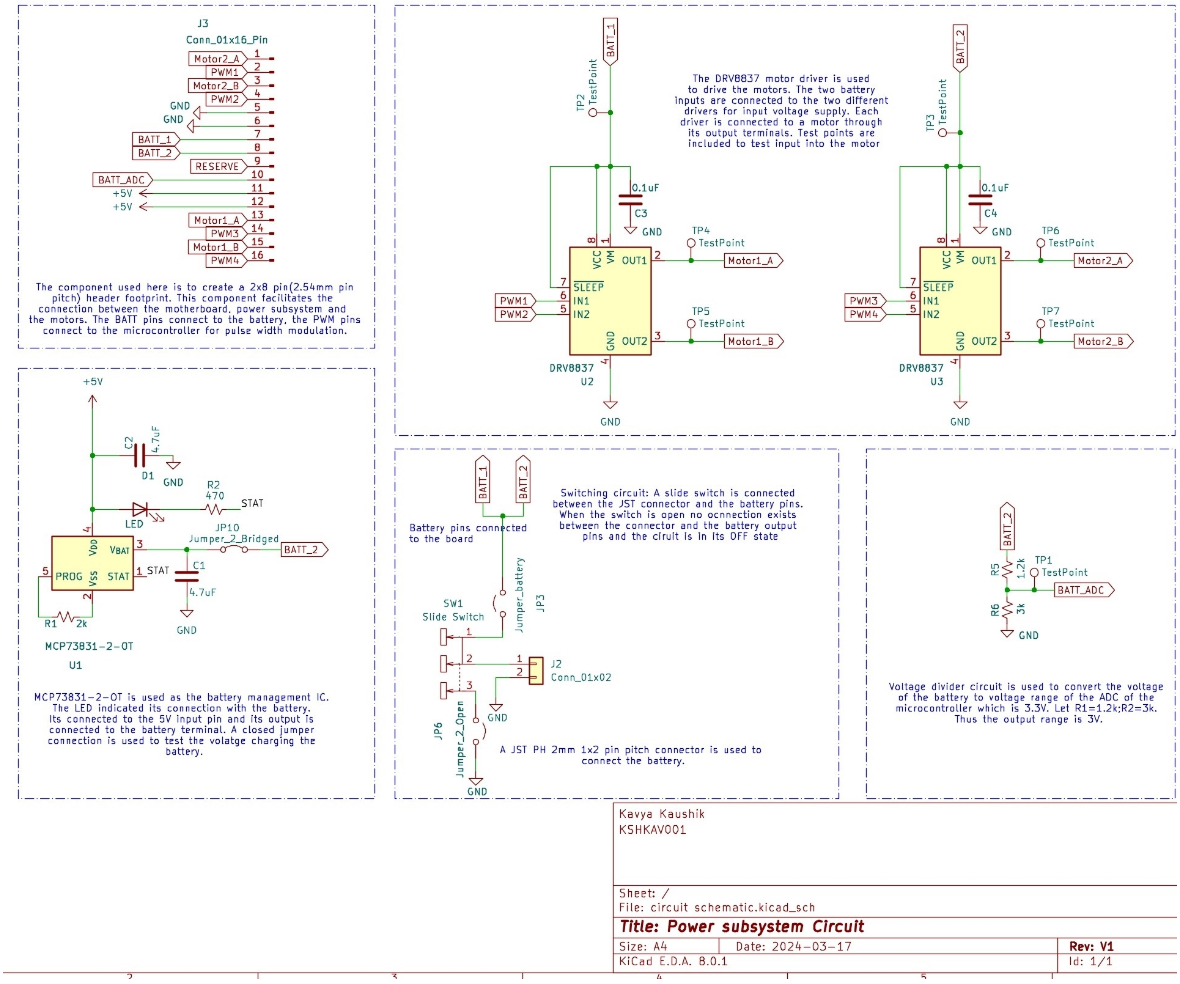


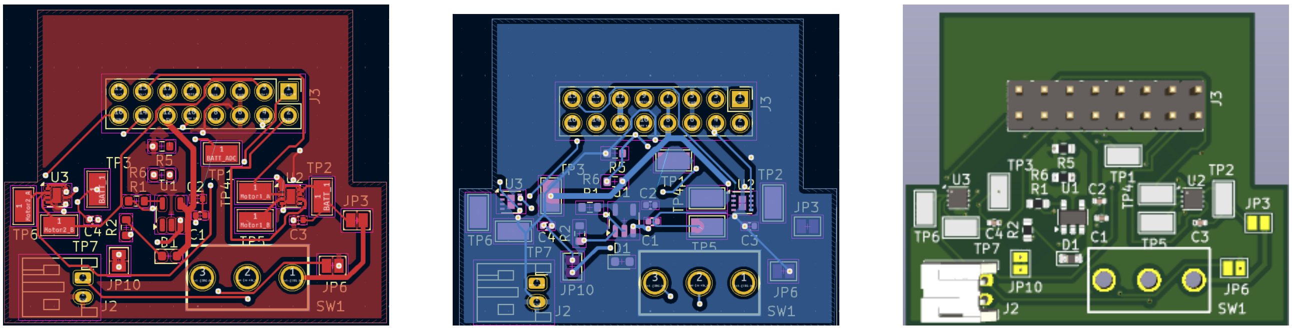
Figure 3.1: Final circuit schematic

3.1.4 Final Design

The final solution of the power subsystem is obtained by combining the final design decisions made in the sections above. The battery management system, motor driver system, switching circuit and analogue signal supply circuit combined together effectively meet the requirements of the project. The final circuit schematic can be seen in Figure 3.1

3.2 Failure Management

The failure management methods for the Power subsystem are listed in Table 3.4



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

Figure 3.2: PCB

Table 3.4: Failure management methods of Power subsystem

Failure management method	**Description**
Component Placement strategy	Strategic placement of components for shorter trace lengths and to minimise signal interference
Battery charging failure	Jumper cables used to check voltage and current supply of battery charger IC
Switching circuit failure	Open jumper cable connected with switch to allow a direct connection incase switch doesn't operate as expected.
Test points	Testpoints used to check current at output of motor drivers to cater for cases where the output requirements for motor driver are not met.
Component overload protection	Implement current-limiting resistors and capacitors to prevent excessive control flow
Component failure management	Include additional parallel resistor and capacitor paths to rectify any issues due to component failure (suggested method not included in current circuit)
DRC and ERC checks	Conduct design and electrical rule check on KiCad to ensure electrical integrity and detect any layout errors
Trace width optimisation	Set trace widths of PCB depending on the voltage carried by the traces to avoid overloading.

3.3 System Integration and Interfacing

The power subsystem is integrated with the rest of the micromouse system as per **??**

Table 3.5: Interface Pin Connections and Description

Interface	**Pin* Connections**	**Description**
1001	• Pin 1 - Output terminal 1 of Motor Driver A • Pin 3 - Output terminal 2 of Motor Driver A	Connect Motor Driver A to motherboard.
1002	• Pin 2 - PC6-9 (PWM1) • Pin 4 - PC6-9 (PWM2)	Interface input logic signal with Motor Driver A
1003	• Pin 5 - GND • Pin 6 - GND	Ground connection of subsystem

Continued on next page

Table 3.5 continued from previous page		
Interface	**Pin* Connections**	**Description**
1004	• Pin 7 - BATT (Battery Terminal) • Pin 8 - BATT (Battery Terminal)	Connect to the two terminals of the battery
1005	• Pin 9 - PD7	Reserve pin, can be used for additional connection
1006	• Pin 10 - ADC	Output analog signal to ADC of microcontroller
1007	• Pin 11 - 5V • Pin 12 - 5V	Connect to input power supply (positive terminal)
1008	• Pin 13 - Output terminal 1 of Motor Driver A • Pin 15 - Output terminal 2 of Motor Driver B	Connect Motor Driver B to motherboard.
1009	• Pin 14 - PC6-9 (PWM3) • Pin 16 - PC6-9 (PWM4)	Interface input logic signal with Motor Driver A
1010	• JST-PH Pin connector - Battery	Connect the battery connector to the terminals of the battery

*pin refers to the pins of the 2x8 pin header

*PWM - pulse width modulation; logic signal of microcontroller

3.3.1 System Inerfacing Diagram

The diagram to visualise the system integration is shown in Figure 3.3

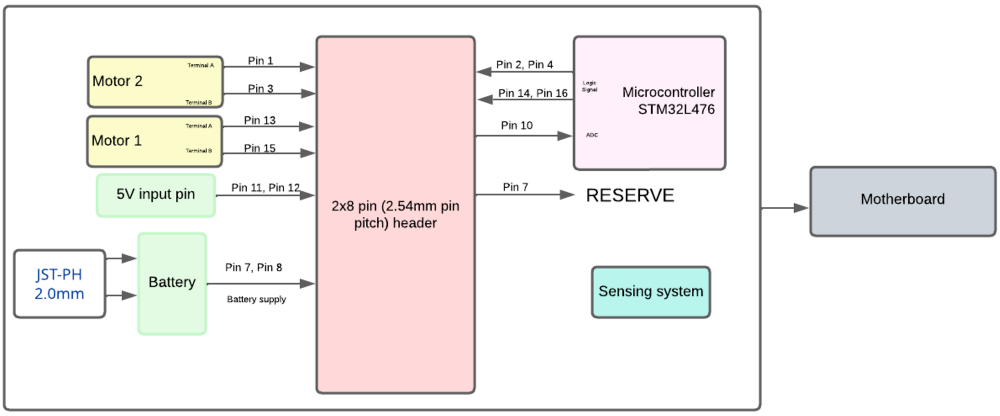


Figure 3.3: System Interfacing diagram

Chapter 4

Acceptance Testing

The testing procedures to test the performance of the PCB are listed in Table 4.1

Table 4.1: Subsystem acceptance tests

Test ID	Description	Testing Process	Pass/Fail Criteria
AT01	Battery voltage requirement	• Use a multimeter to check if the battery is connected and check its voltage reading	• Pass - The voltage reading is 3.7V • Fail - The reading is not 3.7V
AT02	Switching circuit ON state	• Toggle the switch to ON • Use the jumper cable at the switching circuit output to measure current drawn by battery	• Pass - The maximum current reading is 400mA • Fail - The current reading is null or more than 400mA
AT03	Switching circuit OFF state	• Toggle the switch OFF • Use the jumper cable at the Switching circuit output to battery current drawn	• Pass - The maximum current drawn by the battery is 500uA • Fail - The current is more than 500uA
AT04	Input pin connection	• Use a multimeter to take voltage reading of input pin from the pin header	• Pass - Reading of 5V • Fail - Reading is not 5V

Continued on next page

Table 4.1 – continued from previous page

Test ID	Description	Testing Process	Pass/Fail Criteria
AT05	Battery charging IC	• Put the circuit in ON state using the switch • Look at the LED to check if the IC is charging the battery	• Pass - The LED light is ON • Fail - The LED light is off
AT06	Analog output of battery	• Read the output voltage of voltage divider circuit using a multimeter	• Pass - If the reading is in the range of 3.3V • Fail - Reading is null or less than 3.3V
AT07	Current drawn by motors	• Use a multimeter to read current using the test points at the input of the motor driver IC • Repeat for both driver ICs	• Pass - The current reading is a maximum of 200mA for each driver IC • Fail - The current is null or more than 200mA
AT08	Operation of Driver ICs	• Use the test points to check the output current at the driver IC using a multimeter • Repeat for both output terminals for both driver ICs	• Pass - Maximum current of 200mA • Fail - Current greater than 200mA or no current reading
AT09	Dimensions of PCB board	• Measure the width of the tab • Measure height of the tab	• Pass - height $>$ 18mm and width $<$ 35mm • Fail - Height $<$ 18mm and/or Width $>$ 35mm
AT10	Budget	• Calculate total cost of manufacturing PCB using Bom and a maybe through a receipt	• Pass - Cost of PCB for 2x mounted boards is less than $30 • Fail - Cost of PCB is more than $30