Mechatronics/Electrical Engineering Design

EEE3099/98S

Status Report on EEE3088F's Micro-mouse Project

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Plagiarism Declaration

1. I know that plagiarism is wrong. Plagiarism is to use another's work and pretend that it is one's own.
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Signed by:

Ronald Walters: RW

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D. Nguyen

Contents

I, <u>Ronald Walters (WLTRON002)</u> have completed the following pages for this group report:

Background on the EEE3088F Micro-mouse Project: 85% of pages 4 & 5.

Design of the Micro-mouse: 100% of page 6.

Subsystem Interdependency & Independence: 100% of pages 8 & 9.

I, <u>Anh Duy Nguyen (NGYANH002)</u> have completed the following pages for this group report:

Background on the EEE3088F Micro-mouse Project: 15% of pages 4 & 5.

Design of the Micro-mouse: 100% of page 7.

Subsystem Interdependency & Independence: 100% of pages 10 & 11.

Background on the EEE3088F Micro-mouse Project

This report outlines three topics of interest detailing the status of work already completed.

i) The broad scope of the EEE3088F Micro-mouse Project, and the outcomes achieved therein.
ii) How the design of two of the Micro-mouse's four subsystems was conducted and debugged.
iii) The independence and interdependence each subsystem have within the Micro-mouse.

Overview

The task of designing and testing **two** of the four compartmentalized subsystems, which comprise the hardware of an autonomous vehicular maze-solving robot was outlined in the EEE3088F project brief. Colloquially called a micro-mouse, the robot (system) consists of the motherboard, micro-controller, **sensing**, and **power** subsystems.

The power subsystem was tasked with:

- Driving two brushed DC motors each drawing a maximum of 840mW,
- Providing the batteries State of Charge (SOC) to the micro-controller's (μC's) Analogue to Digital Converter (ADC),
- Charging the Micro-mouse's 3.7V LiPo battery from a 5V input to the subsystem,
- The ability to switch the system off (with less than 0.5mA current being drawn) and on (supplying the peak system current) through the batteries connection to the system via the power subsystem.
- Ensuring compatibility with the motherboard via a 2x8 pin header connection.

The sensing subsystem was tasked with:

- Enabling the Micro-mouse to detect walls and obstacles in its surroundings
- Maintaining low power consumption to avoid prematurely depleting the provided LiPo 800mAh 3.7V battery
- Ensuring 2x14 header compatibility with the provided STM32 motherboard
- Keeping the PCB size within maze constraints to allow for optimal rotational motion.

After gaining familiarity and understanding of the requirements, the first stage of the design process was to conduct research, from which we derived specifications which would enable the designed subsystems to be verified.

Simulation did not form part of this design procedure.

After testable specifications were drawn up for each subsystem, component specific design decisions were taken in conformity with the subsystem budget constraint and availability of said components on the jlcpcb.com/parts webpage. Breadboard prototyping and testing were conducted using exact or equivalent components wherever possible.

Thereafter, the component's symbol (.elibz) and footprint (.efoo) files were downloaded from the EasyEDA link on the jlcpcb.com/parts webpage and imported into KiCAD to construct the production files required for the subsystem's manufacturing. An alternative component library like Ultra Librarian was also used for obtaining component footprint and symbols. Additionally, failure management was conducted, and test points were added to aid in debugging the designed subsystems.

After the subsystems were sent off for manufacturing, we were tasked with authoring an individual interim report detailing the design procedure followed in the production of our subsystems, which included a group GitHub link, providing verifiable collaboration utilizing version control which facilitated project management.

Once the manufactured sensing and power subsystems arrived, testing and debugging began. This allowed us the opportunity to verify the expected operation of the subsystems, while debugging any unforeseen errors which the manufacture made or which we unknowingly provided to them within our production files.

Maintaining a record of these tests conducted was a key part in this phase of the process, as this would form the basis of the new sections added to our interim report which formed our final report, the critical analysis of our test results.

Penultimately, there was a demonstration of our subsystems. The power and sensing subsystems were tested using additional testing PCBs, and not under the conditions as described and designed for in the project brief. The sensing subsystem additionally had to write/modify code enabling the sensing subsystem to be demonstrated.

The conclusion of the EEE3088F Micro-mouse project was a final individual report detailing the procedural and quantitative approach taken to aid the design, synthesis, and testing of one of the four compartmentalized subsystems comprising the hardware of the Micro-mouse.

EEE3088F Micro-mouse Project Achievements

The following achievements were accomplished within this project's scope.

Project Assessment marks obtained	Ronald Walters	Duy Nguyen
Interim Report	61%	78%
Practical Demonstration	43%	50%
Final Report	76.7%	74%
Final Course Mark	70%	72%

Additionally, the following skills were attained over the course of the EEE3088F Micro-mouse Project:

- Competency in KiCAD and overall PCB Design.
- Teamwork specifically in communication, and perseverance.
- Systematic analysis and review of the system design and its requirements.
- Competency in component datasheet review and LCSC component library.
- Competency in LaTeX and GitHub Usage.
- Meta-analysis from the Breadboard Assignment through the Interim Report to the Final Report.

Design of the Micro-mouse

Power Subsystem Final Design and Testing

The final power subsystem design was segmented into micro-systems to ensure the power subsystem fulfilled its required concepts of operation.
The power distribution micro-systems motor driver circuity was assessed on the following: on-state resistance, PWM compatibility, and quiescence current drawn. After considering these relevant factors the **DRV8837** IC was selected.
The power availability micro-system was designed using first principles. It implemented a large ohmic-valued voltage divider, to sense the battery voltage and scale its output to be below the µC's ADC's maximum input voltage. This sensed voltage was fed into a first-order RC low-pass filter to reduce noise. The filtered output was then fed into an op-amp in a non-inverting voltage follower configuration. The op-amp acts as a buffer and stabilizes the voltage divider's transfer function. The choice of op-amp was decided based on the following specifications: minimum single rail supply voltage, input impedance, and quiescent current drawn. From these, the **LM321** op-amp was selected.
The power supply charging micro-system was decided upon according to the following factors: maximum programmable output current, Electrostatic Discharge (ESD) rating, protection features provided and quiescent current drawn. This resulted in the **BQ24092** IC being chosen.
***The power isolation microsystem*'s** components were judged according to its on-state contact resistance and operational life span. Additionally, the specification that it should be a latching, Single-Pole-Single-Throw (SPST) on-off-on (states 1, 2, and 3 respectively) switch would ensure that zero current could be drawn from the battery when in the off state (state 2). Based on these criteria the **2BS3T1A1MZQES** was chosen, with state 1 connecting the battery to the power distribution micro-system, and state 3 connecting the battery to the charging supply micro-system.
All the ICs were implemented according to the manufacturer's (Texas Instruments) specifications.

Testing/Debugging *began by setting the switch to state 1*:
The power availability micro-system was debugged by applying a 3.7V to the power subsystem's battery terminals via a bench-top power supply. It was observed on an oscilloscope how the SOC output signal varied with the change in input voltage to the subsystem. When 4.2V (the battery's maximum voltage) was applied the SOC output signal was 3.3V, well below the µC's ADC maximum input voltage of 3.6V and this was considered a **success**.
With the bench-top power supply still powering the subsystem the **DRV8837** was debugged and tested by applying PWM inputs, generated by benchtop function generators, to the subsystem and the output was observed on an oscilloscope. The observed output corresponded with the datasheet's graphs, and this was considered a **success**.
The **BQ24092** was debugged by setting the switch to state 3 and inputting 5V to the power subsystem via a benchtop power supply. Thereafter, the BQ24092 entered its battery detect mode as observed on an oscilloscope, oscillating between 3.9V and 4.1V with a period of 50ms, with the Power Good, green LED turning on. This was expected in accordance with the datasheet, and this is considered a **success**.
By setting the **2BS3T1A1MZQES** to state 2 (off), the current flowing from the power supply (set at 4.2V) connected to the battery terminals on the power subsystem was measured with a multimeter in series. This was done with test points, on both the power distribution micro-system and the power supply charging micro-system, yielding no change to the multimeter output, indicating zero current drawn. This is considered a **success**.

Lessons learnt in designing and debugging the power subsystem include the importance of conducting research and understanding datasheets. Most importantly I learnt that thorough and rigorous datasheet analysis can suffice when there is an inability to conduct simulation testing.

Sensor Subsystem Final Design and Testing

A systematic review of the sensor subsystem requirements reveals that the final design for the Micromouse incorporates infrared (IR) sensors to detect walls and obstacles in its surroundings. These sensors were chosen after careful consideration of the budget and the availability of basic components (frequently used parts already loaded on P&P machines, which reduces costs) in the LCSC Component library.

An IR sensor consists of two primary components:

1. IR Emitter LED: This component (the SFH 4544 from Osram. It is bright and has a good spot size for a suitable receiver) produces infrared light. When the IR emitter emits light, it reflects off nearby objects.

2. IR Receiver (Photodiode): The IR receiver (PD333-3B/H0/L2, chosen due to high view angle of 80°), which is a photodiode, detects the reflected IR light. The photodiode generates varying electrical values based on the distance to the reflecting object.

These values are then processed by a MCP6002T-I/SN voltage comparator (chosen due to its low operating voltage) and its output is sent to the microcontroller. Additionally, a 10K potentiometer is used to calibrate the sensor output to meet specific requirements. The figure on the right shows a typical depiction of the functional operation of an IR Sensor.

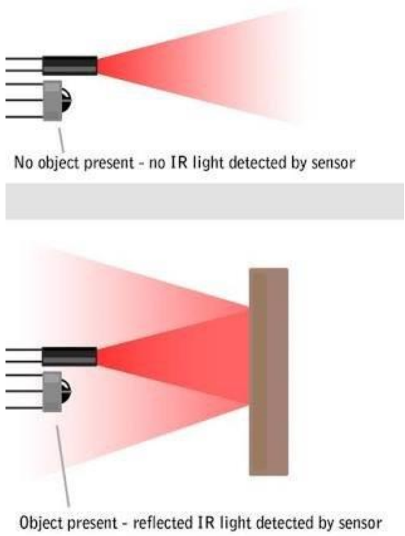

Figure 1) Depiction of the operation of an IR Sensor

Testing/Debugging:

Testing involved initial visual inspections to confirm whether the manufacturer, JLCPCB has properly soldered and reflowed all the THT (Through-Hole) and SMD (Surface Mount) components, as well as to confirm that traces where in fact connected properly. These tests were aided using an inspection device like a magnifying glass, a multimeter, schematic and varies test points that were strategically laid out through the PCB. It was confirmed that JLCPCB soldered the IR LEDs and photodiodes the wrong way around, despite the correct footprint being used to indicate the position of the cathode and anode. The components had to be desoldered and resoldered. A GND test was conducted and no shorts to ground were found.

Additional tests were conducted by soldering the necessary jumper pads to supply the subsystem PCB with VBATT (3.3-4.2V) through the corresponding headers. Further soldering was needed to connect the correct resistor value to the IR LEDs as numerous values were placed as fail safes. To verify the functionality of the IR LED, a camera with a non-polarizing filter was used, confirming the presence of IR light. The photodiode was tested by connecting the output of the op-amp to an oscilloscope, which confirmed its detection of IR light through the observed signal fluctuations on the oscilloscope. In conclusion, testing confirmed that the Sensing Subsystem PCB was working as intended.

Lessons Learned:

The lessons learned were that thorough visual inspections were required to ensure that the manufacturer manufactured and assembled the PCB as intended. The importance of researching and understanding component datasheets was proven crucial to identifying which components were most suitable to the subsystem requirements. A meta-analysis of existing IR sensors helped identify and narrow down critical components amongst the thousands of which are available.

The Micro-mouse’s Subsystems: Independent Functionality and System Integration

The Motherboard Subsystem

The motherboard subsystem is the key system interface of the micro-mouse, on which the three other subsystems are mounted. It connects the processor subsystem to the sensing and power subsystems and additionally connects the brushed DC motors to the power sub-system. The motherboard subsystem is best described visually, seen below in Figure 2.

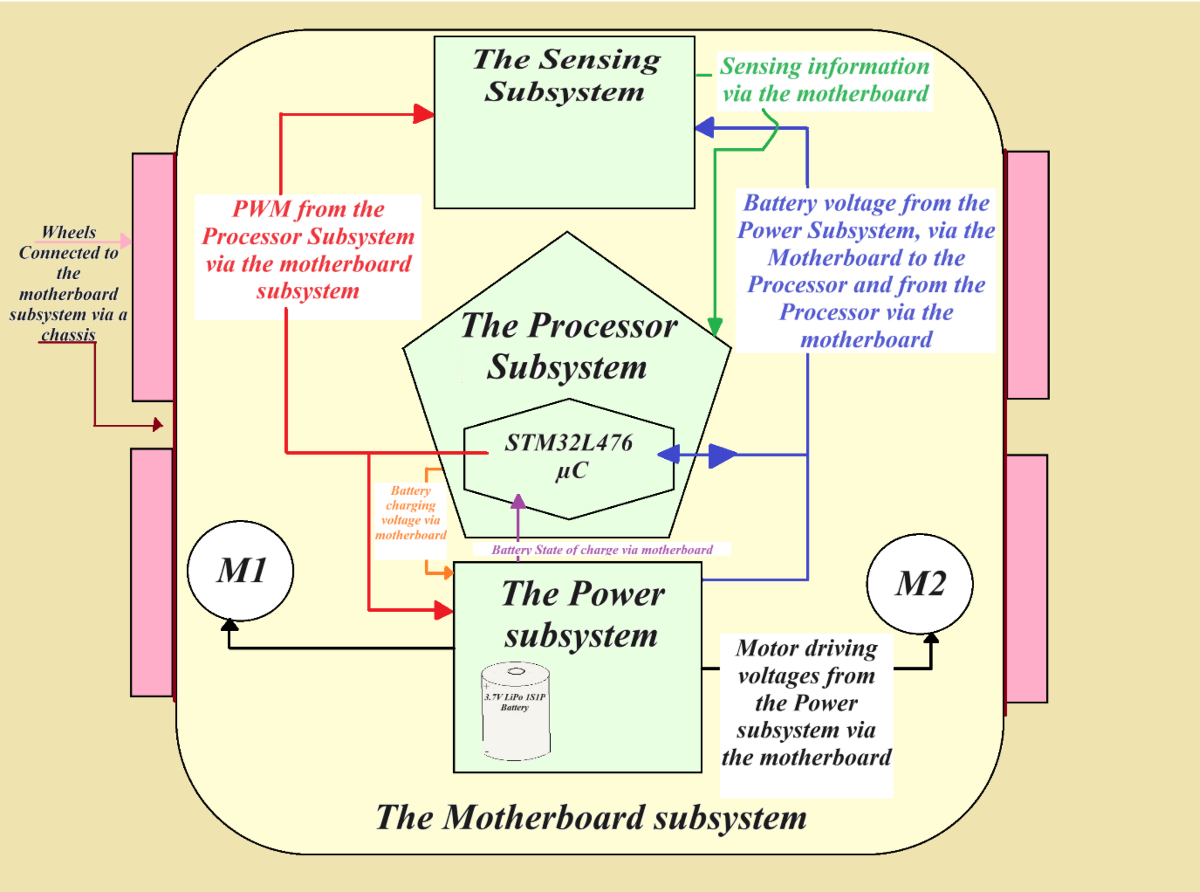

Figure 2) The Motherboard Subsystem's interfacing diagram.

The motherboard subsystem operates independently as the backbone of the micro-mouse, providing each of the additional three subsystems their pin header connection tab. Furthermore, the motherboard subsystem contains the location of its centre of rotation. This is an important independent function of the motherboard subsystem.

The interdependence of the other subsystems with the motherboard hinges on the following criterion:

- The physical dimensions of power, sensing and processing subsystems must be compatible with that of the motherboard subsystem.
- The power, sensing and processing subsystems must orientate their pin header connections in correspondence with that of the motherboard subsystem.
- The power and sensing subsystems must minimize the moment arm of their heaviest components by reducing their PCB's distance to the motherboard's centre of rotation.

The Power Subsystem

The power subsystem operates independently, through its isolated micro-systems and their interaction with the 2x8 pin header tab. The pin header tab connects the power subsystem to the motherboard, which facilitates the interdependence of this subsystem with the entire micro-mouse.

The key intra-dependence of this subsystem is described below:

The power distribution micro-system: Receives battery power from the power isolation micro-system (in state 1) and distributes power within the subsystem to the power availability micro-system. It also distributes power to the 2x8 pin tab header (2 battery voltage pins and 2 ground pins) and to the motor driver IC's (which take 4 PWM inputs from the 2x8 pin tab header) which output the motor driving voltages to four pins on the 2x8 pin tab header.

The power availability micro-system: Receives the battery voltage from the power distribution microsystem, and outputs its SOC signal to the 2x8 pin tab header.

The power isolation micro-system: Acts as an interface between the power distribution micro-system or the power supply charging microsystem and the systems battery.

The power supply charging microsystem: Receives two 5V inputs from the 2x8 pin tab header which is used to charge the system battery through the power isolation micro-system (set to state 3).

The interdependence of the power subsystem with the additional three subsystems of the micro-mouse is best described visually, seen below in Figure 3).

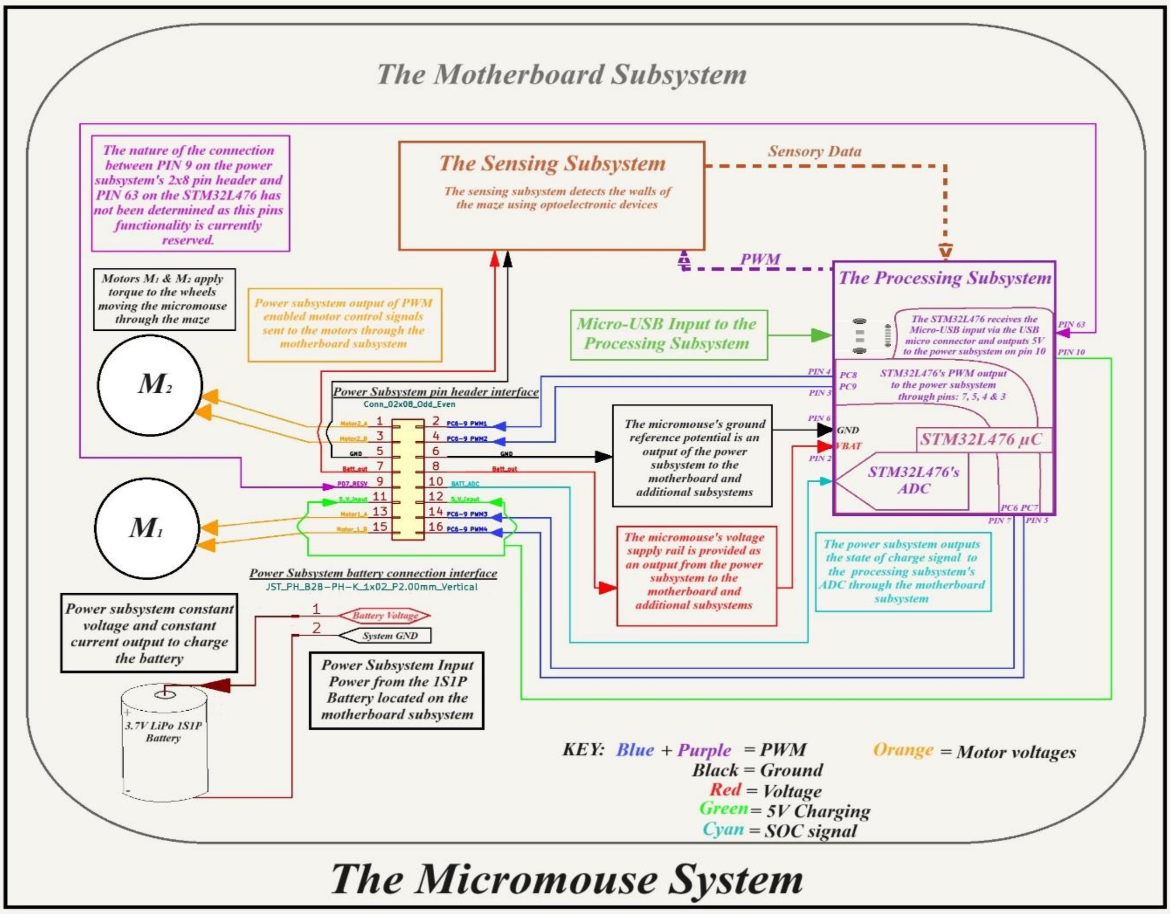

Figure 3) Power subsystem's 2x8 pin tab header interfacing with the three additional subsystems.

The Processor Subsystem

The processor subsystem is based on STM's STM32L476 ultra-low power MCU [microcontroller unit]. The subsystem was designed and provided by Technical Officer Justin Pead. The below figure 4) shows a 3D-rendering of the subsystem. A total of 76 pins were provided for, these pins were divided across each respective subsystem on the motherboard.

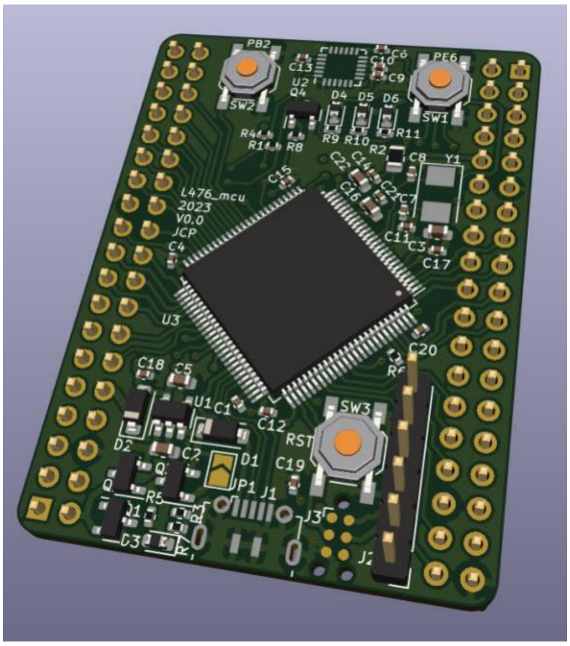

Figure 4) Pin-view of the MM Processor PCB

Interdependence:

> **Inputs:** Sensory data, Voltage, Micro-USB charger, SOC (State of Charge) battery information (via ADC)
>
> **Outputs:** PWM (Pulse Width Modulation), 5V battery charging, Visual indication LEDs for obstacle confirmation

Independence:

i) Processing sensory information from sensing subsystem
ii) Using the processed sensory information to output the correct PWM driving the motors via the power subsystem
iii) Processing the SOC signal to determine the remaining battery capacity.

The Sensing Subsystem

The sensing subsystem is an independent unit that incorporates four pairs of IR sensors arranged in a semicircle/rectangle shape. Received data from these sensors is read through the analogue input pins of the STM32 motherboard. The subsystem's effectiveness is largely due to the adjustable 10k potentiometers, which allow for straightforward calibration and sensitivity adjustment of the IR sensors. Additionally, the subsystem employs 2N7002 MOSFETs as PWM switching devices, providing a power-saving solution optimized for the low-capacity 3.7V LiPo 800mAh battery. The figure below shows the interface of the sensing subsystem.

Independence:

- Receives IR light from IR LEDs
- Converts received IR light to electrical signals

Interdependence:

Inputs: Power, PWM and IR Light

Outputs: Electrical Signals

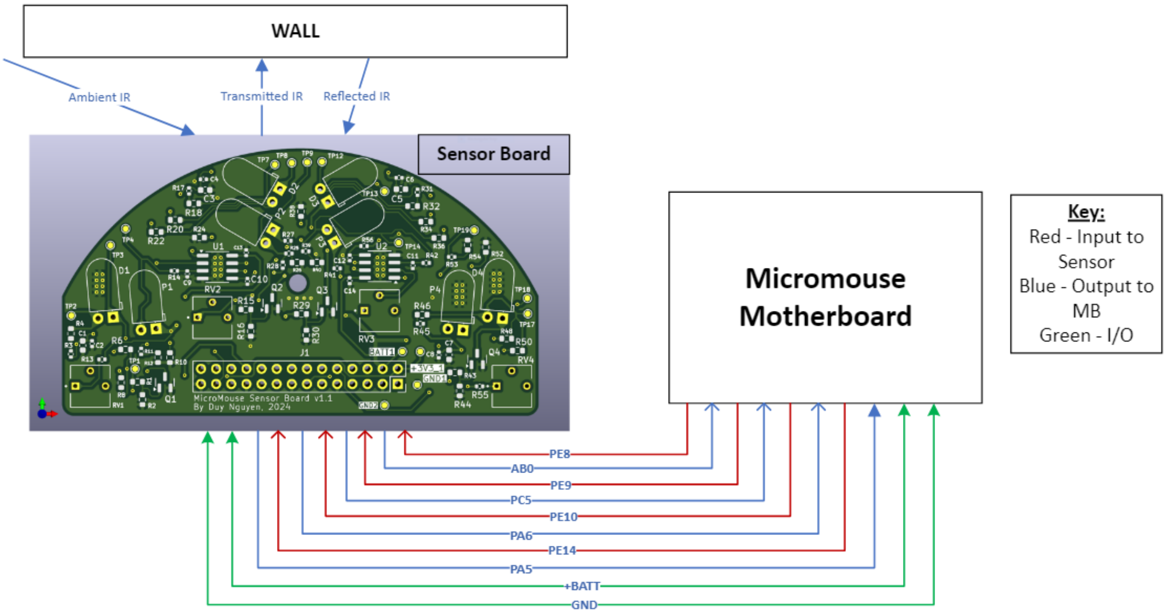

Figure 5) Interface Diagram