Sleep Position Trainer

ECE 445 Design Document - Spring 2026

Group # 48

Brian Park (brianp7), Kyle Lee (klee281), Nick Tse (nstse2)

Professor: Arne Fliflet

TA: Po-Jen Ko

Contents

1 Introduction

1.1 Problem and Solution:

The main goal of our group's sleep position trainer is to encourage users to develop healthier sleeping habits by promoting side sleeping positions, which are known to help reduce symptoms associated with acid reflux and other sleep related health issues. Additional benefits to sleeping on your side includes reduced snoring and sleep apnea. With this in mind, maintaining proper sleep posture throughout the night remains difficult because individuals naturally change positions while asleep, creating a need for an automated and non-intrusive solution.

Our proposed solution introduces a wearable sleep position trainer capable of monitoring body orientation in real time and providing gentle feedback when an unhealthy sleeping position is detected. Unlike traditional methods such as positional pillows or bulky wearable devices, our design focuses on comfort, low power consumption, and continuous motion sensing using embedded inertial measurement technology. This system uses a combination of compact hardware, position detection, and adaptive feedback from a motor intended to retrain user behavior over time rather than simply restricting movement. By offering an affordable and user-friendly alternative to existing sleep training products, our system aims to improve sleep quality and reduce health risks associated with improper sleeping posture.

1.2 Visual Aid

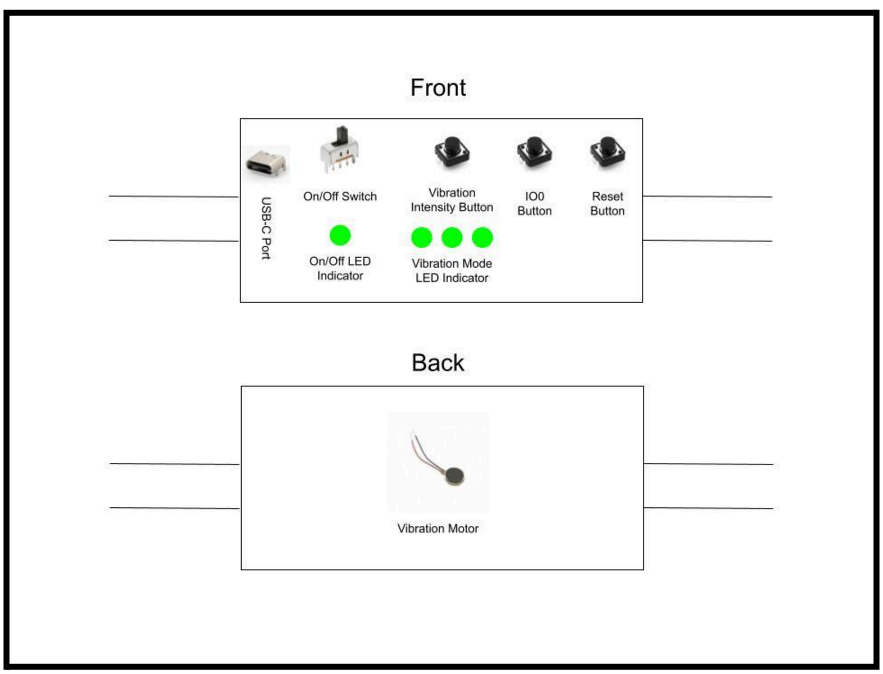

Figure 1: Visual Aid

This visual representation of our project provides the necessary parts and equipment that will help the user train their sleep position. The vibration mode button will help users calibrate the vibration strength to their preference with LED indicators. Our design also includes an on/off switch with a USB-C charging port that will interface with our LiPo battery. The backside of our device will include the vibration motor which will be in contact with the user's back. The case will be 3-D printed, and a strap will be added so the user can wear our device.

1.3 High-Level Requirements List:

Vibrate Upon Movement: The device must vibrate when there is a change in the orientation of the device. This includes the x, y, and z axis since any deviation from the original sleeping position is considered bad. The exact sensitivity of our device (the threshold to activate vibration) will need to be determined via testing.

Wireless Functionality: The device must be able to function without being plugged into an outlet. The LiPo Battery will be rechargeable, and must continuously power the device throughout the night.

Multiple Modes: The device must be able to have multiple settings for the strength of the vibration. A button will be used to switch between 3 different Vibration modes in order to accommodate the needs of the user.

On & Off: The device must have a power on and off switch to help the user conserve power or to simply turn off the device when not in use. There will also be a small LED that will indicate whether or not the device is on or not.

2 Design

2.1 Block Diagram:

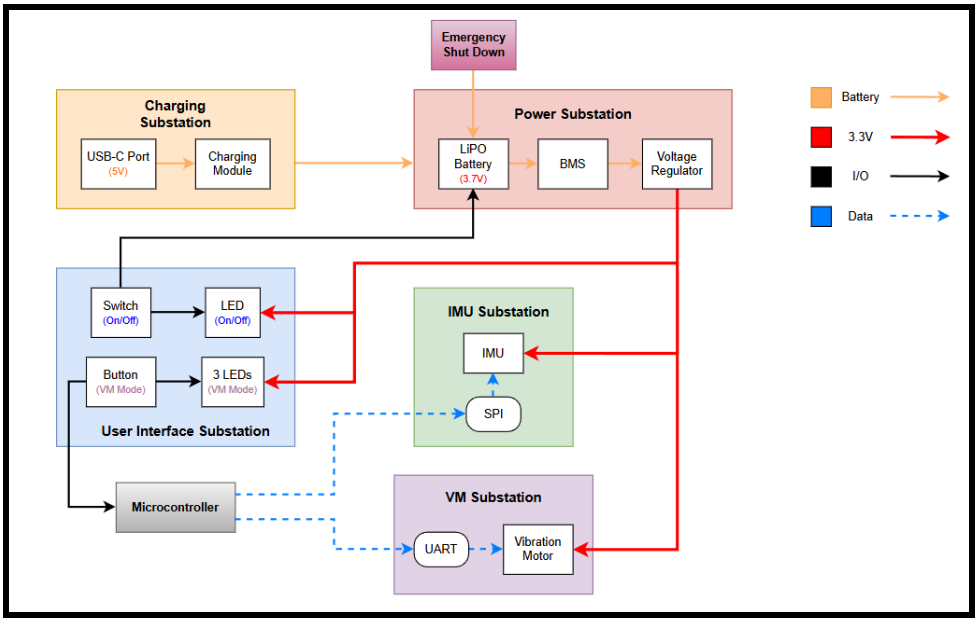

Figure 2: Block Diagram

This Block diagram encompasses all of the subsystems in our design. We have labeled the different signals within our block diagram such as 3.3V power and I/O signals. A USB-C cable will be connected to the charging port in order to charge the battery.

2.2 Physical Design:

For our physical design, we will 3D print a case that will hold the PCB, battery, motor, and all the other components required for the sleep position trainer. We have not quite figured out the final physical design for what will be 3D printed because we have not finalized or PCB design as there might be a change in size, permutations of parts, and other considerations when it comes to the physical design. We have included the image of our PCB which has dimensions of 50mm x 50mm so that would be the approximate size of the case but specific design will be decided later after full functionality is completed.

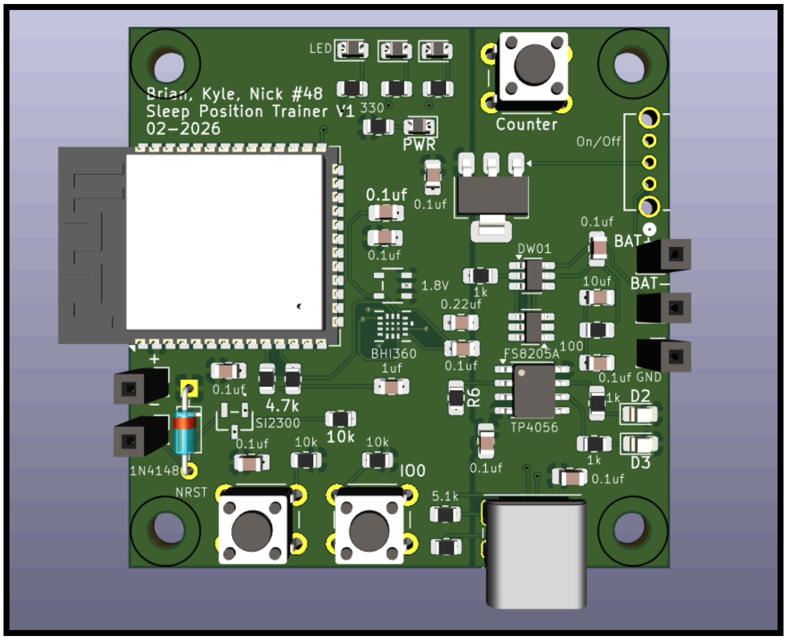

Figure 3: Image of our Physical PCB

As you can see on our PCB and through the Visual Aid, our project features a USB-C charging outlet, a power on button with an accompanying on/off LED, a VM mode button with 3 indicator LEDs, and an emergency reset button. Whether or not this current design will stay the same as our final submission has yet to be determined, but we believe we have all the necessary components to make our project succeed.

[Subsystem 1: Position Sensing]

This subsystem includes the IMU primarily for the purpose of position tracking. The IMU will then relay that information back to the microcontroller. Additionally, the IMU will get power from the power management system.

The position sensing subsystem is responsible for detecting the user's sleeping orientation and motion. It utilizes the Bosch BHI360 Inertial Measurement Unit (IMU), which contains an accelerometer and gyroscope. This data allows the system to determine how the user is laying down. According to the Bosch BHI360 IMU datasheet [1], the IMU communicates directly with the microcontroller over a digital interface (I^2C or SPI), providing real time motion and orientation data. This subsystem serves as the primary input to the system, enabling the microcontroller to make decisions about when to trigger user feedback.

If this subsystem were to fail, then the sleeping position of the user would be unknown. This might cause unknown data to be sent to the MCU and give false or inaccurate information throughout the whole system.

Requirements	Verification
• The system must obtain accurate position data from the IMU with a sufficiently high update rate to enable reliable motion tracking.	• Verify proper I2C communication by confirming successful data transfer between the IMU and the microcontroller by using the serial monitor. • Monitoring real time position data while also confirming accurate and responsive changes based on position.
• The system must include initialization or calibration procedures to ensure consistent orientation measurements between uses.	• Verify calibration effectiveness by operating the device for an extended period and confirming that orientation measurements remain stable with minimal interruption . • Confirm successful initialization by observing position and orientation feedback through the Arduino IDE serial monitor after each system startup.

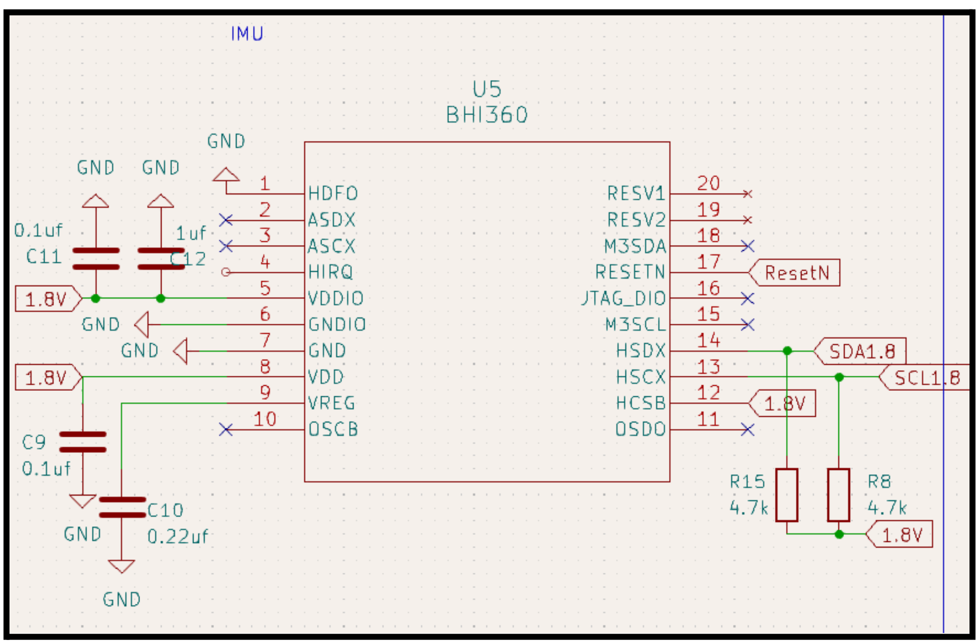

Figure 4: IMU Schematic

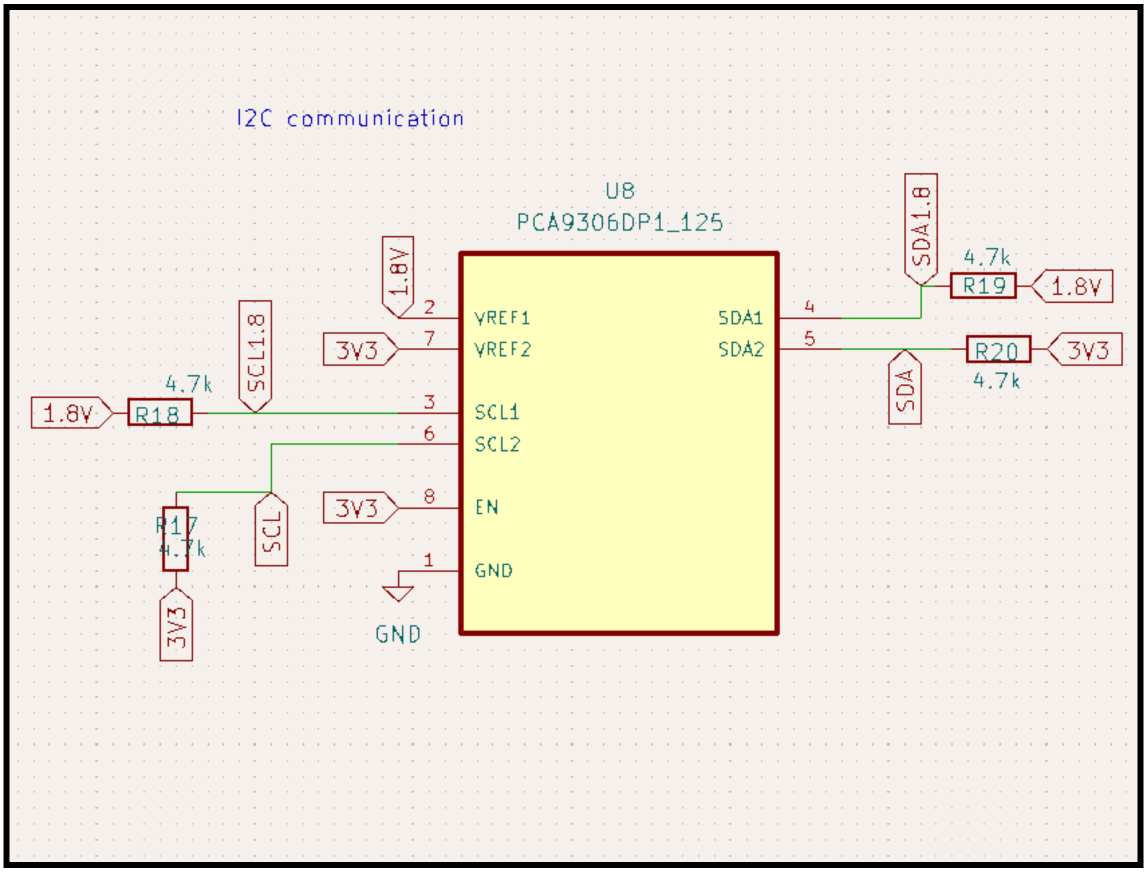

Figure 5: 2-bit dual bidirectional I2C-bus Converts 1.8V I2C to 3.3V I2C for the MCU

[Subsystem 2: User Alert System]

This system includes the ERM which will receive PWM data from the microcontroller whether or not the motor should be spinning or not. This is the system that will alert the user depending on their sleeping position.The system will include an N-channel MOSFET connected with a flyback diode to ensure safe operation when driving the ERM vibration motor.

The user alert subsystem provides physical feedback to the user through a vibration motor Adafruit 1201 ERM vibration motor, 5V, 11,000 RPM. When the microcontroller determines that the user has been in an undesired sleeping position for a prolonged period, it activates the vibration motor to gently prompt the user to reposition. The vibration intensity and duration can be controlled by adjusting the PWM signal from the microcontroller, allowing for customizable feedback that is noticeable but not overly disruptive to sleep. There will be customizations to the strength of the vibration. This strength will be indicated by LEDs. This subsystem is directly controlled by the microcontroller and draws power from the power management subsystem. If the VM (Vibration Motor) does not activate, then the device is basically useless. There would be no indicator to make the user return to their original sleep position. On the other hand, if the VM activated indefinitely, then it would just be an extremely annoying buzzer.

Requirements	Verification
• The ERM vibration motor alerts the user when a bad sleeping position is detected.	• The IMU communicates to the microcontroller regarding the user's position, then based on the position, the ERM vibration motor will alert the user. • Confirm proper motor driver operation by measuring the motor driver output and observing that the ERM vibration motor activates only during intended alert conditions.
• ERM vibration motors can be adjusted to different strength settings.	• A counter from 1-3 is added to the microcontroller that keeps track of the strength of the ERM vibration motor, the higher the counter, the stronger the strength will be. • LEDs will be attached in order to indicate selected vibration level and strength.

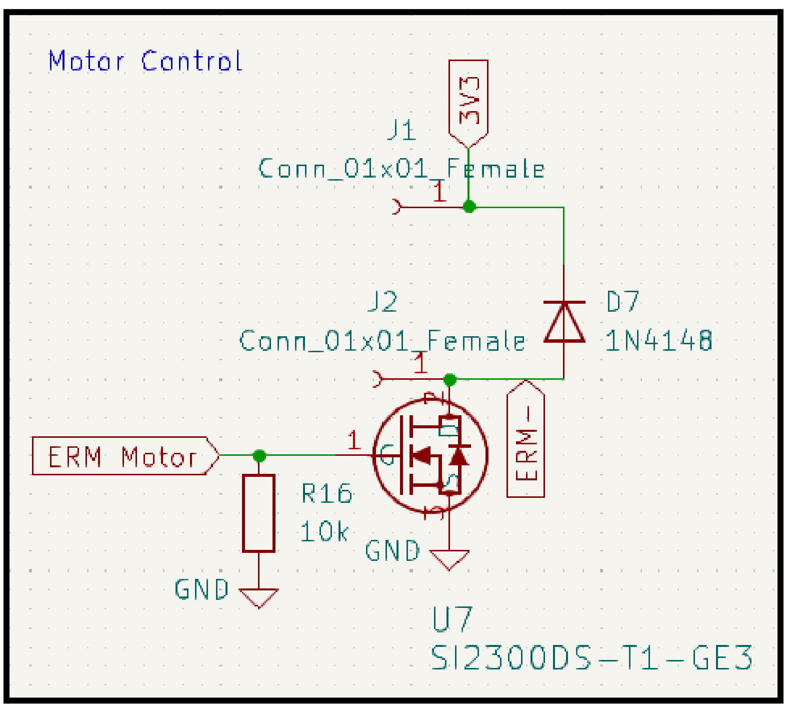

Figure 6: Motor Driver

[Subsystem 3: Microcontroller]

This system includes the microcontroller which acts as the brain of the system. This will receive input and output signals from different subsystems and determines how the subsystems will react according to the data received.

The microcontroller subsystem, based on the ESP32-S3-WROOM module, acts as the central processing and control unit of the device. It collects sensor data from the IMU, processes the information to determine the user's sleeping position, and decides when to activate the vibration motor. The ESP32-S3 also manages timing, logic, PWM, and other functions This subsystem interfaces with all other subsystems, including the position sensing subsystem for input, the user alert subsystem for output, and the power management subsystem for regulated power delivery.

The Microcontroller provides the Control Signals for all other sensors on the board and analyzes their data output. If this component were to fail then any number of issues could arise within our device such as not turning on, not vibrating, not responding to user inputs, etc.

Requirements	**Verification**
● The microcontroller must obtain motion and orientation data from the IMU.	● Validate program operation by displaying real time IMU sensor data through the serial monitor and confirming correct data updates when device orientation changes.. ● Read and display real time sensor data from the IMU and confirm that the values change appropriately when the device orientation is altered.
● The microcontroller must control the ERM vibration motor operation.	● Verify proper programming by implementing firmware that generates a PWM signal from the microcontroller to the motor controller and confirming correct PWM output during execution. ● Validate software control by confirming that programmed vibration strength settings produce corresponding changes in motor vibration intensity.

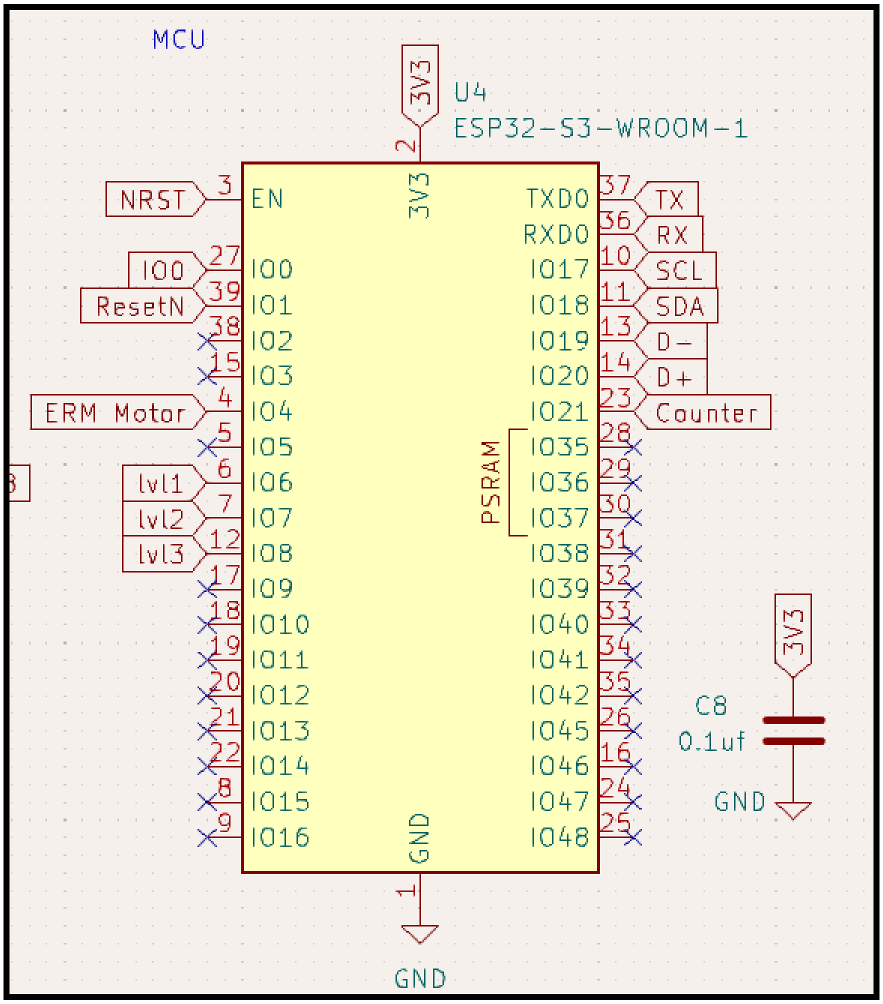

Figure 7: ESP32-S3-WROOM Microcontroller

[Subsystem 4: Physical Build]

The physical build subsystem will primarily consist of the case surrounding the system which will be added to the user. This subsystem holds the whole PCB and the parts of the system.

The physical build subsystem encompasses the mechanical enclosure and mounting structure for all electronic components. The enclosure is designed using CAD software and fabricated via 3D printing to match the PCB layout and component placement. This subsystem ensures that the IMU is securely positioned for accurate motion sensing, the vibration motor is mounted to effectively transmit feedback to the user, and the battery and microcontroller are safely housed. The physical design also plays a role in user comfort, durability, and overall usability, serving as the integration platform that connects all electronic subsystems into a single wearable device.

Requirements	Verification
• Must be able to safely encase and protect the components within the device in order to keep the components safe and functional.	• Under the weight determined that will represent the weight of a human body, the device should not implode and damage the internal components of the device.
• The design must be able to withstand the weight of a human body while the user is sleeping.	• The 3d printed encasing for our device must withstand at least a weight of 150 pounds. This number takes into account that the pressure the human body puts on the device is about 50% of a human body's weight.
• The design has to have a material that is safe for the user	• We will verify that the encasing doesn't include toxic materials or extremely hard materials where it can harm the body.

[Subsystem 5: Power Management]

This subsystem consists of the LiPo battery used as the power source for the whole device. All components from the separate subsystems will need power in order to function accordingly. Additionally, the power management system will include the LiPo battery's recharging system.

The power management subsystem supplies and regulates power to all components in the system. It consists of a 3.7V 500mAh (might adjust according to testing) LiPo battery for portable operation and a TP4056 battery charging IC to safely manage charging from an external power source with USB-C. Voltage regulation circuitry ensures that the microcontroller, IMU, and vibration motor receive stable and appropriate operating voltages. This subsystem connects to every other subsystem by providing power and is critical for ensuring safe operation, long battery life, and reliable overnight use of the device. Additionally, features such as safety shut down will be added in order to prevent any possible issues with the LiPo battery.

Requirements	Verification
• The design must maintain regulated output voltage during the entire battery discharge process and include automatic low voltage cutoff protection	• To verify that the low voltage cutoff protection mechanism functions properly, we will test our device with the necessary 5V. We will then

to prevent operation when the battery voltage becomes too low.	alternate to a lower voltage to ensure our device automatically starts the low voltage protection. ● We will verify that the device properly shuts down quickly enough to not damage the device.
● Use USB-C that supplies 5V throughout the board and is able to charge the battery.	● Verify proper power distribution by using a multimeter to confirm that regulated voltage is supplied to all required components on the board. ● Confirm battery charging functionality by measuring the battery voltage over time and verifying that it increases while connected to the USB-C power source.

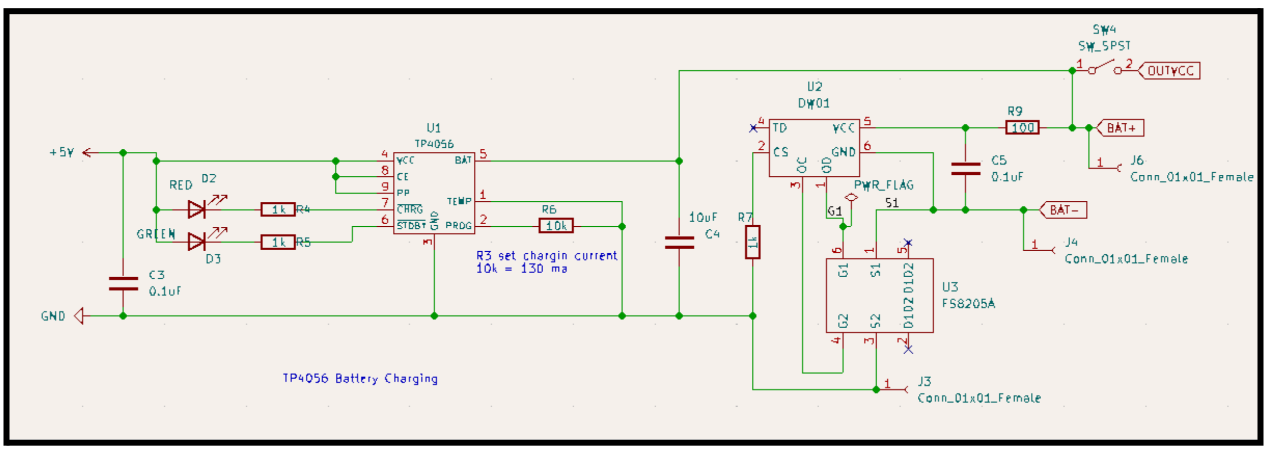

Figure 8: TP4056 Charging Module

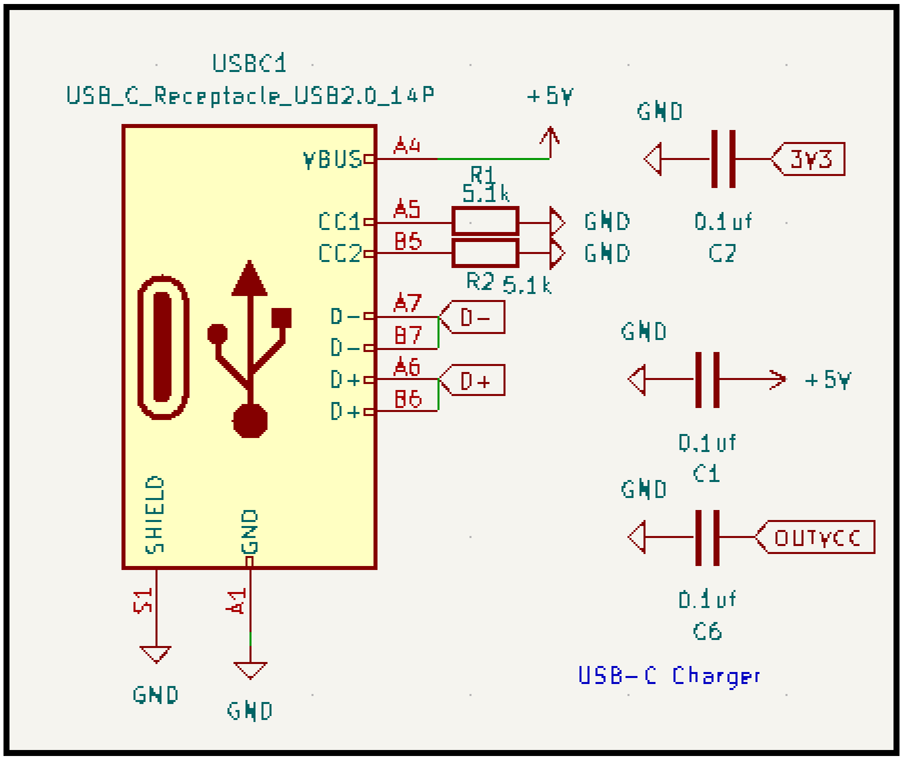

Figure 9: USB-C to charge battery and program MCU

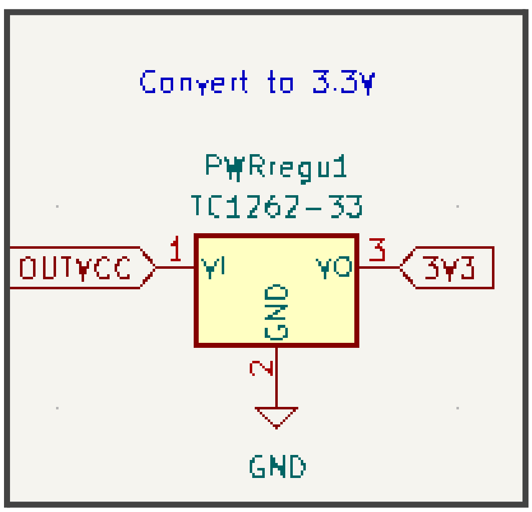

Figure 10: LDO that converts Battery 3.7V - 4.2V to 3.3V for MCU

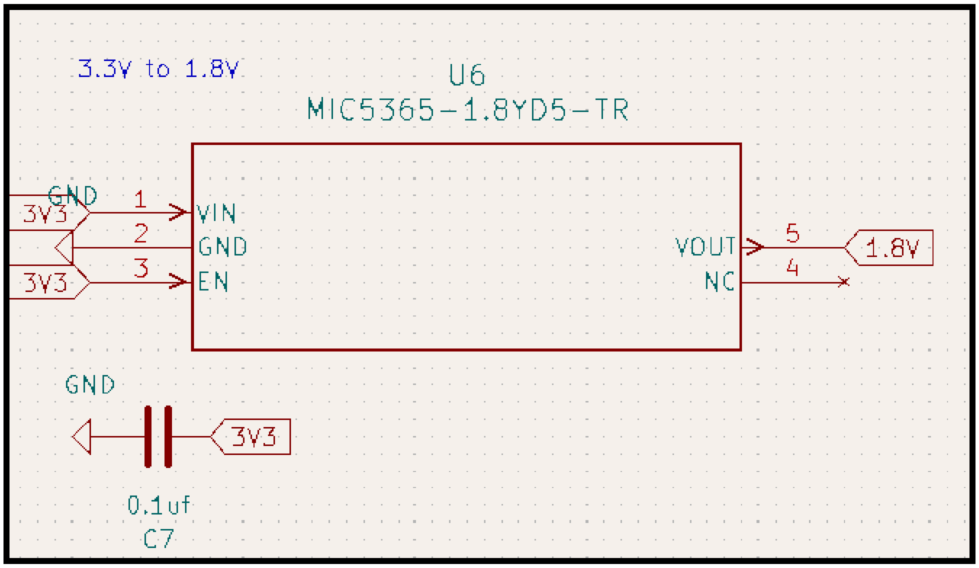

Figure 11: LDO that converts 3.3V to 1.8V

2.3 Software Design:

The Microcontroller is the brain of our project. It is tasked with using data obtained from the external devices and user inputs, and deciding what the proper behavior of our device should be. Our microcontroller takes in the following inputs: On/Off Switch, Reset Button, VM Mode Select Button, and the IMU Data. Our algorithm will take these inputs into account, as well as what operational state it is in to determine what an appropriate choice for the next state would be. Figure 12 shows a flowchart that describes the operation of our project.

The possible states of operation are as follows:

START: This is the default state in our flowchart. We could have made “VM MODE 1 (Inactive)” the initial state, but using start makes our flowchart more readable.

OFF: The device enters this state when the On/Off switch is set to off.

HALT: Our device will enter this state from any other state when the Reset button is pressed. You can only exit the Halt state by pressing the Reset button a second time.

VM MODE 1 (Inactive): The power level of the VM is set to 1 (out of 3), and it is not currently vibrating.

VM MODE 2 (Inactive): The power level of the VM is set to 2 (out of 3), and it is not currently vibrating.

VM MODE 3 (Inactive): The power level of the VM is set to 3 (out of 3), and it is not currently vibrating.

VM MODE 1 (Active): The power level of the VM is set to 1 (out of 3), and it is currently vibrating.

VM MODE 1 (Active): The power level of the VM is set to 2 (out of 3), and it is currently vibrating.

VM MODE 1 (Active): The power level of the VM is set to 3 (out of 3), and it is currently vibrating.

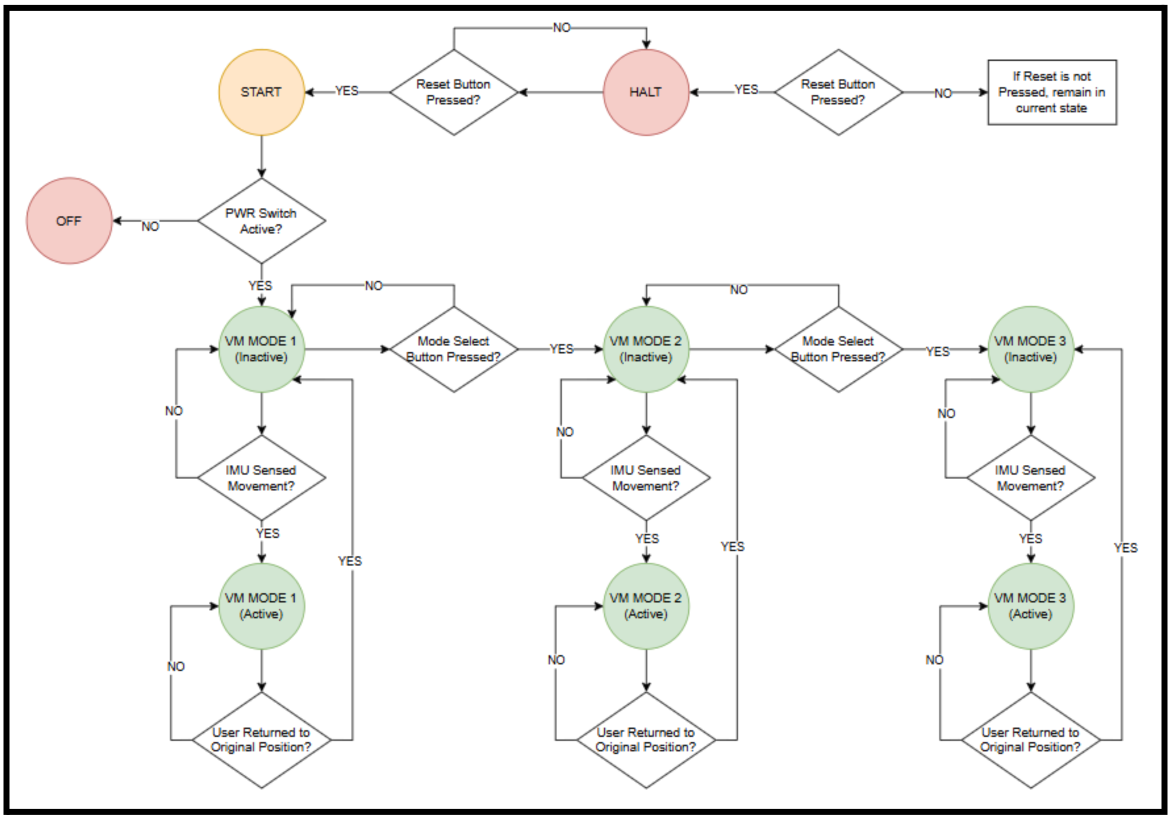

Figure 12: Sleep Position Trainer Operational Flowchart

2.4 Tolerance Analysis:

Given our current design, the IMU will be the most risky component. It is well-known that inertial devices can be rather inaccurate or sensitive, so it will take some time to get the sensitivity of our device just right such that the device does not vibrate from something harmless like the rising and falling of the user's diaphragm as they breathe.

In addition, we previously considered adding a Heart Rate Sensor to our device, but are now treating it as an optional add on. The purpose of this sensor would be to track the user's sleep quality and to see if there were improvements following the activation of our device. The primary issue with this extra sensor is how it limits where our sleep training device can be equipped. For example, if our device were to be worn on the wrist (typically where heart rate sensors operate), then simple actions like scratching one's nose would set off our device, which would act more like a disturbance rather than a useful trainer.'

The sleep position trainer device will have to withstand a certain range of movements when defining a vibration-activation threshold that distinguishes meaningful posture changes. We will need to gather data to ensure the sensitivity of our device is proper and does not vibrate from movements that aren't rolling over. Some movements that affect this threshold include

The BHI360 typically has an accelerometer noise density of approximately :

$$n_a = 160\ \mu g / \sqrt{Hz}$$ [1]

Assume a bandwidth of:

BW = 25 Hz

RMS acceleration noise:

$$a_{noise} = n_a\sqrt{BW}$$

$$a_{noise} = 150 * 10^{-6} * \sqrt{25}$$

$$a_{noise} = 150 * 10^{-6} * 5$$

$$a_{noise} = 7.5 * 10^{-4} g$$

Convert to m/s^2:

$$a_{noise} = 0.00736\ m/s^2$$

3 Cost and Schedule

3.1 Cost Analysis:

To begin our cost analysis, let's assume a salary for each team member:

- First, assume each team member gets paid $35/hour
- Let's say we each work 7 hours a week for the 10 remaining weeks of the semester
- Per member, our salary would be $35/hour x 70 hours x 2.5 = $6,125
- Multiplied by 3 for each member makes $18,375 total

Therefore our total labor cost is $18,375

PARTS OBTAINED ONLINE

Description	Manufacturer	Quantity	Extended Price	Link
Dual N-Channel Enhancement Mode MOSFET (FS8205A)	Fortune Semiconductor	3	$1.02	Link
Linear 1-Cell Li-Ion Battery Charger (TPB4056A20-ES1R)	Top Power	3	$1.41	Link
SPDT Slide Switch 100 mA 12 V	C&K Components	3	$1.95	Link
100 Ω 1% 0805 SMD Resistor	Vishay Dale	3	$0.30	Link
5 V ERM Vibration Motor (11000 RPM)	Jinlong Machinery & Electronics	3	$5.85	Link
Li-Ion Battery Protection IC (DW01)	Fortune Semiconductor	3	$0.30	Link
3.7 V 500 mAh Li-Polymer Battery	Generic / Li-Poly Manufacturer	2	$13.08	Link
6-Axis Smart IMU (BHI360)	Bosch Sensortec	3	$16.68	Link

1.8 V Linear Voltage Regulator (MIC5365)	Microchip Technology	3	$0.51	Link
N-Channel MOSFET 30 V 3.6 A (SI2300DS)	Vishay Siliconix	3	$1.98	Link
Switching Diode 100 V 200 mA (1N4148)	Diodes Incorporated	3	$0.30	Link

Figure 13: Itemized List of Components and Costs

PARTS OBTAINED FROM ECE SHOP

Capacitor 0.22 µF 10 V Ceramic (0603)	Murata Electronics	10	$0.60	Link
Capacitor 0.1 µF 25 V Ceramic (0805)	Murata Electronics	20	$1.00	Link
Resistor 4.7 kΩ 0603	Yageo	10	$0.20	Link
Resistor 10 kΩ 1% 1/8 W 0805	Vishay Dale	10	$0.25	Link
Capacitor 1 µF 25 V Ceramic (0805)	Murata Electronics	10	$0.70	Link
Linear Voltage Regulator LD1117-3.3 (SOT-223)	STMicroelectronics	10	$3.50	Link
Resistor 1 kΩ (0805	Yageo	10	$0.20	Link
Capacitor 10 µF Ceramic (0805)	Murata Electronics	5	$0.75	Link
Resistor 330 Ω (0805)	Yageo	5	$0.15	Link

ESP32-S3-WROOM Microcontroller Module	Espressif Systems	3	$18.00	Link

Figure 14: Itemized List of Components and Costs from The ECE Shop

The total cost of the parts obtained on digikey as of now is $43.38

We will also add $25.35 as the cost of parts obtained from the ECE shop, resulting in $68.73

In addition, PCB ordering on JLCPCB will cost $5, which brings our total cost to $73.73 pre-tax

*Although the ECE shop parts are free, it would be easiest to apply the tax and shipping cost to all parts to find a safe upper bound for our total cost

Assuming a 10% Sales Tax and a 5% Shipping Cost, makes our total parts cost sum to:
(73.73 x 1.10) + (73.73 x 1.05) = $158.52

Finally, the sum of our labor cost ($18,375) and our parts cost ($158.52) bring our total cost to:

$18,533.52

3.2 Schedule:

Week	Task	Person
1 - 6 January 20th - March 1st	- Choose a project - Submit RFA - Submit Project Proposal - Start PCB Design - Submit Design Document	Everyone
7 March 2th - March 8th	- Do Design Review - Make Assemble PCB V1 - Submit PCB - Order Parts - Test programming on the ESP32	Everyone Brian Nick
8 March 9th - March 15th	- Prepare for 2nd round of PCB orders - Trouble shoot PCB - Write Code to control the VM - Trouble shoot Code	Everyone Nick

(SPRING BREAK) March 16th - March 22th	- Enjoy Spring Break today - Ensure we are able to program our components	Everyone Nick
9 March 23th - March 29th	- Prepare for 3rd round of PCB orders - Trouble shoot PCB - Update PCB - Test components functionality with power source	Everyone Brian Kyle
10 March 30th - April 5th	- Prepare for 4th round of PCB orders - Design physical enclosure using 3D modeling	Kyle
11 April 6th - April 12th	- Solder 4th round of PCB orders - Program IMU with microcontroller - Stream data from IMU with I2C to ensure proper measurements from gyroscope	Brian Nick Kyle
12 April 13th - April 19th	- 3d print our physical enclosure - Ensure the physical enclosure can connect to the belt - Make sure the belt is adjustable - Create buckle for the strap	Brian Nick Kyle
13 April 20th - April 26th	- Add PCB and other components to the physical enclosure - Power the device and ensure proper function - Mock demo	Everyone
14 April 27th - May 3th	- Finalize demo requirements - Coordinate demo timeline	Everyone
15 May 4th - May 10th	- Prepare for showcase - Demo functionality - Ensure seamless creation	Everyone

Figure 15: Schedule for Project Progression

4 Ethics, and Safety Considerations:

Discussion of Societal Impact, Engineering Standards

4.1 Engineering Standards (IEEE, ACM, UL, etc.)

In terms of safety, the user will be asleep while it runs, so if there is an issue with the device, the user will not be immediately conscious to deal with any potential threats due to malfunction. In addition, we also need to think about water damage and battery puncturing. The physical design of the device could definitely cause physical harm like choking hazard and loss of blood circulation.

The following ethical considerations will be incorporated to the design of the project:

- ACM
- ACM 1.3
- ACM 1.6
- IEC 62133-2
- UN 38.3 transportation testing

Regular Use Safety Risks:

- Battery overheating, swelling, fire, or burns
- Skin irritation
- Excessive vibration
- Electrical hazards

4.2 IEEE/ACM Codes of Ethics

Ethical Consideration Explanations:

- ACM 1.2 – This code discusses the safety of our design. We will test for hazardous scenarios (long runtime, repeated vibrations, charging behavior) and implement methods to prevent problems that could arise from these cases. [3]
- ACM 1.3 – We will not claim any guaranteed health or treatment outcomes for our device, unless extensive and justifiable evidence is found. [3]
- ACM 1.6 – If the system stores or transmits any sleep-position data (even just timestamps or posture labels), we will minimize data collection, store it locally when possible, and avoid collecting identifying information. [3]
- IEC 62133-2 – safety requirements and tests for portable sealed rechargeable lithium cells/batteries, including foreseeable misuse. [2]
- UN 38.3 transportation testing – relevant if shipping batteries or a finished product, and required for lithium batteries offered for transport. [4]

Safety Risk Explanations:

- Battery overheating, swelling, fire, or burns – Lithium-ion batteries can overheat and ignite if charging is not properly designed. [2]
- Skin irritation – This wearable can cause irritation if not properly cleaned or worn.
- Excessive vibration – Excessive vibrations could reduce sleep quality.
- Electrical hazards – Shorts or incorrect connections could create heat or shock risk.

4.3 Electrical and Mechanical Safety Concerns

Electrical: Our project involves a battery and chagrin module, which introduces the risk of overcharging and potential fire hazards. We have implemented an emergency shut off feature in order to limit the harm that our project can cause.

Mechanical: Given that our physical device will have an elastic strap for wearing the device, it could be possible that the user would accidentally strangle themself during their sleep. However, this is highly dependent on how the user equips our device, or their sleep habits, so we can add some recommended guidelines in a future safety manual if one is needed.

There have been no new ethical or safety concerns related to our project since the project proposal. We may encounter more difficulties as we continue to develop our project, and we will be sure to acknowledge them in future documentation.

4.4 Mitigate the Safety Concerns of Your Project.

This is not an aspect of our project that we can fully realize at the moment. However, we are currently brainstorming guidelines that we would have in a safety document. These include: Recommendations to avoid overcharging or overheating the LiPo battery, Recommendations on how to wear our device safely to avoid asphyxiation or physical harm, and Recommendations on what to do in case of physical malfunction of our device.

5 Citations:

[1] “BHI360 Programmable, low power, Inertial Measurement Unit with integrated sensor fusion library BHI360 Datasheet.” Accessed: Feb. 28, 2026. [Online]. Available: https://www.bosch-sensortec.com/media/boschsensortec/downloads/datasheets/bst-bhi360-ds000.pdf

[2] “IEC 62133-2 Edition 1.1 2021-07 CONSOLIDATED VERSION INTERNATIONAL STANDARD NORME INTERNATIONALE Secondary cells and batteries containing alkaline or other non-acid electrolytes -Safety requirements for portable sealed secondary cells, and for batteries made from them, for use in portable applications - Part 2: Lithium systems.” Available: https://cdn.standards.iteh.ai/samples/21479/fc1425401c494ac88927998737150b9b/IEC-62133-2-2017.pdf

[3] Association for Computing Machinery, “ACM Code of Ethics and Professional Conduct,” *Association for Computing Machinery*, Jun. 22, 2018. https://www.acm.org/code-of-ethics

[4] United Nations“Lithium metal and lithium ion batteries” in Recommendations on the Transport of Dangerous Goods: Manual of Tests and Criteria, 8th rev. ed., New York and Geneva: United Nations, 2023, Section 38.3. [Online]. Available: unece.org

[5]Mayo Clinic, “Sleep apnea - Symptoms and Causes,” *Mayo Clinic*, Apr. 06, 2023. https://www.mayoclinic.org/diseases-conditions/sleep-apnea/symptoms-causes/syc-20377631

[6]“Does Tossing and Turning Affect Sleep Quality?,” Biology Insights, Dec. 14, 2025. https://biologyinsights.com/does-tossing-and-turning-affect-sleep-quality/ (accessed Feb. 28, 2026).