ECE 445

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Team # 48

Sleep Position Trainer

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1) Introduction

a) Problem:

All humans need to sleep. We spend almost a third of each day resting and recovering so that we can be productive and healthy while we are awake. However, many people find themselves waking up in unfamiliar positions, which is the result of constant tossing and turning during their sleep cycle. While not always harmful, this excessive movement can hinder sleep quality by interrupting periods of deep REM sleep (biologyinsights.com).

This involuntary restlessness of the body can potentially be solved by factors such as room temp, stress reduction, and light stretching. But, we propose an alternative method. We want to develop a device that can detect a person's sleeping position and provide gentle feedback, via vibration, to prompt repositioning. This device is intended to help users improve and maintain healthier sleep patterns so they can be more rested when they awake.

b) Solution:

In order to maintain healthy sleep posture, we propose a wearable sleep monitoring device that detects a user's sleeping position and provides gentle vibration feedback when an adjustment is needed. Our device continuously monitors body orientation during sleep and encourages repositioning when prolonged or unhealthy postures are detected, helping users develop healthier sleep habits over time. Ideally this device will be worn around the chest or abdomen since movement of the legs, arms, and head are not considered extreme deviations from the original position.

Our device differs from existing sleep training devices like the Side Sleeping Backpack and Bed Wedges. Rather than physically restricting the user's ability to move, our device uses gentle vibration to condition the user to return to a more comfortable sleeping position. Our goal is that the user does not become reliant on our aid, but instead begins to move less in their sleep due to the feedback from our device.

The system will incorporate a Battery, Microcontroller, Inertial Measurement Unit (IMU), and Eccentric Rotating Mass (ERM) motors to develop a small wearable sleep position trainer. This trainer will also feature a basic user interface for the user to turn on and off the device, as well as to control the strength of the vibration.

c) **Visual Aid:**

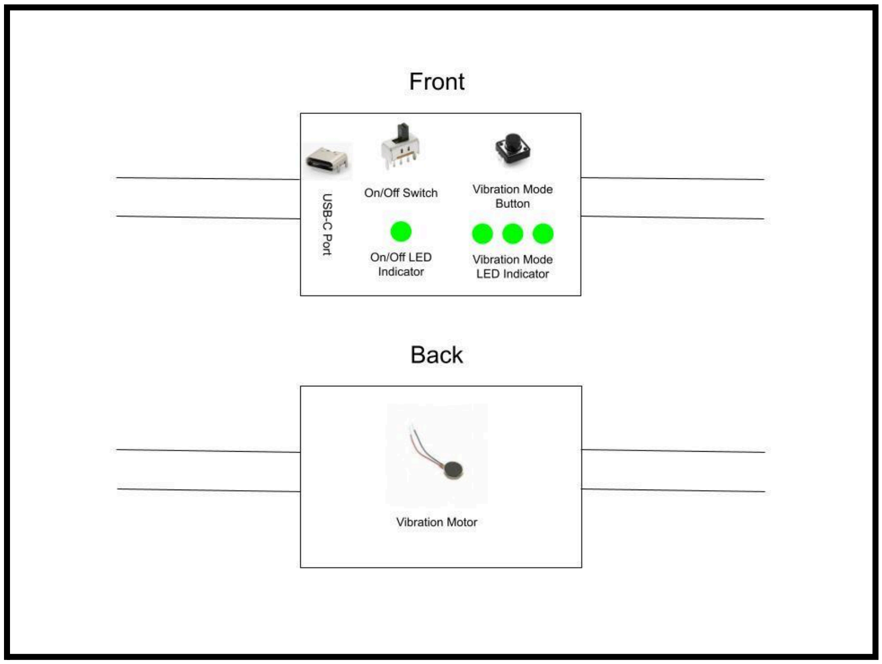

Figure 1: Sleep Training Device Visual Aid

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.

d) **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

a) Block Diagram:

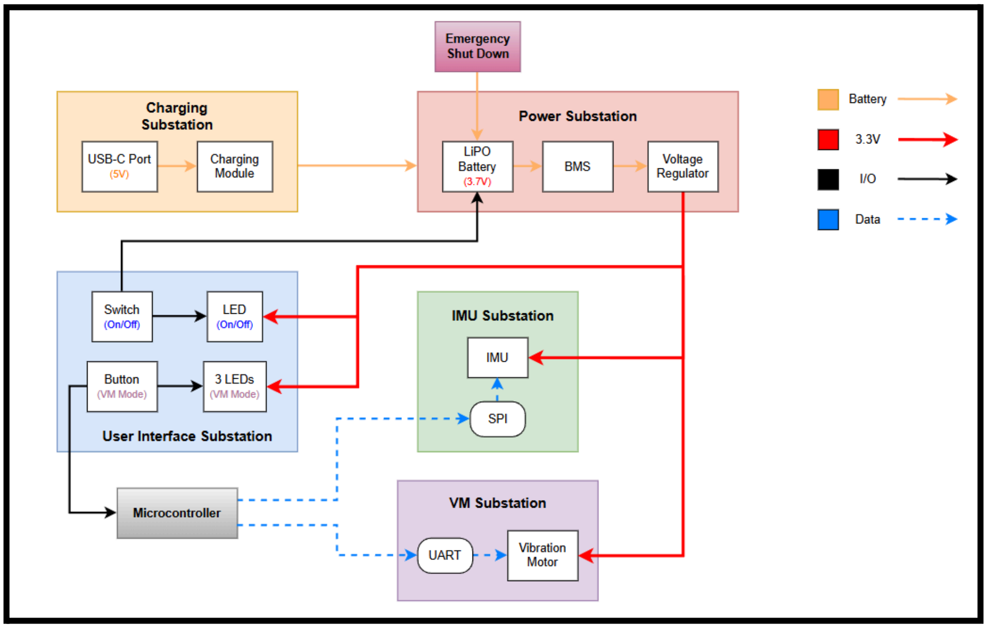

Figure 2: Sleep Training Device Block Diagram

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.

b) Subsystem Overview:

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.

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.

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.

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.

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.

c) Subsystem Requirements:

Subsystem 1: Position Sensing

The position sensing subsystem is responsible for detecting the user's sleeping orientation and motion. It utilizes the Bosch BMI270 Inertial Measurement Unit (IMU), which contains an accelerometer and gyroscope. This data allows the system to determine how the user is laying down. 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.

Subsystem 2: User Alert System

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.

Subsystem 3: Microcontroller

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.

Subsystem 4: Physical Build

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.

Subsystem 5: Power Management

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.

d) **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.'

3) Ethics and Safety

a) Ethical & Safety Issues:

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 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.
- ACM 1.3 – We will not claim any guaranteed health or treatment outcomes for our device, unless extensive and justifiable evidence is found.
- 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.
- IEC 62133-2 – safety requirements and tests for portable sealed rechargeable lithium cells/batteries, including foreseeable misuse.
- UN 38.3 transportation testing – relevant if shipping batteries or a finished product, and required for lithium batteries offered for transport.

Regular Use Safety Risks:

- Battery overheating, swelling, fire, or burns – Lithium-ion batteries can overheat and ignite if charging is not properly designed.
- 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.

b) Societal Impact:

We are uncertain about the full societal impact of our device. On one hand, it has the potential to improve users' sleep quality by promoting healthier sleeping positions. Sleep is a critical aspect of overall health and well being. On the other hand, the device may introduce sleep disturbances if the vibration feedback or movement causes fragmented or interrupted sleep, which could negatively affect overall sleep quality. Our device is made to aid individuals who have bad sleep habits, and is not intended to change the world.

c) Cost & Schedule:

Cost: This is not an aspect of our project that we can fully grasp yet. However, we don't think our device should be especially costly since the necessary PCB parts are fairly priced, and our casing would be 3-D printed. We will review alternatives and available parts and determine what is best for testing and what we could use for the final project's outline.

Schedule: We will try our best to stay aligned with the class schedule listed on the ECE 445 website, however, depending on how much trouble we run into when testing this may vary. There is always a difficulty when debugging hardware and software that could be unknown. We will try our best to debug the issues in order to have the best final result possible.

4) Citations and References

Sleep Health:
Sleep apnea - Symptoms and causes - Mayo Clinic
Does Tossing and Turning Affect Sleep Quality? - Biology Insights

ACM code of ethics:
https://www.acm.org/code-of-ethics

IEC 62133-2:
https://cdn.standards.iteh.ai/samples/21479/fc1425401c494ac88927998737150b9b/IEC-62133-2-2017.pdf

UN 38.3
https://unece.org/fileadmin/DAM/trans/danger/publi/manual/Manual%20Rev5%20Section%2038-3.pdf