ECE 445 Senior Design Lab Proposal: Smart Insole

Team 41: Ramsey van der Meer, Alyssa Huang, Tony Leapo

Introduction

Problem: Include any relevant references to justify the existence or importance of the problem.

Many people enjoy hiking since it allows for people of all fitness levels to experience the outdoors. However, oftentimes the constant repetitive pounding on hikers feet can lead to soreness or even injury. Many factors contribute to the injury risk factor including a hiker's gait, fitness level, the amount of weight carried, terrain, and much more. Currently, there are no products on the market which can deliver personalized feedback on foot stresses experienced over the duration of a hike. This information can be crucial in selecting appropriate footwear or even improving walking techniques to prevent injuries. Additionally, this information could be repurposed to provide a metric to measure the difficulties of hikes, as trails that place a lot of pressure on your feet can be shared amongst avid hikers.

Solution:

Our solution is to develop an insertable insole equipped with many integrated pressure sensors and external accelerometers, and gyroscopes. These sensors will help monitor the dynamics of the foot during a hike by capturing data on the distribution of pressure across the foot, as well as the intensity of impacts, and the foot's orientation and movements.

The insole will be constructed with durable but comfortable materials to ensure it does not alter the hiking experience negatively. It will connect to an external part that clips to the outside of the shoe. This external portion will contain the microcontroller and any other sensors such as a gyroscope and an accelerometer. The device will be able to connect wirelessly through BlueTooth to a smartphone interface, enabling hikers to receive real-time feedback of the sensor data during their hike. After the hike, the interface will provide a comprehensive summary of the collected data, presenting insights into areas of the foot that experienced the most stress and impact, as well as other data collected about the user’s walking habits. This summary will include visual representations such as heat maps and graphs, illustrating the pressure points and movement patterns.

Additionally, the interface will offer personalized recommendations based on the collected data. These could include suggestions for foot exercises, guidance on improving hiking techniques, and advice on selecting the right type of hiking footwear for individual needs.

By providing hikers with this detailed and personalized information, our solution aims to enhance the hiking experience, reduce the risk of foot injuries, and contribute to the overall well-being of hiking enthusiasts. The insole will be designed to ensure compatibility with a range of different types of shoes, and the type of data we will be collecting can be generalized to solve other orthotic issues.

Visual Aid:

High-level requirements list:

Accurate Pressure and Sensor Values:

- Integrate the pressure sensor to be able to track pressure changes in distinct regions of the foot, these regions having a maximum area of 3 inches squared.
- The sensors will need to track foot pressure distribution, impact intensity, and foot motion using the accelerometer, pressure sensor, and gyroscope. We expect sensors to be accurate within 10%.

Accurate and Intuitive Data Integration:

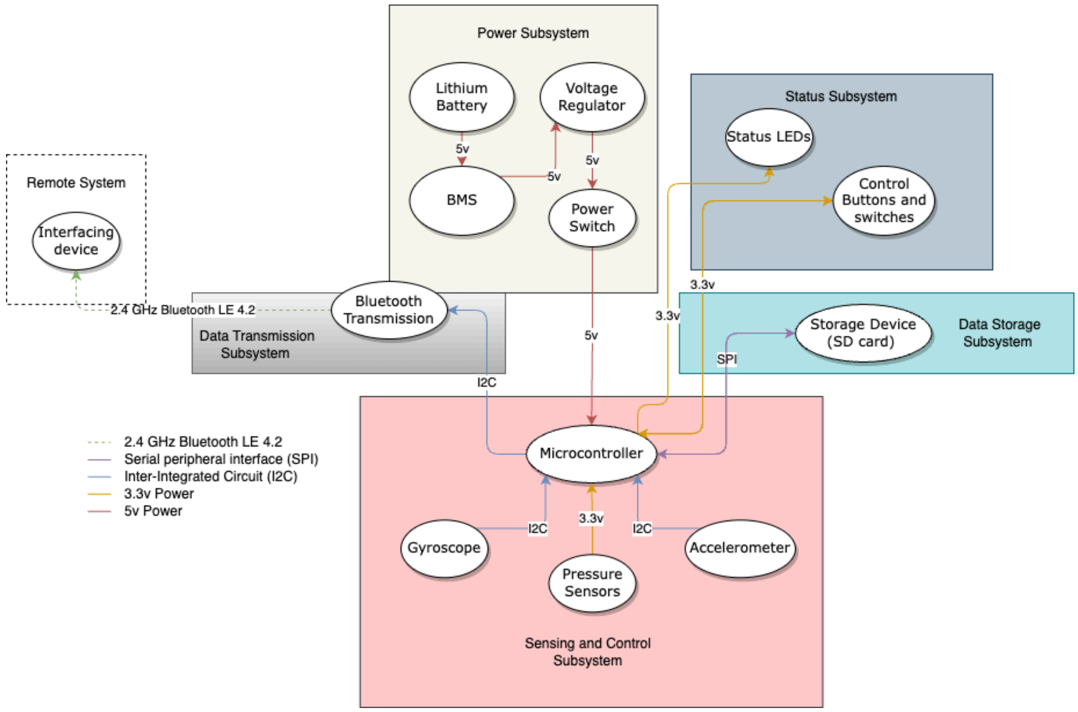
- Once we properly collect the data from the physical foot exerting pressure, we want to make sure we can properly store, transport, and intuitively represent the data.
- For storing and transporting, we will either store it within the microcontroller, or send it in real time over Bluetooth to a separate device. We want real time transmission to not be significantly lossy, and only drop less than 5% of packets.
- For visualizing the data, we have chosen a heat map on our user interface to graphically show where the pressure distribution is.

Wearable/Modular Physical Implementation:

- We want our device to be adaptable to various types of hiking boots, which is why we chose an insole that can be slipped in easily.
- We want our device to be wearable and enable our users to have 100% range of motion so that it does not deter from the hiking experience at all.

Design

Block Diagram:



Subsystem Overview:

1. **Remote Interface Subsystem:**
    a. Function: Utilizes data from the sensing subsystem to provide a user-friendly interface for monitoring foot dynamics during hikes, displaying data in various formats such as heat maps and pace charts.
    b. Interaction: Interfaces with the Data Transmission Subsystem through Bluetooth, sending information to the device such as connection status and receiving sensor information from the device.
2. **Data Transmission Subsystem:**
    a. Function: Facilitates reliable and secure transfer of sensor data from the insole to a smartphone or other devices for real-time monitoring and analysis.
    b. Interaction: Communicates with the microcontroller through I2C in the Sensing Subsystem to receive and transmit data between the remote system and the device. This includes sensor information from the microcontroller and connection status from the remote system.
3. **Data Storage Subsystem:**
    a. Function: Employs an SD card for storing sensor data when immediate Bluetooth transmission to the remote interface is not possible, ensuring data integrity and availability.
    b. Interaction: Offers read/write access to the microcontroller through SPI.
4. **Sensing Subsystem:**

a. Function: Integrates an accelerometer, gyroscope, and pressure sensors for tracking foot movements and pressures, using an ESP32 microcontroller for processing and Bluetooth data transmission.
b. Interaction: The microcontroller receives power from the power subsystem and communicates with the Data Storage Subsystem (read/write sensor data), Data Transmission Subsystem (Bluetooth transmission data), and Status Subsystem (User control and device status data).

5. **Status Subsystem:**
   a. Function: This subsystem includes LEDs to visually indicate power status, Bluetooth connectivity, and sensor malfunctions, providing a low-power alternative to screen interfaces for user awareness of device status.
   b. Interaction: Sends its button/switch data to the microcontroller, receives power and to light up status LEDs.
6. **Power Delivery Subsystem:**
   a. Function: The power subsystem uses a lithium-ion battery with a capacity of 200-300mAh to ensure sufficient power for a hike lasting 4-6 hours, powering sensors, a microcontroller, LEDs, and a Bluetooth module.
   b. Interaction: Directly supplies power to the Sensing Subsystem to power the Microcontroller, which will handle all other power distribution.

Subsystem Requirements:

- **Power Subsystem:**
  - The power subsystem would contain a lithium-ion battery. Due to its compact size, rechargeability, and widespread availability, we find lithium-ion batteries to be the best battery type to integrate. We would mount this battery externally from the insole to power the device within the control box, placing it on the back of the shoe so as to not inhibit the motion of the user. Considering the power requirements of the sensors (accelerometers, pressure sensors, and gyroscopes), the microcontroller, LEDs, and the Bluetooth module for data transmission, a battery capacity in the range of 200-300mAh would likely be sufficient. For reference, a FitBit sense worn on the wrist has a battery of about 266 mAh at 3.85 V. This capacity should provide enough power for a hike (approximately 4-6 hours) on a single charge, assuming moderate data recording and transmission frequency. The battery would be placed away from the insole, in the back of the shoe. Its physical locations and dimensions are indicated in the visual aid.

Requirements	Verification
• Consistent power delivery	• Measure voltage delivered to

	microcontroller and validate that it is consistent at 5v

• Rechargeability	• Use the device until it runs out of battery
	  ○ Measure voltage of battery
	• Charge the battery until fully charged
	  ○ Measure voltage of battery
	• Show that we can run the device on the recharged battery

• Last all hike	• Test it out and run it for as long as possible and see when it runs out of battery • Make sure it lasts more than 6 hours

- **Status Subsystem:**
  - LEDs will be added to provide clear, visual indications of various statuses. We would include a power status LED indicating when the device is running. This LED could be repurposed for power status, and change to a green color when the insole is charging. It might flash red when the power is low. We could also incorporate LEDs for other statuses, such as Bluetooth connectivity (whether or not bluetooth is activity paired or if it is in pairing mode), or a warning LED for sensor malfunction or disconnection. These LEDs will not only provide an additional interface for users to look at and easily understand the status of their device. This would also have the benefit of having much less power draw than a screen interface.

Requirements	Verification
• Users can tell status of device	• Make sure LEDs light up at the right times to indicate status of device

- **Sensing Subsystem:**
  - For the insole, we will integrate a combination of sensors to accurately track and analyze foot movements and pressures during hikes. These sensors will include an accelerometer, gyroscope, and pressure sensors.
    - Accelerometer: This sensor we will use to measure movements that users will make as well as sudden changes to motion to better get a sense of where and when impacts happen.

        - Gyroscope: The gyroscope sensor will measure the rotational movements and orientation of the foot. This would provide insight into how the foot moves during a hike.
        - Pressure Sensors: These sensors will be distributed across different areas on the insole to map the pressure exerted on different parts of the foot. This data is crucial for identifying high-stress areas and potential points of discomfort or injury. We could use thin and flexible pressure sensors like a Velostat conductive sheet.. This sensor works by increasing resistance as the sheet bends are applied to it, which we can measure with a voltage divider and see a change in voltage.
    - The data from these sensors will be collected and processed by a microcontroller unit external from the insole. This microcontroller would have to be capable of handling multiple inputs simultaneously from different sensors. We think the ESP32 fits the bill for a low-power, efficient microcontroller. This also includes Bluetooth for wireless data transmission to a smartphone interface.

Requirements	Verification
• Accelerometer can track velocity and acceleration	• Move accelerometer around • Make sure that the movement is read
• Pressure sensor can track pressure	• Put pressure on the sensor. • Make sure that there is a change in voltage and it is read by the microcontroller
• Gyroscope can track direction	• Change the orientation of the device. • Make sure that this is picked up by the microcontroller.

- **Data Storage Subsystem:**
    - The data storage subsystem will be in place to collect and store data that isn't able to be immediately transferred to the remote interface. The microcontroller will be able to read and write data into an SD card. It will store sensor data for future Bluetooth transfer by the microcontroller. This subsystem will be put to use in the case where the microcontroller disconnects from the interfacing device or as a buffering system if Bluetooth is unable to transfer the data being collected fast enough as sensor data is read.

Requirements	Verification
• Data can be stored on device	• Record data for a few minutes on the

	deceive. ● Check if storage has been modified correctly
● Data can be read off device	● Make sure data can be read by the microcontroller for later transmission.

- **Data Transmission Subsystem:**
    - The Data Transmission Subsystem is needed to facilitate the seamless transfer of data from the insole's Sensing Subsystem to the Remote Interface Subsystem for further analysis and user interaction. This subsystem ensures that the comprehensive foot dynamics data collected by the insole's sensors is reliably and securely communicated to the user's smartphone or another designated device for real-time monitoring and historical data analysis.

Requirements	Verification
● Data can be transmitted to another device	● Validate bluetooth packets are being sent with programs like wireshark.

- **Remote Interface Subsystem**
    - The Remote Interface Subsystem for the smart insole leverages the comprehensive data collected by the Sensing Subsystem to provide a user-friendly interface for monitoring and analyzing foot dynamics during hikes. The Sensing Subsystem, which includes an accelerometer, gyroscope, and pressure sensors, collects valuable data on foot movements, orientation, and pressure distribution. This data is essential for understanding the wearer's gait, the impact on different parts of the foot, and identifying potential areas of discomfort or injury.

Requirements	Verification
● Receive data transmitted from device	● View data acquired through bluetooth connection.
● Display data to users	● Show users acquired data in heat map, elevation gain, average pace and more charts.

Tolerance Analysis:

The largest potential risk would be the ability of the microcontroller to maintain the draw of everything it is connected to. The microcontroller we plan on using is an STM32-F3 which operates within 2.0-3.3V, and on average draws 8-40 mA at 3V according to its datasheet. This should be enough current draw to supply our sensors and LEDs at this voltage. The sensors will draw approximately 3 mA per sensor at 3.3V, and the LED should draw approximately 15 mA at 3.3V according to their respective datasheets. Since we have 3 sensors (gyroscope, accelerometer, and pressure sensor), and a single multi-colored LED, this places the total current draw at roughly 24 mA at 3.3V. This is within the operational range for the STM32-F3. One aspect that may need further analysis is whether the microcontroller can withstand adding the SD card storage system to it, but it should be able to as the average current draw for the STM32-F3 is about 150-200 mA away from its maximum current draw. We are not worried about overheating as the microcontroller isn't near max draw and physically won't be confined to an extremely small space, as it will rest on the shoe near or around the tongue.

3 Ethics and Safety

Ethical Concerns:

- Privacy: Privacy is of vital importance for all devices integrated into the daily life of the users. For securing privacy, we will have a very clear user interface and set of LEDs that will indicate when the device is recording data, and there will be physical buttons or a clear button in the user interface to end the recording.
- Data: We will ensure that user data is not being tracked when not permitted by the user. We also will not track any data that is not necessary to the operation of the device. All the accelerometer and gyroscope data will be the relative motion of the foot, as there will be no location tracking with our device. We will be compliant with the IEEE standards on wearable electronics [4] and their security objectives, specifically the objectives regarding data processing terminal application software and wireless communication.

Safety Concerns:

- Physical Safety: Physical safety is our top concern as we want to ensure that our device does not impede on the hiker's ability to conduct their hike. This will be achieved through our design and placement of the sensors to ensure the hiker has full range of motion while walking.
- Electrical Safety: Since the electronics in the design of this project are relatively low voltage and current, there are not major safety concerns. When assembling the circuitry we will follow relevant safety standards and ensure all wires are properly grounded, not exposed, or close to shearing. Accidental/incidental misuse of our device should not

result in significant harm, as the maximum voltage on this system is 5V. We will make sure our system is compliant with the IEEE standards on wearable electronics [4], specifically the minimum requirements for our type of lithium cell and battery and their discharge rate.

[4] "IEEE Standard for Wearable Consumer Electronic Devices--Overview and Architecture," in IEEE Std 360-2022 , vol., no., pp.1-35, 25 April 2022, doi: 10.1109/IEEESTD.2022.9762855.