IntelliSOLE

Project Proposal
ECE 445 (Spring 2022)

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1. Introduction

1.1. Description of Problem

Walking and running are activities many of us take for granted. Yet, any disruption to these activities could pose enormous challenges to our daily lives. As such, studying human motion is important in monitoring health and preventing injury. Mapping foot plantar pressure in real-time can provide insights into the wearer's foot posture, and identify potential health issues that stem from having abnormal gait, which range from flat feet to feet ulceration problems caused by diabetes [1]. While there are solutions for foot pressure mapping, such as pressure mats and treadmills, these are often high-cost products that are not easily accessible to the average person. Current pressure-mapping shoe insoles on the market also suffer from the issue of high-cost, and face many complaints of being uncomfortable and bulky to wear.

1.2. Solution

We aim at developing a low-cost, comfortable solution to mapping foot plantar pressure in real-time and provide the average user with information regarding their foot posture without having to see a doctor or spend lots of money on. We plan to develop a shoe insole sensor that is compatible with any shoe and pair it with a mobile device application that allows the user to see their foot pressure in real time.

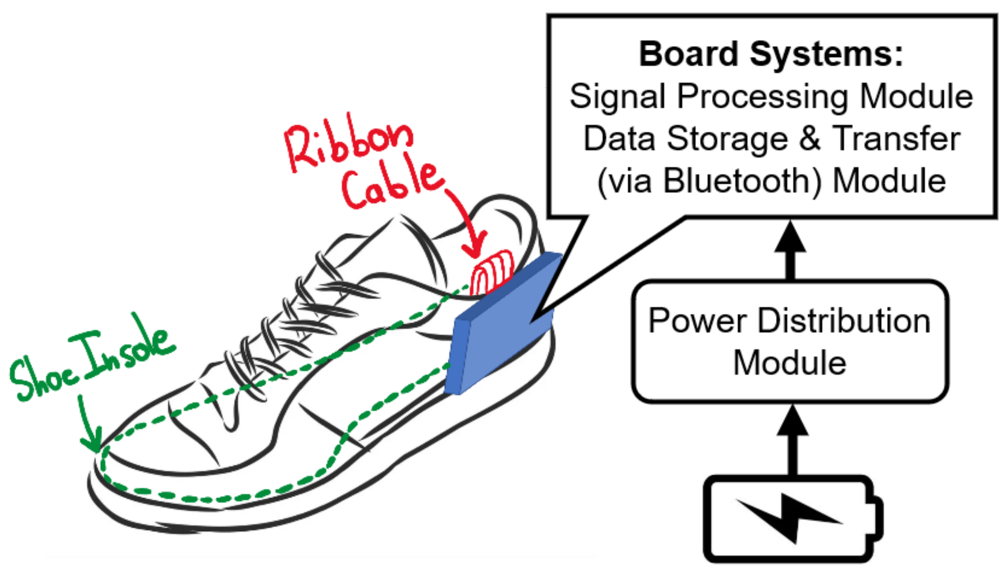

Figure 1.2.1. High-level Overview of Product Components (Visual Aid)

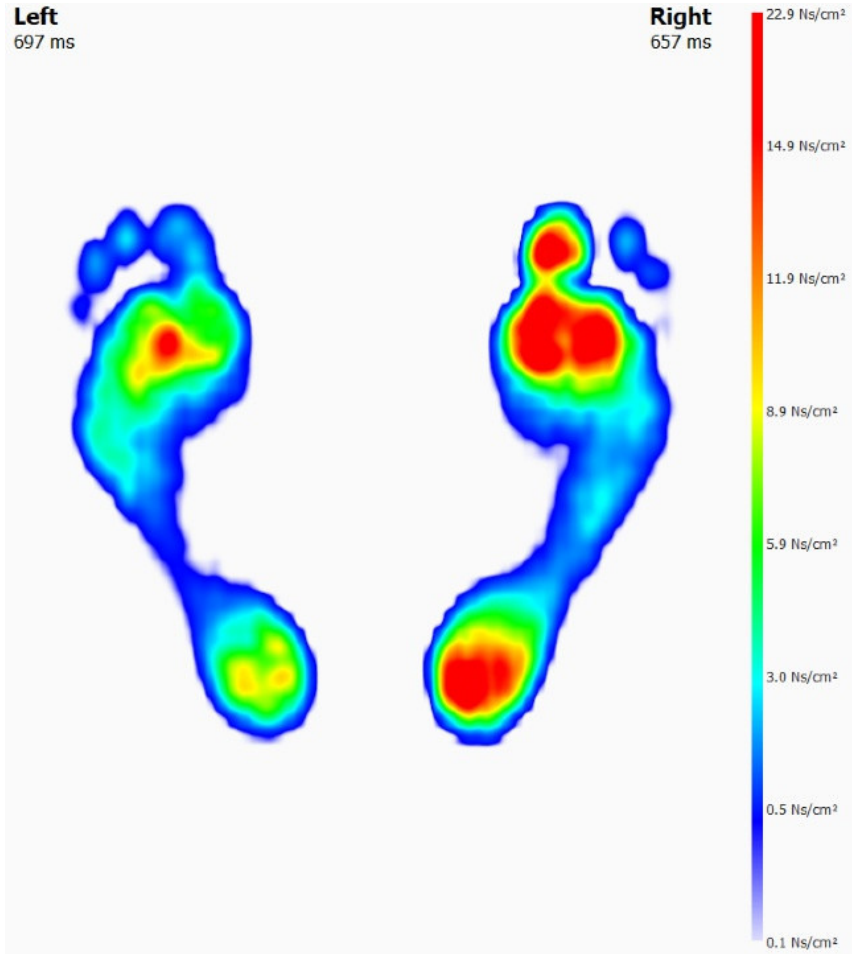

Figure 1.2.2. A visual representation of a pressure heatmap for both feet [2]. The scale bar (left) indicates foot pressure, from lowest (blue) to highest (red).

1.3. High-level Requirements List

Our success is defined by our ability to meet the criteria below:

1) Ability to sense pressure ranging from 1 kgf to at least 20 kgf for each sensor.
2) Develop a heatmap corresponding to this range, with blue indicating ~1kgf to red showing ~20 kgf of pressure.
3) Sample sensor data 10 times per second and store at least five minutes' worth of data.

2. Design

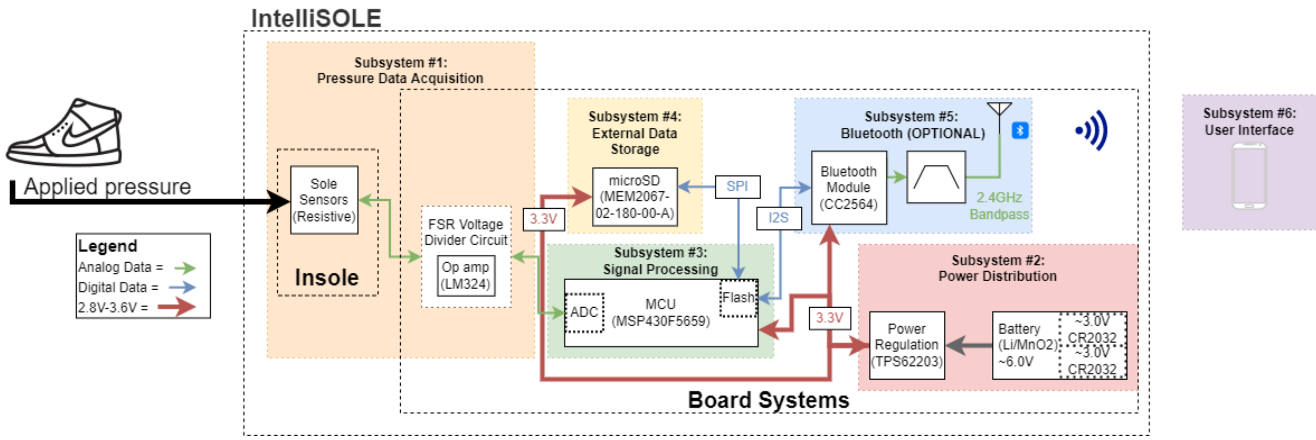

Figure 2.0.1. Subsystem Block Diagram

2.1. Subsystem Overview: Pressure Data Acquisition

The Pressure Data Acquisition subsystem is made up of a resistive matrix mat in the shape of a sole. The matrix consists of a layer of conductive copper rows and a layer of conductive copper columns with semiconductive material in between, such as Velostat. When pressure is applied to the resistive matrix, the corresponding row and column short a resistor in parallel. This short allows for detection of the applied pressure as a cartesian coordinate along the resistive matrix. The number of rows and columns scale directly with the resolution in the sensing.

<u>Subsystem Requirements:</u>

- Activation force at most 0.5kgf

2.2. Subsystem Overview: Power Distribution

The power distribution subsystem is incharge of powering all the board system components. All components of the system require an operational voltage between 2.8V and 3.6V. The power is supplied by two CR2032 batteries in series outputting a max voltage of ~6V. The voltage is stepped down by the TPS62203 step down converter from 6V to 3.3V with 95% efficiency. The TPS62203 has a maximum current limit of 300mA which will be limited by passive elements.

<u>Subsystem Requirements:</u>

- Steady output of 3.3V +/-0.3V
- Current output is limited at 250mA

2.3. Subsystem Overview: Signal Processing

The MSP430F5659 microcontroller samples the analog resistance coming in from the pressure data acquisition subsystem and applies an embedded FIR filter to remove noise. After the filter is applied, the filtered values are stored onboard flash. If bluetooth is not connected, the data is written to the external memory in the form of microSD. ADC convergence timing of 1000ns so the convergence frequency is 1MHz convergence frequency.

<u>Subsystem Requirements:</u>

- Resistance data sampling frequency of 1KHz

2.4. Subsystem Overview: Data Storage

The filtered data from the signal processing subsystem need to be stored on the microSD via SPI. Once the data is written to the microSD, the data on the microSD can be used by the device with the user interface subsystem implemented on it. The Bluetooth data transfer module is intended as a convenient alternative to transfer data between the microcontroller and the phone.

<u>Subsystem Requirements:</u>

- SCLOCK frequency of 400kHz
- Store at least 256KB of data

2.5. Subsystem Overview: Bluetooth Data Transfer (OPTIONAL)

The bluetooth module serves as a more convenient medium to communicate data from the microcontroller to the device with the user interface module. The module uses the CC2564 bluetooth module. The bluetooth module receives the data from the MCU via the I2S protocol. The bluetooth module encodes the data and runs through a bandpass filter before it is transmitted by a 2.4GHz antenna printed on the PCB.

<u>Subsystem Requirements:</u>

- Successfully pair with an android device
- Transfer at least 256KB of data between the MCU and user interface device.

2.6. Subsystem Overview: User Interface

The user interface interprets the sensor data and displays a heatmap for the user to visualize the foot pressure over time. This user interf

<u>Subsystem Requirements:</u>

- Read at least 256KB of data from microSD
- Generate a heatmap with real time data

2.7. Tolerance Analysis

One aspect of our design that poses the greatest challenge to the success of our project stems from the ability to acquire accurate data from the sensors. These components will experience a high degree of mechanical stress, and so it is important to verify that the sensor outputs remain consistent and reliable for a long period of time. The tolerance of pressure measurement can be limited to ±0.2 kgf, which is one percent of the expected maximum pressure value (as outlined in Section 1.3).

Another critical aspect of our design is the ADC conversion rate. Our design needs to be able to sample all sensor values. The ADC conversion period is 1000ns so the conversion rate is 1MHz. This means the out data can be sampled at a maximum frequency of 1MHz per ADC. We have 12 ADC's on board the MCU thus our implementation can sample 12 different values at 1MHz.

3. Ethics and Safety

The primary aim of this project is to map the user's feet plantar pressure in real-time in order to provide information on the wearer's foot posture. This correlates with IEEE's Code of Ethics Section I.2, which is to "improve the understanding by individuals of the capabilities of conventional and emerging technologies, including intelligent systems," as we are providing information regarding the wearer's health.

The mapping of the user's feet plantar pressure will be done by obtaining a finite set of sensor values from the shoe insole and using software to generate a continuous heatmap visualizing high and low areas of pressure (see Figure 1.2.2). As such, we need to ensure that the visuals seen by the user are as accurate as possible to the data collected. However, in accordance with IEEE's Code of Ethics Section I.5, we must acknowledge that there will be limitations of this accuracy based on the sensor resolution and sensitivity, the placement of sensors on the shoe insole, and the algorithms used in software to generate the pressure heatmaps.

As this is a wearable product meant for regular use, extra steps must be taken to ensure the safety of the user and prevent injury, in accordance with IEEE's Code of Ethics Section I.1. This device uses electrical circuitry powered by a battery, which has the potential to cause serious burns if power distribution is poorly handled. As such, fail-safe mechanisms designed to cut-off battery power must be implemented to ensure user safety. In addition, design considerations such as choosing slim sensors and keeping the microcontroller/battery assembly as light as possible must be considered to improve user comfort. This is particularly important as this product is aimed to be worn for long periods of time.

4. References

1. Razak, A. H., Zayegh, A., Begg, R. K., & Wahab, Y. (2012). Foot plantar pressure measurement system: a review. *Sensors (Basel, Switzerland)*, *12*(7), 9884–9912. https://doi.org/10.3390/s120709884
2. Image Source: *https://www.themedical.co.uk/blog/news/how-a-footscan-gait-analysis-will-help-you-get-the-best-3d-custom-orthotics*