Foot Posture Sensor Insole

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Group 29

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1. Introduction

1.1 Objective

Some patients with injuries develop a bad foot posture while walking, which can lead to knee issues and muscle mass loss. For growing children, if bad foot posture is not corrected, it can lead to significant muscle loss and even uneven growth in height of legs. Patients with mild cases of cerebral palsy also suffer from this and the only solution currently is physiotherapy and slings.

We propose to design shoes with pressure sensors embedded into the sole which will be prescribed by physiotherapists for patients. The sensors will detect bad foot configurations as determined by a physiotherapist and we will provide haptic feedback (vibrations) to alert the patient and to help them change their habits.

The device will be programmed by the physiotherapist using software we will provide. The device itself will have a start/stop recording button. The software will display a picture of the foot with all the pressure sensor positions shown on it. The physiotherapist will press start and ask the patient to walk and then press stop. After transferring the data over a micro-USB the software will display the different readings from the sensors as they had occured in real-time. This will let the physiotherapist know what he or she is dealing with. Next, he or she will have to choose when the vibrations go off based upon the relative difference in the readings from the sensors. He or she will then upload this data into the PCB through the micro-USB.

If someone has bad posture, they continuously keep their feet in the same wrong orientation while walking (confirmed by a physiotherapist). Therefore, once programmed, the insole will not need to be continuously updated, though occasional check-ups and reconfigurations may be necessary.

On the ankle band we will have a button that can be pressed which will shut off the vibration in cases where the user doesn't want vibration like sitting or other situations. The ankle band will be an extra piece to wear, but is a much better alternative to bulky slings.

1.2 Background

This posture correcting insole will be especially designed and catered for the use of posture correction by physiotherapists. Currently, people with long term injuries or mild cases of cerebral palsy undergo therapy sessions to bring back muscle mass/strength by performing repetitive exercises and wearing bulky slings. The patients suffer from muscle strength loss because they get used to orienting their foot a certain way due to long term injuries.

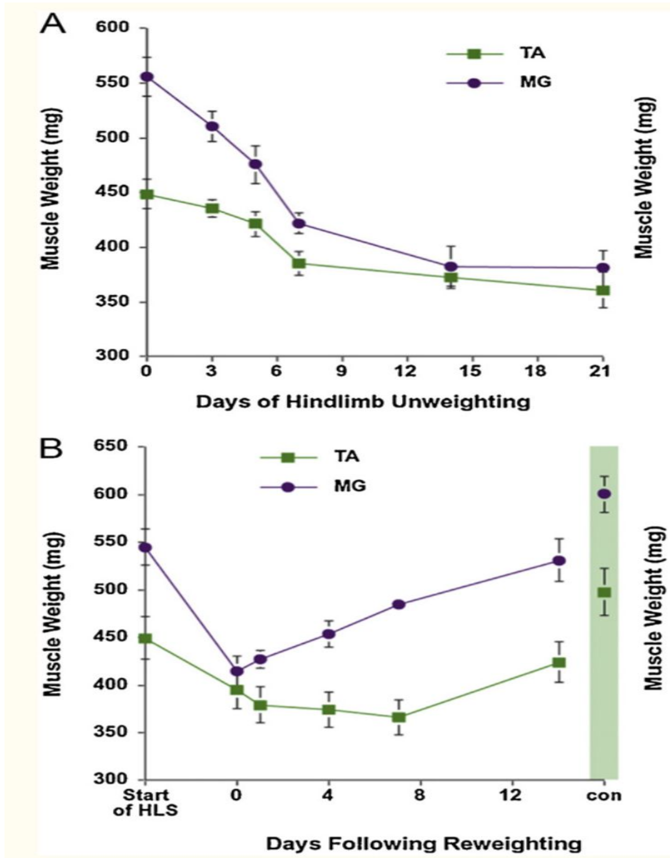


Fig 1. Bodine, S. (2020). Disuse-induced muscle wasting. [online] National Institute of health. Available at: Disuse-induced muscle wasting [Accessed 14 Feb. 2020].

The above graphs generated from a study represents how quickly the muscle weight can decay with disuse. When a patient walks with a wrong foot posture; for example, if the patient puts too much weight on the outer side of the foot the toe muscles are not utilized which decay over time. This will affect the soleus muscles located in the inner calf and eventually with continued improper walking posture the size of the leg and muscle strength will decrease. Long term, this may lead to limping due to weak muscles in the leg with improper walking posture. All these issues can be avoided if the patient can be continuously reminded to maintain proper walking posture during recovery period.

Currently, there are devices to map and record weight distribution (such as Tekscan Force Sensitive Insole and the SPI Foot Insole Sensor System), but they do not give real time feedback to help adjust posture right away. Our implementation is specialized for patients with long term injuries who develop bad walking foot posture to give them real time feedback.

1.3 High-Level Requirements

1. The pressure sensor insole can accurately and reliably transmit weight distribution data to microprocessor to map/visualize foot orientation.
2. If the user has an incorrect foot posture, the device should set off a vibrational reminder to correct foot posture.

3. Device can be controlled and data can be visualized through a software application.

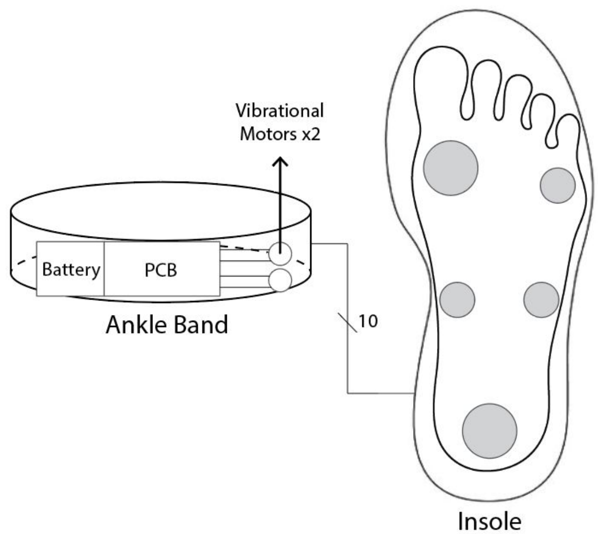


Figure 2. Physical design sketch.

Figure 4, is a representation of the physical layout of the shoe sensor insole that can be inserted into any shoe. The sensor insole containing 5 sensors will be connected to the ankle band via 10 wires. The ankle band will contain the Battery pack, PCB board which will be enclosed in a black box only displaying the status LEDs, and the vibrational motors (x2) will be connected on either side of the ankle band.

2. Design

The design will have 2 main components to it: the pressure insole and the ankle band. The pressure insole will have 5 pressure sensors. The pressure sensors will be connected to a processor on a PCB that we will design. The PCB, battery, buttons, vibration motors will be located on the ankle band.

The main blocks as shown in the block diagram are Power, Control Unit and the Pressure Sensors embedded into the insole.

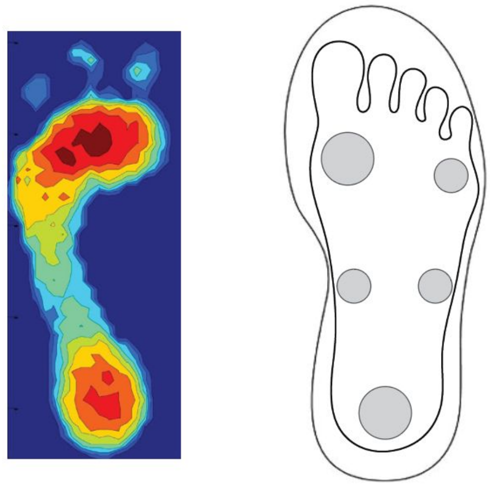


Fig. 3A High pressure zones of a foot (left)
Pressure sensor insole showing the sensor configuration(right)

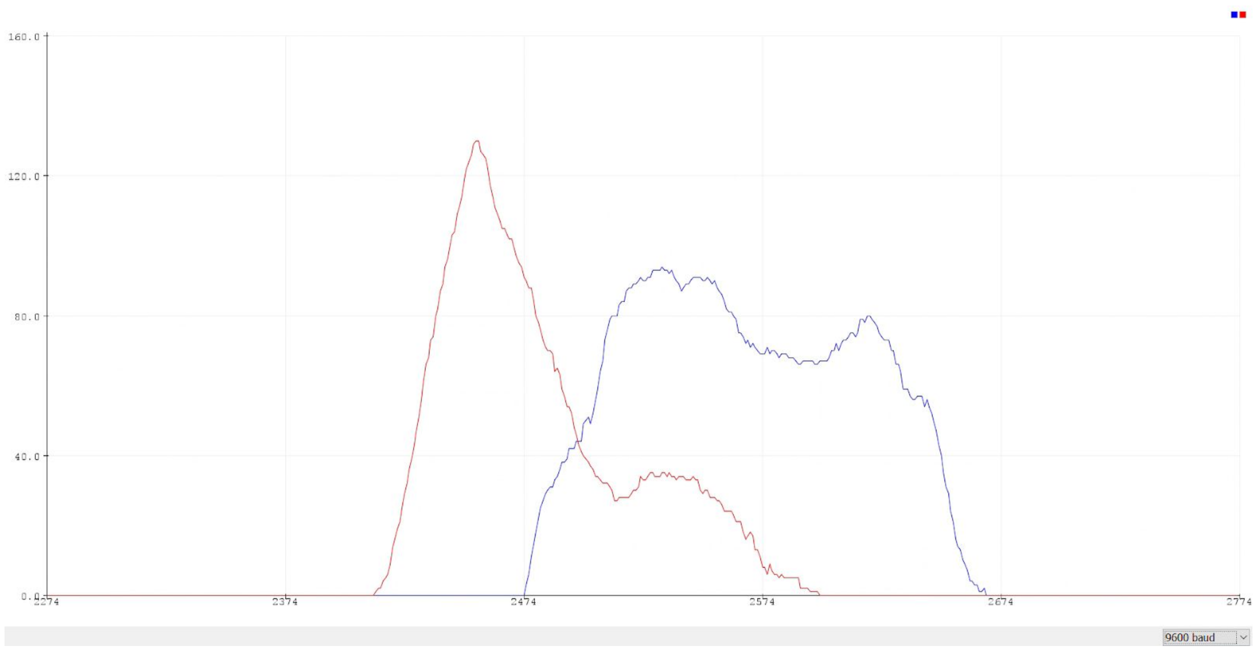


Fig. 3B Shows a normal response to a step: the red graph shows the heel sensor response and the blue graphs represents the front left sensor on the right foot.

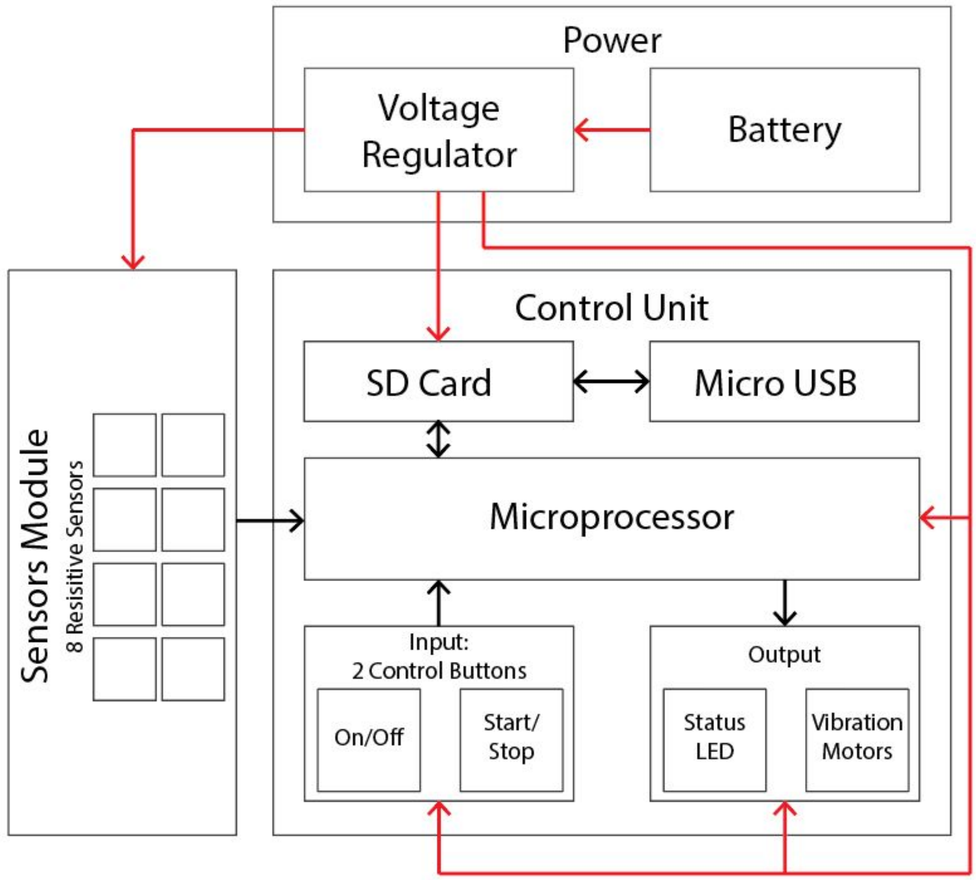


Figure 4. Block Diagram. Power is red and data is black.

2.1 Power

The power block is responsible for providing power to the PCB control unit. A battery pack will be attached to a voltage regulator to maintain the voltage level for the sub-components. The battery and voltage regulator will be attached onto the ankle band along with the control unit, in order to minimize bulkiness within the shoe. Rather than using a linear regulator, we will probably be using a switching regulator, since it is more efficient. Although linear regulators are less complicated, they are less efficient; any waste will be emitted through heat, which could potentially bother or harm someone using the device for prolonged periods of time.

2.2 Sensors Module

This includes the 5 pressure sensors which will be embedded into the insole. They will be wired to the ankle band containing the Control unit PCB and power. These sensors will be responsible for continuously collecting data points and feeding the data into the processor.

Requirements	Verification
1. *These will need to respond to pressure changes in under 100-200ms so that we do not miss any foot configurations.* 2. *These will likely need to be less than or equal to 2cm in diameter so that we can localize where the pressure is occuring. (We need to know how you are stepping rather than that you are stepping.)* 3. *These will need to be long-lasting and quite durable since they will be located in a challenging environment. In particular, if any change their response to pressure post doctor configuration, then this has the possibility of making the device useless or even harmful until a reconfiguration can occur.*	1. *We use an oscilloscope to measure how long before the voltage level reaches its max after setting a 5-kg weight on the sensor.* 2. *We use a ruler to measure the diameter. If the diameter is over 2cm then it fails.* 3. A. *For any sensor we plan to use, we measure its responses by placing weights of 3kg, 5kg, 10kg on top of it and then measuring its resistances in each case using one of the multimeters in the lab. Then, we put the sensor under pressure for a week with either with a 10kg weight or with a vice and check how its response changes afterwards. If any of the responses change by more than 10% then we have a problem.* B. *We have someone wear the insole for a day and verify that that it goes off for the same foot positions at the end of the day as in the beginning of the day.*

2.3 Control Unit

The control unit will be responsible for coordinating the bad foot posture with haptic feedback. It will have the processor which will be responsible to analyze the data points being fed to it by the pressure sensors and provide the user with vibration to remind them to correct their foot posture. It has an input block (control buttons), output block(status LEDs and vibration motors) and data management block (SD card and micro-USB).

1. Processor

The processor will always look for a match b/w the physiotherapist fed data points (the values of the sensor pressures when the wrong foot posture is achieved) and the data points collected. The data points being collected will be converted into an array and processed. Whenever a match is found the the processor will send a signal to the vibration motors to send haptic feedback to the user to remind them to correct their posture.

Requirement	Verifications
1. *This needs to be able to take a variety of input and output. It will be communicating with 5 pressure sensors, the SD card, and the vibration motors.*	*1.* *A. Verify before purchasing that it can accept input from 5 ADC pins concurrently, while outputting a True or False value on a separate pin and communicating with an SD card.* *B. Run alongside an Arduino to check that they produce similar outputs/graphs generated during preliminary tests.*

2. Input Block

The input has 2 control buttons -- on/off and start/stop. The on/off button enables the user to turn off the haptic feedback feature. There are many situations where the user may not want to get vibrations such as when the user is sitting. The start/stop button is for the physiotherapist to record the wrong foot posture and save those data points so that the processor can look for a match. The data being recorded during the start/stop by the physiotherapist will be sent to the SD card where it will be stored.

Requirements	Verifications
1. *Must be easy to press.* 2. *Must not record false events during vibration or normal movement.*	*1. Set 5kg weight on each button if it doesn't trigger then it fails.* *2.* *A. Connect this to the arduino. Then, we move around, and see if the arduino ever records a voltage over 1.3V.* *B. We jump up and down and see if the arduino records a voltage over 1.3V.* *C. We set off the vibration motors and see if the arduino records a voltage over 1.3V.* *D. We press each button and verify a smooth non-jumpy transition using an oscilloscope.*

3. Output Block

The output block has the status LED and the vibration motors. The status LED will be a multi-colored LED. It will let the user know if the vibration has been turned off (red) or on (green). The vibration motors are for the user haptic feedback. These vibration motors on the ankle band will be connected to the power and the processor. The processor will send a turn on/off signal to the vibration motors for the haptic feedback.

Requirements	**Verifications**
1. *Vibration must be felt even when moving.* 2. *Multi-colored LEDs must be visible from 1 meter away.*	1. *Have someone move around and check that they can still clearly feel the feedback.* 2. *Verify that you can clearly see whether the device is on or off while seated.*

4. SD Card

The SD Card is responsible for storing the bad foot posture data points when the physiotherapist records them. This will be powered by the voltage regulator (from the battery). The microprocessor will sift/process all the data and it will be sent to the SD card where it will be saved. Anyone can access this data through a micro-USB that connects to the SD card. The physiotherapist can also redownload new data points back to the SD card for new evaluations.

Requirement:

1. *Needs to be able to store physiotherapist's recorded data. This should be under 10MB at maximum. It is likely much much lower, we are only collecting 8 data points at a rate of less than 20Hz. Also, this collection should not be happening all the time, but only in the doctor's office during set-up.*

5. Micro-USB

The micro-USB enables the physiotherapist to download and visualize the data using software that we will provide. The physiotherapist will be able to see the data points, edit them and reload them to the SD card. There will also be a picture displaying the high pressure zones/ low pressure zones similar to (1a.). This will give the physiotherapist more control over the haptic feedback that the patient will receive.

Requirement:

1. *Needs be able to transfer data from the SD card and display the data points using software.*

2.6 Schematics and Graphs

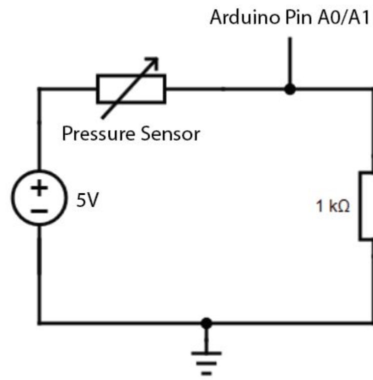


Figure 5. Internal schematic of the sensor insole connected with an Arduino.

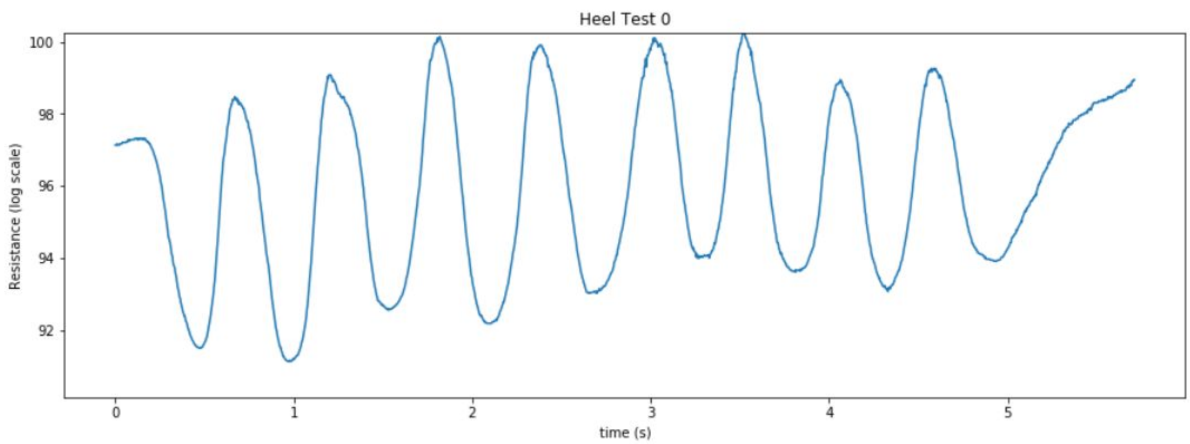
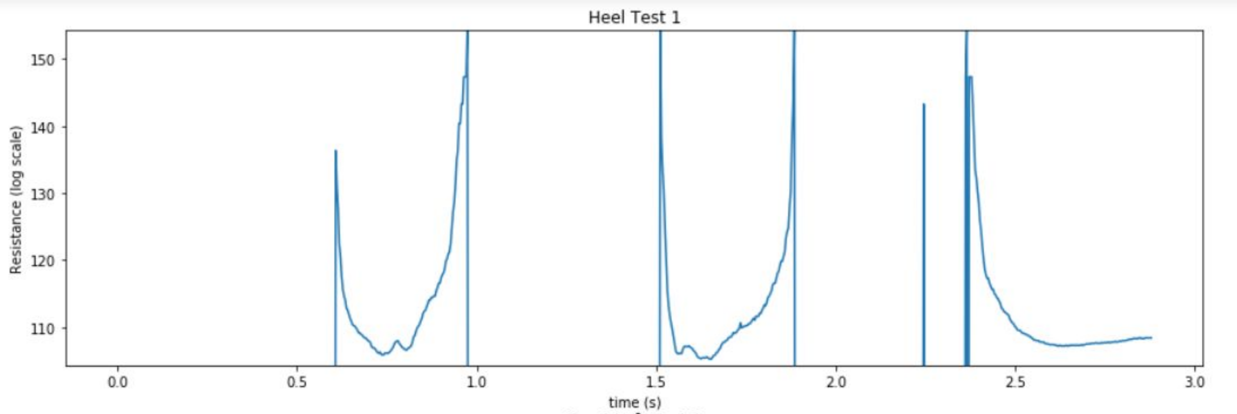
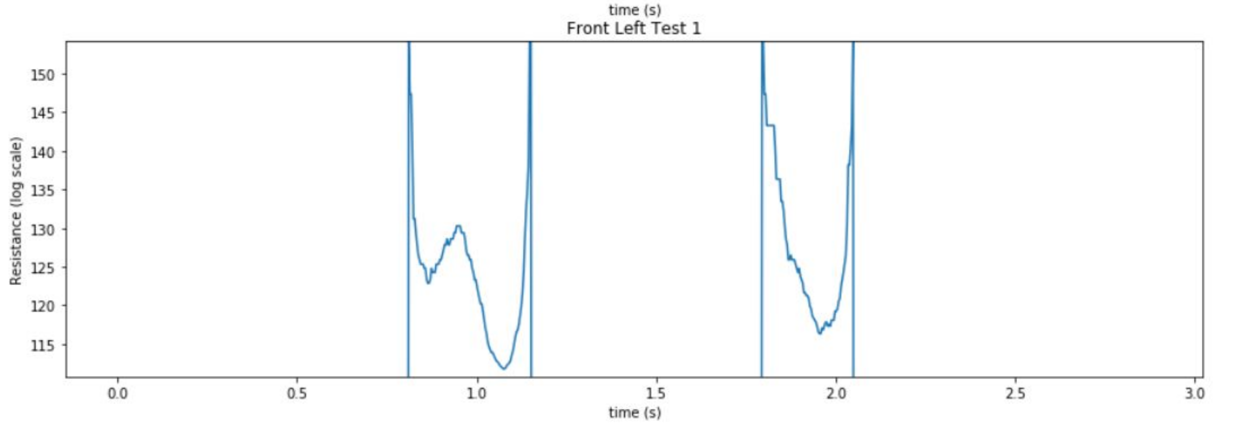
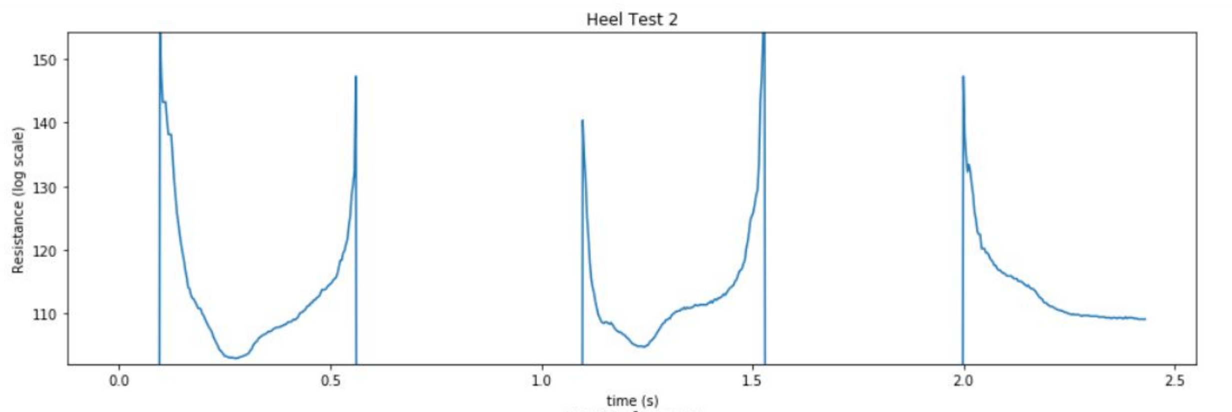
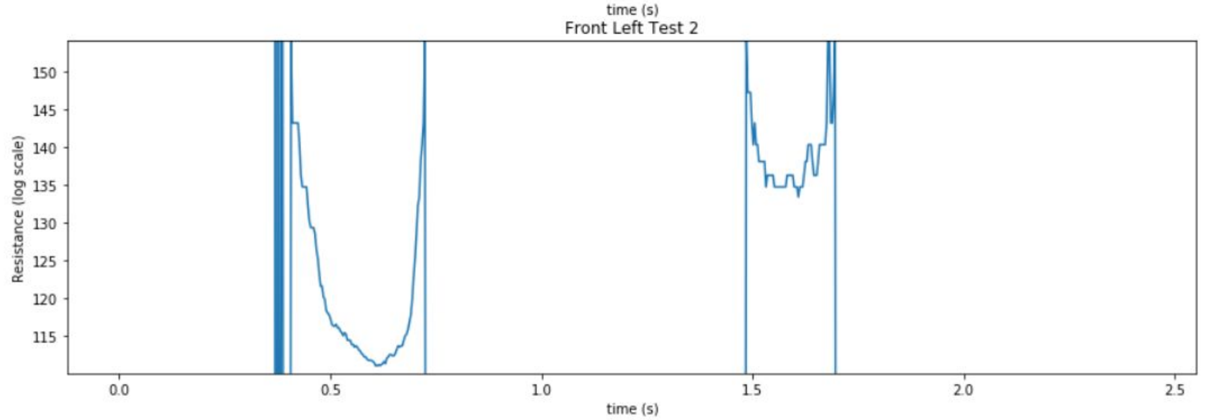


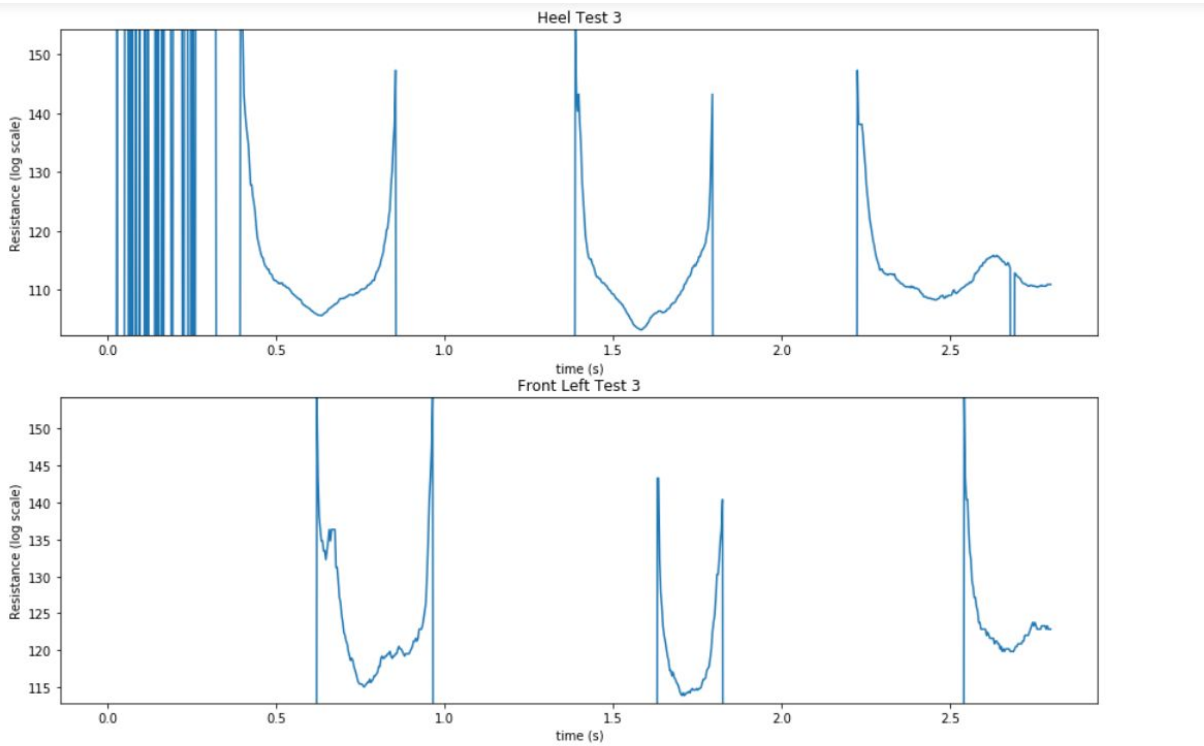
Figure 6. Initial data collection from the heel while bouncing foot. This was done by using force resistive resistors taped on the bottom of a foot and then inserted into a shoe (followed schematic in figure 5.) Initial readings were in milliVolts, but were then converted to the resistance of the pressure sensor using the following formula: $R = 1$ if $V = 0$ and $R = (5000 - V)/(V) * 1000$ otherwise where R was the resistance of the pressor sensor and V was the reading on the Arduino pin.


Heel Test 1
Resistance (log scale)
150
140
130
120
110
0.0
0.5
1.0
1.5
2.0
2.5
3.0
time (s)


Front Left Test 1
Resistance (log scale)
150
145
140
135
130
125
120
115
0.0
0.5
1.0
1.5
2.0
2.5
3.0
time (s)


Heel Test 2
Resistance (log scale)
150
140
130
120
110
0.0
0.5
1.0
1.5
2.0
2.5
time (s)


Front Left Test 2
Resistance (log scale)
150
145
140
135
130
125
120
115
0.0
0.5
1.0
1.5
2.0
2.5
time (s)



Figures 7-12: Subsequent tests performed while taking steps. In each test the top graph is from the sensor on the heel and the bottom graph is from a sensor on the front left of the right foot.

3. Risk Analysis:

Our riskiest module is probably our pressure sensors. They are going to be in a harsh environment and we need them to be consistent over time . If our sensors change their responses over time, then we can end up looking for different configurations than we were set to look for. This can cause it not to go off for the cases where it was supposed to or provide bad feedback by going off for ok foot configurations. This has the possibility of either further exacerbating the original problem by allowing the current bad habit to fester or introduce new problems for the patient by causing new bad habits. Additionally, unlike other potential problems our options are potentially limited by the characteristics of the hardware.

3.1 Test:

For any sensor we plan to use, we measure its responses, then put the sensor under pressure for a week or two and check how its response changes afterwards. If the responses change substantially then we have a problem.

3.2 Possible Solution Options (from most to least reliable):

Option 1:

Try a different type of sensor.

Option 2:

Occasionally have the user place the insole under a dozen books (or something else that should give uniform pressure.) They press a configure button and then our sensor handling adjusts based on the collected data.

Option 3:

Weather sensor before send off:

If the sensor changes a lot in response to extended pressure, but the changes drop off over time to the point where towards the end it is usable, then we could expose them to pressure before we send them out.

Option 4 (Most problematic):

Change configurations over time based on expected wear patterns (dangerous).

4. Safety and Ethics

4.1 Over-Corrections

One concern about our eventual product is that it might cause over-correction. For instance, there are probably certain configurations of one's foot that make sense if done occasionally but would be bad if done repeatedly over a long range of time. We don't want to cause the patient to avoid using the configuration in the instances where it makes sense.

As part of our design process we plan to do some testing on the sensors (finding the best place to put them, making sure our pressure range is adequate, etc…) we can have part of that testing be walking normally and checking the readings to forecast how many false positives we think we will have for instantaneous readings. If we decide that we are having too many, then we can change our approach to instead look at a range of readings over time and if we are spending a lot of time in a bad configuration, then activate feedback. (We should make sure sensors in combination are reading improper foot posture, instead of singular sensors setting off the vibrational motor. We could also implement an algorithm that would need a series of incorrect footsteps to activate the feedback, rather than one incorrect footstep, which could have been accidental.)

4.2 Distractions

Frequent responses from the vibrational module could become inhibiting and distracting. To counter this, we can apply similar techniques to the over-correcting problem. By making criteria for the vibrational feedback be a series of mistakes rather than a singular incorrect footstep, we can reduce the chances of unnecessary vibrations.

As with all medical devices, this insole should be used with care. This project design allows the user to turn off the vibrations to minimize distractions in dangerous situations or situations where the vibrations can distract the user. Wearing this device while doing activities like driving may be very distracting and lead to distracted driving/accidents.

The freedom over device control also gives the patient the luxury to switch off the device whenever they want to and reduce its effectiveness if they don't ensure its proper use. It is very important that the patient is self-driven to wear this device and ensure that it is worn as much as possible while walking.

Our beliefs align with the IEE Code of Ethics, #3: "to be honest and realistic in stating claims or estimates based on available data" [2]. We wish to achieve our results reliably by using data we collect and helping the patients. Our device can be misused by the patient if they do not wear it the number of recommended hours per day but the current solution are slings which have the same issue. We will try to ensure that our device provides real time feedback reliably.

5. References

1. Bodine, Sue C. "Disuse-induced muscle wasting." *The international journal of biochemistry & cell biology* vol. 45, *Biochemistry & Cell Biology*, U.S. National Library of Medicine, Oct. 2013, www.ncbi.nlm.nih.gov/pmc/articles/PMC3856924/.
2. Ieee.org, "IEEE IEEE Code of Ethics", 2016. [Online]. Available: http://www.ieee.org/about/corporate/governance/p7-8.html. [Accessed: 13- Feb- 2020].