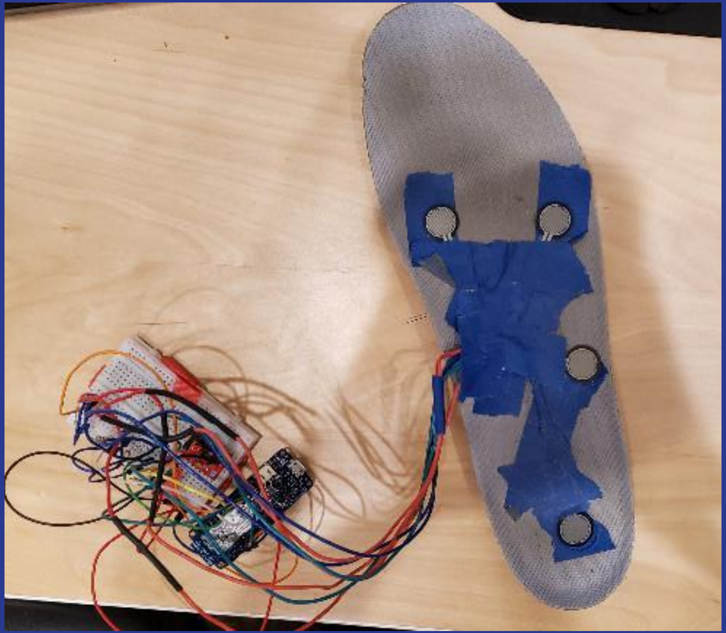
Building a wearable device to analyze Gait and Foot Pressure

Senior Project by Sahil Agrawal, May 2022



Objectives

- Project objectives
  - Design and build a wearable device to analyze foot pressure and gait
  - This analysis is aimed to detect body imbalances to prevent knee and ankle pain and injuries
  - It can also help promote knee and foot health by improving standing and walking habits
  - Multiple ankle and knee injuries while playing tennis inspired me to take on this project
- Learning objectives
  - Learn more about the kinesiology of the knee and ankle
  - Apply physics, computer science and engineering to find a solution to a real life problem in the field of health-care
  - Explore the potential of interdisciplinary learning

Terminology Used

- Pronation
- Supination
- Heel Strike
- Foot Flat
- Heel Off
- Stance Phase
- Swing Phase

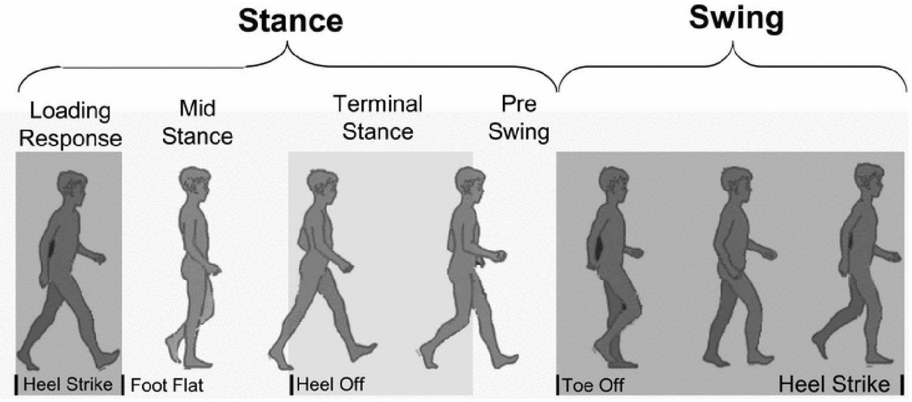
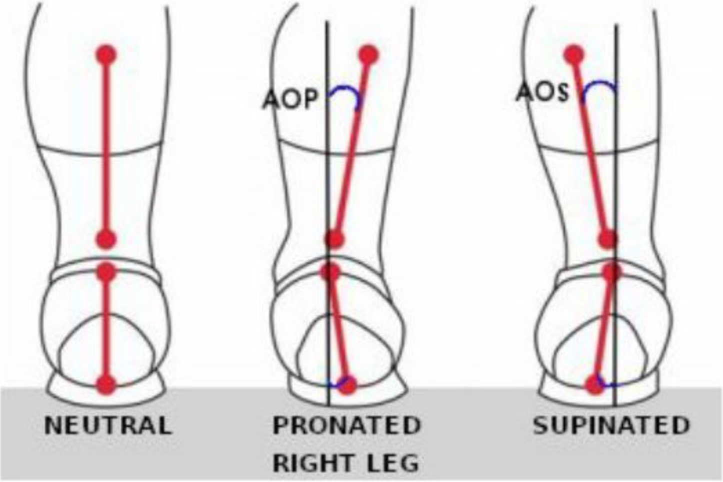


Image courtesy of U.S. Dept. of Veteran Affairs



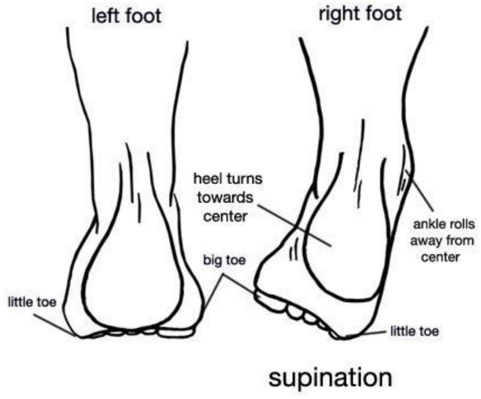
Feet Imbalances: Pronation and Supination

Caused by:

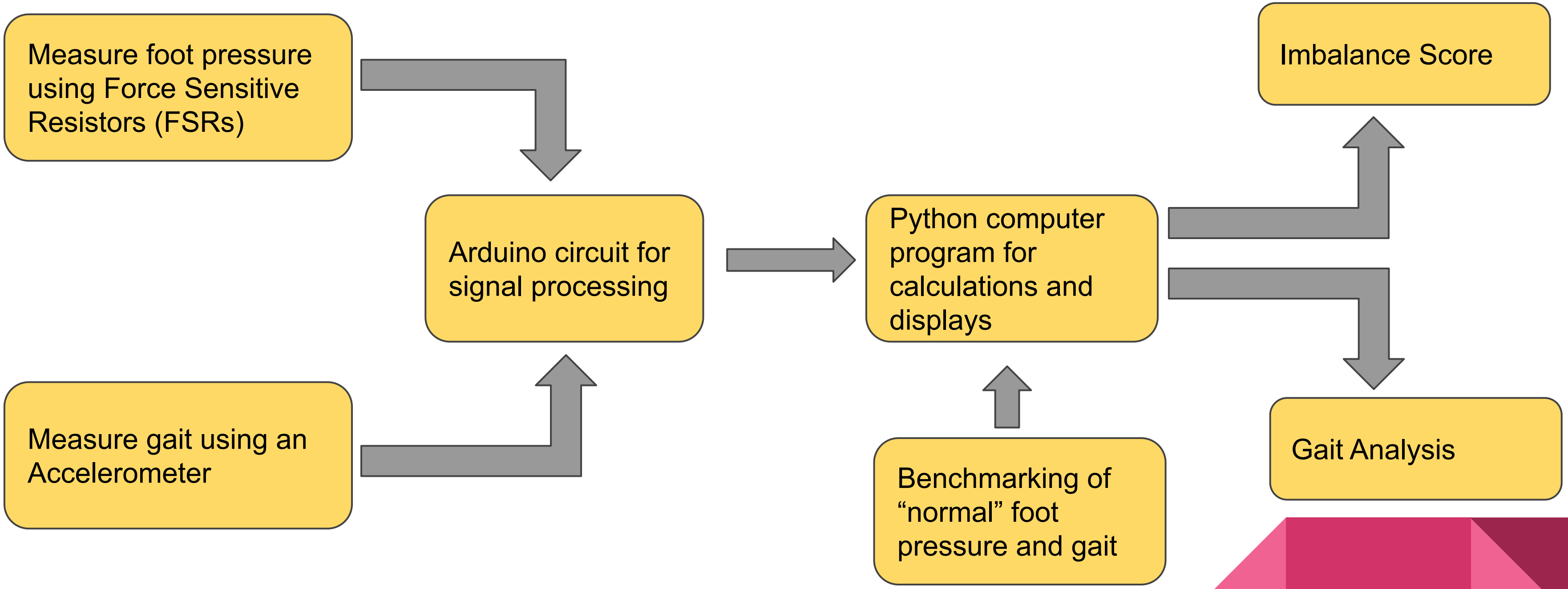
- Poor habits
    - Ex: Standing on the outer edge of foot
- Poor footwear
    - Ex: Wearing worn-down shoes
- Sports
    - Ex: Sudden stops and turns in tennis
- Past Injuries
    - Ex: Ankle sprains can result in a tendency to pronate or supinate

Result in:

- Knee, ankle, and foot pain/injuries
- Supination → ankle sprains, knee stress
- Pronation → plantar fasciitis (arch pain)



Overview of the Solution

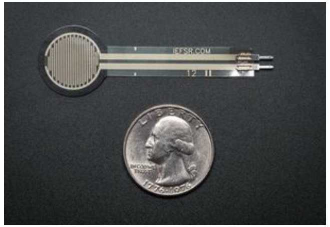


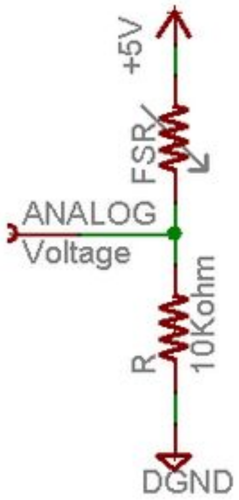
Measuring foot pressure using FSRs

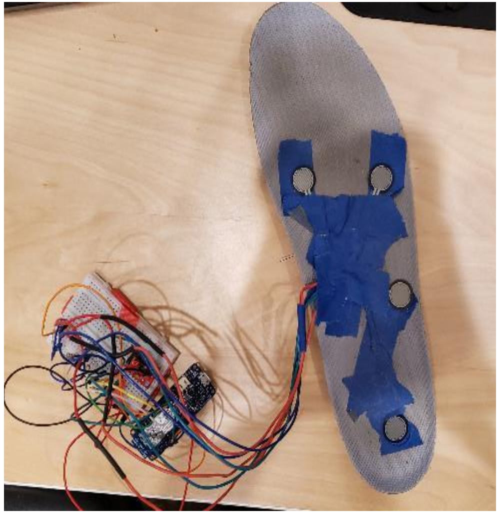
FSRs are variable resistors whose resistance varies with pressure applied.

Varying resistance is converted to analog signal using a voltage divider circuit.

Four FSRs are used to map the pressure distribution across the foot.







$$Vo = Vcc\ (\ R\ /\ (R + FSR)\ )$$

Measuring gait cycle using an accelerometer

Use accelerometer placed on back of the heel to identify location of the foot in the gait cycle

Minimum → heel strike
Middle → flat foot
Maximum → heel off

Create foot pressure maps for each stage of the gait cycle by combining data from FSRs and accelerometer

More useful than measuring the pressure map of just the standing foot

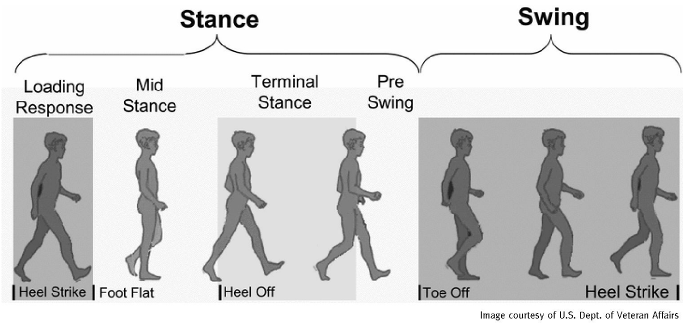
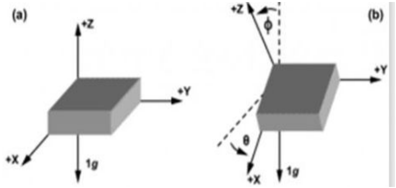
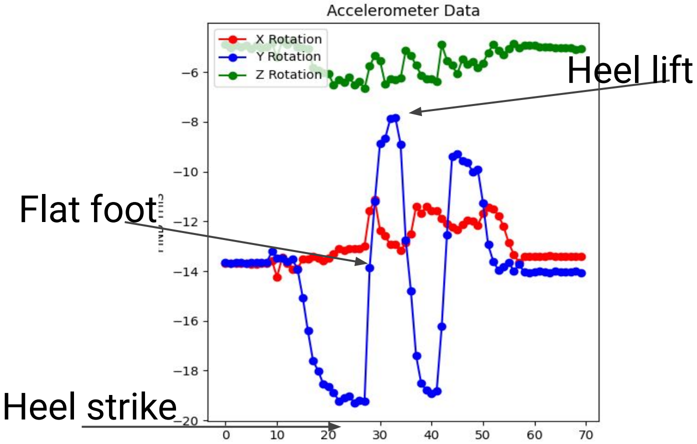


Figure 2: The Gait Cycle





Accelerometer measures changes in x, y, z angles (x, y, z rotations), which can be related to the stages of the gait cycle.

Arduino circuit and Python software

An Arduino circuit is used to read the analog data from the sensors, and convert it to digital signals

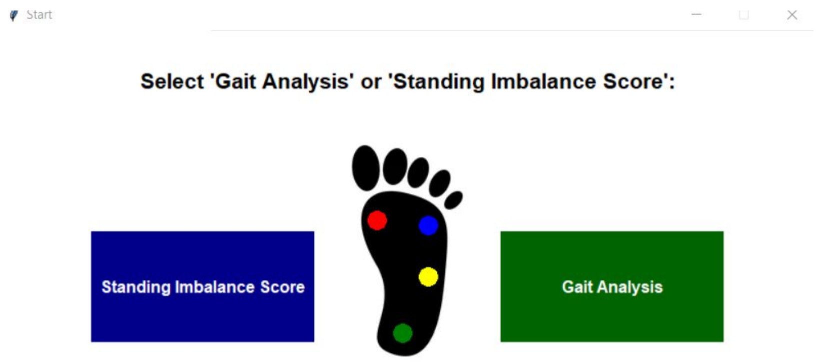
Original plan: Send the digital data to the IoT platform called Thinger.io.

- Thinger.io didn’t work - no way to do calculations with this data, and issue of Wifi latency

Revised plan: Send the digital data to Python using PySerial module. Python can do data calculations, as well as displays

The Python Program

- Functions of the program:
    - Take in Arduino input
    - Create a user-friendly interface
        - graphics
    - Show live graphs of the data
        - matplotlib
        - drawnow
    - Calculate imbalance scores for both standing and walking
        - numpy

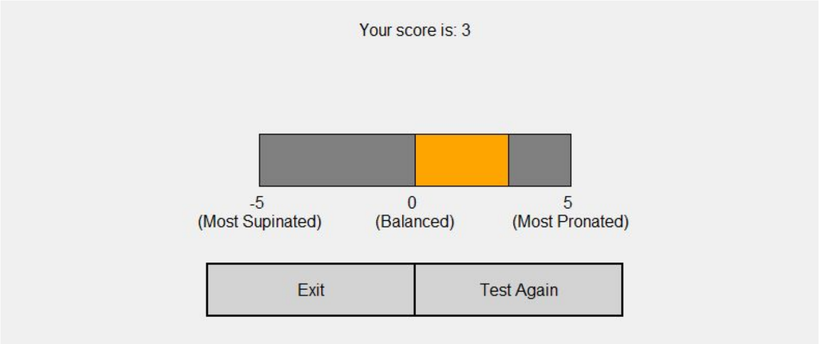


A user-interface lets the user select imbalance analysis while standing or walking

Calculation of standing imbalance scores

Benchmarking

- To quantify the imbalance, the first step is to assess the pressure map of a balanced (or normal) foot. Use pressure map data from a physical therapist and a chiropractor to determine the benchmark for a balanced foot.
- All pressure map data is converted into proportions of total pressure so that we can compare across users of varying weights.
- To find the imbalance score for a given subject, find the percentage of total pressure applied at each point and compares it to the benchmark data.
- Based on this comparison, the python program determines an imbalance score on a scale of -5 (most supinated) to 5 (most pronated).



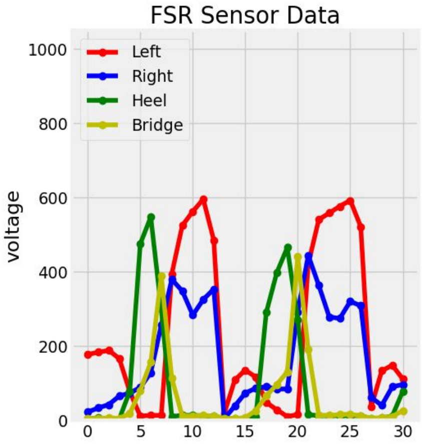
Gait Analysis

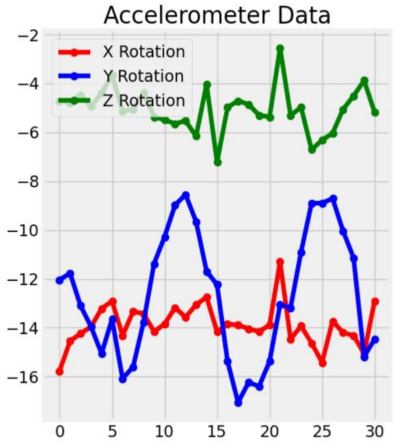
Gait Analysis produces two graphs:

On the right is the gait cycle graph in blue (foot location vs time). For example, heel strike occurs at t=6 and t=17 seconds when the blue graph is at the lowest points

On the left is the corresponding foot pressure map. For example, heel pressure (green) is at its maximum during heel strikes at t=6 and t=17 seconds

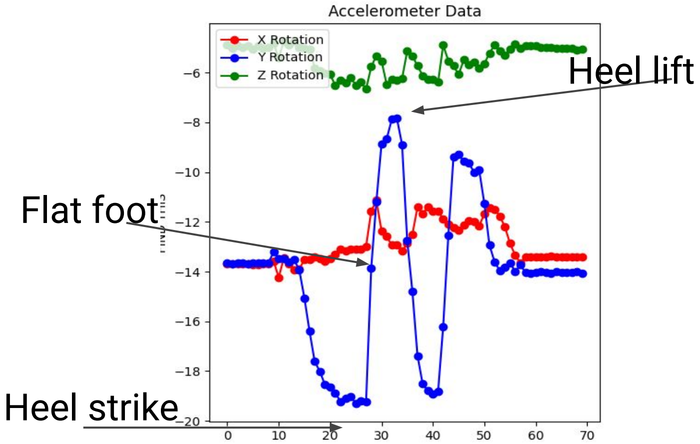
Left and right pressures peak during heel lift at t=12 and t=25s. Left pressure is higher than right pressure. Is that normal or abnormal? That has to be benchmarked by observing the pressure maps of normal subjects.

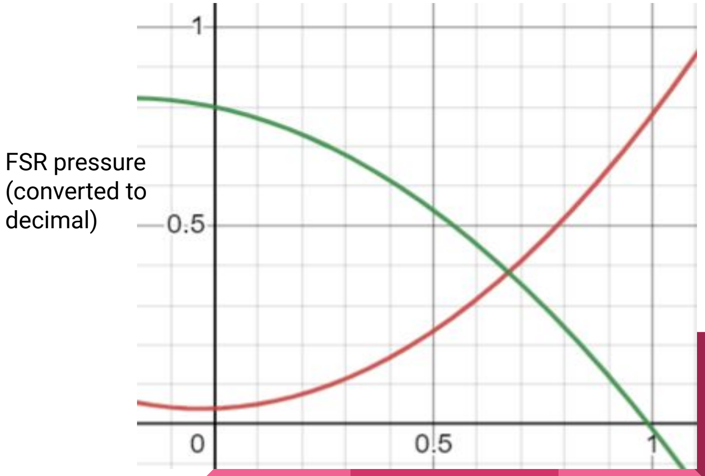




Calculating Imbalance Scores for the three stages of the Gait Cycle

- Use the accelerometer output (labeled as y-rotation) to identify the location of the foot in the gait cycle
  - y-rotation at low values → heel strike
  - y-rotation at middle values → flat foot
  - y-rotation at high values → heel off
- Continuous values of y-rotation are first rescaled to x=[0-1] range by turning them into percentages of the range (max-min), and then the continuous values are grouped into 3 categorical values corresponding to the above 3 stages. Grouping helps mitigate the noise in accelerometer data.
- Determine normal pressure map (benchmark) for each stage of the gait cycle using data from a chiropractor and a physical therapist. Fit a quadratic model to relate each stage of the gait cycle to the benchmark pressure values.
  - Examples: Front FSRs see high pressure in heel lift (x=0) stage (function1), while heel FSR has high pressure in heel strike (x=1) stage (function2).
- Evaluate a user's imbalance as a deviation from the above benchmark for each stage of the gait cycle.





Accelerometer Value (converted to decimal)

Red Line = Inside of foot, Green Line = Heel

Demo

Performed a live demo of the working model of the wearable device

Conclusion

Achieved both project objectives and learning objectives

- Designed and built a working wearable device to measure foot imbalances in standing as well as moving states. Gave live demos where users can see their own scores. Scores and methodology vetted by medical professionals.

- Learned that interdisciplinary work across physics, engineering, computer science, and biomechanics can lead to productive outcomes. Learned time management, organization, risk-taking and entrepreneurship.

- “Expect things are going to go wrong. And we always need to prepare ourselves for handling the unexpected.” - Neil Armstrong

Next steps: How would I take it further?