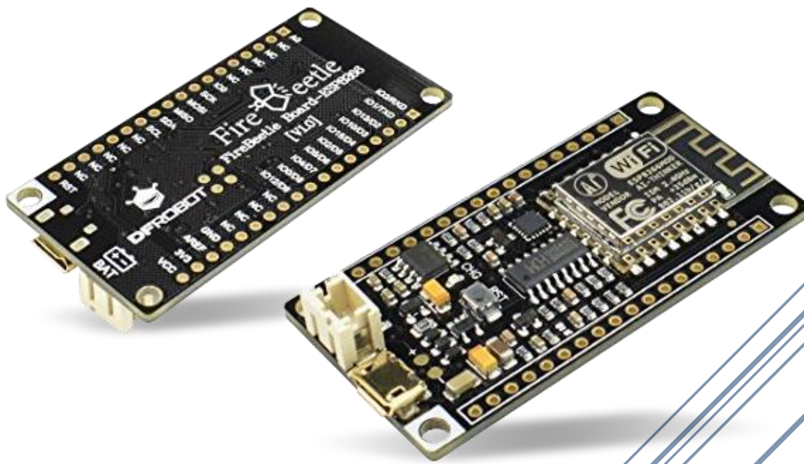
GAIT ANALYSIS

Smart-Shoe Insole Lab



Wearable Technology Laboratory (BME/CS 479)
Fall 2021 – Lab 3

Materials

1. FireBeetle Board-328P with BLE4.1
2. Micro USB Interface Cable
3. Rechargeable Lithium Battery
4. MPU-6050 (GY-521) Accelerometer
5. Your shoe outlines
6. Force Sensitive Resistors (FSR) x 4
7. LED x 4
8. Resistor (3.3 KOhm) x 4
9. Wire Wounding Wire & Tool
10. Proto board
11. Soldering tools
12. Female Headers

Background

Walking and running are convoluted combinations of multiple functions including balance, timing, and weight distribution that occur over each stride. Gait analysis is a method used to evaluate one's walking and running profile to identify pathological gait in cases of biomechanical abnormalities. Gait analysis is widely used in sports biomechanics to enhance athletes' efficiency in performing movements. In a healthy population, walking patterns vary amongst individuals; for example, some individuals favor the right or left side of their foot while stepping which could lead to an imbalance in weight distribution throughout the body. These patterns, in the long run, could lead to joints and cartilage complications. In extreme cases, these pathological abnormalities in gait could result in spinal cord-related complications such as disk degeneration. Gait analysis is mainly performed using force platforms that measure ground reaction forces exerted on the muscles. The forces are used to calculate electromyography (EMG) which indicates muscle activity. Often high-speed motion analysis videos are used in conjunction to force sensing to analyze motion. In this lab, we will be developing a wearable smart shoe insole with force sensors and accelerometers to analyze the user's gait.

Relevant Terminology

Before we start building our smart-shoe insole let's get familiar with some terminology:

- The walking cycle consists of two phases for each foot: a *Midstance Phase* and a *Swing Phase* (*Toe-Off* & *Heel-Strike*) (Fig 1). There are two periods of *Double Support* and one period of *Single-Leg Stance* during the walking gait cycle.

Figure 1: The gait cycle of a single foot.

- The spatial descriptors of gait are *Stride Length* (distance between two consecutive initial contacts of the same foot), *Step Length*, and *Step Width* as represented in Fig 2 and defined in Table 1.
- The temporal descriptors of gaits are *Stride Time* and *Step Time* that are respectively associated with the time it takes to complete the stride length and step length.

- The gait descriptors that involve both spatial and temporal are *Cadence* (number of steps per minute) and walking *Speed* (distance covered in a given amount of time).

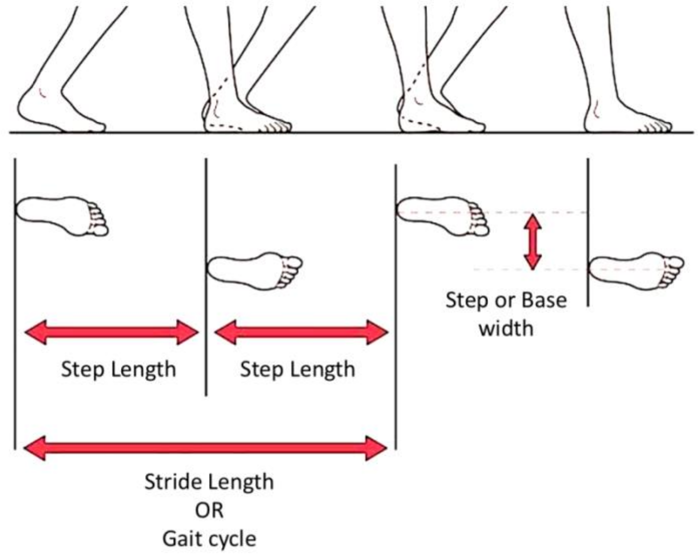


Figure 2: Gait Cycle, Step length and Step width.

Table 1: The Gait Cycle Terminology *(reference: https://clinicalgate.com/assessment-of-gait/)*

Gait Terminology	***Terminology Description***
Stride	*The sequence of events between successive heel strikes of the same foot*
Step	*The sequence of events between successive heel strikes of the opposite feet*
Stride length	*The distance between two successive heel strikes of the same foot*
Step length	*The distance between successive heel strikes of two different feet*
Step or Base Width	*The lateral distance between the heel centers of two consecutive foot contacts*
Cadence (step rate)	*Number of steps per minute*
Stride time	*Time for a full gait cycle*
Step time	*Time for completion of heel strike of right foot to heel strike of left foot*
Walking or gait speed	*Distance covered in a given amount of time*

- Another important spatial descriptor of the gait cycle is the *foot angle.* Some individuals have the tendency to turn their feet inwards instead of pointing straight ahead, this condition is referred to as *In-toeing* (where the angles between the heels is greater than 180 degrees). The counter condition is when the individual has the feet pointing outwards this condition is referred to as *Out-toeing* (where the angles between the heels is less than 180 degrees).

Figure 3: Feet position in Normal Gait, In-toeing, and Out-toeing.

Device Design

To create a smart insole wearable, you need to develop a force pad using Force Sensitive Resistors (FSR). FSR are sensors that consist of a dual-layer conductive ink that in theory acts as a variable resistor. When no pressure is exerted on the sensor the resistance value of the resistor is high (S_{ensor} = ~10 Mega Ohms). When an increasing force is applied to the sensor, the resistance of the sensor decreases exponentially with respect to the force exerted on the sensor. To develop the force pad, follow the following steps and the video:

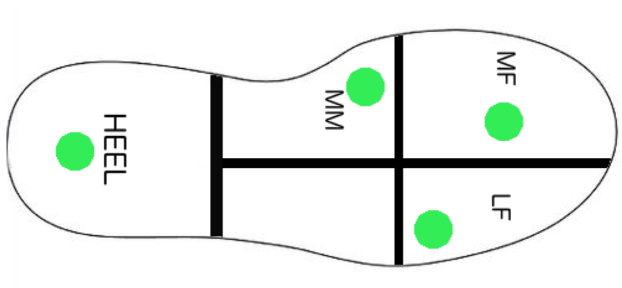


Figure 4: FSR sensor locations.

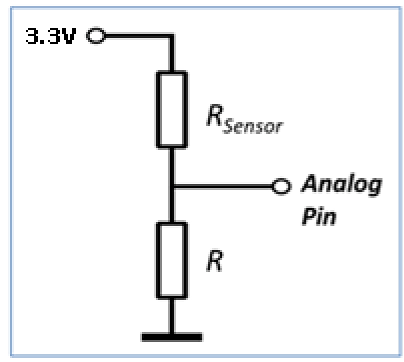


Figure 5: One FSR sensor circuit

Step 1. Create an outline of your shoe.
Step 2. Place FSR sensors at the Medial Forefoot (MF), the Lateral Mid-foot (LF), the Medial Mid-foot (MM), and Heel as shown in Fig 4.
Step 3. Create a voltage divider using the FSR and a 3.3 KOhm resistor (R) according to Fig 5.
Step 4. Setup the board to read the voltage from each FSR sensor.
Step 5. Place four LEDs between the ground and digital pins of the board. In the IDE code map the raw data from each FSR sensor to one of the four LEDs. Vary the LED brightness according to the force exerted on the FSR sensors. For example, if the user is tiptoeing, the forward sensor would experience the most force compared to the other sensors, which would result in the corresponding forward LED to light up brighter than the rest.

Important:

- For changing the LED intensity, connect them to the PWM digital pins (D3, 5,6,9,10,11).
- DO NOT solder to the FSRs.

Data Collection

Section I:

Measure your *Step length* and calculate your *Stride Length*. Attach the device to your shoe and ankle and walk for 2 minutes. Using the collected data calculate the following parameters:

1) *Cadence* (Number of steps per minute) 2) *Step Count*

Choose a user-friendly data visualization technique to present the calculated parameters. Show graphs corresponding to the output reading for each of the sensors.

Section II:

Wear the device and walk for 30 seconds according to each of the following five gait profiles. Save the output data for each profile of walking for further analysis:

Profile 1) *Normal Gait* (walking straight, feet parallel)
Profile 2) *In-toeing*
Profile 3) *Out-toeing*
Profile 4) *Tiptoeing*
Profile 5) *Walking on the heel*

To develop a metric for differentiating between the five profiles of walking, the Medial Force Percentage (MFP) value must be calculated. MFP is the impulse force percentage exerted on the medial section of the foot. MFP is calculated from cumulative pressure measurements taken during the stance phase according to the following equation:

$$MFP = \frac{(Pressure_{MM_t} + Pressure_{MF_t}) * 100}{Pressure_{MM_t} + Pressure_{MF_t} + Pressure_{LF_t} + Pressure_{Heel} + 0.001}$$

Calculate MFP for the above walking profiles. Analyze your data to identify metrics that could be used for automatic distinction of the profiles of walking. To test this metrics, perform the five profiles of walking in a random manner and test the algorithm for its efficiency in distinguishing walking profiles.

Section III:

In this section, you will be working with a 3-axis accelerometer and Gyroscope. The output of the accelerometer includes the orientation along X, Y and Z direction and its acceleration. Download the MPU-6050 Accelerometer libraries and utilize the included examples. Use the accelerometer to detect when the user is in motion (as opposed to standing still). Your interface should indicate the user's status by printing the appropriate message: "In Motion" or "Standing Still". Calculate the period of activity of the user.

Section IV:

Work with your group to implement a cool idea that would add an interesting feature/application to this wearable.

Module Requirements:

You will be graded on:

- *A working prototype for each member at the end of the module.*
- *A well organized and scientifically composed presentation (max 5 min).*
- *Your presentation should include all required graphs and visuals with accompanying interpretations of results.*
- *All team members are knowledgeable and able to build and use the circuit and the UI.*
- *Your creativity in representing your data.*
- *The uniqueness of your extra application for your device. (Section IV)*

Grading Rubric

Hardware:

- *Does the device work?*
- ***How compact and easily wearable the device is****?*
- *Size constraints consideration*
- *Are the soldering and arrangement of parts efficient and clean?*
- *How user friendly is the device?*

Interface & data processing:

- *User-friendly (effectiveness in data communication/ legibility of the UI)*
- *Accuracy of the data*
- *Noise reduction & signal processing algorithms*

Lab specific Calculations:

I. Parameters that need to be calculated, and the appropriate graphs:

- *Step length*
- *Stride length*
- *Cadence (Number of steps per minute)*
- *Step Count*

II. Different profiles of walking and calculating MFP:

- *Normal Gait (walking straight, feet parallel)*
- *In-toeing*
- *Out-toeing*
- *Tiptoeing*
- *Walking on the heel*

III. Accelerometer

- *In motion/standing still*
- *Period of Activity*

IV. Section IV

- *Creativity*
- *Implementation*

Presentation style in the video submission:

- *Each group member presented.*
- *Does everyone understand the concepts and demonstrate knowledge of the design?*
- *Are the figures and graphs logically designed and presented?*
- *Are the parameters clearly calculated?*
- *Is the data presentation clear and concise?*
- *Does the presentation last within the time frame?*

Partner Evaluation (each group member is evaluated by other group members)