BIOE/CS 494 Lab 3: GAIT ANALYSIS - Smart-Shoe Lab

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Abstract— During this Lab we assembled a wearable device equipped with 4 LEDs, 4 Force Sensitive Resistors (FSRs) and an accelerometer. The pressure signal, provided by the FSRs integrated into the sole of the shoe, gives information about where the subject is exerting pressure on the sole of the foot. The acceleration on three axes, provided by the accelerometers integrated in the peripheral board, allows to identify if and in which direction the subject is moving. Furthermore, the device is connected via bluetooth to the PC and transfers the data obtained to the Arduino platform. This platform reads the data and then sends them to a web page where they are processed and displayed in a user interface. The developed system calculates and shows the user his cadence and step count (Section 1), analyze and distinguish 5 different gait profiles (Section 2), determines when the user is in motion and calculates the user's activity period (Section 3). Furthermore, the device is able to use a rehabilitation mode that checks the correct positioning of the feet during the patient's walk (Section 4).

I. INTRODUCTION

Wearable health monitoring technologies, including smart watches and fitness trackers, have attracted considerable consumer interest over the past few years. Not only this interest has been mainly encouraged by the rapid demand growth in the wearable technology market for the ubiquitous, continuous, and pervasive monitoring of vital signs, but it has been leveraged by the state-of-the-art technological developments in sensor technology and wireless communications. Currently, modern wearable devices are no longer only focused on simple fitness tracking measurements such as the number of steps taken in a day, they also monitor important physiological considerations, such as Heart Rate Variability (HRV), glucose measures, blood pressure readings, and much additional health-related information. [1] Among the numerous vital parameters measured, gait analysis and the parameters connected to it are among the most studied thanks to the fact that it is possible to measure them with cheap tools. Over the years gait analysis technologies have been greatly improved to address the ever-changing requirements of their users, specifically in terms of measurement accuracy and wearing comfort.

In this lab 3 module, the sensors used for the purposes of creating a wearable fitness and gait analysis system were 4 Force Sensitive Resistors (FSR) and an accelerometer. The FSR sensor works on the physical principle of piezo-resistance: a particular resistive element follows the deformations of the surface of a sensor element (a sheet, a membrane, a wire, or other) to which it is fixed; these deformations (typically lengthening and shortening) cause a change in the electrical resistivity of the resistor material, and consequently its electrical resistance. By connecting to this element a measuring system capable of reading slight variations in resistance, it is possible to trace the extent of the deformation, and consequently the extent of the physical quantity that caused it. [2] The GY-521 module is a breakout board for the MPU-6050 MEMS (Microelectromechanical systems) that features a 3-axis gyroscope, a 3-axis accelerometer, a digital motion processor (DMP), and a temperature sensor. The sensor values are retrieved by using the I2C serial data bus, which requires only two wires (SCL and SDA) [3].

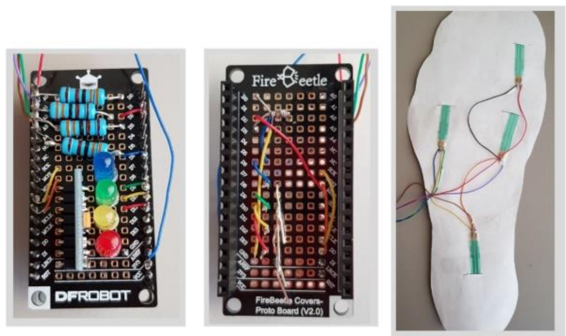

Figure 1. Connections and welded parts

In this lab we wanted to exploit the properties offered by pressure signals on the sole and the acceleration of the ankle to develop a wearable device able to record, analyze and extract features from gait.

II. METHODS

In this section, will be described how we developed the hardware and software components of the device.
In the figure 1 the connections done are shown. The electrical connections to each component were made via wire wrapping and soldering.

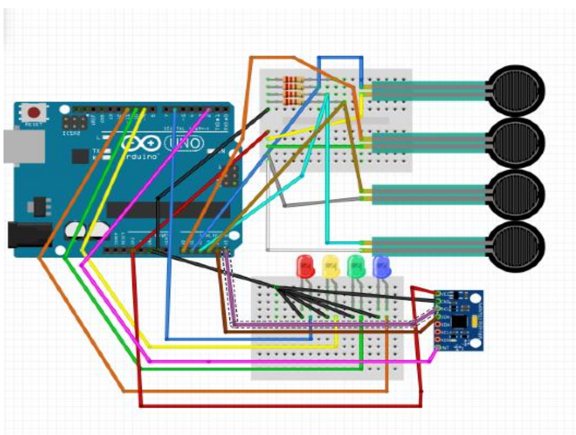

Figure 2. The Fritzing electronic diagram

A. Hardware

The electronics consisted of:

- FireBeetle Board-328P with BLE4.1 x 2,
- MPU-6050 (GY-521) Accelerometer,
- Micro USB Interface Cable,

- Rechargeable Lithium Battery,
- FireBeetle Proto Board,
- FSR x 4,
- 3.3 kOhm Resistor x 4,
- Elastic Band,
- Tape or Glue,
- Wire and Wire Wrapping Tool,
- Solder and Soldering Iron
- 3D Printed Clasp
- Athletic Tape

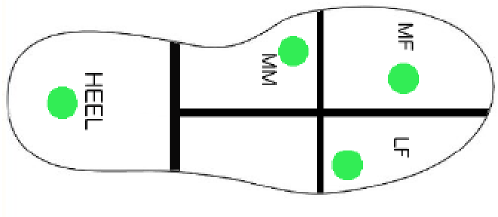

Figure 3. Adopted from Dr. Esmailbeigi's BIOE 494 Fall 2020 Lab 3 Manual.

The Fritzing electronic diagram shown in the (figure 2) displays the electrical routing of the components. Please note, that a Firebeetle board was used in place of an Arduino; however, the pins and connections are equivalent. It is important to underline how fundamental the positioning of the device is. The quality and the repeatability of the pressure signal is closely related to the location of the device. For optimal acquisition we followed the schema in the figure 3.

B. Software

The software developed for this project must be able to monitor the path and extract the necessary parameters to allow the operation and show the 4 modes. The software used for this Lab are: Arduino IDE, P5.js and an HTML editor like Visual studio. All Arduino, P5 and HTML codes are attached with our report submission as supplemental documents.

C. Section I – **Walking mode**

In this section the user, after wearing the device, should walk for two minutes. The device thanks to the measurement of the step length must be able to calculate the Stride length, the number of steps per minute (cadence) and step count. The interface should show graphs showing the sensor outputs.

D. Section II – **Walking profile recognition mode**

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

Figure 4. MFP formula. Adopted from Dr. Esmailbeigi's BIOE 494 Fall 2020 Lab 3 Manual.

While the Section 2 is active, the device should be able to:

1) collect 30 sec per each of the 5 profiles (Normal Gait, In-toeing, Out-toeing, Tiptoeing and walking on the heel)
2) Use a metric for differentiation the five different profiles of walking. An example of metric can be MFP (figure 4). MFP is the impulse force percentage exerted on the medial section of the foot.
3) Analyze the data collected and keep updated the interface as the user change his walking profile.


Figure 5. Final device

E. Section III – **Motion detection mode**

While the Section 3 is active, the device should be able to:

1) Use the 3-axis accelerometer and Gyroscope to detect when the user is in motion on in static standing position.
2) Show the user status in the interface with the message: "In Motion" or "Standing Still".
3) Compute the period of activity

F. Section IV – **Rehabilitation mode**

This mode should be an innovative application for this wearable. While the Mode 4 is active, the device should be able to:

1) monitor the gait of the user continuously
2) Check if the user is walking heel to toe
3) Alert the user when he is not walking in a physiological way


Figure 5a. Wearable strap on user to demonstrate use.

III. RESULTS

A. Device Housing (Figure 5)

The structure of my final device is composed of:

- an elastic band used to keep the device attached to the ankle,
- cardboard case for the peripheral board and the battery,
- a paper sole where the FSR sensors are attached,

The threads have been organized and rolled up (with athletic gauze) in such a way as to reduce bulk to a minimum. The sensors and the threads were secured to the sole by means of an adhesive tape.

B. Assembly

Apart from the final device presented in the video (figure 5 and 5a). Each member of the group created their own wearable device. To do this, only the tools present in the kit provided by the professor were used. The device built by me is the one shown in the video.

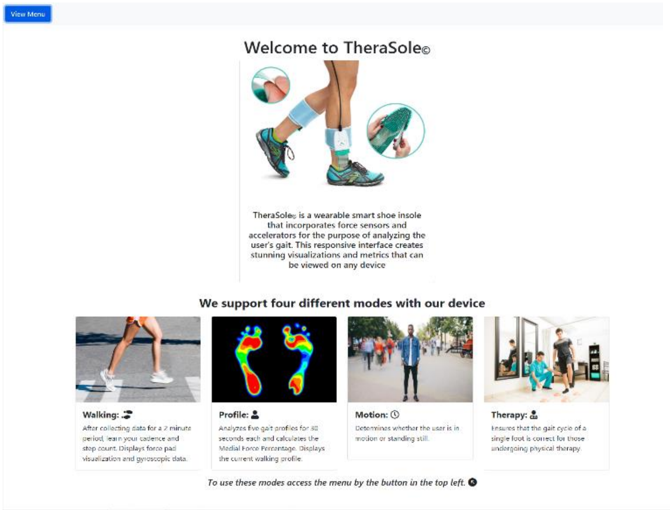

Figure 6. The home page

C. Interactive Home Screen

Figure 6 shows the first interface that appears as soon as the user open the HTML page.

This web page shows the device name and its functionalities in a user-friendly way. Here the user can learn how to use the device because all four modes are explained through the use of simple images and a brief explanation. From here the patient can also open the sliding window at the top right and select the mode they prefer.

D. Section I - Walking mode (Figure 7)

When the user selects mode 1, the interface asks to walk for two minutes. During these two minutes the system is able to calculate the stride length, the cadence and the number of steps in real time. Furthermore, while the subject is walking, 4 different graphs appear on the interface showing the value that the respective FSR is recording.

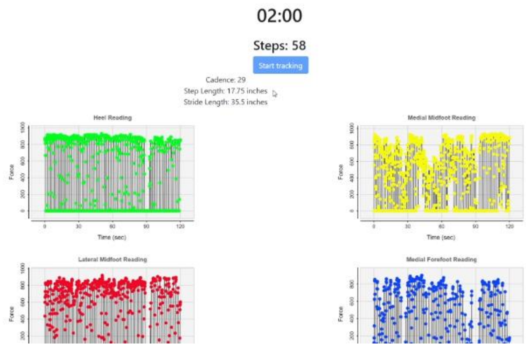

Figure 7. Section 1 – Walking mode

E. Section II - Walking profile recognition mode

When the patient selects mode 2, the interface that appears (Figure 8) asks the patient to calibrate the device for each gait profile. It takes 30 seconds for each profile. Once the calibration for each profile is complete, the interface changes, indicating with a green tick which are completed and which are not.

Once all the profiles have been calibrated (Figure 8a), the system allows the patient to start the recognition of the walking profile. During this phase the patient can change the walking mode to her liking and in real time the interface shows which walking profile she is recognizing. To recognize the type of path, the system uses the average values of the MFP and of the individual outpus FSRs recorded during calibration.

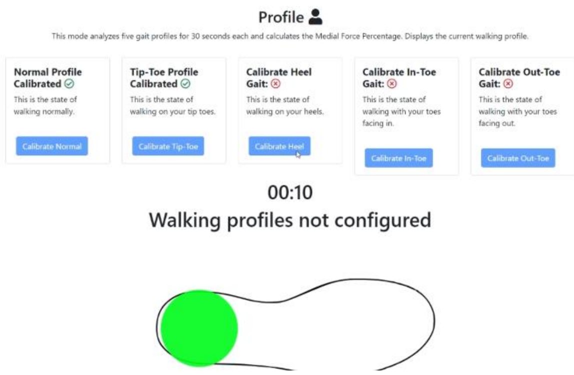

Figure 8. Section 2, Calibration interface

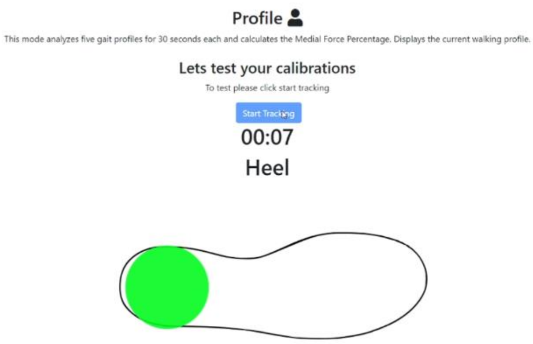

Figure 8a. Section 2, Walking profile recognition interface

F. Section III – Motion detection mode (Figure 9)

When the user uses mode 3 the interface indicates whether the patient is in motion or in a static position. To do this, use the accelerometer positioned on the peripheral board that is in the box near the ankle. Furthermore, the system is able to measure the activity time of the subject showing a timer that is increased accordingly to the movement activity.

G. Section IV

The innovative application for this wearable is: the rehabilitation mode. This mode is designed for patients who have suffered accidents and must resume normal walking activity. During this mode the device continuously checks whether the patient is walking in a physiological way by first positioning the heel, then the central sensors and finally the toe [4]. If the patient does not meet these requirements then the system notifies the patient that she is not walking correctly. To do this the interface shows a written message and also a sound notification.

IV. CONCLUSION

The final device proved to be a tool for

- monitoring normal gait,
- recognize the user's walking profile,
- detect if the user movement
- help and alert the user during rehabilitation sessions.

It is a device intended for a wide variety of subjects. Every healthy person can use this device so to measure their activity time and detect their walking profiles. However, the main target of this device are the elderly or people who have had an accident and must undergo periodic rehabilitation sessions. This device can allow them to carry out rehabilitation sessions independently and at the same time keep track of activity time.

It is important to specify that the device described in this report is not a finished product but rather a prototype that can be used as a basis for the design of a more compact and convenient device to use.

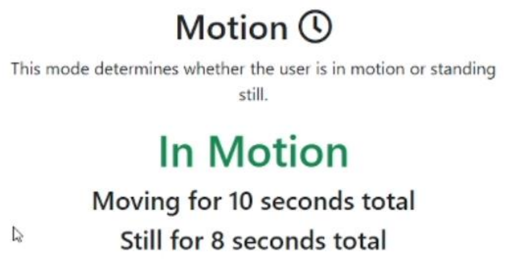

Figure 9. Section 3 Interface

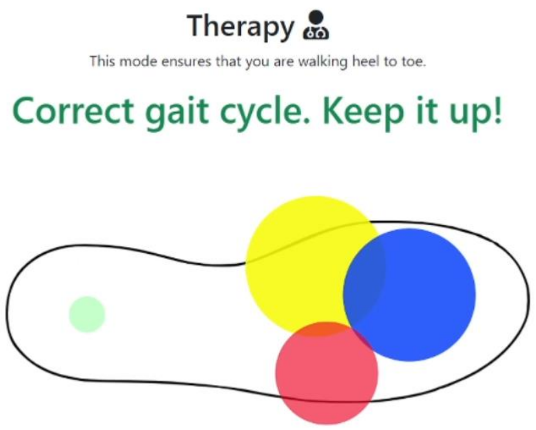

Figure 10. Rehabilitation Mode

A. Limitations

During this Lab some limits were found regarding the sizing of the device. The device is particularly bulky on the ankle. This is the downside of using multi-function boards like the Firebeetle. This type of board allows to interface many sensors but is at the same time rather bulky. The same goes for the MPU-6050 (GY-521) Accelerometer. It is an excellent sensor for prototypes but not optimal for building the construction of the final device. Another limitation of our design is the paper sole used to hold the FSR sensors and the cables. Not being custom designed, it leaves some room for movement for the sensor during exercise. This worsens the quality of the recorded signal, especially for the ECG signal. And also the paper sole start breaking after few trials due to the heat of the foot in the shoe.

B. Future Developments

This device is designed for people who need to resume and monitor their walking activity. In the future, new modes may be developed for sportsmen such as a running or yoga mode. Furthermore, the section for recognizing the type of path can be improved with the use of more elaborate measures that allow a clearer distinction of the various profiles.

REFERENCES

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