BIOE/CS 494 Lab 2: Heart Rate and Breathing Rate Strap

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BIOE 494 - Wearables Technology Lab - Spring 2021 - Lab 2 - February 23, 2021
BIOE Master - University of Illinois in Chicago (UIC)

Abstract—During this Lab we have designed and assembled a wearable device equipped with an ECG and a pressure sensor. The ECG signal, provided by the heart monitor board, give you information about the electrical activity of the heart. The Force Sensitive Resistor (FSR), incorporated in the chest strap, allows you to measure the changes in chest size so to compute the respiratory rate. Furthermore, the device is connected via bluetooth to the pc and transfers the data obtained on the Arduino platform. So we processed the data obtained and we programmed an interface capable of communicating with the user. This interface measures the heart rate at rest, the user's health parameters during exercise (Mode 1), evaluate the user's stress state (Mode 2), evaluate if the user is meditating (Mode 3) and measures user's health parameters during sleeping (Mode 4).

I. INTRODUCTION

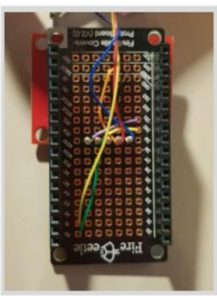
Wearable health monitoring technologies, including smart watches and fitness trackers, have attracted considerable consumer interest over the past few years. Not only this interest has been mainly encouraged by the rapid demand growth in the wearable technology market for the ubiquitous, continuous, 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. Among the numerous vital signs measured, the heart rate (HR) calculation and the respiratory rate have been some of the most valuable parameters. Traditional cardiac monitoring technologies using the ECG signals has undergone continuous improvements for decades to address the ever-changing requirements of their users, specifically in terms of measurement accuracy and wearing comfort. In this lab module, the sensors used for the purposes of creating a wearable fitness and stress tracking system was a heart rate board (with its electrodes) and Force Sensitive Resistor (FSR). The principle on which the measurement of the electrical activity of the heart is based is purely physio-logical: the onset of impulses in the myocardium leads to the generation of potential differences that vary in space and time and which can be acquired through electrodes. The acquisition of the potential difference by electrodes placed on the body surface occurs thanks to the conductivity of the interstitial fluid of the human body. The acquired signal is transformed into the electrocardiographic trace which represents the easiest, least expensive and most practical method to observe if the electrical activity of the heart is normal or if there are mechanical or bioelectrical pathologies. 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. In this second lab we wanted to exploit the properties offered by the ECG signal and FSR sensor to develop a smart band able to record and analyze fitness activities and track stress events.

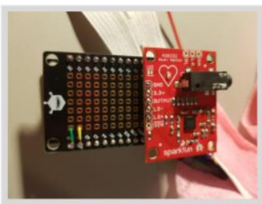
II. METHODS

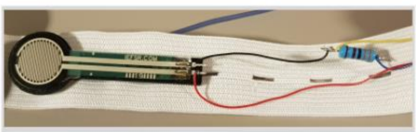
In this section, will be described how we developed the hardware and software components of the device.

A. Hardware

Aside from the PPG sensor, several other electronic and non-electronic components were used in the development of the smart fitness and stress tracker watch. The electronics consisted of: FireBeetle Board-328P with BLE4.1 x 2, Micro USB Interface Cable, Rechargeable Lithium Battery, FireBeetle Proto Board, AD8232 Heart Monitor, ECG Leads x 3, Snap-On ECG Electrodes, FSR 10 k0hm Resistor, Elastic Band, Tape or Glue, 3D Printed FSR Backing, 3D Printed Clasp, Wire and Wire Wrapping Tool, Solder and Soldering Iron, Athletic Tape







The Fritzing electronic diagram shown in the figure 1displays 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 of the ECG signal is closely related to the location of the device. For optimal acquisition, it is recommended to keep at a height that is under the chest and above the abdominals, at the height of the diaphragm.

B. Software

The software aim of this project is writing a code able to calculate the respiratory rate, the inhalation period, and the exhalation period, and display it on a interface. The software used for the completion of the project were: Arduino IDE, SparkFun BioSensor Hub Library, Processing, G4P Library and G4P GUI Builder Tool. All Arduino and Processing codes are attached with our report submission as supplemental documents.

C. Mode I - **Fitness Mode**

While the fitness mode is active, the device should be able to:

1) Calculate the resting heart rate of the user by collecting a 30 second baseline
2) After the 30 sec initial data collection, the interface compute the user-specific cardio zones. In order to do that it computes the maximum HR as:
   MaximumHR= 220−UserAge
   Then, the cardio zones are defined as showed in the figure 0. For example, a user with a maximum heart rate of 200 and with a current heart rate at 165 bpm would be in the hard cardio zone.

Figure 0. Fitness zones corresponding to heart rate ranges. Adopted from Dr. Esmailbeigi's BIOE 494 Fall 2020 Lab 2Manual.

3) Collect data while the user is performing a physical task, like running up and down the stairs. The task must be challenging enough to change the user cardio zone.
4) Show an interface able to display the user fitness activity.
5) Analyze the collected data and have the Interface display the user activity graph. This activity graph should be color-coded according to the period of the time you were at each cardio zone.

D. Mode II - **Relaxed vs Stress Mode**

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

1) collect 30 sec baseline data from the user and use it to display the resting heart rate and respiratory rate of the user.
2) measure the user hearth rate while the user is listening to some relaxing music and is trying to relax. The device should be able to report if the user is relaxed by comparing the resting HR with current user HR.
3) measure the user hearth rate while he/she is thinking of something particularly stressful for at least 60 second. The device should be able to report if the user is stressed by using the resting HR and the data recorded.
4) incorporate the emotion recognition mode in one inter-face.

E. Mode III - **Meditation Monitoring Mode**

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

1) collect 30 sec baseline data from the user and use it to display the resting heart rate and respiratory rate of the user.
2) measure the user hearth rate while the user is meditating
3) evaluate if the inhalation period is one third of the exhalation period.
4) interface should continually check to make sure if this breathing pattern is achieved. If for 3 consecutive breaths this criterion is not met an indicator on your interface should be activated.

Figure 1a. Wearable strap on user to demonstrate use.

F. Mode IV - **Sleeping Mode**

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

1) collect 30 sec baseline data from the user and use it to display the resting heart rate and respiratory rate of the user.
2) measure the hearth rate and breathing rate while the user is sleeping
3) evaluate how much time the user is in REM phase.

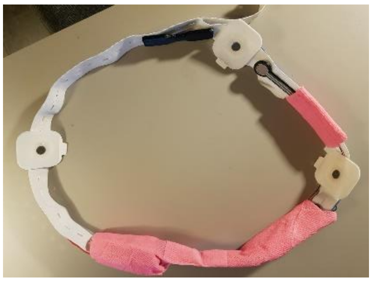


Figure 1. Final device of the group

III. RESULTS

A. Device Housing

The structure of the final device of the group is composed of an elastic band that acts as the backbone of the device. the various sensors are attached to it. The threads have been organized and rolled up in such a way as to reduce bulk to a minimum. The sensors and the threads were secured to the elastic by means of an adhesive gauze.

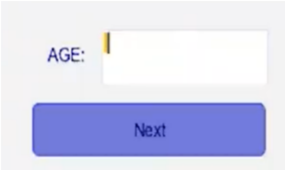


Figure 2. Enter your age

B. Assembly

Apart from the final device presented in the video (figure 1). 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.

C. Interactive Home Screen

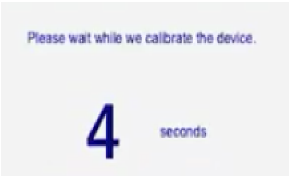


Figure 3. Calibration

Figure 2 shows the first interface that appears as soon as the device is turned on. In this interface the user is asked to enter his age. This data will then be used later to calculate the cardio zones.

After that the interface changes (figure 3) and ask the user to wait 5 seconds to allow the system to calibrate the FSR sensor. During calibration, the system is computing the threshold for the FSR sensor. With this threshold, the system is able to determine in a more accurate way the data about respiration.

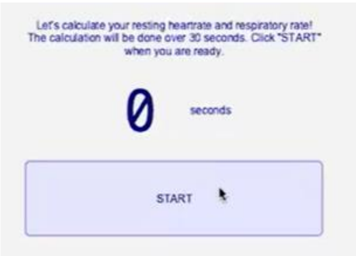


Figure 4. 30s resting recording

Then the 30 second resting calculation start. When the resting HR and RR (respiratory rate) calculation is finished, the home page appears. Here all the information found during the previous part is displayed. Figure 5 shows one of the test made.

D. Mode I

When the user selects mode 1, the system offers two buttons: "Start Checking" and "Stop Checking". Once the button "start" is pressed the interface will show the user exercise time. When the user decides to terminate the activity, he presses the appropriate button and the screen showing the analysis of the collected data will appear. The final screen (Figure 6) of the fitness model presents the graph showing the HR trend (as you can see it is extremely disturbed). While the bar chart above to be visible requires at least one minute of recording for each cardio zone to be visible. The bar chart intends to show the cardio zones and the time that the user spends within them. It also indicates the average inhalation and exhalation time with the number of breaths per minute.

We worked a lot of ours to make it work but the ECG signal presents too much noise during exercises to makes the peak recognition reliable. From the graph we obtained in the figure 6 we can see a general average trend of the heart rate but overall the software needs more time to make it work in a reliable way. And also the device is almost unusable during exercise due to the noise created by the muscle

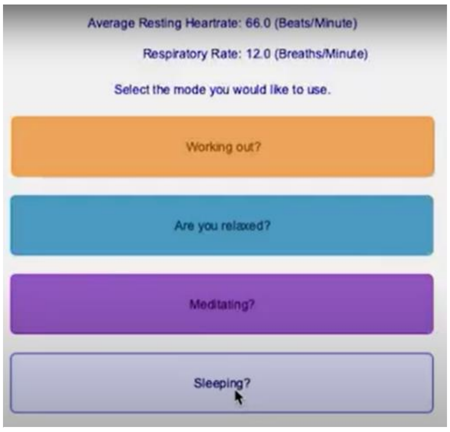


Figure 5. The Home page

E. Mode II - Stress monitoring mode

During the stress monitoring mode HR and RR are measured. The measurements taken are then used together with the baseline heart rate and RR to determine the user's stress state. If the heart rate is higher than 10 bpm compared to the baseline value and if the breaths are 4 units above the baseline then the interface alerts the patient of his state of stress (Figure 7). These values were retrieved from the literature [S. Hammoud et al., 2018; W. M. Suess et al.].

F. Mode III – Meditation Mode (Figure 8)

During the meditation monitoring mode, the HR and RR recorded and the baselines were used to determine the breathing patterns during meditation. Specifically, the expiration time and inspiration period are calculated. The ratio of the two values is used to determine if the user is meditating. As the inhale time is one third of the exhalation period, the meditation breathing pattern is achieved and the interface will display a message stating, "**You are**

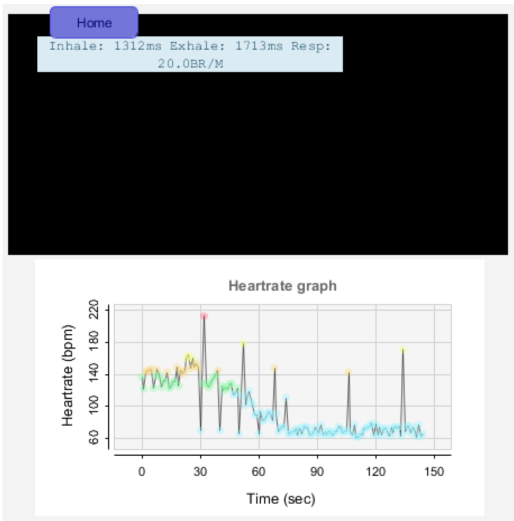


Figure 6. Fitness Mode – Final Graphs

meditating". Conversely, if the breathing pattern was not met for three consecutive breaths, the interface will display a message stating, "**Work on your breathe**".

G. Mode IV - Sleep mode (Figure 9)
The innovative application for this wearable is**: the sleep mode**.
During this mode the baseline HR and RR are compared to the instantaneous measures in order to determine in the user is in rapid eye movement (REM) sleep. During REM sleep, an individual's heart rate increases approximately 10 beats per

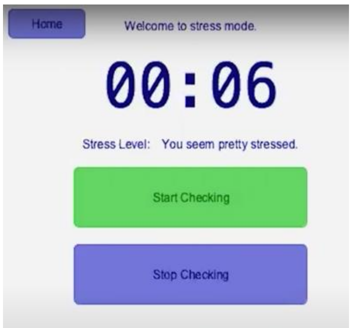


Figure 7. Stress Mode Interface

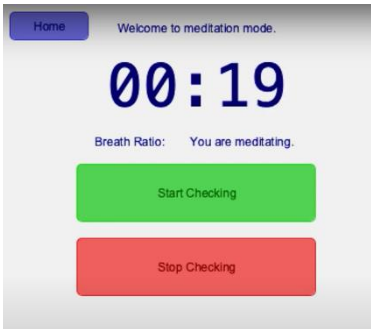


Figure 8. Meditation Mode Interface

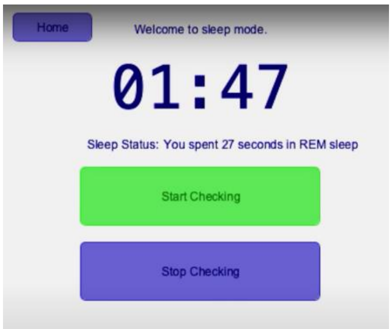


Figure 9. Sleep Mode Interface

minute (bpm), which could be used to determine if the individual is, in fact, in this stage of sleep [M. Bonnet et al., 1997]. Once the user selects to end this mode, the interface shows you how much time the user were in the REM mode.

IV. CONCLUSION

The final device proved to be a tool for measuring sports activity, the user's state of stress, meditation and sleep monitoring. It is a device intended for any subject. From the student who wants to monitor his state of stress to a sportsman who wants to measure his heart rate during physical activity. Also, elderly people can use this kind of device so to monitor their sleeping. 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.

A. Limitations
During this lab some limits were found regarding the sizing of the device. The device is particularly bulky on the chest. 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 Sparkfun sensor. 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 piece of gauze used to hold the 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.

B. Future Developments
The analysis of the user's stress state in this device is done only on the basis of the heartbeat. More thorough and in-depth research may be done in the future to determine other health indicators for stress. To improve the device and detect new parameters, new sensors can be added on the hand, such as the sensor for measuring sweat. The data obtained by the sensors can be processed and combined to generate increasingly clear and direct graphics, which can communicate to the user a more complete view of his state of health. Also design a band such that electrode placement is better for measuring the ECG signal.

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