BIOE/CS 494 Lab 1: Wearable Photoplethysmogram (PPG)

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***Abstract*—During this Lab we have designed and assembled a wearable device equipped with a photoplethymographic sensor. This PPG sensor allows you to measure heart rate and blood saturation. 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) and it is able to evaluate the user's stress state (Mode 2). The device is also able to communicate to the user through a buzzer that his stress level is too high.**

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 has been one of the most valuable parameters. Even though 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 ability as shown in, these techniques, up to now, have not been enhanced to the point of offering the user flexibility, portability, and convenience. Furthermore it has been demonstrated that by using detailed signal analysis, the PPG signal offers an excellent potential to replace ECG recordings for the extraction of HRV signals, especially in monitoring healthy individuals. Therefore, to overcome the ECG limitations, an alternative solution based on PPG technology can be used [1].

In this lab module, the main sensor used for the purposes of creating a wearable fitness and stress tracking system was a photoplethysmogram, otherwise known as a PPG sensor. PPGs consist of a light-emitting diode and a photodetector to measure variations in light absorption. During the cardiac cycle, the heart pumps blood to the periphery such as the fingertips. The change in volume caused by the pressure pulse is detected by measuring the amount of light reflected back to the photodetector after the skin is illuminated with the light-emitting diode. The delay between the emission and detection of the light is used to determine a pulse signal. It is noteworthy that the dimensions of the sensor are fairly small, which makes it's suitable for monitoring heart rate and blood oxygentation levels in a smart, wearable fitness and stress level tracker.

In this first lab we wanted to exploit the properties offered by the PPG sensor and develop a smart band able to record and analyze fitness activities and track stress events.

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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:

- Two Firebeetle Boards-328P with BLE4.1, a central and peripheral for wireless programming
- Micro USB interface cable
- Battery
- PPG Sparkfun Sensor
- Male headers
- Velcro and Velcro Band
- Soldering Set
- Buzzer
- Wires and wire wrapping tool
- 3D printed case - PLA

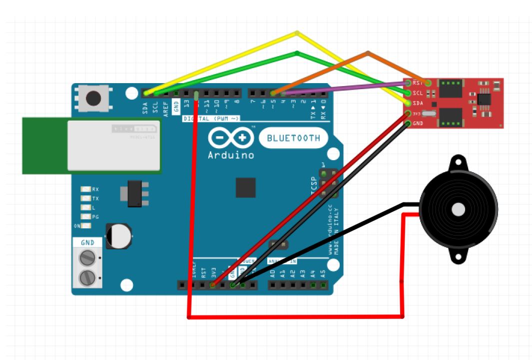

Fig. 1: Final wiring connections between peripheral board

The Fritzing electronic diagram shown in the figure 1 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.

To assemble the electronics as a wearable, smart watch, a housing was 3D printed from PLA material. On the bottom of this housing, there is a small hole that the buzzer fits and creates contact with the wrist. This buzzer alerts the user of instances of high-stress, indicated by an increase in monitored heart rate. The housing and PPG sensor was attached to the wrist/finger via velcro straps to secure the fit.

B. Software

The software used for the completion of the project were:

- Arduino IDE
- SparkFun BioSensor Hub Library
- Processing
- G4P Library
- 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) Compute the user-specific cardio zones. In order to do that it compute the maximum HR as:

$$MaximumHR = 220 - UserAge \tag{1}$$

Then, the cardio zones are defined as showed in the figure 2.
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.

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

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) measure the user hearth rate while he/she 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.
2) 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.
3) incorporate the emotion recognition mode in one interface.
4) If the user is in stress mode, have the buzzer turn on 2 times in a row in order to make the user cautiously aware of their mental status.

III. Results

A. Device Housing

The structure that houses the final group device is composed of a hollow parallelepidet designed and 3D printed. The material used for printing is PLA. In the part below the case there is a cavity dedicated to house the buzzer. To ensure that the device is firmly on the wrist and cannot move during sports, we used one of the Velcro bracelets available in the kit. Another smaller piece of Velcro was used to hold the sensor firmly on the finger.

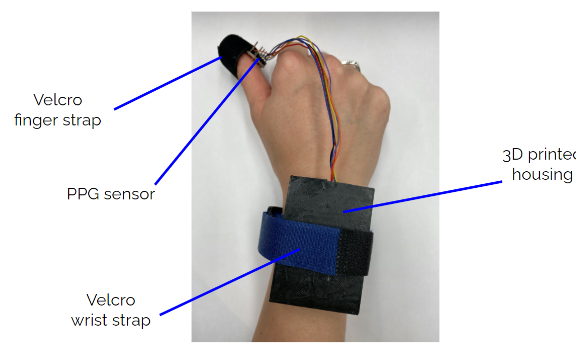

Fig. 3: Final device of the group.

B. Assembly

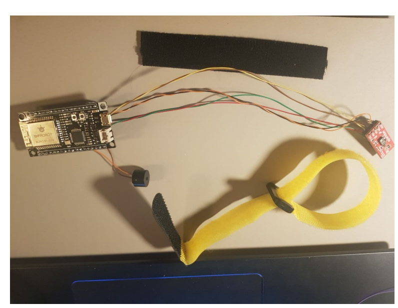

Fig. 4: The housing of the wearable heart rate and breathing rate device.

Apart from the final device presented in the video (figure 3). Each member of the group created their own wearable device. To do this, only the tools present in the kit provided by the teacher were used. The device built by me is shown in the figure 4 and 5.

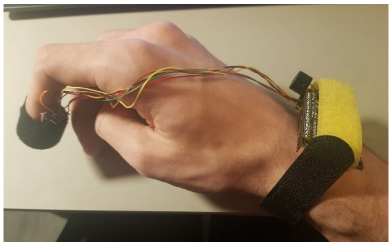

Fig. 5: Wearable strap on user to demonstrate use.

C. Interactive Home Screen

Figure 6 shows the first interface that appears as soon as the device is turned on. In this interface you are asked to enter your age. This data will then be used later to calculate the cardio zones.

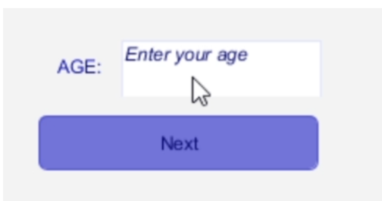

Fig. 6: Insert your age

After that the interface changes (figure 7) and asks the user to put on the device and press start when ready. During this phase we want the user to be at rest, so as to be able to calculate the most truthful resting heart rate possible. This phase lasts 30 seconds. The count down is shown during execution.

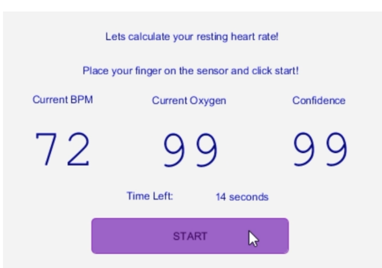

Fig. 7: Compute your resting HR.

When the resting heart rate calculation is finished, the home page appears. Here all the information found during the previous part is displayed. Figure 8 shows one of the tests made.

D. Mode I

If the user selects mode 1, the interface asks the user to press the button when he wants to start physical activity. Once the

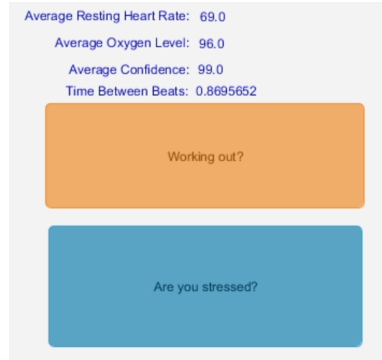

Fig. 8: Interactive home screen.

button is pressed it will show the user his current heart rate and the heart zone he is currently in (figure 9)

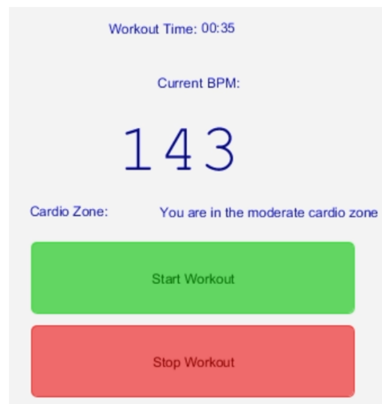

Fig. 9: Mode I data visualization during activity.

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 (figure 10). Below we find the graph of the heart rate trend. This graph changes color based on the user's heart zone at that specific time of physical activity. At the top we find a histogram that shows the heart areas belonging to the user. For each of these areas, the time the patient was in those areas is also reported.

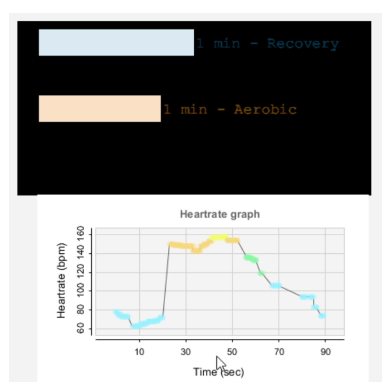

Fig. 10: Mode I end-activity visualization.

E. Mode II

When the subject selects Relaxed vs Stress Mode in the Home interface, the interface change and become like in fugure 11. With the value of the resting HR (computed during at beginning) and the use of literature tables the program determines a minimum same threshold. We considered the threshold for stressed mode as 10bpm higher than the resting according to Hammoud et al.. [2].

If the subject's hearthrate value exceeds the threshold for 5 seconds then the device assumes that the subject is stressed. A sound produced by the buzzer, integrated in the device, notifies the subject of his state of stress. Furthermore the interface tells you your stress status.

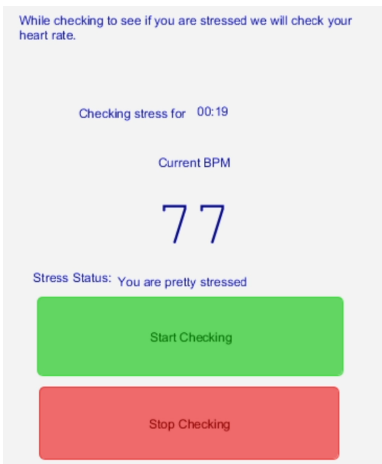

Fig. 11: Mode 2 data visualization.

IV. Conclusion

The final device proved to be an excellent tool for measuring sports activity and the user's state of stress. 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. 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 wrist. 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 velcro used to hold the PPG sensor on the finger. Not being custom designed, it leaves some room for movement for the sensor during exercise. This worsens the quality of the recorded 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. From an external design point of view, the piece of Velcro used to hold the ppg sensor in place can be replaced by an elastic plastic cap or by a plastic clip.

References

[1] Mohammad Ghamari. A review on wearable photoplethysmography sensors and their potential future applications in health care. *International Journal of Biosensors & Bioelectronics*, 4(4), 2018.

[2] Sabah Hammoud, Rita Karam, Rabih Mourad, Iman Saad, and Mazen Kurdi. Stress and Heart Rate Variability during University Final Examination among Lebanese Students. *Behavioral Sciences*, 9(1):3, December 2018.