Heart rate monitoring during physical exercise

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***Abstract*— To improve the signal-to-noise ratio for heart rate monitoring during exercise, a multitude of photoplethysmographic sensors were employed. To eliminate motion artifacts due to physical exercise a nonlinear signal processing algorithm was implemented in an embedded processor. Preliminary results demonstrated accurate heart rate detection through two pairs of reflective sensors on the radial and ulnar arteries at the wrist. Photoplethysmography is a common technique for monitoring heart rates.**

I. Introduction

Advances to modern technology have generated many options to monitor the heart rate. A common technique is photoplethysmography (PPG) due to it being inexpensive to implement and low power. Wristband PPG sensors, while useful due to unobtrusiveness during many exercises, are impacted by motion artifacts [5]. These wristbands use PPG signals to evaluate the heart rate of the user by measuring the intensity of a light reflected off the skin.

A photoplethysmogram uses light to detect the volume in an organ. It uses a pulse oximeter, which uses an LED, or light-emitting diode. The pulse oximeter measures the difference in the brightness of the light reflected from the skin. The change in this light intensity correlates with the changes in cardiac cycles and rhythm. Most blood flow occurs in the arteries; more blood flow occurs during the systolic phase than the diastolic change. Thus this change detected from the light identifies heartbeat [1]. These heart rates are just as accurate as ECG signals [4] and when in motion, the signal is distorted, therefore advanced signal processing must be use to filter the signal to the desired PPG signal. The algorithm presented in this report, is less complex and more accurate and reliable than leading heart rate detecting systems.

II. Methods

Based on a finger PPG design, the wrist type pulse oximeter extends to two infrared LEDs to increase signal power. One infrared is located on the ventral ulnar artery and the other on the ventral radial artery. Each infrared LED is paired with an adjacent photodiode to sense the reflected photoplethysmographic signal, thus detecting the heart rate.

In order to reduce the multiple signals to one estimate of the heart rate, an operational amplifier based summing circuit is implemented. An Arduino Uno R3 drives the infrared LEDs with a 1KHz square wave.

The connection of the output PPG signal will be attached to the Arduino analog pin which will then display on an LCD the user's heart rate in beats per minute.

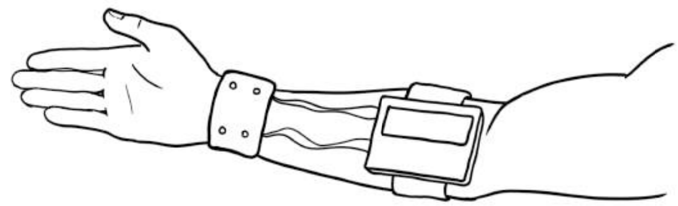

Fig. 1. Wrist PPG device for heart rate monitoring during exercise.

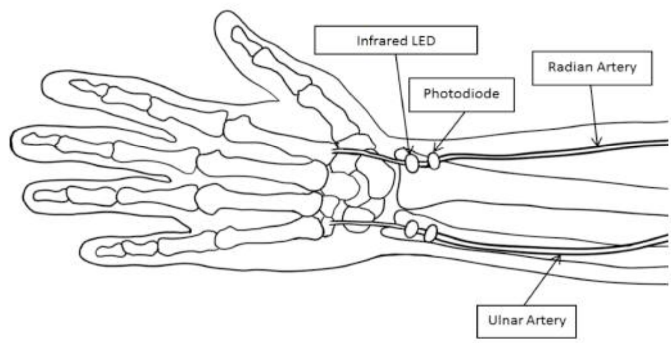

Fig. 2. Specfic placements of LED's and photodiodes on the wrist.

The circuit is soldered onto a printed circuit board and placed with the Arduino into a compartment. The compartment is placed on the inner forearm of the user to safely and securely house the circuitry. The LCD screen is located on the outside of the compartment so the user can view his or her true heart rate quickly and easily. Wires extend from the compartment to a wrist band which houses the two LED's and two photodiodes. See Fig. 1 below for detail drawing of the device and Fig. 2 for the location of the LED and photodiodes.

Since there are many motion artifacts due to the wrist's high muscle movement and blood pumping during exercise it is hard to receive a clean, noiseless PPG signal. Thus implementing a Multiplication of Backwards Differences algorithm (MOBD) will increase the signal to noise ratio by removing the motion artifacts and giving an extremely accurate heart rate meter during exercise. The algorithm employs nonlinear transforms and provides a very good performance balance between accuracy and response time [2]. The MOBD algorithm is computationally efficient while providing a good accuracy and a fast response time. The algorithm is therefore chosen for the real-time implementation of the PPG heart rate detector in this project.

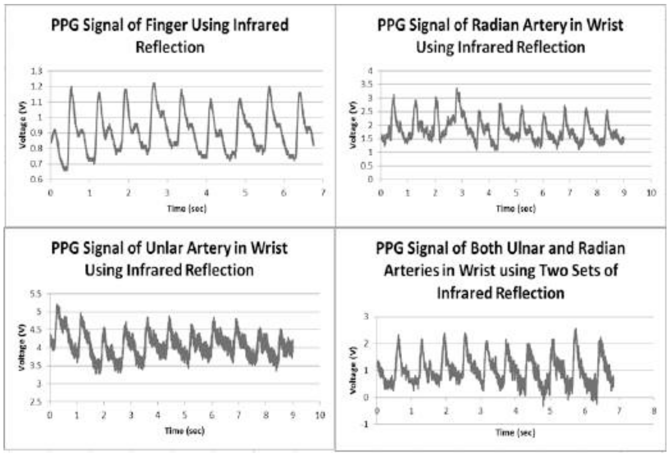

Figure 3. PPG waveforms obtained at the finger (upper-left), the radian artery in wrist (upper-right), the unlar artery in wrist (lower-left) and by combining the radian and unlar sensors.

III. Results

Photoplethysmogram waveforms were captured and analyzed from the same subject by attaching an oscilloscope to the output leads of the device. Figure 3 shows the preliminary results of four PPG waveforms captured by the wrist device. Upper-left panel shows the PPG waveform of a finger using infrared LED reflection method. This waveform is used as a reference. The vasculatures are denser and closer to the surface of the skin than those in the wrist. In addition, the PPG in the finger is obtained with a transmission arrangement, whereas the PPG in the wrist is obtained with a refection arrangement. Thus, the PPG signal from the finger shows a higher signal-to-noise ratio.

In Fig. 3, the upper-right panel and the lower-left panel show a single LED-sensor pair attached to the radian artery and the ulnar artery, respectively, in the wrist. The lower-right panel shows a PPG waveform by combining the two LED-sensor pairs from the radian and ulnar arteries. Connecting two sets of LEDs and sensors to the ulnar and radian arteries, respectively, in parallel gives a PPG wavform of a higher signal-to-noise ratio as compared to those obtained from the individual artery.

IV. Discussion

There were several obstacles to overcome during the development of the wrist type PPG device. The infrared LED was found to be better in retrieving a PPG signal than the white, infrared and yellow LED. Infrared LEDs, though harder to test provide a stronger signal-to-noise ratio due to the low frequency waves easily penetrating through the body tissue. This was analyzed and accomplished by trying different LED's in each PPG finger and wrist circuit, and viewing the results on an oscilloscope. In conclusion, the infrared LED gave a stronger PPG signal than the other LEDs. It is because the infrared easily penetrates the skin and can easily be used for the reflection method applied to the wrist prototype [3].

In general, there are two different methods in detecting PPG. One way is detecting the PPG signal through the reflection of the light hitting the skin, which is implemented in the wrist device. Another way is detecting the PPG signal through means of sending an infrared light through the skin and the photodiode on the other side of the organ, receives the PPG signal; this was implemented in the finger model. It was realized that sending infrared light through the wrist is not strong enough to receive a clear and accurate PPG image. The finger PPG idea of sending the wavelength through the finger and hitting a sensor was successful. This is because there are not a lot of components obstructing the signal. The signal merely goes straight through the finger and hitting the sensor, thus detecting heart rate. But do to the many components inside the wrist, i.e. bones, ligaments, muscles, veins, arteries and thicker skin, the signal was not strong enough to go through, and created a noisy signal. So it was realized the reflection method was the correct course of action. The method was first tried on the finger type PPG device. The signal using reflection delivered a larger signal-to-noise ratio than the previous method. When the LED and sensor were placed next to each other on the radial and ulnar artery of the wrist, the signal received was a good-quality PPG signal. Through the development process, the PPG signal was best visualized using a reflection of light technique. The use of reflection and infrared LEDs, though not normally used together, was found to produce the best signal.

This study demonstrated that the multiplication of backward differences (MOBD) algorithm, originally developed for QRS detection [2], can be effectively adapted for monitoring heart rate from the PPG signal.

A final obstacle was the development of the wristband to house the two infrared LEDs and the two photodiodes. The wristband needed to be sweat proof so people running would not short-circuit any of the electrical components attached but also needed to be flexible so it would be comfortable to wear during exercise.

V. Acknowledgment

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VI. References

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