Heart Rate Monitoring During Physical Exercise

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***Abstract*— Photoplethysmography (PPG) has become a growing new technology for detecting heart rates. They have been used predominantly for stationary wearable devices. New processes have allowed PPGs to measure heart rates during exercise. Using ultra bright LED's and phototransistors, a wearable wrist PPG is created to allow users to keep track of their heart rate during physical exercise. A PIC processor coded through the language C++, will allow the creation of a PPG signal while also performing signal processing algorithms to filter out the noise due to movement.**

I. Introduction

Exercise and fitness is an important part of people's lifestyle. With modern technology growing, it is becoming easier to monitor your progress by detecting heart rate. Wearable devices such as wristbands allow users to monitor their heart rate and show if they are pushing their body too hard. The wristband uses photoplethysmographic (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. These heart rates are just as accurate as ECG signals (Figure A. below), when the user is standing still. When in motion, the signal is distorted, therefore signal processing must be use to filter the signal to the desired PPG signal (Figure B).

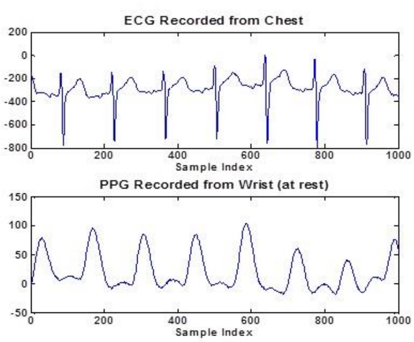


Figure A. ECG vs. PPG Signals at Rest

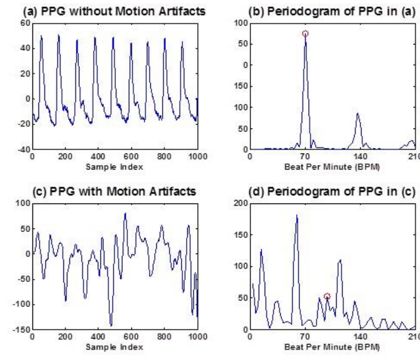


Figure B. PPG Signal: Motion vs. Rest

II. Project Management

The manager of the project will be Anthony D'Onofrio, the software engineer is Kyle Sexton, and the hardware engineer is Christian Chipouras. First the hardware engineer will create the PPG device for a finger to understand how the tracking of the signal and hardware work. Then he will develop our own PPG device for the wrist using multiple LED's and sensors. Multiple filters will be loaded onto the PIC processor by the software engineer to allow accurate detection of the heartbeat while exercising. While this in production, the software engineer will also be using Matlab for the IEEE competition to filter out the PPG noise given to us. See appendix for timeline.

III. ENGINEERING STANDARDS

One engineering standard, in the IEC60601 clause 10 subclause 10.4 states which lasers and light emitting diodes are safe to use and at which temperatures are safe to work with. In subclause 16.2 it states the body sensors, which are going to be in use for our wrist type device, should be safe and not cause any heat or electricity charge to the patient externally on the skin. In AAMI EC11 3.1.1.3 under Electrical Safety states there should be markings clearly visible on the electrocardiograph instrument that warn the user of a potential shock hazard from accidental contact with electronic parts or high current overload. In table 5 of the AAMI EC11, explains the summary of performance requirements including minimums and maximums of voltage, frequency, temperature, leads, DC gain control, and more of our wrist-type PPG device.

IV. DESIGN PROCESS

The goal for the design is to first create a prototype using the PPG signal developed through the scanning of a finger to create an idea of what the signal should look like. Then we will create our wrist type photoplethysmogram using two ultra-bright LED's on the ventral ulnar artery and two ultra-bright LED's on the ventral radial artery. On the dorsal side of the wrist, there will be four sensors detecting the light illuminating through the skin, thus detecting the heartbeat. We will be using a PIC processor to program the wrist device using C++ programming. Once we have the device, we will create filters in C++ programming to eradicate the noise due to physical exercise. We will use the same filters created for our IEEE competition.

There is a large list of filters we can implement for the Matlab IEEE challenge. We can do moving average filter, which is commonly used to reduce motion and works well with limited range, but it does not account for sudden change. We can also do Fourier analysis, which only works with periodic signals, thus cannot be applied to a PPG signal. But to overcome this problem, Fourier analysis can be applied only by a cycle by cycle basis which helps in removing high-frequency noise. Another signal processing technique the group can use is adaptive filtering, which removes unwanted signal from the PPG signal, by using peak frequencies of the signal. Figure C below is a block diagram of an adaptive filter with an accelerometer which helps us understand how it can be implemented by removing noise to the PPG. [1] Another technique is the least mean square adaptive algorithm which removes motion noise by estimating the noise reference signal and adapting the filter coefficients based on the filter order. Kalman Filters can also be used as a smoother to estimate motion reduction. In "Wearable Photoplethysmographic Sensors—Past and Present," journal explains that the Kalman Filter has shown to provide reliable information from the recreated PPG signal. The last technique to use is time-frequency methods and wavelet transformation which also proved to be very useful in taking out noise from a PPG signal. We will be trying these unique signal processing filtering techniques to see which has a better signal to noise ratio.

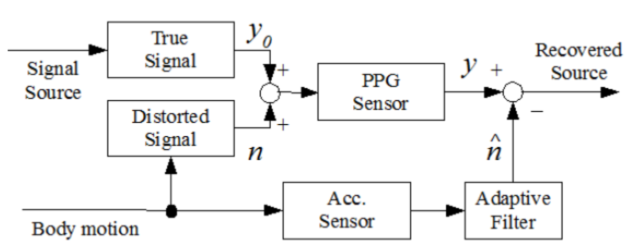


Figure C. Block Diagram of an Adaptive Filter

V. METHODS

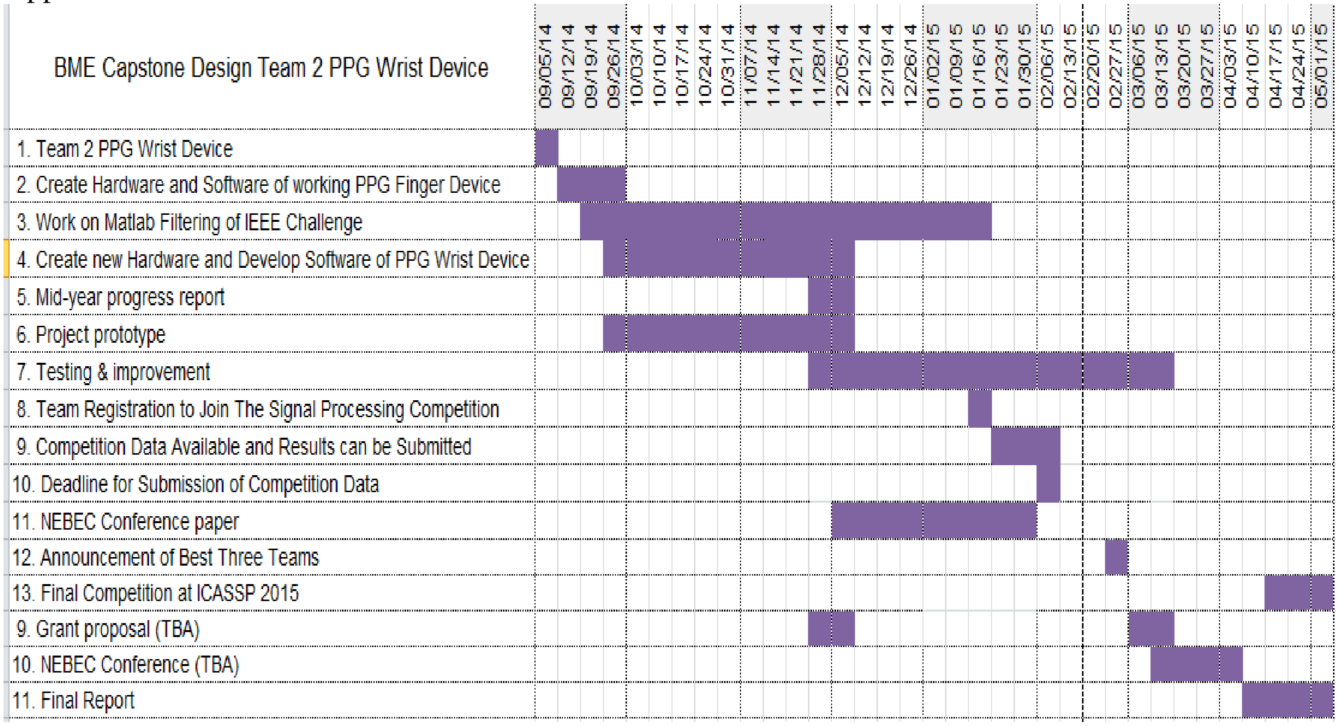
First the hardware engineer, Christian, will build the hardware for the wrist-type photoplethysmogram. He will use schematics created from previous PPG finger device to give an idea on how the hardware and circuit works. He will implement this circuit to develop his own heart rate monitor PPG signal for the wrist. He will be using solder, basic analog components, including resistors, capacitors, operational amplifiers, and diodes, photo sensors, a printed circuit board, battery, PIC microcontroller and AC to DC converter. Our software engineer, Kyle will build the software for the PIC microcontroller. He will be using MPLAB and C++ programming to program the wrist type device to create the PPG signal. He will also implement filters to allow proper processing to receive an accurate heart beating reading while the user is exercising. The software engineer will also use the same filters in Matlab for the IEEE Signal Processing competition. The manager Anthony will oversee and organize the group. He will be helping both groups throughout their tasks and making sure everyone is following the timeline.

REFERENCES

[1] Tamura, Toshiyo, "Wearable Photoplethysmographic Sensors—Past and Present." *Electronic Journal. 15 April 2014. J*ournal. 19 September. 2014.

[2] Zhang, Zhilin. "2015 IEEE Signal Processing Cup." *2015 IEEE Signal Processing Cup*. IEEE, 2014. Web. 10 Sept. 2014.

Appendix:


BME Capstone Design Team 2 PPG Wrist Device
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1. Team 2 PPG Wrist Device
2. Create Hardware and Software of working PPG Finger Device
3. Work on Matlab Filtering of IEEE Challenge
4. Create new Hardware and Develop Software of PPG Wrist Device
5. Mid-year progress report
6. Project prototype
7. Testing & improvement
8. Team Registration to Join The Signal Processing Competition
9. Competition Data Available and Results can be Submitted
10. Deadline for Submission of Competition Data
11. NEBEC Conference paper
12. Announcement of Best Three Teams
13. Final Competition at ICASSP 2015
9. Grant proposal (TBA)
10. NEBEC Conference (TBA)
11. Final Report