High Level Design

‘Work Smarter, Not Harder’

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**Table of Contents**

**1** **Introduction**…………………………………………………………….... 3

**2 Problem Statement and Proposed Solution**……………………….. 3

**3 System Requirements**…………………………………………………. 4

**4 System Block Diagram**………………………………………….……... 7

4.1 Overall System…………………………………………………….. 7

 4.2 Subsystem and Interface Requirements………………………... 8

 4.3 Future Enhancement Requirements…………………………....10

**5 High Level Design Decisions**………………………………………...10

**6 Open Questions** ………………………………………………………..12

**7 Major Component Costs** ……………………………………………...12

**8 Conclusions** …………………………………………………………….13

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# **1 Introduction**

This project will expand upon a project from last year’s senior design class, which used photoplethysmography to monitor heart rate and blood oxygenation in order to detect the symptoms of cardiomyopathy. Cardiomyopathy, also known as enlarged heart syndrome, is a condition caused by the thickening of the heart walls, which constricts blood flow and can ultimately lead to unexpected cardiac arrest. Our version of the device will retain the functionality of last year’s project while adding several new features. We hope that the additional features will allow this device to serve as a high-performance activity monitor that provides a robust and detailed assessment of health and exercise efficiency during strenuous athletic activity. The type of data obtained and analyzed by our device and data processing tools could help provide a greater understanding of the body during such activity and ways to optimize health and fitness.

# **2 Problem Statement and Proposed Solution**

While several commercial wearable devices can measure heart rate, there is nothing on the market to monitor other aspects of a person’s health during a workout. We intend to take a pre-existing board that uses photoplethysmography (PPG) to measure a person’s oxygenated and deoxygenated red blood cells and expand its functionality by addressing its shortcomings and adding new features, in particular the measurement of water and lipid levels. The problems with the current design include the inability to determine if movement of the board is negatively affecting recorded data, the inability to measure more than two wavelengths at the same time, the necessity of physical on-board memory, and the fact that the board is too large to be easily worn during exercise. Additional problems that may arise include board fragility or short battery life, both of which could prevent effective use of the device during a workout.

To account for possible noise generated by movements of either the device or the body, we plan on including an accelerometer. If the noise is significantly affecting our other measurements, we will use the accelerometer data to perform the necessary error-correction during data processing to attain more accurate final results.

In order to test for a wider variety of molecules, we need to emit, scatter, and sense more wavelengths. To achieve this, we plan on including two more LEDs of different wavelengths, which will be supported by an additional AFE photodetector chip. This would allow us to test an area of tissue for lipids and water concentration in addition to the currently implemented measurements of oxygenated and deoxygenated hemoglobin.

To improve the ease with which the data can be sent to a computer for further analysis, our proposed solution is to supplement the currently implemented SD card system with a bluetooth transmitter to transfer the completed data file wirelessly, which would be a much quicker method.

Wearability of the device would be enhanced with a strap, and to ensure that the device is compact enough to be portable, we would first verify that Brendan’s compact design is functional, and then expand on that.

 To improve durability, we could place the device in a container, and to ensure longevity we will include a large capacity battery for the device to run off of.

# **3 System Requirements**

The overall system requires communication between several components. The microcontroller will set the blinking rates of the four LEDs. Once the light from the LEDs travels through the skin and blood vessels, the photodiode will capture any light not absorbed by the body, and convert that light into current. The AFE4490, once again, will take the current signal from the photodiode and convert the data from analog to digital for it to be passed to the microcontroller. Additionally, our added accelerometer will output its own sensory data to the microcontroller. Once the microcontroller receives this signal, it will send the data to the micro SD card for storage, in addition to sending the data to bluetooth transmitter for wireless data transfer. In general, the embedded intelligence of the system relies on communication between the microcontroller and all other elements.

 The final prototype of our design aims at continuously collecting data on the wearable device. In order to achieve this, the wearable device will be powered by a battery. The micro SD card, which will store the data, LEDs, photodiode, accelerometer, bluetooth transmitter and microcontroller, will all require power. The end goal is to be able to use a 3.7V rechargeable LiPo battery to power the entire device to ensure portability, but for testing purposes it’s worth it to create an initial prototype that runs off of the power from a computer while being plugged in via a USB port (this functionality is absent from the current build).

 Only 1 device needs to be supported, as the data transfer we need is only sending to a computer. The maximum functional range of a standard bluetooth device is 100m, which is adequate for our needs, as you wouldn’t be able to use a computer from 100m away anyway.

The user interface will be a computer program that takes the data from the micro SD card and interprets it. The program will include a GUI that allows the user to choose what he/she wants to see. The capabilities of the program will include graphical presentation of the heart pulse and oxygenation levels and warnings if abnormalities of these measurements are reflected in the data.

The system will be a wearable device you can place on your finger and it will be powered by a battery for continuous use. When the record button is pushed, four flashing LEDs will produce light, the blood and skin will absorb some of the light, and the photodiode will capture the excess light and send the signal to the microcontroller through the AFE4490. An accelerometer will send motion data to the microcontroller to be stored in the microSD card as well. A microSD card will store the data sent from the microcontroller. The microSD card can be extracted from the wearable device at any time and connected to a computer, and the device will also contain a bluetooth transmitter for wireless transfer of the data. When a data transfer button is pressed, the board will take the stored microSD card data and transmit it wirelessly using the bluetooth transmitter. Once connected to a computer, a program created by last year’s team will take the data and interpret it into graphs and readable format. We will need to edit this program to incorporate accelerometer data. Because the project aims at determining issues with heart pulse or oxygenation levels, any abnormalities will be flagged by the program and prompt the user to consider further testing from a trained physician.

If you project involves voltages and or currents that may be dangerous, what are safety requirements associated with your system.

Since our device directly interacts with the human body, voltage and current levels are important to consider. The human body should never be in contact with currents over 5 mA. The amount of voltage a human can handle varies based on resistance, but voltages over 40 V with no resistance are extremely harmful. Device currents can reach a maximum of 200 mA for the AFE4490 and 300 mA for the microcontroller. Voltages can reach a maximum of 3.3 V. Therefore, we will need to insure the electrical systems are well insulated.

A heavy watch weighs up to 150 grams, so the maximum weight should be less than 150 grams. The goal of size requirements for the device is to create the lightest device possible. The microcontroller, AFE chips, battery, microSD card, LEDs, accelerometer, bluetooth transmitter and photodiode will all affect the weight of the device. The sensor must be small enough to fit on a finger, and ideally the entire device will be able to fit on an armband. The AFE4490 is only 6mm x 6mm, and photodiodes, accelerometers, bluetooth transmitters and LEDs should also be fairly small and light, so the feasibility of this goal isn’t unreasonable. The largest contributions to weight and size will be the printed board and battery.

# **4 System Block Diagram**



## **4.1 Overall System**

Once the board receives power and the record button has been pressed, the LEDs attached to the AFE chip will blink and the photodetector will read the number of photons of each frequency being reflected back by the user’s body as well as the frequency of fluctuations in order to determine the user’s heart rate. This information will be saved onto the microSD card, along with motion data from the accelerometer. Once the user chooses to transmit, the information will be read from the SD card and transmit by the bluetooth chip to the user’s computer or smartphone. The user will also have the option to read the information from the SD card directly using his/her computer and the provided MATLAB software.

## **4.2 Subsystem and Interface Requirements**

The requirements of each subsystem or major interface are described here by subsystem. These lower level requirements support the overall system requirements. Note that major interfaces (such as a wireless interface) should be described like any other subsystem. Don’t forget that there will be software as well has hardware in many of the subsystems, and that software will have requirements.

**Microcontroller dictates LED-flashing rates:** The microcontroller and AFE4490 sensor combination will dictate the rate of the LEDs using SPI. The LEDs will flash in a sequence and the blood and skin will absorb this light at different wavelengths. The wavelengths of light utilized need to be one that is absorbed by the blood. It should have a high enough intensity to pass through human tissue and be detected on the other side. The maximum current that the LED can draw is 200 mA.

**Photodiode captures LED light:** The photodiode will capture the transmitted light from the LED as inputs. Then, the photodiode will convert the light into current and output that current to the microcontroller. The photodiode must be sensitive enough to detect minute fluctuations in light. It should detect light at the wavelengths that the LEDs and lasers emit.

**Accelerometer reads motion data:** The accelerometer will record the movement of the board in the x-, y-, and z-directions. These readings will be converted to a signal and sent to the microcontroller.

**Microcontroller receives current signal:** The microcontroller with receive the current signal in a Serial Peripheral Interface (SPI) bus format.

**Microcontroller sends data to storage unit:** For storage, we need to be able to store at least four hours’ worth of data at a sampling rate of 5 KSPS at 22 bits. It must be able to write in real time, so at a speed of 13.75 kB/s. This will not be a problem as most commercial micro SD cards are Class 10 and therefore write at a minimum of 10 MB/s. At the highest resolution and sampling rate, we would need to store 198 MB in four hours.

Calculations:

Maximum desired writing speed:

$$5000 \frac{samples}{sec}\*24 \frac{bits}{sample}=13.75 \frac{kilobytes}{sec}$$

Storage for one hour:

$$13.75 \frac{kilobytes}{sec}\*60\frac{seconds}{minutes}\*60\frac{minutes}{hour}=49.5 \frac{megabytes}{hour}$$

**Storage unit stores data sent from microcontroller:** The microcontroller is going to send the data to the micro SD card, which will store it until the information can be transferred to a computer or smartphone.

**Microcontroller reads data from the SD card:** When the transmit button is pressed, the microcontroller will send a command to the SD card and read the data in order to send it to the bluetooth transmitter.

**Bluetooth transmitter sends data:** The bluetooth transmitter will transmit the data it receives from the microcontroller. This information can be read by a computer or smartphone. The bluetooth transmitter will also transmit a signal from which the computer/smartphone can identify the device before the actual data is sent.

**Battery powers all components:** The AFE4490 requires a voltage between 2 and 3.6 V. The energy requirement will be dependent on the LED/lasers, photodiode, accelerometer, bluetooth transmitter, and microcontroller we elect to utilize in our final product. The power source, a battery, will power all systems in the wearable device.

**Software algorithm:** The MATLAB program must be able to process large quantities of data given to it by the data storage unit. The program will graphically display the data for the user.

**4.3 Future Enhancement Requirements**

 Due to time constraints, we will not feasibly be able to implement all the features that we think would make an exemplary device. Some of the components that we believe could be enhanced in the future are: incorporating a smaller chip and smaller battery to optimize the size and weight of the device; supplementing the device with an LCD screen that could inform the user if the bluetooth was enabled, the data was successfully transferring, or potentially display a live data feed right on the device. Additionally, the device data storage could be increased, which would be beneficial for prolonged activity (e.g., a long run or hike), and a button could be added so that the user could enable or disable wireless data transfer (which could save battery power). Finally, a future development could be a mobile app that could analyze data in real time and enable the device to become completely portable.

# **5 High Level Design Decisions**

**Microcontroller dictates LED flashing rates:** We will be using the microchip PIC32 microcontroller that communicates with the AFE4490 via an SPI interface in order to control the LED current and flashing rates for the four LEDs. We will use the PIC32MX695F512H, the same microcontroller used in class, because it operates from 2-3.6 V, which is the same voltage range as our chip. Additionally, it can communicate via SPI, which we will also use with the AFE4490 chips.

**Photodiode captures LED light:** The photodiode will need to be able to capture the light from the four LEDs (red, infrared, in addition to two LEDs of undetermined frequency within the visual spectrum, for testing both water and lipid content), with high efficiency so that the device can give accurate representation of the pulse, oxygenation, water and lipid levels.

**Accelerometer reads motion data:** The accelerometer will be able to sense motion data from tremors or vibrations that could provide a source of noise within the data, and pass this data in current signal form to the microcontroller.

**Sensor receives current signal:** The AFE4490 will receive the analog current signal from the photodiode. It will then perform the analog-to-digital conversion in order to pass the data to the microcontroller.

**Microcontroller sends continuous data to storage unit:** The current signal data from the photodiode and accelerometer that the microcontroller receives is then transmitted onto the storage unit. The storage unit will be a microSD card with 32GB capacity so that it can record data up to at least one month since, as calculated above, the device would need approximately 49.5 MB per hour when running at the highest resolution and sampling rate.

**Microcontroller reads data from the SD card:** In order to transmit the stored data, the PIC32 microcontroller acts as the mediary between the SD card and the bluetooth transmitter component. The first step to this process is reading in the data from the SD card in chunks into the microcontroller memory to be sent.

**Bluetooth transmitter sends data:** Once the PIC32 microcontroller has read the SD card data into memory, the data can be transmitted wirelessly to an external device through the bluetooth transmitter.

**Battery powers all components:** For initial testing, we would like to be able to utilize a USB port and cable to power our device, for simplicity. Once we have progressed further in the design, we will use a rechargeable 3.7V LiPo battery for testing. It should give the same functionality of the USB cable. The size and power of the battery will be dependent on the final choice of LEDs and the length of time we will be recording data for, while staying within the weight limit for the wearable device.

**Software and user interface:** The MATLAB software algorithm will take the data from the chip and turn it into useful information that will will be displayed as plots or values in our GUI. The program will be able to show plots of the heart rate, blood oxygenation levels, water levels, and lipid levels, and adjust calculations based on the user’s age and weight. The program would also include warnings for any abnormalities found.

# **6 Open Questions**

If we encounter major issues implementing the Bluetooth, we are open to using the current design (SD card transfer) or a form of wired transfer (e.g., mini-USB).

We are also not completely sure of what changes we will need to implement to ensure that the device is wearable, somewhat comfortable, and working as intended.

When we incorporate a second chip, how much of hardware and software will we need to adjust? (i.e., will we need to make an entire new board, or can we just edit the current one? Will it be easy to edit the software, or will we need to fundamentally alter it?)

# **7 Major Component Costs**

AFE4490 chip- $17, or can get free samples

PIC Microcontroller- $20

Accelerometer- <$1

Bluetooth transmitter- $10

LEDs <$1 each

Board- $50

All other components can be obtained for free from the closet in Stinson-Remick 205

# **8 Conclusions**

By expanding upon last year’s ‘Heart of the Matter’ project, which utilized photoplethysmography to monitor heart rate and blood oxygenation in order to detect the symptoms of cardiomyopathy, we hope to develop a robust and sophisticated high-performance activity monitor. Our version of the device will retain the functionality of last year’s project (measuring oxygenated and deoxygenated blood), but also obtain readings about lipid and water levels by incorporating two additional wavelengths. Additionally, we’d like to supplement last year’s device to make it more user friendly and adaptable to error. We will integrate wireless data transfer capabilities for live analysis of data, and include an accelerometer to account for movement and noise while wearing the device. These features will enable this device to serve as a precise assessment of health data during strenuous physical activity, and monitor and optimize performance.