Photoplethysmography to Measure Cardiac Activity in Modified Headphones

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team-sjb 6.1820[6.808] Final Project Proposal

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1 Project Statement

We plan to create a modified set of headphones to estimate cardiological activity, including heart rate and blood pressure, without invasive or pressurized devices.

With inspiration from Sogo Toda and Kenta Matsumura [1], we intend to create augmented headphones that can conduct photoplethysmography. These over-the-ear headphones will be equipped with Red, Green, Blue, and near-IR LEDs, as well as a photodiode on the earlobe to measure the reflection across different wavelengths. We can then use photoplethysmography to measure key features of cardiological activity, which identifies patterns due to reduced reflection. These patterns are indicative of blood volume flow and pulse rate. We will also utilize the cuffless blood pressure estimation equation from section 2.2 in their paper to identify the approximate blood pressure. In the end, we should have a replacement for a PPG sensor and cuff-based blood pressure monitor.

2 Methodology Statement

Our methodology for developing cuffless blood pressure monitoring headphones draws inspiration from Toda and Matsumura's [1] research on optimal light source wavelengths for PPG-based blood pressure estimation. We will implement a multi-wavelength photoplethysmography system integrated into over-ear headphones, focusing on earlobe measurements. The earlobe provides an ideal measurement location as it contains rich microvasculature and allows for consistent placement with minimal motion artifacts compared to fingertips or wrists.

We will incorporate four different LED light sources (blue-470nm, green-528nm, red-620nm, and near-infrared-870nm) and a photodiode detector in the reflectance mode configuration within the earpiece of the headphones. Following Toda and Matsumura's approach, we will extract heart rate (HR) from the peak interval of the PPG waveform and calculate the modified normalized pulse volume (mNPV) from the AC/DC ratio of the signal. Using these physiological indices, we will apply the log relationship established in the paper $\log(BP) = \log(HR) + \log(mNPV)$ to estimate blood pressure without cuff pressurization. Based on the research findings, we will utilize near-infrared wavelength measurements for systolic blood pressure estimation and blue wavelength measurements for diastolic blood pressure and mean arterial pressure to achieve optimal accuracy. Our system will require an initial calibration with a standard cuff sphygmomanometer to establish baseline values, after which continuous monitoring can proceed without further cuff measurements. Our proposed diagram can be found in Figure 1.

3 Plan & Schedule

In week 1 and 2, we will start by devising a more detailed schematic of the device and then purchasing parts. We will then assemble the headphones with the LEDs and photodiodes. Next we will assemble the Arduino to ensure we are getting any signal.

At this point in week 3, we get into the part of the project related to health signals. We will need to write a software to obtain the heart rate and blood pressure from this signal. Depending on the quality and noise, we may need to use other techniques such as filters and FFTs to remove some noise.

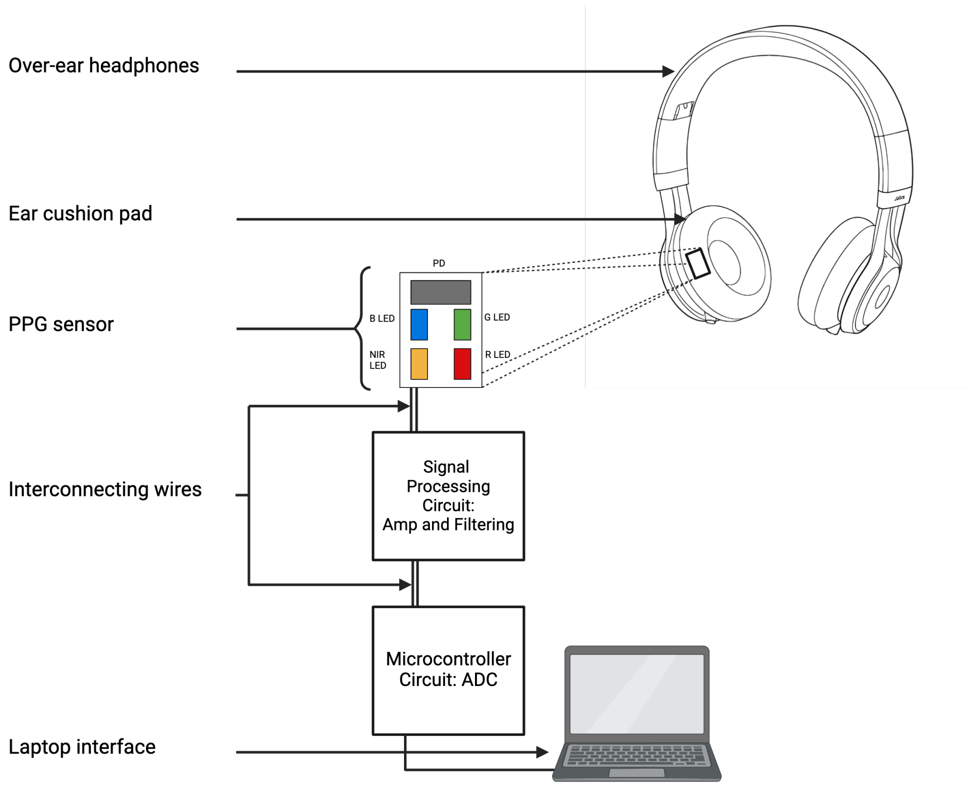

Figure 1: Integrated Photoplethysmography System for Headphone-Based Physiological Monitoring: System architecture showing multi-wavelength PPG sensor placement in over-ear headphone cushion, with signal conditioning, microcontroller processing, and computer interface for cuffless blood pressure estimation.

In week 4, we then need to benchmark and test the system against the arm-band measurements to determine the accuracy. Throughout the project we will necessarily need to revise our design based on new learnings and iterate.

4 Deliverables & Metrics

The key metric to evaluate the system will be the ground truth blood pressure via the standard upper-arm band used in a doctor's office. We hope to see correlation between the LED-ear method and the arm-band method.

In terms of heart rate, the same blood pressure armband in the parts list should also give a ground truth heart rate which can be used to evaluate the system

It is hard to pinpoint and exact accuracy target for either heart rate or blood pressure, but our main goal is to see the same order reflected in both techniques as well as correlation between the two: i.e. if the arm-band measures a 20% higher systic and diastolic blood pressure in person A than person B, then we hope our system detects similar measurements and a similar rationale for heart rate.

A successful project consists of a system that actually does this. It consists of over the ear headphones that have been modified to include the LEDs and photodiode to complete the measurements and is wearable and gives a measurement of blood pressure and heart rate that correlates with the ground truth measurements from the armbands.

5 Resources Needed

1. Over the ear headphones
2. RGB LEDs

3. Near IR LED
4. Photodiode (TEMD5510; Vishay Semiconductors, Malvern, PA, USA)
5. Arduino
6. Photoresistor
7. Blood pressure and pulse monitor

6 List to Order

Matching section 5...

1. $5.49 x 3 https://www.amazon.com/Koss-KPH7-Lightweight-Portable-Headphone/dp/B006T9ZKAQ
2. $8.99 https://www.amazon.com/Tricolor-Multicolor-Lighting-Electronics-Components/dp/B01C19ENDM
3. $5.49 https://www.amazon.com/HiLetgo-Infrared-Emitter-Receiver-Emission/dp/B00M1PN5TK
4. $2.23 x3 https://www.digikey.com/en/products/detail/vishay-semiconductor-opto-division/TEMD5510FX01/1681184
5. $19.99 https://www.amazon.com/LAFVIN-Board-ATmega328P-Micro-Controller-Arduino/dp/B07G99NNXL
6. $5.89 https://www.amazon.com/eBoot-Photoresistor-Sensitive-Resistor-Dependent/dp/B01N7V536K
7. $19.99 https://www.amazon.com/Pressure-AILE-pressure-Adjustable-automatic/dp/B0BF9YHRFM

7 Questions & Clarifications Needed

We are most curious for your feedback on the overall design and which parts you think could be particularly difficult to implement. We are also open to suggestions on our parts list – i.e. what could be better choices for this implementation.

8 References

[1] Sogo Toda and Kenta Matsumura. Investigation of optimal light source wavelength for cuffless blood pressure estimation using a single photoplethysmography sensor. *Sensors*, 23(7):3689, 2023.