Bone Conduction Health Headphone: Providing Hear Rate Information Discreetly

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Abstract
This paper describes a new way to monitor one's pulse and other health-related bodily functions discreetly using bone conduction headphones. The headphones consist of piezoelectric transducers, through which amplified audio signal is sent. The headphone also houses an Arduino and a Bluetooth module for wireless comfort. Since the sound is transmitted through the temporal bone of the user, no one else can hear it. Furthermore, it distracts the user much less when compared to traditional headphones, which can be vital in certain situations. The sensor pack consists of a heart rate and oximeter sensor along with an Arduino and a Bluetooth module.

Author Keywords
Bone conduction; Arduino; headphones; sensor; Bluetooth; health monitoring.

ACM Classification Keywords
Experimentation, Sensor applications and deployments; Sound-based input / output; Emerging interfaces; Health informatics

Introduction

Due to our hectic lifestyles, stress can be big factor in our lives. Stress has been studied from a medical point of view and large amount of studies show that negative emotions, such as stress, are tied to poor physical health [1]. Therefore, continuous monitoring of stress might help users understand their stress patterns and maintaining better health [2]. A plethora of gadgets have emerged, which either focus on or include functionalities of measuring pulse. According to the "Global Optical Pulse Sensor Market 2018-2022" report [3] the market of optical sensors will grow at CAGR of 11,28% during the next four years, so clearly there exists a demand for these. One might argue though, that checking your smartwatch or app on a phone to know your pulse might be cumbersome. This, combined with the recent rise of intuitive user interfaces [4], is why we embarked on an experiment to devise a new way of interfacing with health data; the bone conduction health-headphones.

Background

As the increase of the living quality, people tend to pay abundant attention to their health, while the condition is unconsciously affected by daily routine. Many a little effects makes a mickle consequence, thus leading to the need for health related self-monitoring technologies, which monitor and report the deviant health condition timely. These health related self-monitoring technologies have the potential of improving quality of life. During the background research we found some very interesting novel methods of measuring health related information from skin using a second skin type of patches [5] [6]. Even though this type of measuring would be ideal for our idea of discrete health monitoring, we don't have resources for such implementations.

Inspired by these self-monitoring technologies, we proposed the idea of a novel health monitoring device that provides health condition through bone conduction technology to convey information to any person with normal hearing or even hearing impairment in an easy and unobtrusive way. During the background research, we considered monitoring user's surroundings, using distance measurements or even object recognition, and providing it as audio information in order to help visually impaired persons. However, due to the popularity of pulse monitoring devices, we decided to deliver information about user's health condition by measuring heart rate and oxygen saturation. These measurements help to find cause of symptoms from an irregular or rapid heartbeat [7] as well as stress level [2]. When the current heart rate and oxygen saturation are abnormal from the initial data, the audio would be played with the Arduino to warn the users of the unexpected condition.

Measuring heart rate and oxygen saturation

Research shows that the normal resting heart rate for adults over the age of 10 years, including older adults, is between 60 and 100 beats per minute (bpm). Highly trained athletes may have a resting heart rate below 60 bpm, sometimes reaching 40 bpm [8]. The heart rate changes depending on what you're doing, therefore, we programmed a resetting interface to collect the initial data for the current mode, and monitor the distinct variation based on that.

In this way, MAX 30102 Pulse Oximeter & Heart-Rate Sensor is applied to measure these two parameters. It

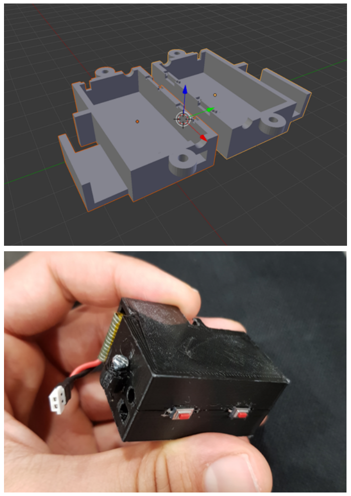

Figure 1: (a) 3D-model of the casing for the headphone components. (b) 3D-printed prototype of the casing with battery and buttons attached.

Figure 2: 3D-printed headset with piezo-electric transducers.

is composed of internals LEDs, photodetectors, optical elements, and low-noise electronics with ambient light rejection. It is a mature sensor to measure heart rate by photoplethysmogram [9]. The output of the sensor includes the current heart rate, oxygen saturation and the validation for these parameters, which are monitored every second after calculation from 25 samples. The research also indicates that the wrist is the best location to monitor heart rate [8], therefore, we decide to put the sensor package around the wrist to achieve accurate results.

Bone conduction headphone

Bone conduction is the principle of transmitting sound to the inner ear by sending vibrations through the bones of the skull, namely the temporal bone [10]. These vibrations will be interpreted as sound by the inner ear and brain, just like the vibrations emanating from the eardrum via air. One of the main benefits of bone conduction versus traditional headphones is increased situational awareness as your ears remain unobstructed. In our project, a piezoelectric transducer is used for sending the vibrations via the temporal bone, either in front or behind of the ear. This way, one can freely and discreetly get personal information about their health at any time.

Playing audio with the Arduino

The output of the bone conduction headphones could have been done in many ways. Various ways of communicating with audio were discussed. We even tested few text-to-speech libraries, but in the end it was decided that spoken word audio clips would be tried out first and if that would fail, "beeps" would be used to indicate the heart rate. The "beeps" would indicate heart rate by having the same frequency as the heart rate.

Execution

Prototyping

For prototyping the headphones, it was important to have a casing for all the headphone components and a way to hold headphones in place with an ease. Due to time constraints, the prototype had to be built simultaneously when we developed actual headphones. At that time the headphone consisted of two piezoelectric transducers, an audio amplifier, a Bluetooth serial module, a mini Arduino board and a battery. To keep the casing simple and compact, and for making it easy to change the battery, we decided to include only the amplifier, Arduino and the Bluetooth model inside the casing and keep a battery holder on the side of the case. For easier control purposes, we also ordered and included a power switch and two volume buttons that could possibly be used for different mode selection too. We then measured and 3D-modelled all the components and based on these and the estimation of the space needed for wires, we made a 3D model design of the casing seen in figure Figure **1**a. This model was then successfully 3D printed and the resulted prototype with the battery and buttons included can be seen in figure Figure **1**b.

Our first idea to hold the headphones in place was to have the piezos in a second-skin type of patches, that could be easily attached on the skin. However, for more easy demoing purposes and lack of proper patches, we decided to 3D-print the headset and attach the piezos to the printed headset which is shown in figureFigure **2**.

The audio level of the piezos was too quiet when they were directly connected to the Arduino, so an amplifier needed to be used to raise the audio level. PAM8403 audio amplifier was used for this.

Because of the space constraints of the Arduino a SD-card reader had to be used to store the audio output of the headphones. SimpleSDAudio-library [11] was used to store and play the audio clips. Numbers 1-9, 10, 20, 30, 40, 50, 60, 70, 80, 90, 100 and phrase “your heart rate is” were pre-recorded and stored on the SD-card and combined to achieve wanted result. For example, if the Arduino, connected to the headphones gets information that the heart rate of the user is 186, audio clips “your heart rate is”, 100, 80 and 6 would be played.

Programming
Arduinos were chosen due to the author’s previous experience with them. We chose to go with Arduino pro minis for their small size and the ability to run on 3.3 volts.

Both, the headphones and the sensor pack, begin their program by performing a custom made handshake protocol via Bluetooth. This ensures that both modules are connected and functioning properly. After this, both modules move to a simple state-machine -style loop. The sensor pack retrieves the current pulse at predetermined intervals of 9 seconds. This is done with the use of *millis()*, to prevent overloading the timers on the board. This allows the pulse sensor to function properly. When the pulse is read, the program transmits this data via Bluetooth using our custom packet format, which can be seen in figure 3.

index	0	1	2	3	4	5	6	7	8	9
package	P	U	L	S	E	:	1	2	0	#
description	Identifier					Packet type	Possible payload			Termination character

Figure 3: Custom packet format used in Bluetooth transmission

The handshake also used this packet format, along with everything which is passed via Bluetooth (HELLO?# -> HELLO!#). If either of the modules loses connection (noticed by the lack of pulse or acknowledgement from the other module), the program instantly tries to initiate the handshake sequence again.

On the headphone side, the program updates the current and last pulse as new packets arrive. Depending on the initial pulse received upon starting, thresholds for low, normal and high pulse are calculated. A similar state-machine as in sensor pack checks in which state the users pulse is. If the pulse is within normal thresholds, the notification period is longer than with low or high pulse levels. When it’s time for a pulse notification, the program reads the proper vocal files (as byte arrays) from an SD-card and plays the pulse as audio through the piezos.

The MAX 30102 pulse sensor is utilized in conjunction with its library. It offers simple functions to get (supposedly) a well filtered signal and raw pulse.

Electronics
The final list electronics parts that we used were: two Arduino pro mini / Arduino Uno R3, two HC-05 Bluetooth modules, MAX 30102 pulse and oximeter sensor, On/Off-Switches, Push buttons, PAM8403 2-channel audio amplifier and SD-card reader module.

The planned schematics for the headphone module can be seen in figure Figure **4** and for the sensor pack in figure Figure **5**.

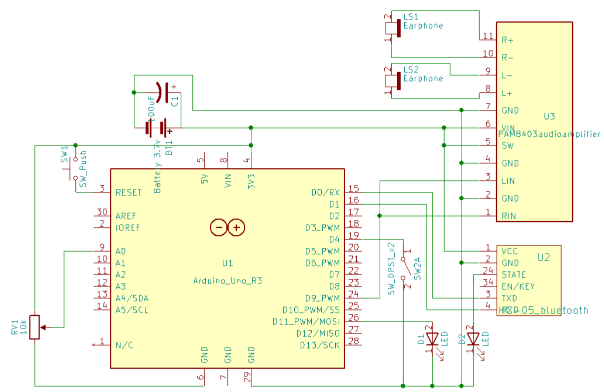

Figure 4: Planned schematics for headphone.

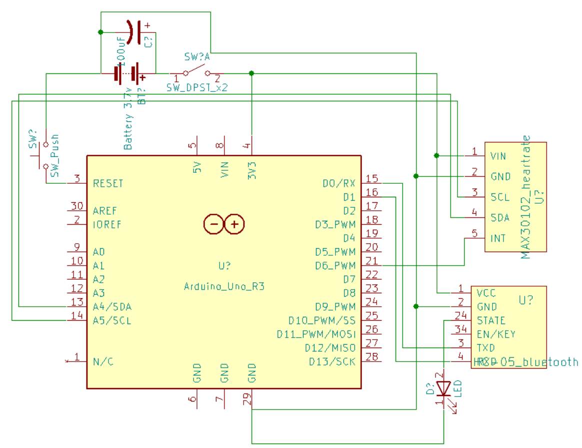

Figure 5: Planned schematics for sensor module.

Challenges

The use of PAM8403 audio amplifier resulted in large amounts of noise in the audio signal. To get rid of this, various RC filters were used, but we did not manage to get the audio in quality to be listenable. The Bluetooth modules also required a lot of research and work. Wrong modules and configurations caused a lot of trouble in the beginning. Finally, after trying to migrate the working project to the Arduino pro minis, we found that for reasons unknown, the Bluetooth didn’t work anymore.

We also couldn’t get a stable reading from the pulse meter, even after thorough research. It is unknown, whether this was due to a malfunctioning sensor or software problem. This was after we had first received a malfunctioning sensor, so problems with the vendor can’t be ruled out. Closer to the demo day we even tried to build a pulse sensor from scratch using simple infra-LED lights, but the second sensor (that replaced the first malfunctioning sensor) arrived before we got the own sensor working.

Overall, the greatest challenge of all was the sheer scarcity of time. Due to the low budget, all components needed to be ordered from China. This naturally takes a long time which left us without anything concrete to do. We naturally used this time to research the various components that we would use, but in practice, many of the things weren’t so straightforward.

Conclusion

The goal of this project was to make a bone conduction headphone, which would inform its user information about their health. The final plan was to make a system which would use MAX 30102 Pulse Oximeter & Heart-

Rate Sensor to measure heart-rate of its user and inform the user by outputting spoken word audio clips through the bone conducting headphones. Because the heart-rate sensor would be on the hand of its user and the headphones on the head, Bluetooth communication would be used to accomplish connection between the two parts.

Most parts of the project including the Bluetooth connection, code used for communication, headphones and audio payback were working at one part of the project, but when it was time to combine all these parts, complete prototype was not accomplished. This was partly because some of the parts needed for the project (like the heart-rate monitor) were shipped to us just days before the final presentation.

During this project we learned that it is possible to make a bone conduction headphone from quite simple components, and in some point of the projects, providing the audio information with piezo-electric transducers, seemed really promising. However, the audio quality and better options for text-to-speech should be investigated. We also learned a lot about the challenges that rise from this kinds of do-it-yourself projects and should've earlier try to iteratively combine the working parts and components as the combining of parts brought a lot of unforeseen problems. Even though a lot of people thought the idea seemed really useful and interesting during several discussions, the project lacked of proper user testing and research due to the challenges we met. After getting the parts of the porotype working well together, the future work would include more user research to improve the usability of the product and especially, to elaborate the needs and configure the information that is provided. In addition to these the future work should include investigating of different more discrete methods of measuring health information. Ideally this would mean that both the headphone and the measuring would be done in the same unobtrusive patch, without needing to use separate sensor pack and Bluetooth modules.

Roles of the authors

Panajis Rantala
Developing the prototype, programming and electronics, Bluetooth and piezos, making report.

Satria Sutisna
Developing the prototype, 3D-modelling, electronics, background research, ordering components, making the video, making report.

Yue Yang
Testing the sensor, background research, making report.

Joonas Tuovinen
Programming, electronics, audio, making the video, making report.

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