Haptic Headset Final Report

ECE 445, Senior Design

By

Tasho Madondo

(madondo2)

And

Danny Pellikan

(djp8)

Abstract

In this report we go over many of the important topics regarding our decision to make our haptic headset for our senior design project along with the process of building/completing it. We start with our goal to help the hearing impaired and move to the overall objective of creating a headset that takes in audio from the world and turns it into vibrations that hard of hearing people can hear. We then go into detail of the original plans and block diagrams that we had to alter throughout the course of the project in order to get ot working properly. The information and data we collected here was essential to the final success of our project even though we were only able to get one half of the headset working correctly due to lack of time and resources. While of course it could have been better, we are happy with the results of our project, and hope the ECE 445 team is as well.

Contents

1. Introduction

The property of hearing offers great advantages for survival as most alerts can be heard before they are ever seen. Deaf individuals, and those hard of hearing, have lost those advantages; Due to this, they lack the awareness of their environment offered with sound. Statisticians estimate that a little over 6% of the world is either deaf, or has experienced severe hearing loss throughout their life. While only 2-3 out of 1,000 babies on average are born deaf, roughly 15% of adults (+18) report that they experience some form of hearing loss from ages 18-69. These percentages may seem small right now, but when scaled to the massive population of the Earth, over 450 million people are affected by deafness and hearing loss. These people have lost a key sense that is vital in mitigating their safety in everyday life as a pedestrian. They are forced to go about their days without the ability to sense people and automobiles that aren't within their line of vision. The National Library of Medicine states that very little has been done in terms of research worldwide to remedy these struggles based on a study done in the UK. We aim to mitigate some of the struggles of those with deafness and hearing loss and contribute our aid to an issue that has received little acknowledgement in the past. As a solution, rather than relying on the sense of sound, they can use the sense of feeling to get information they need from their immediate surroundings with directional haptic feedback. Haptic feedback is the use of vibration to convey information to the user (for example play station controllers or phone notifications). The idea is to place individual vibration motors along the outer rings on each side of over-ear headphones or ear mufflers. When a loud enough sound is played from any direction to the user, each individual motor vibrates in a way to give the user a sense of directional feedback. The goal of this device is to give the user heads up on where to look to see where the sound came from regardless of how little they can hear from their surroundings.

2. Project Outline

2.1 Introduction

Our design did not change very much from our original plans. The nature of our signal processing subsystem moved to include the microcontroller, but other than that our building went according to our original plan. In figure 2.1 and 2.2 you can see the difference in the location of the microcontroller from the original block diagram to the final one. The requirements of our final project were that it would pick up substantially loud sounds compared to the measured environment with microphones, use signals from microphones and select vibration motors based on direction of the sound, comfortably fit the user, and have user efficiency so the person wearing the headset would successfully be able to tell where the sounds were coming from. One final requirement would be the completion of both sides of the headset, but due to numerous complications that wasn't possible.

2.2 Design

2.2.1 Design Procedure

For each subsystem the designs were fairly simple. Power involved a rechargeable lithium ion battery, a common voltage regulator and the built in BMS for the ESP32-S3. The microphone subsystem incorporated the microphones, each connected to an amplifier, then fed through an anti-aliasing bandpass filter, and a signal compressor. This information was then sent to the microcontroller in the signal processing subsystem where it then underwent analog to DC conversion and filtering to correctly select which microphones were being triggered. Once that was determined the triggered microphones would correctly select the vibration motors in the motor subsystem that would alert the user where the sound is coming from.

Figure 2.1 Original Block Diagram

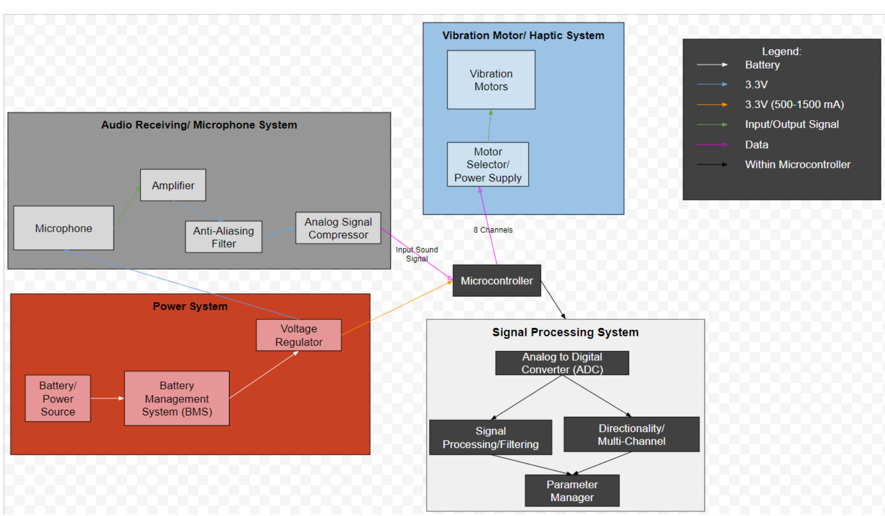
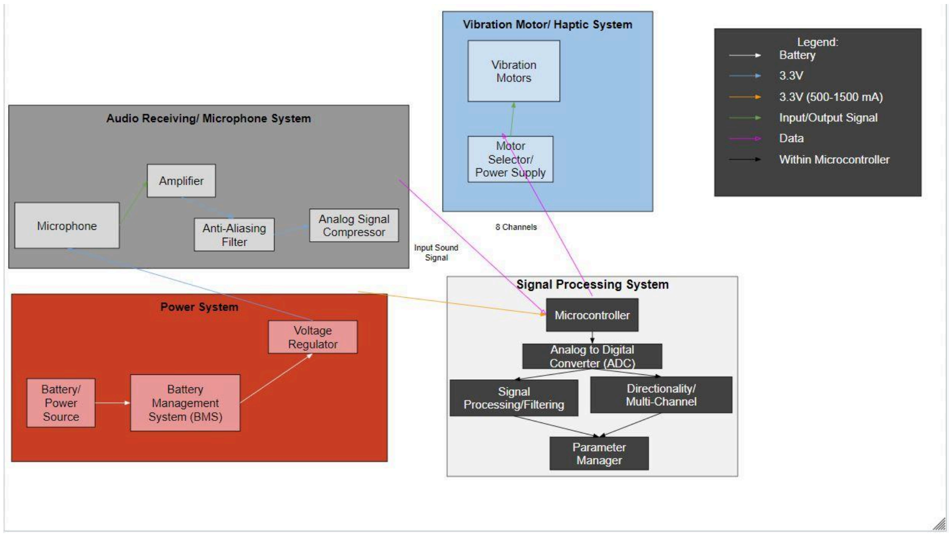


Figure 2.2 Finalized Block Diagram



The comfortability was also an important feature for the headset so we made sure to design the project with the user in mind.

Figure 2.3 Ear muffs before embedding electronics

Figure 2.4 Motor and Microphone diagram

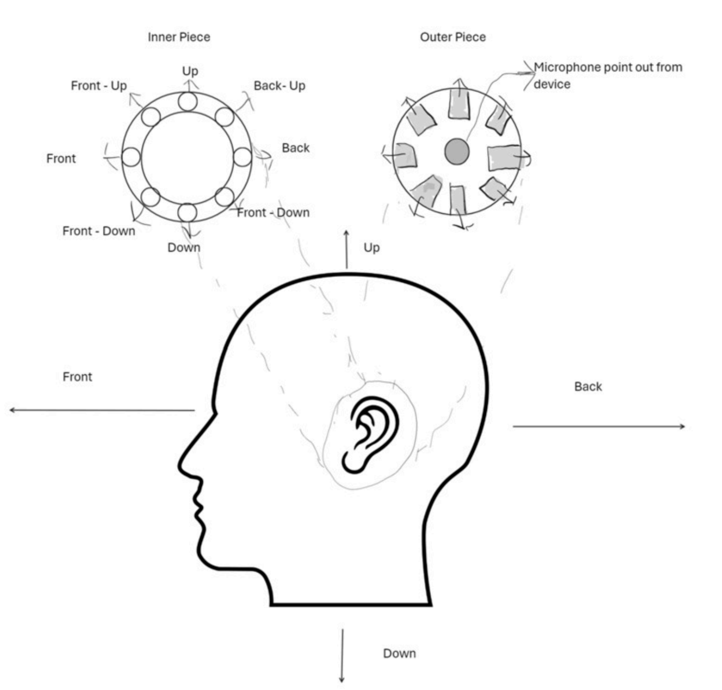


Figure 2.5 Power System Schematic

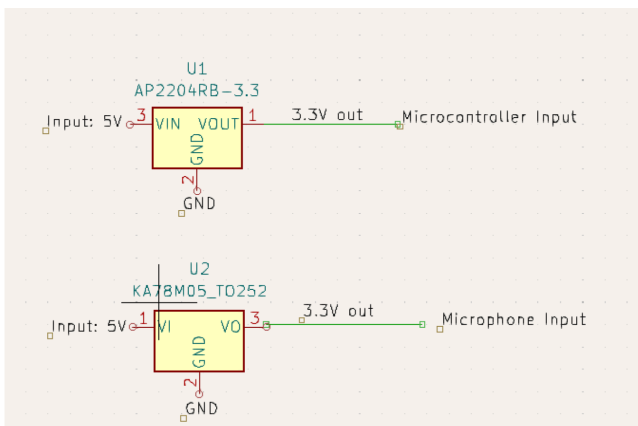


Figure 2.6 Microphone Subsystem Schematic

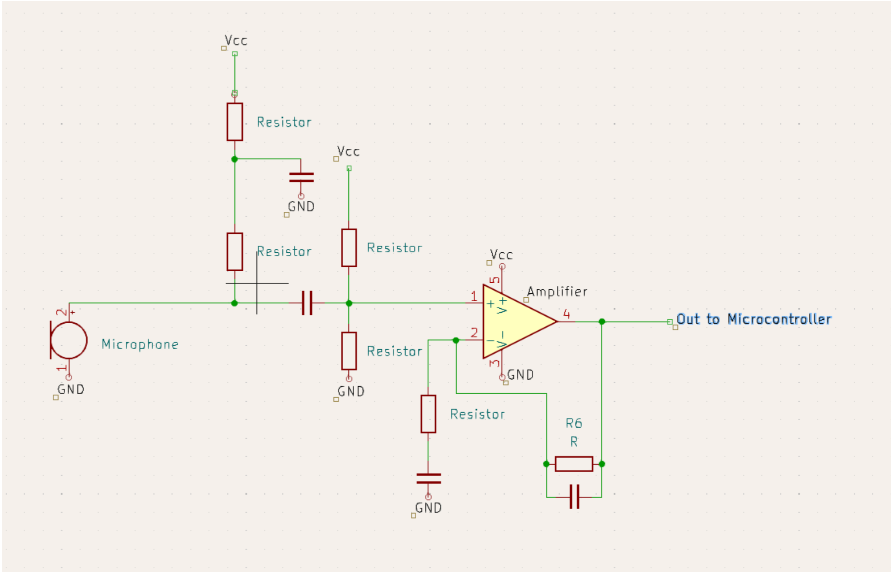
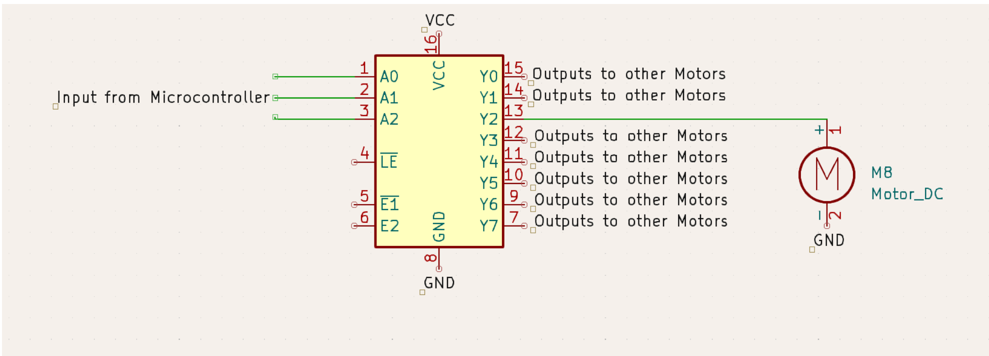


Figure 2.7 Motor Subsystem Schematic



2.2.2 Design Details

The overall design was the result of the thoughtful combination of each of the aforementioned subsystems. The most important calculations were done in the signal processing portion of the device. The device, when turned on, will give a short vibration of all the motors to notify the user that it is reading the room. It would then vibrate again to alert the user that the microphones had successfully recorded the ambient noise level of the room and set the base. After these steps have been taken, the headset is then ready to use and will pick up noise from the outside world. The ambient noise level is recorded because the user's environment may differ and we wanted to accommodate that. If the user is walking down a crowded street and the ambient level is too low, around 50-60 dB, (the average sound of a street and traffic is about 75 dB) the headset would be going off nonstop. Likewise, the headset would need to set a frequency threshold to tackle the same task. Normal conversation stays around 90-150 Hz while ambulance sirens can range from 400-900 Hz.

If recorded freq/dB > ambient room freq/dB, activate motors [1]

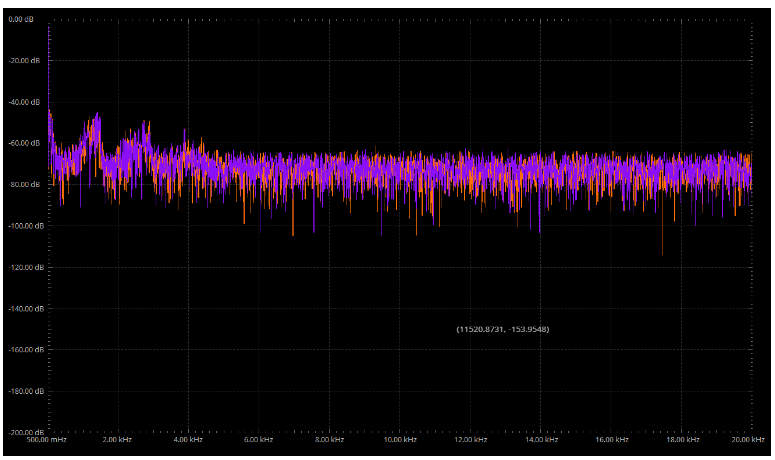
If the user is in a quiet place, the headset is more sensitive and vice versa in a louder setting. We were originally going to use the method of beam forming to take analog signals from the sound to convert them into digital and operate with them from there and that involved heavy formulas. Instead we took the frequency and dB values being polled from the microphones and compared the values being emitted from them.

dB value Mic 1 > dB value Mic 2 > dB value Mic 3 [2]

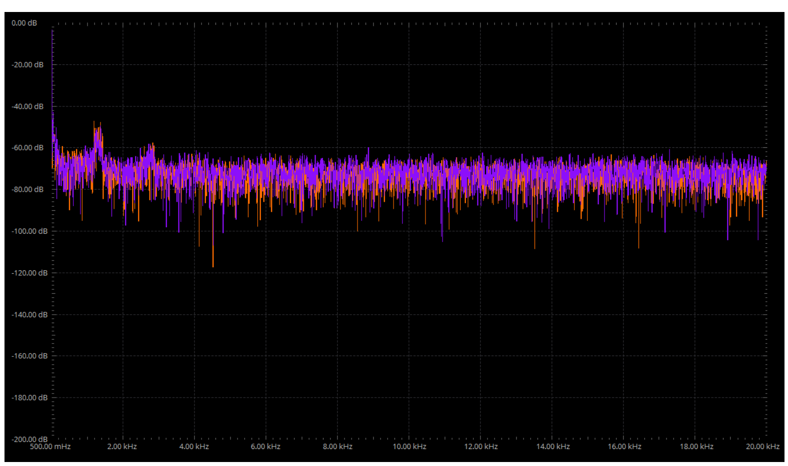
Given this information the headset would select Mic 1 as the strongest signal and activate that microphones given motor.

Figure 2.8 Frequency/dB Readings from microphone for Ambulance Sirens

1 meter away



15 ft away



2.3 Verifications

The testing involved for our project was relatively straightforward. Before we put the components into the headset, we connected them outside and played various noises from the speaker to ensure that we got the correct motor response. Our verifications and tolerance analysis remained the same throughout our project and you can see them outlined below.

2.3.1 Verifications

Table 1. Power Subsystem R&V Table

Requirements	Verifications

For ESP32-S3, supply 3.3V +/- 0.3V & [500, 1500] mA	1. Place a voltage sensor between the 3.3 V power rail and ground.
	2. Disconnect the power line to the microcontroller from the microcontroller.
	3. Make sure the power subsystem is turned on.
	4. Verify that the voltage between the power line and ground is below 3.6V.
	5. Verify upper power limit:
	  1) Place a 2Ω (±0.2Ω) resistor between the power line and ground.
	  2) After 1 minute, measure the voltage again and verify it is <= 3.3 V.
	6. Verify lower power limit:
	  1) Place a 6.8Ω (±0.2Ω) resistor between the power line and ground.
	  2) After 1 minute, measure the voltage again and verify it is >= 3.3 V.

Table 2. Microphone Subsystem R&V Table

Requirements	Verifications
- Keep noise floor 10dB below sound of interest from 3m away before signal compression - Verify that signal bandwidth is below 20k Hz to avoid aliasing	1. Make sure microphone subsystem is receiving proper power supply 2. Disconnect microphone subsystem from signal compressor & microcontroller 3. Connect oscilloscope probes to signal and ground

	4. Run frequency analyzer 5. Capture snapshot of frequency analyzer when there's no sound playing; calculate average/ RMS noise level 6. Play sound of car siren from phone at max volume 3+/- 0.1 m away from subsystem 7. While the sound plays, capture snapshot of frequency analyzer 8. There should be certain frequencies (most likely around 1k Hz) at least be 10 dB higher than other frequencies on the spectrum 9. Verify that frequencies after 20k Hz are at noise floor level
Input voltage to ADC pins must be <= 3.3 V	1. Make sure microphone subsystem is receiving proper power supply 2. Disconnect microphone subsystem from microcontroller 3. Connect voltage sensor in parallel to output signal from an arbitrary channel in microphone subsystem 4. Play constant loud noise directly into microphone corresponding to chosen channel 5. Verify that the output voltage is always <= 3.3 V even with complete audio clipping

Table 3. Motor Subsystem R&V Table

Requirements	Verifications
When a sound of interest is played within range (as previously specified), microcontroller must be able to give appropriate input signals to motor selector	1. Make sure microcontroller and motor subsystem are receiving proper power supply 2. Connect oscilloscope probes to microcontroller ground and output

- Select input & enable bits to turn on correct motor/ motors/ no motor - Vary Vcc so that motor selector outputs [2.5, 5] +/- 0.5V depending sound intensity	pins connected to motor selector 3. Hardcode direction & (varying) intensity in microcontroller for each possible motor position 4. When no motor is selected, select enable should be off 5. When a motor is selected, select enable should be on and correct voltages should be sent to select input bits - Voltage for select/ enable low should be 0 +/- 0.5 V - Voltage for select/ enable high should be [Vcc - 0.5 V, Vcc] 6. Vary vibrational intensity for selected motor from lowest intensity above threshold to maximum intensity - Voltage for lowest intensity should be 2.5 +/- 0.5 V - Voltage for highest intensity should be 5 +/- 0.5 V

Table 4. Signal-processing Subsystem R&V Table

Requirements	Verifications
Able to isolate the sound of interest (ex: car horn, siren, bike bell) & identify direction of sound - Correctly identify noise floor within 5 dB - When a channel receives audio of sound of interest 10 dB above noise floor, it recognizes it as a sound of interest - The subsystem must be able to distinguish the direction of sound sources within 45 degrees.	1. Make sure microphone subsystem and signal-processing subsystem are receiving proper power supply 2. Choose an arbitrary channel in the 2 subsystems 3. Connect oscilloscope probes to input signal to compressor and ground for that channel in the microphone subsystem 4. While there’s only ambience sound, run frequency analyzer on oscilloscope to estimate ambience level 5. Compare ambience level estimated by

	oscilloscope to ambience level estimated by signal-processing subsystem & verify that the latter falls within +/- 5 dB of the former 6. Play the sound of a car siren to the Left-Back of the microphone subsystem loud enough to be at least 10 dB louder than previously determined ambience level using oscilloscope 7. Verify that the signal-processing subsystem recognizes the sound of interest 8. Verify that the signal-processing subsystem recognizes the direction of the sound to be one of the following: - Left-Back - Left-Back-Up - Left-Back-Down - Left
The subsystem must be capable of doing the above in real-time (within 1 second).	1. Record a slow-motion video doing the above verification steps 6-8 2. Verify that the signal-processing subsystem gets the correct results within 1 second after from when the siren sound is played

2.3.2 Tolerance Analysis

The biggest hurdles that our project must overcome will be picking up the noise through the microphone effectively, processing the noise within the microcontroller, and determining the direction of one or even multiple sound sources. When it comes to sensing the sounds from the environment, the capability of the hardware is limited. We must find microphones that can reliably pick up sounds coming from the direction they are pointing at and ignore the sounds coming from different angles. The importance of finding reliable microphones will directly impact the sound sensing sub system and the noise processing of the microcontroller. When it comes to processing the noise in the microcontroller, we expect to differentiate the various ambient noise of the environment and the sounds that are cause for notice to the user. For the project to be successful, the processing must be fast and efficient from the given signal to the output signal. The area of risk is programming the microcontroller to process many sounds from different environments at different intensities and determining what to send to the motors and what to ignore. Many microcontrollers are efficient in audio processing; Arduino is compatible with many controllers such as the ESP32 and the STM32 which do have capabilities with sound processing. Furthermore, many microphones are capable of reading noise from only the direction they are pointing at a frequency range around from 100Hz and 20kHz. Thirdly, when it comes to determining the direction many complications can arise with the varying distance, presence of echoes and the potential of multiple sound sources feeding into the headset at once. The device should be able to take in all the various inputs and only vibrate to the sources of sounds (either one or multiple). This requirement will be difficult as it relies on both the hardware of the microphones and the capability of the signal processor. Finally, the micro controller must be able to process the many inputs of each unidirectional microphone to determine the direction of the sound. This requirement poses a risk as the microcontroller may not be able to handle the number of inputs. A solution to this could be to limit the number of inputs and outputs. This solution will also limit the precision device for the sake of hardware, precision limitations can be a benefit to the other subsystems such as the sensors as they will not need to signal as many different directions.

Table 5. Accuracy Error:

Sound Sensing in Microphones	Frequency Range: 100Hz(±30Hz) – 15000Hz (±1000Hz) Temperature range: -10℃-50℃ (±10℃)
Environmental Variability Directionality/ Distance/ Multiple Sources	Angle Accuracy: < 45° Distance Range: 0m-5 m respectively of Hz. Number of Sources read: 2 if distinct.

Noise Processing	Noise threshold: 75dB (Sound of a Person Yelling or Normal voice when close) Midrange frequency (5kHz- 10kHz) priority (Sound of Alarms and Sirens)
Input and Output Channel Limitations	8 input channels up to 3.3V input 8 output channels up to 5V output to motors

2.4 Costs

Component	Description	Quantity	Price	Total
Earmuffs	Manufacturer: Procase Earmuffs Part Number: N/A Desc: Headset for user to wear with microphones and motors attached. Link: here	1	$10.00	$10.00
ESP32-S3	Microcontroller Component Manufacturer: Espressif Part Number: ESP32-S3-DevKitC-1 Desc: Microcontroller used to process input. Link: here	2	$15.00	$15.00
Vibration Motors	Manufacturer: DFRobot Part Number: 1738-FIT0774-ND Desc: Motors for user Haptic Feedback Link: here	16	$0.99	$15.84
Microphones	Manufacturer: CUI Devices Part Number: 102-1728-ND Desc: Mics for Sensors in the Device Link: here	18	$1.63	$29.34
Amplifier	Manufacturer: Analog Devices Inc./Maxim Integrated Part Number: MAX4466EXK+T Desc: Audio Amplifiers for Mic	18	$0.90	$16.20

	Link: here			
Resistors 2kΩ 10kΩ	Manufacturer: Edgelec (Various) Part Number: EFR-W0D50-A:MF Desc: Resistor for circuits	108 54 (Round up: 100) 54 (Round up: 100)	$12.60 per 200 $6.30 per 100 $6.30 per 100	$12.60
Capacitors 0.01µF 0.1µF	Manufacturer: E-Project Part Number: B-0004-H15 Desc: Capacitor for circuit	72 36 36	 $5.41 per 25 $6.99 per 120	$17.81
8-Out Decoder	Manufacturer: Texas Instruments Part Number: SN74HC138DR Desc: Used in Motor Selector. IC DECODER/DEMUX 3:8 Link: here	2	$0.42	$0.84
Lithium Ion Battery	Manufacturer: EEM3 Part Number: A11777 Desc: Used to power the device Link: here	2	$13.99	$27.98
Parts Total:				$145.61
Hourly Salary: $40 Hours per Week: 10 Number of Weeks: 9 Number of People: 2 Labor Total: ($40.00) * (10* 9 * 2) * 2.5 = $27,000				$18,000
Grand Total				$18,145.61

Figure 2.4.1 Final Headset

3. Conclusion

Overall we would register our project as a success. While we were unable to complete both halves of the headset, the results we got out of the one side were very promising. If we were to develop this project on a wider,more user friendly scale, we would definitely need to go back to the drawing board for some refinement. On our current design there are wires sticking out of the side of the ear muff and the microphones are exposed, while these are fine for our purposes, an actual product would need to be much more streamlined. If we were to pursue this further, we would also like to toy with moving averages and possibly a sensitivity dial so the user can specify how they want the headset to react. We are grateful for the opportunity that ECE 445 has given us to broaden our engineering experience and we will use what we've learned here in our careers of the future!

4. References

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