Psychoacoustics – Portable Binaural Recordings

Physics 498 – Physics of Music/Musical Instruments

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I. Introduction

Acoustics involves the scientific study of sound that deals with production, control, transmission, reception, and effects of sound. Using this definition, one can guess that there are many different branches within acoustics. Psychoacoustics is the field of focus in this project. Since being introduced to the physics of hearing, I have always been interested in psychoacoustics. The details of how the human ear works is quite amazing and dare I say, mind-blowing. From the collection of sound outside of the ear, to the transduction of sound waves to an electrical signal, to the processing our brain uses to decode these electrical signals, the intricacies are a result of thousands if not millions of years of evolution. To duplicate such a system would be very hard to accomplish, but there is a simple way to replicate the human hearing system. This idea is binaural recording. Binaural recordings use a 'dummy head' the same size of a normal human head and also make use of two microphones that are placed inside the dummy's ears. Most binaural recordings are stationary because the head is simply placed on a stand at the same height as an average human and left there for the recording. Using this concept, one can find it hard to locate a source that is directly behind or in front of the 'dummy head.' This makes binaural recordings less effective because we, as humans, can quickly determine the location of the sound source on a horizontal plane. The properties to which we can do this so effectively, include visual recognition, amplitude and phase differences, shoulder, head, and pinna characteristics, and finally brain processing power, which is not fully understood yet. To use all this information and develop a binaural system would involve a lengthy project. Instead, I wanted to use the fact the human head is not always stationary. For the most part, we move our head to the left and right or up and down to help us locate a sound if we can not quickly determine its exact location. Using this simple concept, I wanted to create a portable binaural recording. To do this would mean to create a project where a 'dummy head' could move in all directions even moving forward and backward in space. Implementing this, however, would mean that the 'dummy head' would actually be a human themselves, and of course I would drop the term dummy from this argument. This concept is interesting because as humans, when we listen to music whether it is in stereo or surround sound environment, we are visually locating these sounds much the same way we do in a normal everyday environment. Thus, to do a binaural recording that allows the recording source to move around creates an even more life-like replication of the human hearing system.

II. Research

With most project ideas, it is wise to do a fair amount of research and planning before starting the project. Keeping in mind, when one does start a project, the plan doesn't necessarily always hold true because of time/money constraints, troubleshooting, interfacing, etc that are not taken into account during the planning process. I knew what I wanted my project to do and thus I needed to do research of human hearing characteristics and the parts that were required in order to implement the portable binaural recording.

As mentioned before, the human hearing system is a remarkable interconnected arrangement of passive and active elements that allows humans to process sound waves. These elements are the result of thousands to millions of years of evolution. The human hearing system consists of three parts: the outer, middle, and inner ear. Each part has its own function, which influence the performance of the other components.

Before speaking about the outer ear, it should be mentioned that sound waves can not only travel through the ear canals of the outer ear but also through the human head itself. Sound waves can and do travel through other mediums besides air so it is also reasonable to accept that sound waves can travel through the skin, bones, and fluids of the human head. As stated before, the human hearing system is quite complex and this project does and does not take into account some the characteristics of human hearing.

The outer ear includes the pinna (ear flap) and the ear canal. Sound that travels through air can be transmitted to the outer ear in multiple ways. Sound waves can be on a direct sound path straight to the ear canal. Sounds can also bounce off of the shoulders or the head and then reach the outer ear. Either way, the pinna acts as a sound collector and acts as small amplifier. In my project, I wanted to take advantage of these outer ear characteristics. Creating ear molds is possible, but I instead chose to use a quarter of ping pong ball to represent the pinna of the ear. This would be the sound collector and should also influence the amplitude differences from sounds that are either in front or behind of the portable binaural recording. Sounds coming from the front of the listener would be slightly louder than sounds coming from the back because of shape of the ping pong and the way in which it would collect sounds from those specific locations. This project will take into account the effects that the head, shoulder, and pinna has on human hearing.

There is one more effect that is very crucial for locating sounds. As humans, our brains uses pressure information to keep us balanced and standing and sitting upright. When we shift one way or the other our brain realizes this. Our brain also recognizes when we tilt our head up, down, left, right, etc. For the most part, our heads are not stationary for long periods of time. This fact helps us humans to locate sounds by turning our head (without falling over) to what we think is the location of the direct path from the source of the sound (sometimes we are deceived due to reflections of sound). Then, when we get visual confirmation and also recognition that the sound from the object is plausible, we locate the direct source of sound. I wanted to account for the fact that the movement of our heads and bodies help us locate sounds. Thus, I wanted to create a binaural recording where the head was allowed to move. A movable binaural recording also means that the system has to be portable without much inconvenience. Thus, a portable mixer that can record onto some type of file saving device is required.

The rest of the human hearing system including the individual elements of the middle and inner ear are left for the interested reader. Since I am not trying to duplicate the intricacies of the middle and inner ear, the descriptions of those parts are unnecessary. I do, however, want to be aware of the characteristics of these parts in terms of how they analyze incoming sound waves. For me, I am mostly interested in the frequency response and dynamic range of hearing. It has been determined that the normal range of hearing for humans is from 20 Hz to 20,000 Hz. This characteristic is crucial because of the varying frequency responses of microphones, which I will use to do the recordings. The frequency response curve which describes the different sensitivities of human hearing is not a flat line. But in this project, I will want a microphone with a flat frequency response because when listening back to the recording, the sensitivities of the ear in terms of frequency will do all the work, thus I don't need a microphone that takes those sensitivities into account. The human ear also has a dynamic range in terms of decibels. Decibels measure the loudness of a sound relative to the threshold of hearing. As humans, we can hear sounds that are as soft as 10^{-12} Watts/meter^2 or 0 dB and anything louder than 120 dB is considered painful and also begins to distort and cause hearing damage. Thus, in choosing a microphone, I wanted one that could handle at least 120 dB before distorting. All other hearing characteristics such as Just Noticeable Difference, Masking, Critical Bands, etc do not need to be taken into account since these will all be automatically done when a human listens to the portable binaural recording (ideally through headphones).

III. **Design**

The project idea was set. Create a portable binaural recording system. It is best to approach the description of this project from one end of the audio chain to the other. Thus, I will begin with the microphones. In order to create a movable binaural recording, I determined the best method was to place microphones on the outside edge of a set of headphones. Thus, the microphones had to be small enough to fit inside the casing of the headphones. Also, as pointed out earlier, I needed these microphones to have a flat frequency response with a sufficient maximum sound pressure level. I chose the Panasonic WM-61A's, which are electret condenser omni-directional microphones. I chose omni-directional microphones because typically, these types of mikes are used in binaural recordings and they best represent the polar pattern of human hearing. To install these microphones to the headphones, I first placed the mikes into holders so that the microphones could be easily replaced if damaged. Next, I drilled two small holes of appropriate diameter into the plastic plates on the outside of the headphones. Then, I super glued the holders to the inner rim of the holes and then placed the mikes inside the holders (picture on page 15). Next, I needed to consider how to carry my signal. Since I was doing a binaural recording, I was using two signals, one to each represent the human ears. I decided to make use of a ¼" stereo or Tip Ring Sleeve phone plug. I soldered the right microphone signal to the ring, the left microphone signal to the tip, and then used the sleeve as the common ground for both mikes. When using condenser microphones, a power supply is necessary in order for the mikes to operate. This is because condenser mike capsules use a conductive diaphragm and a metal back plate placed close to each other which need to be charged with static electricity. Then, when an incoming sound wave hits the diaphragm it changes the distance (and thus the capacitance) between the diaphragm and the back plate generating an electrical signal similar to the incoming sound wave. For the power supply, I followed the instructions from John Peluso's 'How to Build a Microphone.' The circuit components list is attached at the end of the project (page 14). Basically, the power supply circuit calls for a couple of capacitors, resistors, and batteries. The basic idea here is to add a battery to increase the electrical signal from the microphones. The microphones can handle anywhere from 2 volts to 10 volts of DC power and I choose to use 9 volts. I used 3V, 20 mm watch batteries as my batteries since they were small. I purchased two battery holders that could each hold three of the 3V batteries. The resistor is a 1% metal-film resistor used in audio circuits for fidelity reasons. There are two capacitors used in this circuit. First, there is a 1000 picofarad capacitor that is placed right after the microphone. This capacitor along with a 2.2 kilohm metal-film resistor and the 9 volts of DC power help power the microphone. The capacitor acts like a secondary battery with a time constant for when it is fully charged (or discharged) given by the simple equation $\tau = R*C = (2.2\ k\Omega)*(1000\ pF) = 2.2\ E^{-10}$ seconds. The reason for this simple RC circuit is so that microphone doesn't get powered with 9 V too quickly that would otherwise damage the mikes. Next, there is a 10 μF capacitor made of metalized polypropylene for audio fidelity reasons. Any resistance added after this capacitance in series will also result in a charging/discharging time constant for the capacitor, again using the simple time-constant equation for RC circuits. At this point, I had a signal with the appropriate voltage and impedance (mike level impedance) that I could be able to plug into a studio or live sound mixer. However, in order for this project to be portable, I required a smaller mixer that could be easily transportable. After using a suggestion from the lab TA, I went online and found the Zoom PS-04 Palmtop Studio 4 Track Recorder. This mixer is meant for guitar players to input and record their guitar into the mixer while playing with an already prerecorded drum track and bass guitar track. I, however, wanted to make use of the 1/8" stereo line input of the mixer which would allow me to record both the left and right microphone at the same time. When connecting two devices, in this case the microphones and the mixer, the microphones are referred to as the source and the mixer is referred to as the load. The goal when connecting two devices is to make sure that the impedances of the source and the load are of appropriate values. In this situation, the source needs to be of low impedance because the load is high. Doing this will result in the maximum voltage transfer from the source to the load. Also, there should be no distortion or frequency response change caused by this connection. Another good property of having a low impedance source allows one to use long lengths of cable without picking up much hum or losing high frequencies. In this project, the cable will run only about 3 feet from the headphones to the waist region where the mixer will be located. Taking this information into account it was now time to check the impedance values of the source (microphone) and load (Palmtop mixer). The stereo line input is of high-impedance (10 kilohms) and has a rated input level of -20 dBm. This high-impedance of the mixer (load) means that the output impedance from the microphones had to be of low impedance, characteristic of most microphones. Since the output impedance of the microphones was of relatively low impedance (~600 ohms), I was in good shape. There was, however, one problem with my incoming signal from my power supply that was to be inputted into the stereo line in signal of the mixer. The level of this signal was not strong enough for the stereo line input. Thus, I needed to add some gain to the signal. Using the professor's recommendation, I used an op-amp with a gain stage of 10 using R_2 = 200 kΩ and R_1 = 20 kΩ. The gain stage of the op-amp could be changed depending on the values of the resistors used. This is because of the simple gain equation used for op-amps: $G = (R_1 + R_2)/R_1$. Next, I needed to charge the 10 μF capacitor from the original power supply. Thus, I used 100 kΩ 1% metal-film resistor to give me a charging time constant of 1 second [$\tau = R*C$ = (100 kΩ)*(10 μF) = 1 sec]. Finally, I needed a switch to turn the op-amps on and off so as not to overexert their capabilities and ruin the chip with the op-amps. My final circuit was now complete (schematic on page 13, picture on page 15). I did the necessary soldering on a small solderable perforated board. Last, I needed to place the whole circuit into a small project box that would allow me to walk around with it and thus not be too much of an inconvenience. I drilled three holes into the project box to accommodate for the ¼" input, the on/off switch, and the 1/8" output. I then used a cable with 1/8" plugs on each end to connect the output of the project box to the input of the Palmtop mixer (pictures on page 16).

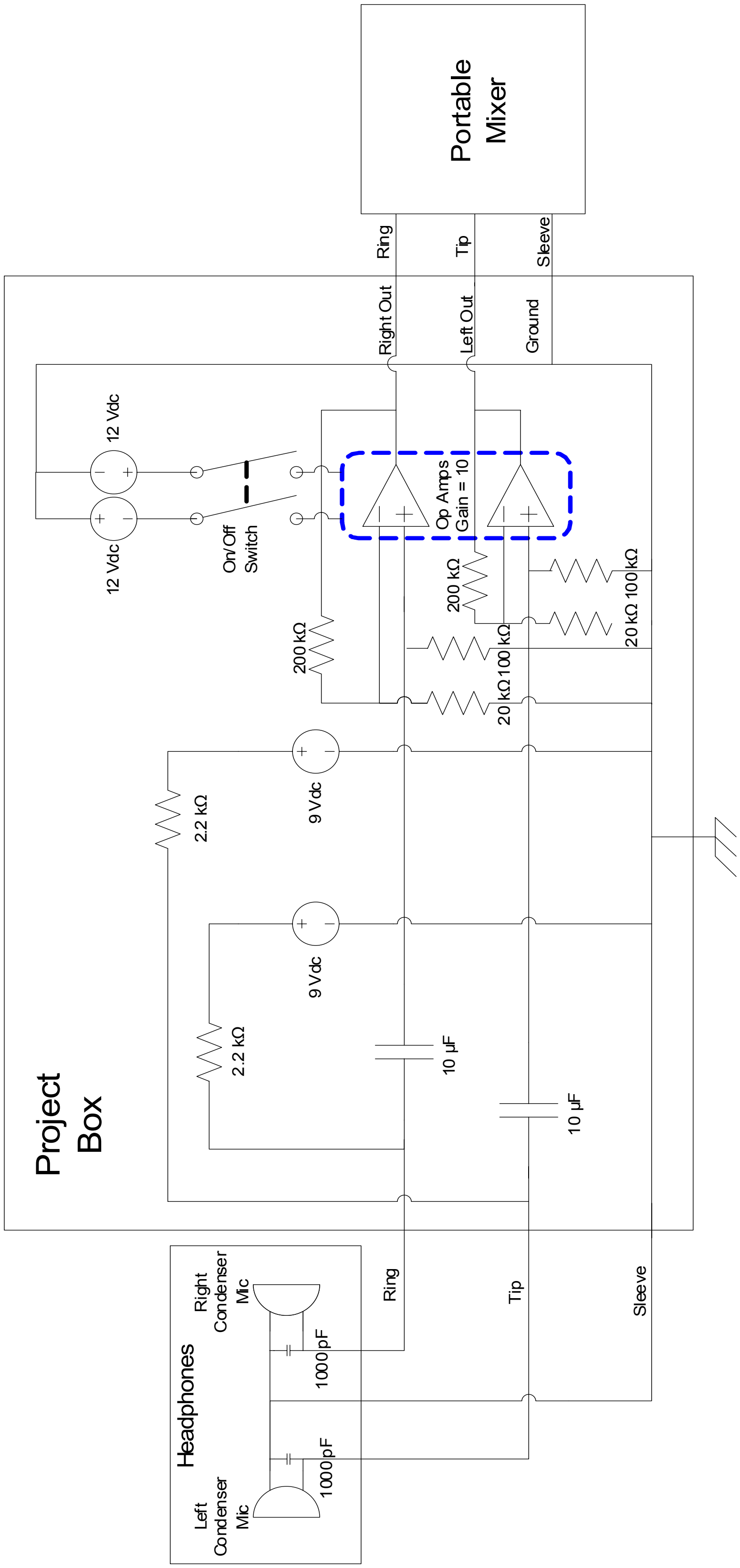
Now it was time to record but where do I start? There is so much sound that is constantly going on throughout our daily lives. The kinds and types of sounds are different depending where you are at and what time of the day it is. Also, of reflection is to think about the types of sounds that were going on 20, 50, 100, 200 years ago as we progressed through day to day routines. Obviously, we didn't hear jet engines or busses 200 years ago. A great advantage of this project is the fact that I have the ability to monitor my recordings in real-time or for later monitoring. This is because, I am wearing headphones and can listen to my recording levels because of the headphone output jack of the Palmtop mixer.

Let's record. The best approach was to just walk around campus and record different environments. I recorded myself walking around the Illini Union including into the bowling alley, up and down the stairs, and into the South Lounge where a piano player was conveniently playing. I also recorded a broomball game at the Ice Arena as well as myself driving the Zamboni machine around the rink. More recordings are yet to come.

IV. Conclusion

Overall, I really enjoyed working on this project. Due to time/money constraints, I did not include some other components to this project that would have made it more exciting and useful. I would have liked to create some programming code that would take in the audio information from the two microphones in the binaural recording and encode that information into a surround sound system environment. I think portable binaural recordings would be useful for military simulations, video games, and even movies. Having someone move around in any environment while recording the video and audio information and then synching those two components together could result in very real simulations when used for playback. I did not, however, have enough time to explore these areas further. Having said that, I am still satisfied with the progress that was completed. One of the results that came from this project is that when one is doing a Portable Binaural Recording it will not actually look like they are. At first look, one would see a person walking around with headphones assuming they are listening to music, but in reality, the microphones are so small and camouflaged with the outside of the headphones that it would be hard to determine the person is actually recording (see pictures of headphones on pages 16 and 17). To end, I would like to thank Professor Steven Errede and Matt Winkler for all their patience and help throughout this project.

V. Circuit Design



VI. Parts List

Part	Quantity	Cost ($)
¼ " Plug	1	0.35
1/8 " Stereo Plugs with 6' Wire	1	1.50
¼ " Stereo Jack	1	0.25
1/8 " Stereo Jack	1	0.35
1000 pF Ceramic Disc Capacitor	2	0.12
10 µF Polypropylene Capacitor	2	3.00
2.2 kΩ 1% Metal-Film Resistor	2	0.10
20 kΩ 1% Metal-Film Resistor	2	0.20
100 kΩ 1% Metal-Film Resistor	2	0.30
200 kΩ 1% Metal-Film Resistor	2	0.40
3V 20 mm Lithium Coin Battery	6	3.04
20 mm Battery Holder	2	2.06
12 V 21/23 Battery	2	6.00
12 V Battery Holder	2	2.00
Electret Omnidirectional Microphone Cartridge	2	3.66
Microphone Holder	2	1.18
Zoom PS04 Palmtop Studio 4 Track Recorder	1	199.94
On/Off Switch 7510	1	2.00
Texas Instruments TL072ACP Op Amp	1	1.50
Ping Pong Ball	1	0.25
Solderable Perforated Board	1	2.00
Project Box	1	3.30
Miscellaneous Wires and Cables		1.00
Good Times	Many	Priceless
	Total Cost (-Good Times) =	**234.50**

VII. Pictures