The Science of Surround Sound

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C O N N E X I O N S

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Chapter 1

Introduction[1]

1.1 Introduction

1.1.1 Background

In today's rapidly growing entertainment industry, many people desire a greater degree of emersion whether it be through 3-D visuals popping out of the screen or surround sound audio making them feel as though they are at the heart of the excitement. Unfortunately, the means to implement these systems can often be out of reach for individuals due to the cost of such systems or their size. Surround sound systems, while not as expensive as one of the new 3-D TVs, are still a significant investment both in money and the time needed to correctly set up the system. Additionally, these systems are by no means portable.

1.1.2 Project Description

Through our project we sought to address both the cost and size issue of surround sound systems by using in-ear microphones to sample a test signal from which a person's particular **head-related transfer functions** (HRTFs) could be calculated. These transfer fnctions could then be applied to input signals and the resulting output signals, when played through stereo headphones, would give the appearance of sounds coming from various directions in a circle around the person's head.

[1]This content is available online at <http://cnx.org/content/m36395/1.2/>.

Chapter 2

Test Sampling and Channel Characterization[1]

2.1 Sample Signal Generation

For our sample signal we decided on a chirp covering the range of human hearing, 15 Hz to 20000 Hz. This signal was created using the Matlab chirp command as follows:

```
%% Chirp Function

Fs = 44100;

f0 = 15;
f1 = 20000;
t = 0:1/Fs:1-1/Fs;
y = chirp(t,f0,1,f1);
```

where f0 and f1 are the edges of the spectrum of human hearing. The vector t has 44100 entries, each separated by 1/44100. Taken as a time vector and with the end time of the chirp set as 1 second, this creates a chirp which goes from 15 Hz to 20000 Hz in 1 second at intervals of 1/44100 seconds, which allows for a clean transition from 15 Hz to 20000 Hz at the standard sampling rate of 44100 Hz.

[1] This content is available online at <http://cnx.org/content/m36396/1.2/>.

2.2 Finding the Transfer Function of the Speaker to Mic Channel

Figure 2.1: Microphone and Speaker Equipment used for signal sampling

In order to find HRTFs we first had to know the transfer function of the speaker to mic channel through air. We did this by first playing our chirp signal at a mic held approximately 3 feet away and recording the mic output. We did this twice and averaged the two outputs to remove any anomalies. Then using the property that for an LTI filter:

$$h_{\text{channel}}(t) * \text{in}(t) = \text{out}(t) \tag{2.1}$$

or in terms of frequency domain:

$$H_{\text{Channel}}(\omega) \cdot \text{IN}(\omega) = \text{OUT}(\omega) \tag{2.2}$$

$$H_{\text{Channel}}(\omega) = \text{OUT}(\omega) / \text{IN}(\omega) \tag{2.3}$$

where $H_{\text{Channel}}(\omega)$is the transfer function of the system and $\text{IN}(\omega)$ and $\text{OUT}(\omega)$ are the fourier transforms of the input and output signals respectively. Thus, by taking the fft of the mic output and pointwise dividing by the fft of the chirp signal (3) (p. 4), we found the transfer function of the speaker to mic channel.

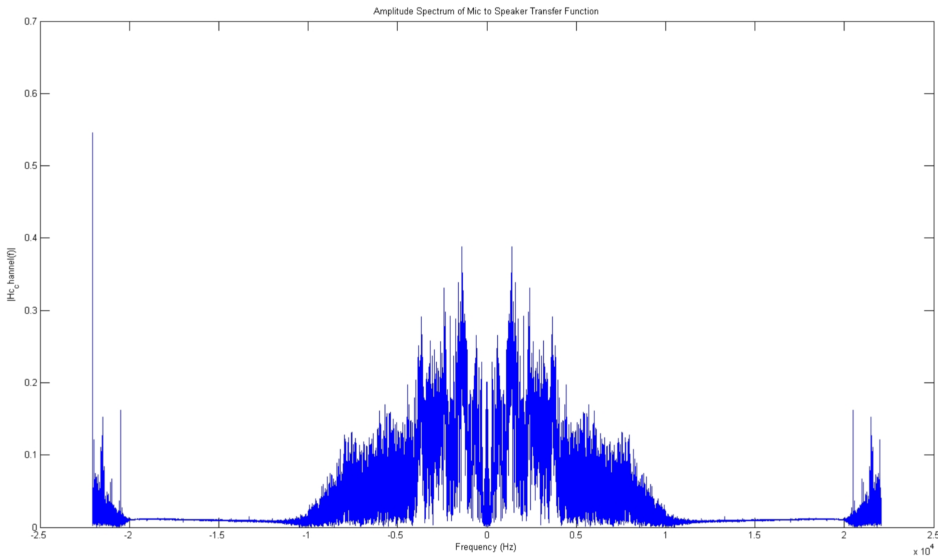

Figure 2.2: Amplitude Spectrum of Mic to Speaker Transfer Function

Chapter 3

Finding Directional HRTFs[1]

3.1 Calculating HRTFs for Signals from Various Directions

3.1.1 Directional Signal Sampling

In order to find directional HRTFs for our test subject, we first had to make recordings of the signals as heard by the test subject coming from different directions. In order to do this, we placed our microphone in the ear to be tested, as shown below.

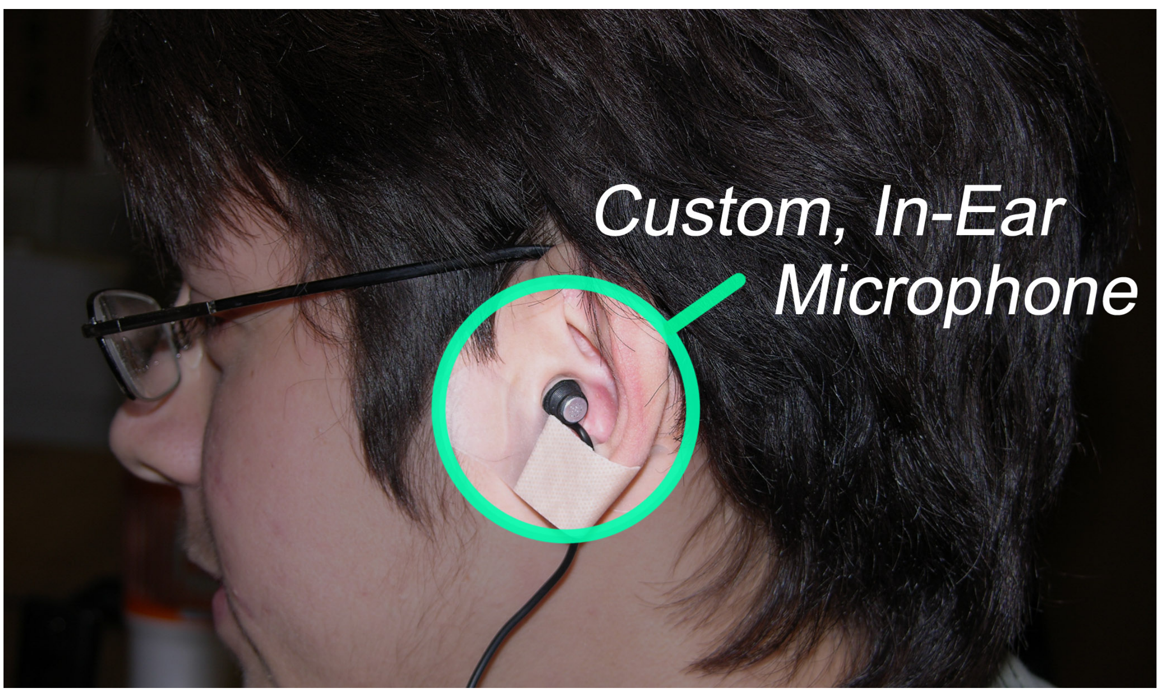

Figure 3.1: In-ear microphone setup for the left ear

[1]This content is available online at <http://cnx.org/content/m36397/1.2/>.

We then played our chirp signal at the test subject from various directions with the speaker at the same distance as in the initial channel characterization. As in the initial channel characterization, we sampled twice for each direction and averaged the two results. After sampling for that particular ear, we then switched the microphone to the other ear and sampled the same directions for the other ear.

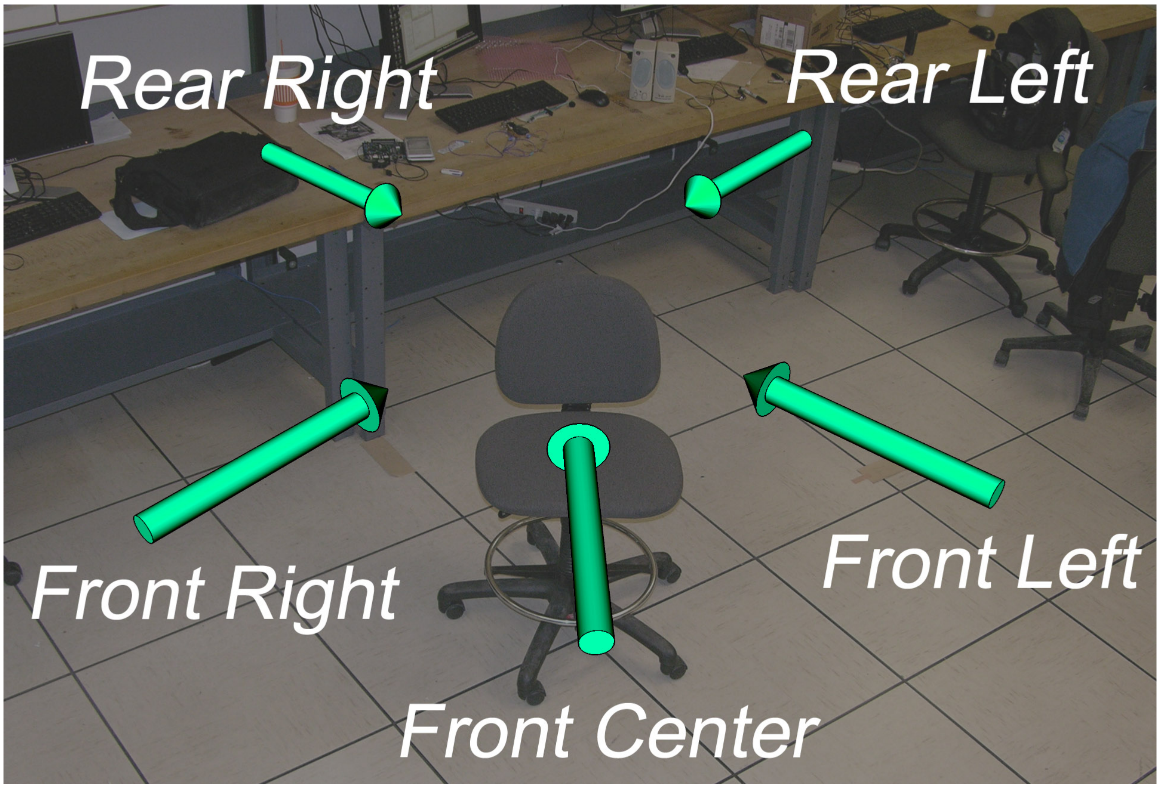

Figure 3.2: The five sampling directions used to find HRTFs

3.1.2 HRTF Calculation

In the initial channel characterization, the transfer function $H_{\text{Channel}}(\omega)$was the only thing acting on the chirp signal. Now, with the microphone situated in the test subject's ear, both $H_{\text{Channel}}(\omega)$ and the directional HRTF for that particular ear $H_{\text{Directional}}(\omega)$act on the chirp signal. In other words:

$$H_{\text{Channel}}(\omega) \cdot \text{IN}(\omega) \cdot H_{\text{Directional}}(\omega) = \text{OUT}(\omega) \tag{3.1}$$

Since we already calculated $H_{\text{Channel}}(\omega)$ and $\text{IN}(\omega)$ during the initial channel characterization, and we can find $\text{OUT}(\omega)$ for each particular ear/direction combination by taking the fft of our recorded outputs, we can therefore calculate $H_{\text{Directional}}(\omega)$using the equation:

$$H_{\text{Directional}}(\omega) = \text{OUT}(\omega) / [H_{\text{Channel}}(\omega) \cdot \text{IN}(\omega)] \tag{3.2}$$

Chapter 4

Surround Sound Simulation[1]

4.1 Directional Test Signal Creation

In order to test the accuracy of our calculated HRTFs, we used 5.1 surround sound test files used to calibrate home theater systems. We first had to downsample these files from their original sampling rate of 48000 Hz to our sampling rate of 41000 Hz. Since the files were all meant to be played at the same time, each file only played sound part of the time. Therefore, we had to cut out the unused parts of each file and create new sound files which included only the testing segment of each directional file. After this process was complete, we were left with five signals, each of which specified which direction the sound was supposed to come from.

4.2 Directional Sound Playback

We then simulated these signals coming from particular directions using the equation from the HRTF calculation:

$$H_{\text{Channel}}(\omega) \cdot \text{IN}(\omega) \cdot H_{\text{Directional}}(\omega) = \text{OUT}(\omega) \tag{4.1}$$

In this case $H_{\text{Channel}}$is the earbud to ear channel transfer function. Unfortunately, we weren't able to characterize this channel with our available resources, so in this instance we assumed that $H_{\text{Channel}} = 1$. This left us with the following equation:

$$\text{IN}(\omega) \cdot H_{\text{Directional}}(\omega) = \text{OUT}(\omega) \tag{4.2}$$

By applying this equation to each calculated $H_{\text{Directional}}(\omega)$for both ears we were able to generate a series of synthesized sound files for each ear which when played in stereo would mimic a cound coming from a particular direction by using the following code:

```
L_OUT=[SYNTH_FL_L, SYNTH_FC_L, SYNTH_FR_L, SYNTH_RR_L, SYNTH_RL_L];
L_OUT=L_OUT';
R_OUT=[SYNTH_FL_R, SYNTH_FC_R, SYNTH_FR_R, SYNTH_RR_R, SYNTH_RL_R];
R_OUT=R_OUT';
FINAL_OUT=[L_OUT, R_OUT];
sound(FINAL_OUT, Fs);
```

In this code, the SYNTH terms are the vectors corresponding to the filtered test signals for front-left, front-center, front-right, rear-right, and rear-left directions. With the left and right ear outputs arranged as shown in FINAL_OUT, the sound command plays the first set of terms to the left speaker/headphone and the second set of terms to the right speaker/headphone as we desired.

[1]This content is available online at <http://cnx.org/content/m36400/1.2/>.

Chapter 5

Results, Conclusions, and Future Applications[1]

5.1 Project Wrap-up

5.1.1 Results

When the synthesized sound playing command is executed, the results are encouraging. Obviously, the surround sound simulation works best for the person who was used in the HRTF calculation step as each person will have different HRTFs. The illusion of sounds coming from different directions is clearly discernible to other listeners, but generally the directions are neither as distinct nor as accurate. The resulting sound is also somewhat noisy, due to the testing environment and the quality of the equipment used.

5.1.2 Conclusion

While this method of surround sound simulation wasn't quite as convincing as a home theater setup might have been, it was quite accurate considering the number of HRTFs used, the testing environment, and its' ability to work in part for more people than simply the HRTF test subject.

5.1.3 Future Directions/Applications

This simulation method, if perfected, could be readily scaled to calculate more directional transfer functions. This would allow the simulation of sound with greater directional fidelity. Possible means of improving this method include:

- Recording in a less noisy, anechoic chamber
- Using higher quality sound production and recording devices with more linear transfer functions
- Recording at higher sampling rates
- Measuring the transfer function between each headphone ear bud and the user's inner ear, and incorporating this into the directional transfer function
- More accurately measuring speaker location/angle to better simulate a home theatre environment
- Use of a nonlinear chirp signal to account for the nonlinearity of human hearing

An interesting hypothetical application of this technology involves noise-cancelling headphones. Such headphones have a small microphone embedded in them for the purpose of sampling environmental noise. These microphones could conceivably be used to sample a particular user's HRTFs if an external speaker was available. These, along with software, could then be used to simulate a multi-directional speaker configuration.

[1]This content is available online at <http://cnx.org/content/m36401/1.2/>.

Chapter 6

Acknowledgements/References[1]

6.1 Acknowledgements

Dr. Don Johnson for his assistance in establishing a testing methodology, identifying potential problems, and imparting to us his knowledge regarding HRTFs and sound sampling.

Dr. Richard Baraniuk for ensuring that we were dealing with a feasible project and for his instruction in the classroom which gave us the knowledge necessary to undertake this project.

Eva Dyer for pointing us in the direction of several HRTF-related resources as well as suggestions regarding possible future improvements.

6.2 References

The Music of Bjorn Lynne. LynneMusic. Web. 14 Dec. 2010. <http://www.lynnemusic.com/surround.html[2] >.

This is where we found our 5.1 surround sound test files which we used to test the accuracy of our calculated directional transfer functions.

[1] This content is available online at <http://cnx.org/content/m36403/1.2/>.

[2] http://www.lynnemusic.com/surround.html

Index of Keywords and Terms

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The Science of Surround Sound

Our Fall 2010 ELEC 301 project dealing with the simulation of surround sound using calculated directional transfer functions.

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