SPATIAL EFFECTS: 3D WITH HEADPHONES – LAB REPORT 1

Daniel Ricardo Jimenez Pinilla 420107583(SID)

Digital Audio Systems, DESC9115, Semester 1 2012
Graduate Program in Audio and Acoustics
Faculty of Architecture, Design and Planning, The University of Sydney

ABSTRACT

This document intends to give the reader a first approach into the spatial effects aimed to recreate three dimensional sound atmospheres using a set of headphones as the auditory source for the listener. Throughout this document the reader will find an introductory approach to the spatial audio effects that will directly affect the results expected of a well-designed simulated 3D sound environment.

The analysis of these effects will allow the reader a better understanding of the expected outcome of their application in recreating such environment through a set of headphones.

1. INTRODUCTION

The human hearing system can process various cues in order to localize with great accuracy the position of a given sound source. This process can be very closely simulated by a filtering effect given by a pinna-head-torso system that directly affects how sounds reach the listener's hearing system.

Taking into account the previous mentioned effects, one could, with fairly great accuracy, position a source in a simulated space by considering the Head Related Transfer Functions (HRTF) that act as filters to a monophonic signal and therefore giving it a location in terms of the interaural differences and coloring it with reverberation effects in order to recreate a virtual space where the sound source is radiating and position the listener in it.

For simulating a 3D environment with headphones we have to take into account three main arguments that help the human hearing system to locate a sound source. These are described by Head Related Transfer Functions and are:

- Head shadowing and Interaural Time Differences.
- Shoulder echoes.
- Pinna reflections.

1.1. Head shadowing and ITD

First of all, analyzing the head shadowing effect, we assume that the head can be described as a rigid sphere that reflects plane waves. This approximation can be represented by a first order continuous system with one pole and one zero in the Laplace complex plane:

$$s_z = \frac{-2\omega_0}{\alpha(\theta)} \quad (1)$$

$$s_p = -2\omega_0 \quad (2)$$

In this pole-zero couple, $\omega_0 = c/a$ where c is the speed of sound in air and a is the radius of the sphere that represents the head. The position of the source is represented in the position of the zero in the Laplace plane and it varies accordingly to the position of the sound source.

$$\alpha(\theta) = 1.05 + 0.95\cos\left(\frac{\theta}{150^\circ}180^\circ\right) \quad (3)$$

This can be used to design an IIR digital filter represented by the following equation:

$$H_{hs} = \frac{(\omega_0+\alpha F_s)+(\omega_0-\alpha F_s)z^{-1}}{(\omega_0+F_s)+(\omega_0-F_s)z^{-1}} \quad (4)$$

As for the Interaural Time Differences (ITD), they can be obtained by a first order all-pass filter. The group delay depends on the angle where the sound source is positioned.

$$\tau_h = \begin{cases} -\frac{a}{c}\cos\theta \,; 0 \le |\theta| < \frac{\pi}{2} \\ \frac{a}{c}\left(|\theta| - \frac{\pi}{2}\right); \frac{\pi}{2} \le |\theta| < \pi \end{cases} \quad (5)$$

1.2. Shoulder echoes

Second, we can represent the shoulder echoes by a simple delay of the sound that reaches the listener's ears. This is, we can simplify this to a single echo with delay time is given in milliseconds by:

$$\tau_{sh} = 1.2\frac{180^\circ-\theta}{180^\circ}\left(1 - 4\cdot 10^{-5}\left((\varphi - 80^\circ)\frac{180^\circ}{180^\circ+\theta}\right)^2\right) \quad (6)$$

Where φ gives the elevation of the source from the listener's line-of-sight. This echo should be attenuated compared to the gain level of the direct sound.

1.3. Pinna reflections

Finally, the pinna reflections can be obtained by a series of delays. These reflections are given by the formula:

$$\tau_{pn} = A_n \cos\left(\frac{\theta}{2}\right)\sin\big(D_n(90^\circ - \varphi)\big) + B_n$$

The parameters for this equation are dependent on the characteristics of the pinna, and the azimuth and elevation of the sound source.

1.4. Application and control

This whole system can be described as a diagram of function relating all the arguments mentioned above.

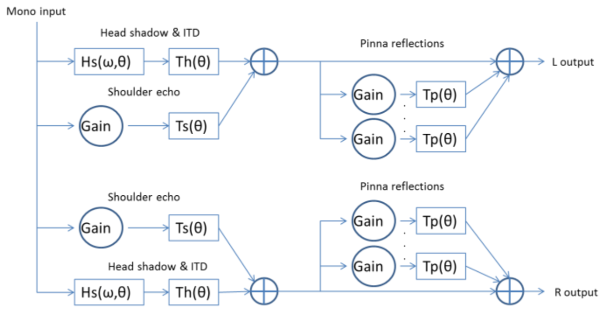

Figure 1: *Block diagram for the head-pinna-torso system.*

2. DISCUSSION

A MatLab implementation of the head shadowing effect and the ITD can be found in Udo Zolzer's "Digital Audio Effects" book. This function uses the matrix form of equations 4 and 5 to process a monophonic audio signal and position it in a virtual 3D environment using gain differences and delays to place it in an angular position given by azimuth angle θ. This function takes the desired angle to place the source. The angle can be varied from $-90° \leq \theta \leq 90°$. The function has to be applied twice, with opposite values of θ, to a single mono signal to render the output for each ear in a stereo pair.

Although this is only one block of the system to acquire a full 3D image of a sound source it gives the most significant cue to locate it in a virtual environment.

The arguments for this function (hsfilter.m) are the input mono signal, the sampling frequency, as it is used as a parameter of the transfer function (equation 4) of the head shadowing system and the azimuth angle; parameter both for the transfer function and the delay function for the ITD.

A function has been written based on equation 6 to generate a single echo with a relative attenuation to the input signal also based on the azimuth angle for the virtual position of the sound source (shoulderreflection.m).

Using these functions mentioned above, another function has been written in order to generate a stereo signal based on the arguments needed for the head shadowing function and the shoulder reflections function (refer to the code for headandshoulders.m).

This last function takes the MatLab code proposed in the "Digital Audio Effects" book, and adds the function to generate a single echo for the shoulder reflection expressed by equation 6.

The sound file used to test all these functions mentioned above is 'anechoic_voice.wav', provided in several laboratory sessions of the Digital Audio Systems course.

3. CONCLUSION

The code given by the "Digital Audio Effects" book is very useful as a first approach to generating a 3D environment since it gives a very good approximation of how the sound is perceived for a binaural listener, but it lacks many other cues that the human hearing system needs to accurately place a source in space.

To the function given has been added a first attempt to generate a simulation of the echo perceived by the shoulder reflection rendering yet another cue to make the simulation closer to a real situation.

Further processing to the signal shall be used in order to generate a credible 3D sonic environment.

4. REFERENCES

[1] U. Zolzer, "Spatial Effects" in *DAFX: Digital Audio Effects*. John Wiley & Sons, Ltd., West Sussex, England, 2002, pp. 137–200.

[2] D. Begault, *3D Sound for Virtual Reality and Multimedia*. Ames Research Center, Moffett Field, California, 2000.