SPATIAL EFFECTS: 3D MOVEMENT OF A VIRTUAL SOUND SOURCE

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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

Spatial effects are used to emulate the human peripheral hearing system. Peripheral hearing is dependent on several factors that indicate the listener the spatial location of a certain sound source; these cues can be processed by the brain to infer the most likely location of the sound source. But this is only just a first approach to the sounds in the environment.

There are two perspectives to take into account for recreating a virtual sound source: firstly, we have to consider the static characteristics of a sound source and how they are perceived by the listener; and second, we have to consider the changes in these cues as the source is moving in space yielding dynamic arguments that will affect the perceived sound.

These processes mentioned above will result in the analysis of the behavior of a signal that implements them with the purpose or recreating a moving sound source in a virtual environment.

1.1. Auditory characteristics from a source under static conditions

The human peripheral hearing allows a listener to locate a sound source in space by a process of comparison of basically three parameters: (1) the apparent amplitude of the sound perceived by each ear, (2) the time it takes for the sound to reach each ear, and (3) the time it takes for the reflections of the sound source, produced by the environment, to reach each reference point of the listener.

These cues that are generated by the cognitive process in the human hearing system can be represented mathematically as transfer functions. The head related transfer functions (HRTF) describe in terms of the position of the sound source how it's perceived by the listener. The position of the source can be easily described by two angles: azimuth and elevation as shown in figure 1.

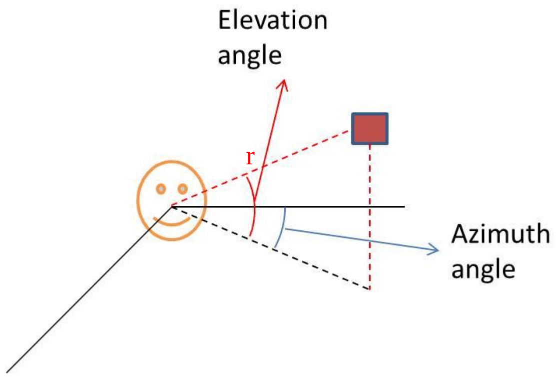

Figure 1: *Taxonomy of spatial hearing in terms of spherical location of the source.*

An approximation to a HRTF can be described by taking into account the different physical characteristics of the human hearing system. These can be narrowed down to two basic considerations: (1) The head shadowing effect and (2) the pinna reflections.

The head shadowing will play an important part in giving the listener a sense of lateralization whereas the pinna reflections will be more closely related to the elevation of the source. Also, the reflections of sound in the shoulder of the listener have an important effect when it comes to representing the elevation of the sound source.

Figure 2 shows a flow diagram of the system described above including both the head shadowing effect and pinna and shoulder reflections. This can yield to a fairly good representation in terms of the azimuth and elevation angles of the sound source.

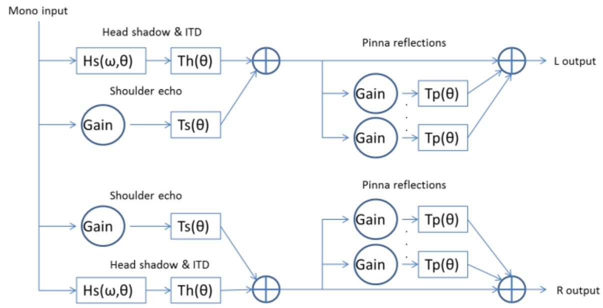

Figure 2: *Structural model of the human hearing system.*

1.1.1. *Lateralization*

One of the most important cues to identify the position of a sound source is given by the relative difference of the sound that arrives to each ear in a horizontal plane. These cues are frequency dependent and are given by time and intensity differences.

The Interaural Time Differences (ITD) and Interaural Intensity Differences (IID) can be calculated in terms of the paths that the waveforms describe from the center of the sound source to each of the ear canals of the listener.

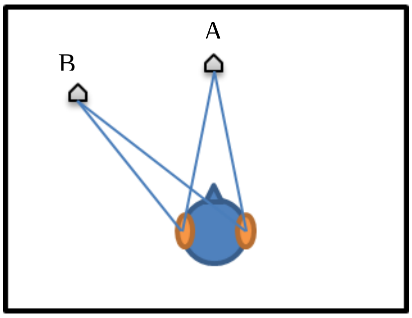

Figure 3: *A listener with a sound source oriented in front of him on the horizontal plane (A) and displaced to 135º azimuth.*

These differences are functions of frequency, as mentioned above as a result of a showing effect produced by the head. Signals with smaller wavelength than the size of the head will be shadowed as the sound source moves away from the center of the head to a lateral position; therefore, the shadowing effect of the head of the head will increase with the increase of frequency. For lower frequencies the waves will tend to diffract around the obstacle minimizing the intensity difference.

1.1.2. Elevation

Since sound sources are not moving in a two dimensional space, a second parameter to analyze in order to spatially localize a sound source is the elevation angle. Since the human hearing system uses cues given by the reflections of the pinnae to determine the elevation of a sound source rather than the information acquired from ITD or IID since the ears are placed in a horizontal plane with no directivity regarding elevation but just laterality.

The pinna reflections are therefore the argument that gives the sense of elevation of a sound source along with the shoulder and torso reflections. These can be modeled as a simple delay and add non-recursive network.

1.2. Auditory characteristics from a source under non-static conditions

When we analyze the case of a sound source that is moving in space we come across dynamic effects related to how we perceive this movement in terms of the distance, speed and direction of the sound source regarded from the hearing position of the listener.

This effect can be regarded as a change in pitch in terms of the distance and can be modeled as a pitch change; therefore a frequency change produced by the change in distance between the listener and the sound source.

1.2.1. Doppler shift

The Doppler Effect or Doppler Shift produces a dynamic change in frequency in terms of a source velocity, i.e. its change of distance from the listener in terms of time.

Equation 1 shows how the frequency of the sound source f_s is affected in terms of its speed c compared to the speed of sound traveling in air (c = 343 m/s; T=20ºC) as it approaches the listener.

$$f_r = f_s\left(\frac{c}{c-v_s\cdot\cos(\theta)}\right); 0<\theta<\frac{\pi}{2} \qquad (1)$$

Equation 2 shows how the frequency of the sound source f_s is affected as it recedes from the listener.

$$f_r = f_s\left(\frac{c}{c+v_s\cdot\cos(\theta)}\right); -\frac{\pi}{2}<\theta<0 \qquad (2)$$

The Doppler Effect considers a sound source that is changing its position with a relative constant velocity to the point of reference, i.e. a static listener, in the simplest of cases and how this movement affects the pitch of the sound source from the listener's point of view as it approaches and moves away.

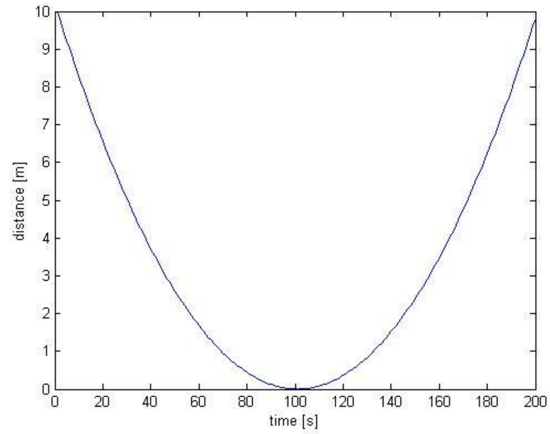

Figure 4: *Sound source trajectory as it approaches and recedes from the listener.*

If we analyze this pitch change for the human hearing system we find that the sound source's waveform is not arriving only to one receptor but in fact each or the ear canals of the listener are being excited by the moving sound source. This yields a small difference in the time that takes the sound to get to each of the listener's ears (see figure 5).

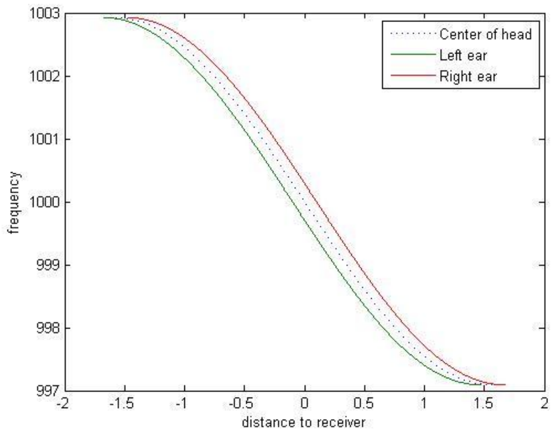

Figure 5: *Change of frequency in terms of distance to receiver from a moving source producing a 1 kHz tone.*

As we can see in figure 3, the difference in pitch perceived from each of the listener's ear canals increases as the source approaches but it is barely noticeable when the source is far away from the listener as it can be regarded as a punctual reference instead of considering the distance between the ears.

1.2.2. Reverberation

Reverberation effects are produced by reflections of a sound source in a particular enclosed environment; in this way they can as well be associated with the cues that indicate the listener how distant is the sound source from its point of reference.

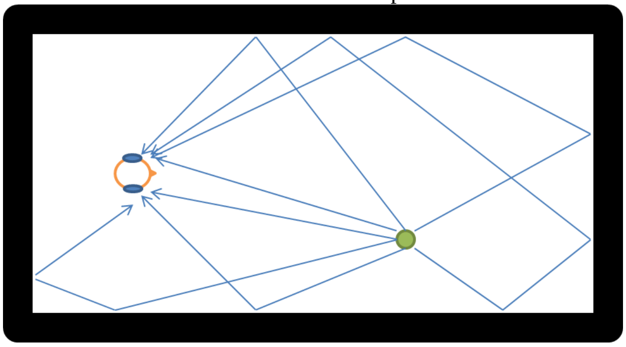

Figure 6: *Physical situation of reverberation reflections in a room.*

Figure 6 shows a scheme of how sound can be reflected in a room. Although is only shows some of the paths that sound can follow, one can see that the walls of a certain room can produce several reflections that act as cues about where the source is located as well as the size of the room in which the source is propagating its sound.

Reverberation as well can produce cues that can mislead the listener regarding the position creating diffuse sound fields.

1.3. 3D with headphones

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.

It is usually preferred to simulate a 3D virtual sound environment through headphones since it allows a better control of the parameters related to the static and dynamic factors that affect the perception of the human hearing system as well as the external factors such as the sound interaction with the room that would be present if the simulation would be made through a set of speakers.

1.4. Aims

Given all the arguments above about the effects that can be taken into account into recreating a virtual 3D spatial environment using headphones, the aims of the project can be listed as follows:

- Propose an algorithm to position a monophonic sound source in a virtual space given a radial distance from the sound source to the listener and an angular displacement from the listener's frontal line of sight and also taking into account HRTF effects.
- Propose an algorithm to emulate a moving source using Doppler Shift effects and placing it in a virtual environment by the use of reverberation effects.

2. DISCUSSION

The idea of this project is to recreate in the closest possible way the effects perceived by the human hearing system taking into account all the phenomena mentioned above that can generate cues in order to recreate a virtual environment for the listener using a pair of stereo headphones.

Whilst all these effects can be regarded as separate acoustic phenomena, and will be evaluated individually as to their contribution to recreating a virtual sound environment, the final objective is to merge them together to obtain a close representation of a simulated 3D environment.

One of the challenges of this project will be simulating movement of the sound source since most of the effects are intended to modify through delay or frequency shifts the apparent position or a stationary sound source.

As mentioned, the effects will be tested individually and chained in order to generate the best outcome.

3. CONCLUSION

Taking into account all the arguments presented in this document, one can determine that, in order to achieve a fairly close representation of a virtual sound environment, audio effects involving pitch and frequency shifting must be applied to a monophonic audio signal as well as the filtering involved represented by the pinna-head-torso system that can be achieved using HRTF effects.

This project can be feasibly accomplished within the established deadlines for the Digital Audio Systems course unit in semester 1, 2012.

4. REFERENCES

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