

# SPATIAL EFFECTS: 3D MOVEMENT OF A VIRTUAL SOUND SOURCE

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## ABSTRACT

This document intends to explain the audio development project proposed to emulate the spatial effect of having a sound source moving in a 3D sonic environment. Throughout this document the reader will see a detailed explanation of how the problem was approached, the specific requirements needed to achieve the result, how these requirements were implemented using MatLab coding and how the end product was tested to evaluate the effectiveness of the solution provided.

MatLab files will also be provided so that the reader can associate the concepts being described in order to have a better understanding of the process followed to develop this application.

## 1. INTRODUCTION

Spatial effects are used to emulate the human peripheral hearing system. For this particular project two approaches have been taken into account:

Firstly, the effects of lateralization have been evaluated in terms of the Head Related Transfer Function (HRTF) and how they affect the perception of a source that is being placed at a different angle around the listener. This first approach emulates what happens when a sound source is displaced in space under near listening conditions.

Furthermore, since the objective is to have a virtually dynamic sound source, a source that is moving in space, the far field effects and effects associated with a moving source were also taken into account.

### 1.1. Near field auditory conditions and HRTFs

Several factors can be analyzed when facing the problem of simulating the human peripheral auditory system. The HRTFs help in characterizing in a highly accurate way the effects of the interaural differences used to locate where a sound is coming from (See Initial Technology Review).

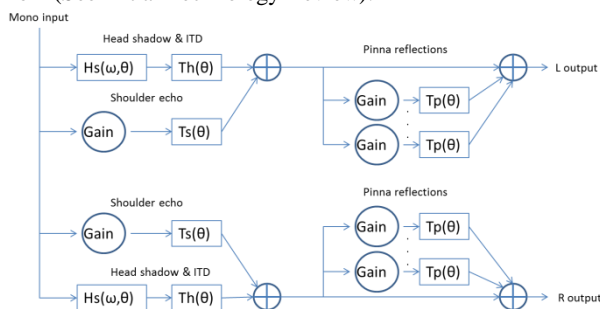


Figure 1: Structural model of the human hearing system.

### 1.1.1. HRTFs

There is a basic set of cues that the human hearing system uses to identify where a sound source is located and these are related to the differences in time and intensity with which the sound reaches each ear.

In figure 1 is shown a basic structural model where the hearing system is divided in three sections. The first thing to note is that the most noticeable cues are being caused by these mentioned above and is due to a head shadowing effect and the time difference with which sound arrives to each ear. These are expressed by the Interaural Time and Intensity Differences (ITD and IID).

A second cue to be taken into account is the shoulder reflections. These, can be expressed by a single reflection adding a delay and add network to the effects caused by the head shadowing and ITD.

Finally, to simulate the complete hearing system, we would have to take into account the pinna reflections. These late reflections with the shoulder reflections are mainly used to identify the elevation angle of a sound source. The differences in perception of the elevation angle are sometimes so small that are barely noticeable.

For this project, only the first part of this of this model has been taken into account since the differences in elevation are barely noticeable and the pinna reflections can be expressed in an infinite number of ways since the pinna of each listener is different. This project will only focus on a horizontal plane of movement.

### 1.1.2. Near field movement

Now if we analyze the effects of a source that is moving very near the listener, and taking into account the effects mentioned above related to the HRTF, we could approach this as a low scale Doppler shift difference.

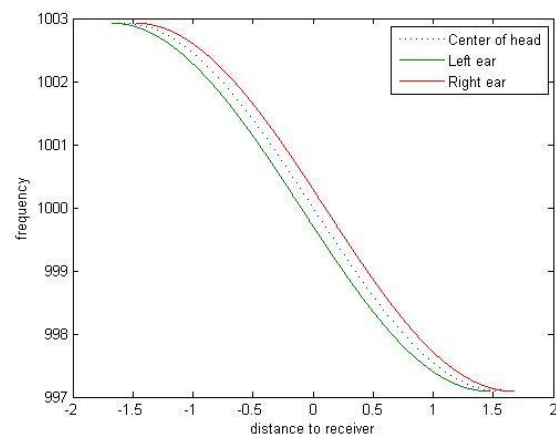


Figure 2: Change of frequency in terms of distance to receiver from a moving source producing a 1 kHz tone.

As we can see in figure 2, the Doppler Effect changes the frequency perceived by the listener as the source approaches and recedes from the listener. Taking into account that in the near field the listener cannot be seen as a point receiver but it has two receptors there is a slight difference directly proportional to the separation of the ears in the head.

## 1.2. Far field auditory conditions

To simulate a sound source that is moving in space we have to consider the changes in frequency and intensity of the sound as it approaches and recedes from the listener.

This effect can be analyzed with the Doppler Effect. This effect modifies the frequency of the sound source as it moves in space.

### 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;  $T=20^\circ\text{C}$ ) as it approaches the listener.

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

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

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

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 (See Lab Report 2).

One could extrapolate the behavior shown in figure 2 to see the frequency shift for far field conditions. Instead of seeing a difference in the time it takes to reach each ear the listener can be seen as a punctual receptor.

## 2. METHOD

In order to implement the effects described above, a MatLab function was written in order to implement and compile an effect that recreates the movement of a sound source in a horizontal plane in a virtual space.

In order to recreate the effects of the near field perception and the HRTFs a function called `hsfilter.m`. This function emulates the head shadowing effect and the interaural time differences that give lateralization cues to the listener by modifying the level of the signal that is going to be reproduced for each ear and the delay perceived by the listener in a given azimuth angular position. The functionality of this is explained in more detail in Lab Report 1 and briefly described in section 1.1.1 of this document.

To this function, an additional enhancement was achieved by the function `panoramawithhrtfchunks.m`; the sound source is

being moved in a horizontal plane in front of the listener from a given angular position to a final angular position. This function only considers the movement of the source for a constant radial distance from the listener. The Doppler shift can be slightly appreciated since this function tries to emulate the listening conditions of a source that is moving very near the listener and not changing its radial distance to the listener. This function can be explored in more detail in Lab Report 2 and its effect is briefly described in section 1.1.2 of this document.

Furthermore, a final function was implemented that incorporates the Doppler Effect achieved with the function `dopplershift.m` to the `panoramawithhrtfchunks.m` function. This final function was called `dopplerhrtf.m`. It implements the interaural differences produced by the human hearing system, the near field Doppler shift produced by the moving source with a fixed radial distance to the listener and the pitch and intensity shift perceived by the listener as a source approaches and recedes from the listening position.

The parameters that can be controlled by the user are the initial and final angular azimuth positions and the velocity of the sound source.

## 3. IMPLEMENTATION

For using the proposed solution given by the MatLab function `dopplerhrtf.m` to the problem of simulating movement of a sound source in a virtual 3D space the user will have the liberty of adjusting a certain number of parameters related to the movement of the source in space.

This application is presented to the user as a plug-in that can be run using a MatLab environment. The user interface for the plug-in has several parameters that can be controlled by the user. Since the application is targeted to simulate the movement of a static sound source the user will be able to control the initial and final angular positions of this movement as well as the distance at which the source is placed from the listener and the source's velocity throughout the displacement.

To save in processing expenses, the monophonic input is not treated for each sample but instead it is split into a small finite number of segments that smoothly represent the transition of the sound source across the virtual space.

## 4. EVALUATION

By using the proposed solution one can effectively perceive a pitch shift due to the simulation of the Doppler Effect on the input signal as well as a gain modification as the sound source approaches and recedes from the listener in the virtual space. Another thing to note is that the effect of the HRTF also gives a more realistic approach by filtering the signal to have a slight difference in the time it reaches each ear.

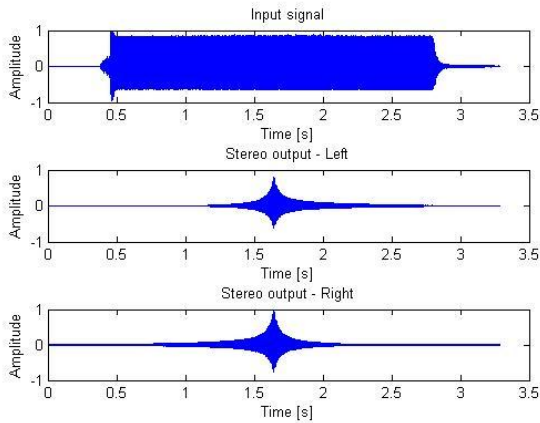


Figure 3: Processed signal of an air horn moving from an angular position of  $-90$  to  $90$  degrees at a horizontal distance from  $-50$  to  $50$  meters as regarded from the listener as the reference point.

In figure 3 is shown how the output of the function has modified a monophonic input into a stereophonic output taking into account the effects described above. As the sound source approaches the listener the intensity of the signal increases and decreases as it recedes from the listener. One can see a slight difference in time where the peak level occurs thus proving that the HRTF is affecting the sound that is reaching each ear as well as an intensity difference due to the head shadowing effect.

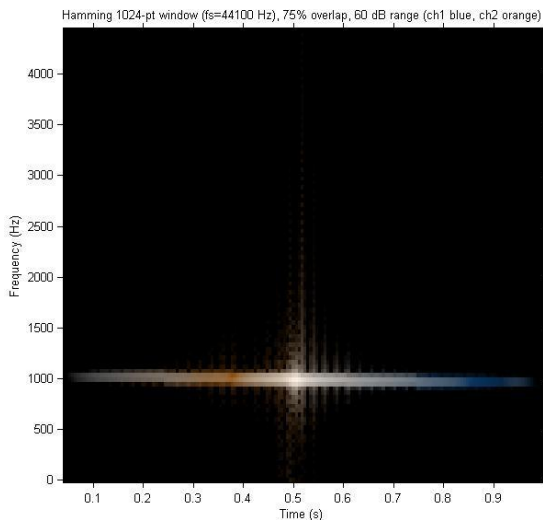


Figure 4: Spectral analysis of a processed  $1$  kHz pure tone.

As shown in figure 4, using a  $1$  kHz pure tone the Doppler effect is in fact modifying the frequency of the input signal by recreating a pitch shift due to the simulation of a source approaching and receding from the listener.

It is important to note that this application works better when using fairly constant level input sounds like the sound of an air horn or a musical instrument playing a sustained note. The input sounds should be of a short length in order to reduce processing times.

A way to assess the proper functionality of this application would be to play recorded sounds of sound sources approaching and receding from a dummy head and then the same sound but processed with the proposed application to a number of

individuals and receive feedback on the level of satisfaction with the simulated sounds.

This can also be assessed by allowing a group of users to experiment with a Graphical User Interface (GUI) designed to modify the input parameters of the MatLab application and create various output sounds simulating the movement of a source under different moving conditions.

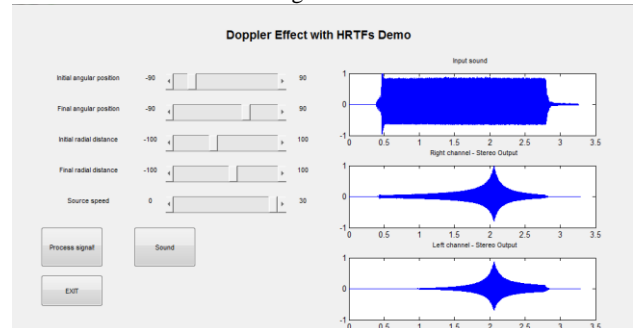


Figure 5: Snapshot of Graphical User Interface of the demo version for the plug-in.

## 5. CONCLUSION

- The application succeeds in applying a fair simulation of the HRTF by implementing both an IIR filter to recreate a head shadowing effect and an FIR filter to produce the ITD of the human hearing system.
- The application processes the sound to simulate the pitch shift produced by the Doppler Effect acting upon a moving source in space as well as the change in the intensity level of the sound source produced by the distance factor between the sound source and the listener.
- This application could be improved by adding a further simulation of the HRTF that includes changes in perception produced by the elevation angle.
- This application can effectively process monophonic sounds to emulate the movement of a sound source that is being displaced in space in a horizontal plane of movement in front of the listener.

## 6. 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.