Chapter 6

Three Dimensional Sound in Virtual Environments

6. Three dimensional sound in Virtual Environments

This chapter is focused on the incorporation of sound into virtual worlds. Nowadays, sound has evolved and its use in interactive environments has become more common. There are different sound techniques, which were reviewed in section 2.3. Additionally some previous works about sound have also been discussed in section 1.5.

In this chapter 3D sound was chosen because provides a high realism level in a virtual environment due to the fact that it has similar characteristics to sound heard in the real world. Furthermore a study of 3D sound in different circumstances is carried out. The results obtained in this chapter are published in the 20th International Conference on Electronics, Communications and Computers. CONIELECOMP 2010 (Mora, et al., 2010). Four virtual worlds are used. The first virtual world is an anaglyphic photograph gallery in which instrumental music is used, the second virtual world is a roman art gallery, which also includes instrumental music, the third one is a computing center; this world requires voices to describe some information about the Solar System and finally, the last virtual world is a depot; in this world a set of sound sources has been included in different places.

This chapter has been organized into the following sections:

Section 6.1 presents the main reasons for including 3D sound in this work.

Section 6.2 describes how to represent 3D objects with their sound sources.

In Section 6.3 there is a description about the manipulation and navigation of an environment using sound.

Section 6.4 describes the incorporation of 3D sound in a virtual world in a set of steps using Delphi and OpenAL.

Section 6.5 focuses on the specifications of the Azimuth Angle.

Section 6.6 describes the specifications of the elevation Angle.

Section 6.7 presents the attenuation model used in this dissertation.

In section 6.8 describe an equation of Doppler Effect using stationary sound sources

Section 6.9 discusses the incorporation of 3D sound into this project.

Section 6.10 describes the problems and solutions on incorporating 3D sound in this work.

Section 6.11 presents a chapter summary.

6.1 Three Dimensional sound as an Immersive tool in a Virtual World

Sound is a useful tool that has many advantages. Fundamentally, sound serves as feedback to some actions and results in better immersion. Even music helps to manipulate user's emotions, including happiness, sadness, nostalgia, peace, etc. The use of sound is mentioned in many references focused on the Human-Computer Interaction topic.

3D sound means that a listener hears sounds from any direction; this sound is generally simulated by a computer. 3D sound has many characteristics that can provide advantages in virtual environments. In this work 3D sound has been incorporated due to the following characteristics:

- 3D Sound provides extra help for the user to find objects when he is navigating, because the hearing system can determine the location of the sound sources.
- The 3D Sound produces a high immersion level in a virtual environment.
- The 3D Sound helps to interpret distances among objects.
- The 3D Sound facilitates a more natural interaction because it is similar to the sound in the real world.
- Sound can provide additional information to a graphic world, by helping users to understand extra information without extra effort.

6.2 Representation of 3D objects with 3D Sound

In the real world every object has a place in the space. When an object produces a sound, it is emitted from an object position, although the sounds can also be caused by a collision between objects, noise in the environment, etc.

It is the same case when 3D sound is used in a virtual world. Virtual worlds can contain different 3D objects with some kind of sound. The sounds have to be heard as if they were being emitted by the objects. Figure 6.1 shows a user seeing through a screen. The user sees a cube which produces a sound; in this case, the sound position is in the cube center. When the object is dynamic and/or the user navigates in the virtual world, the user has to hear that sound continuously emitted from the object.

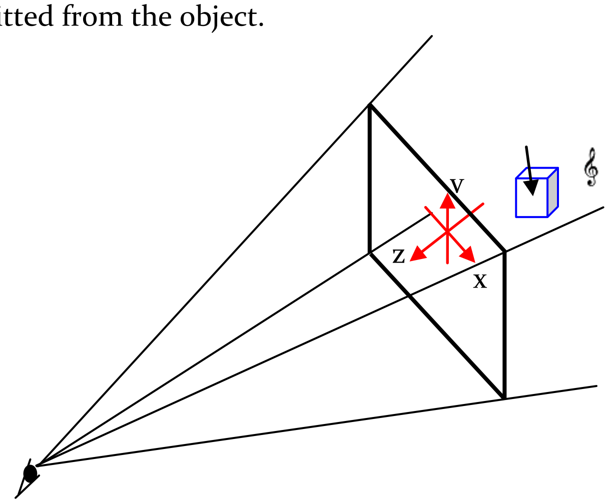

Figure 6.1 A sound emitted from an object

6.3 Manipulation and navigation of a Virtual world using 3D Sound

3D sound is similar to 3D graphics; it uses the positions of the sound sources, besides the listener orientation and position for creating a real effect. The rotations that the listener is permitted to make are called Elevation and Azimuth. See Figure 6.2. Elevation is the angle along the vertical plane. Azimuth is the angle along the horizontal plane. With these rotations user is able to see a virtual world in its entirety and perceive the sound from the new positions.

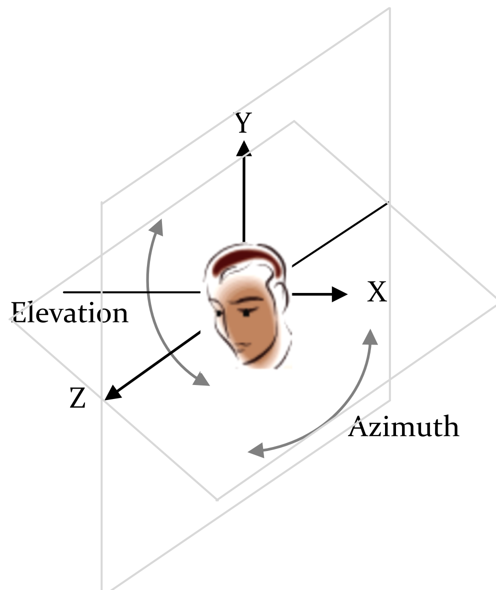

Figure 6.2 Elevation and Azimuth Rotations

The allowed translations in the navigation of this work include *left, right, upward, downward, forward, and backward*.

Three coordinates are commonly used in 3D sound: the positions of the sound sources see Eq. 6.1; the listener position, see Eq. 6.2; and the orientation, see Eq. 6.3.

Eq. 6.1 $$SourcePosition_n = x_n y_n z_n$$

where $n \geq 1$

Eq. 6.2 $$LPosition = L_{xyz}$$

Eq. 6.3 $$LOrientation = R_x, R_y$$

Figure 6.3 shows a scheme of connection between a source sound and a listener. The source intensity and the sound orientation depend on the navigating of a user and the source position. The motions together with the rotations allow for a freer virtual tour. When the motions and 3D sound are combined in navigation, there is an effect in the sound, which is produced by the changes in the distances and the listener orientation.

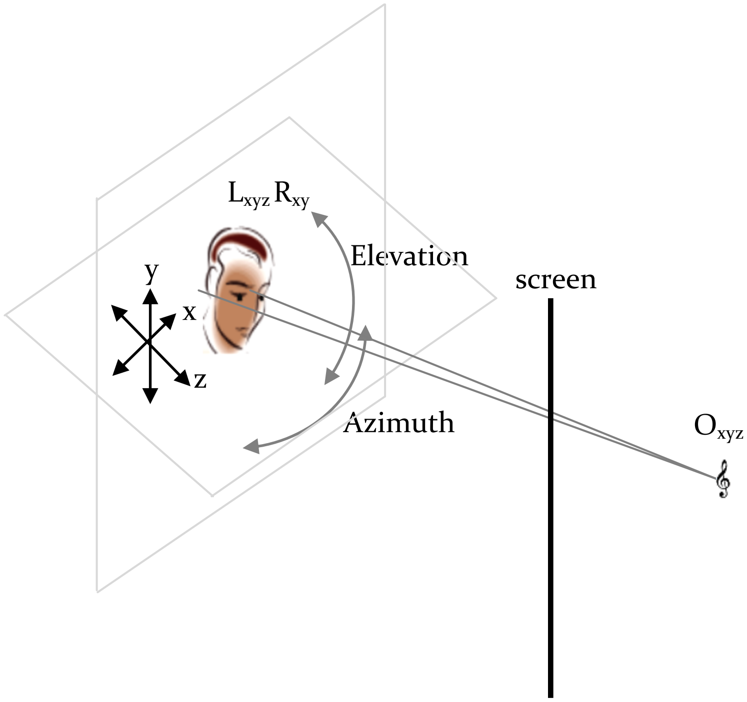

Figure 6.3 Scheme of connection between a source sound and a listener using spatial sound

Figure 6.4.1 indicates that the sound source is near, while Figure 6.4.2 indicates the sound source is far. User can also navigate in the world and determine if the sound comes from the left or the right, see Figure 6.4.3 and Figure 6.4.4.

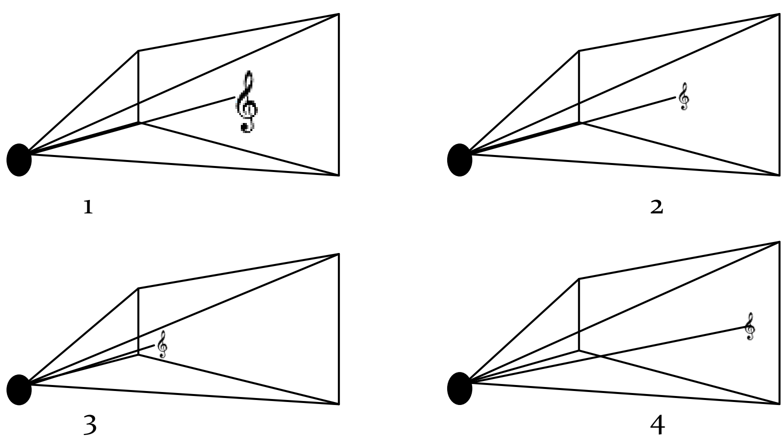

Figure 6.4 Different sound positions

Therefore, if an object with a sound source is placed to the left of the listener, the sound has to be heard from the left side. That is, the left ear will hear it louder than the right ear. Similarly when an object with a sound source is placed to the right, the sound has to be heard from right side. When the sound source is placed exactly in front or behind the listener both ears have to hear the sound with the same intensity. If a user recognizes a sound in the real world, he can also determine the distance of the object. The volume of the object depends on its distance with respect to the user. If the volume is loud the user understands that the object is nearby, if the volume is weak, the object is far.

When the 3D sound is used in virtual environments built with more than one screen, the characteristics above described are considered. In Figure 6.5 there are two screens, which display 3D objects with their sounds. Using 3D sound the listener can determine the location from where the sounds have been emitted actually without seeing the objects, as well as, if the sound is appropriately linked with a object, the user would not only know the position of the sound, but he would also be able to recognize which object it represents. Therefore every source of sound has its own configuration with respect to the user.

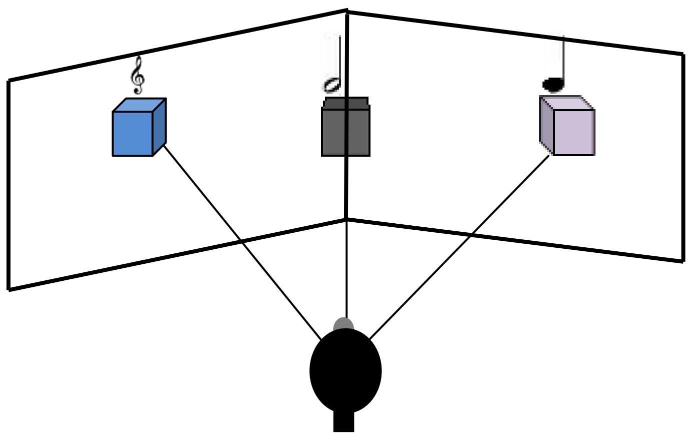

Figure 6.5Three sounds emitted from an object

6.4 Using OpenAL for incorporating 3D sound

In this project OpenAL is used. OpenAL (Open Audio Library) provides developers with a set of tools and Application Programming Interfaces (APIs) for audio creation and implementation. This library does not have platform restrictions. OpenAL features the notion of a listener and sources, which can be positioned in 3D space. The sources have a variety of properties such as gain, frequency etc. The incorporation of 3D sound in a virtual world can be carried out in the following steps using OpenAL:

1. Init the OpenAL library
2. Choose the best sound hardware on the computer
3. Create the buffers to hold the sound data loaded from .wav files, in this case are *n* sounds
4. Load into the buffer the sound data loaded from .wav files
5. Load the position of the objects and the characteristics of the objects
6. Load the listener information
7. Play the sounds
8. Stop the sounds
9. Pause the sounds
10. Actualize the position and orientation listener
11. Destroy the buffers

The following is a Pascal code (using Delphi) which implements the incorporation of 3D sound in a virtual word:

```
1.  InitOpenAl();
2.  AlutInit(nil,argv);
3.   AlGenBuffers(n, @buffer);
4.   For i:=1 to n do
                AlutLoadWavFile(name, format, data, size, freq, loop);
                AlBufferData(buffer[i], format, data, size, freq);
                 AlutUnloadWav(format, data, size, freq);
5.               SoundSources(i,obj[i].X,obj[i].y,obj[i].z,1,1)
6.     AlListenerfv ( AL_POSITION, @listenerpos);
       AlListenerfv ( AL_VELOCITY, @listenervel);
       AlListenerfv ( AL_ORIENTATION, @listenerori);
7.   For i:=1 to n do
              AlSourcePlay(source[i]);
8.  For i:=1 to n do
             AlSourceStop(source[i]);
9.  For i:=1 to n do
             AlSourcePause(source[i])
10.  listenerpos[0]:=X;
    listenerpos[1]:= Y;
    listenerpos[2]:= Z;
    listenerori[0]:=Rx;
    listenerori[1]:=Ry;
    AlListenerfv ( AL_POSITION, @listenerpos);
    AlListenerfv ( AL_ORIENTATION, @listenerori);
11.  AlDeleteBuffers(1, @buffer);
     AlDeleteSources(1, @source);
     AlutExit();
```

6.5 Azimuth Angle

When the viewer is seeing towards the left, the Azimuth angle (A_A) is between -1 to-90 degrees. An angle of 0 degrees means that the viewer is seeing in the front or back. An angle between 1 and 90 degrees indicates that the viewer is seeing towards the right. See Figure 6.6

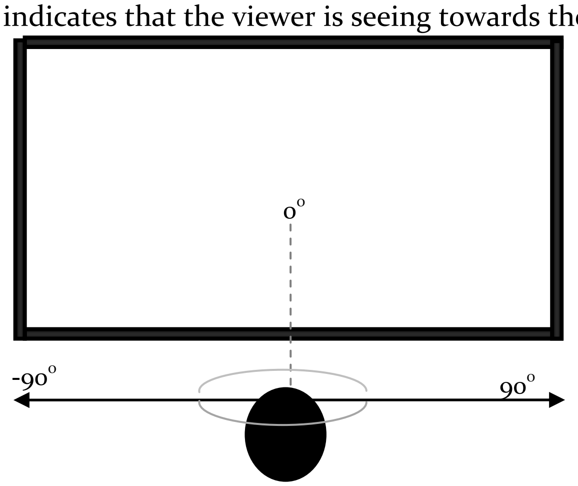

Figure 6.6 Relation of Azimuth turns

In this project the angles using degrees are not used. The orientation ranges used are the following:

-If the viewer is seeing in front or behind, Rx uses the value of 0.
-If the viewer is seeing toward the right side, Rx has to be $0 < Rx \leq 1$, see Figure 6.7.
-If the viewer is seeing toward the left side, Rx has to be $-1 \leq Rx < 0$, see Figure 6.7.

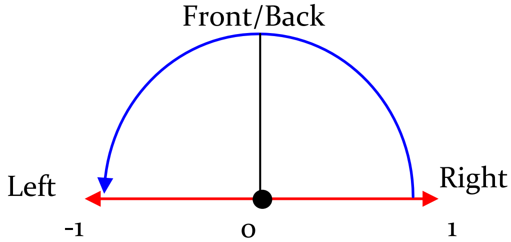

Figure 6.7 Relation of Azimuth angle

Therefore the angle given in degrees is converted, and the range (-1 to 1) is used.

Eq. 6.4 $$Rx = \sin(A_A)$$

6.6 Elevation Angle

When the viewer is seeing upward, the elevation angle (A_E) is between 0 and 89 degrees. An angle of 90 degrees means that the viewer is seeing at the middle of the screen height. An angle between 91 and 180 degrees means that the viewer is seeing downward. See Figure 6.8

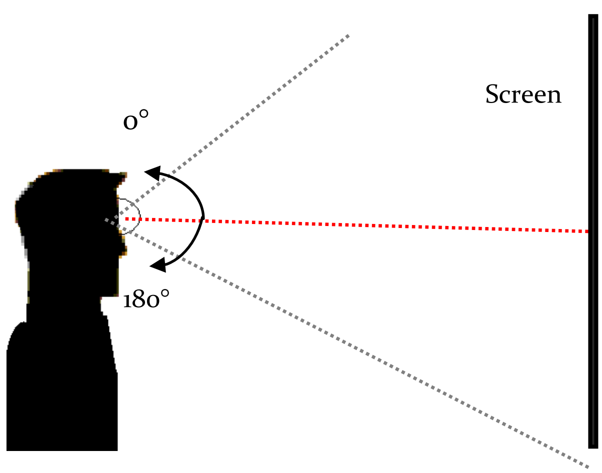

Figure 6.8 Relation of Elevation angle

In this project the elevation angle used is: -1 to 1.

-If the viewer is seeing in front, Ry uses the value 0.
-If the viewer is seeing upward, Ry has to be $0 < Ry \leq 1$, see Figure 6.9.
-If the viewer is seeing downward, Ry has to be $-1 \leq Ry < 0$, see Figure 6.9.

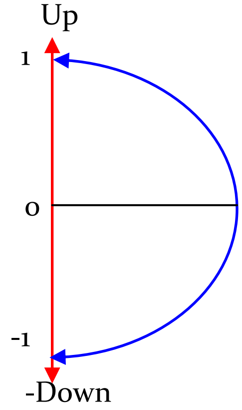

Figure 6.9 Relation of Elevation turns

The angle is converted in a new value using Eq. 6.5.

Eq. 6.5 $$Ry = \cos(A_E)$$

6.7 Attenuation

The effective attenuation of a source depends on many factors. In this project two factors are used for producing a natural attenuation, the first is the distance between source and listener, the second is the listener gain. Source gain is then attenuated by distance

The model used is Inverse Distance Rolloff and it is described in the following:

Eq. 6.6 $$gain = d_{ref} \frac{d_{ref}}{d_{ref} + rolloffFactor * (distance - d_{ref})}$$

Where:

gain	It means source gain.
d_{ref}	It is the distance under which the volume for the source would normally drop by half (before being influenced by rolloffFactor)
distance	It is the distance between the listener and the object.
rolloffFactor	It is the parameter used to increase or decrease the range of a source by decreasing or increasing the attenuation, respectively.

6.8 Doppler effects in our project

The Doppler effect was reviewed in section 2.3.1. It depends on the velocities of source and listener relative to the transmission medium, and the speed of sound propagation in that medium. In this project the sound sources are stationary and the effects of the medium (air, water) moving with respect to listener and source are ignored. Therefore, the speed of sound (v) used for computing Doppler effect is 343 meters per second (in dry air at 20° C).

Eq. 6.7 $v = 343.3 m/s$

The Doppler Effect is used with the following formula:

Eq. 6.8 $f' = DF * f * \left[\frac{v - v_l}{v} \right]$

With

f	original sound pitch
f'	Doppler effect pitch
v_l	velocity of listener
DF	Doppler factor

6.9 Incorporating 3D Sound into different Virtual Worlds

As it was previously mentioned, due to the fact that sound increases the realism in a virtual environment, 3D sound is included in this project, besides a navigation system, a multi-screen system, and a stereoscopic environment. In addition, some virtual worlds have been created; each one has a set of objects with at least one sound source.

The first virtual world is a gallery. This gallery shows a collection of photographs of roman art, see Figure 6.10. This kind of world does not require the use of many sound sources, therefore this gallery only contains one sound source: a loudspeaker placed on the ceiling that plays soft music. When the listener changes his position, it is possible to perceive the loudspeaker continually emitting the music.

Figure 6.10 Gallery of photographs of roman art

Figure 6.11 shows the position of the sound source of this gallery of photographs using a sphere to point the loudspeaker. This position can be visible or not.

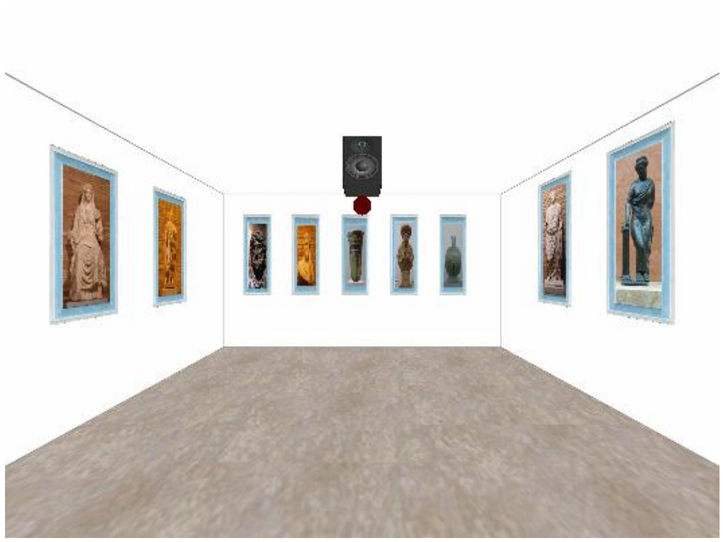

Figure 6.11 Gallery of photographs of roman art and its source sound

The second world is an anaglyphic gallery. This gallery shows a collection of anaglyphic photographs, this implies that 3D sound, 3D objects and stereoscopy are involved in the same world, see Figure 6.12. As the previous virtual world, this gallery does not require many sound sources and therefore it only contains a loudspeaker placed on the ceiling. The spatial effect is perceived when the virtual world is navigated and the sound is heard from the loudspeaker.

Figure 6.12 Anaglyphic gallery

Figure 6.13 shows the position of the sound source of the second gallery of photographs using a black sphere.

Figure 6.13 Sound source of the anaglyphic gallery

The third virtual world that was programmed is a computing center containing nine computers, each one with a sound source, see Figure 6.14. In this case, the 3D sound provides the user with some complementary information about the world. Each computer speaks out using a prerecorded sound clip, specifying details about a planet of the Solar System. As our project is dynamic, when the user navigates through the virtual world, the sounds change too according to the movement made.

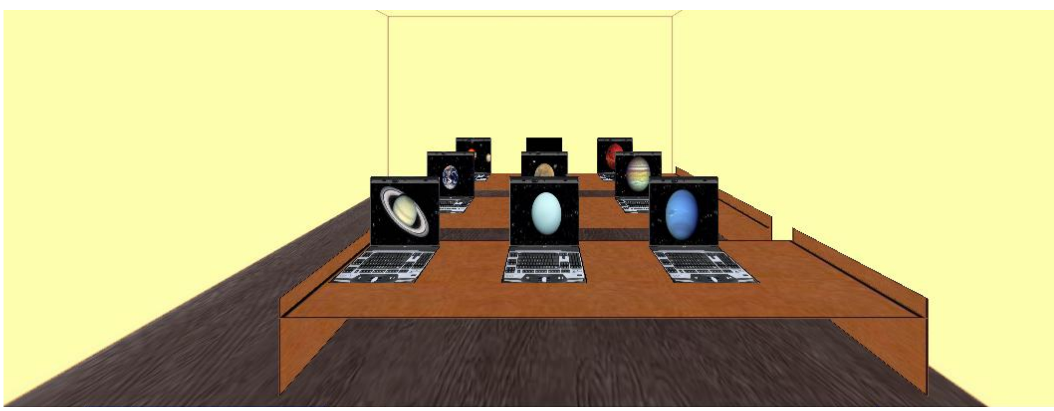

Figure 6.14 Computation center with nine computers, each computer has its sound source.

Figure 6.15 shows the position of the sound sources of the computing center pointed with small spheres.

Figure 6.15 Sound source of the computing center

Figure 6.16 shows two views of the world: Frontal and posterior view

-The first view is the frontal, see Figure 6.16.1. In this image, two laptops are shown. One of them shows the planet Earth and the other one shows Jupiter. Therefore, the explanation heard about Earth is emitted from the left side of the virtual world and about Jupiter from the right side.

-If the same laptops are seen from back, see Figure 6.16.2, the explanations would be listened to from reverse sides; that is, now the explanation about Jupiter will be emitted from the left side and, about Earth, from the right side.

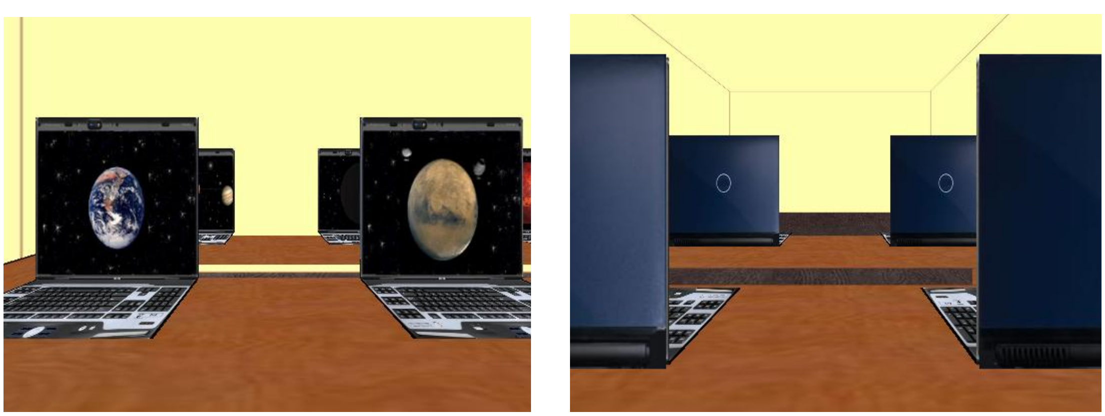

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Figure 6.16 Frontal and posterior view

Figure 6.17 shows other views: Right and Left.

-In the First view there are two nearby laptops, see Figure 6.17.1. The first one shows Jupiter, the other one shows the posterior side of a Laptop (Neptune). When this scene is seen, the explanation about Jupiter is heard on the left side, and about Neptune on the right side.

-In the second view a rotation of 180° is done and an approaching to two computers, see Figure 6.17.2. The posterior side of a Laptop (Uranus) is shown as well as the Laptop of Earth and explanations of the planets are heard. The explanation of Uranus is heard from the left side and of Earth is heard from the right side.

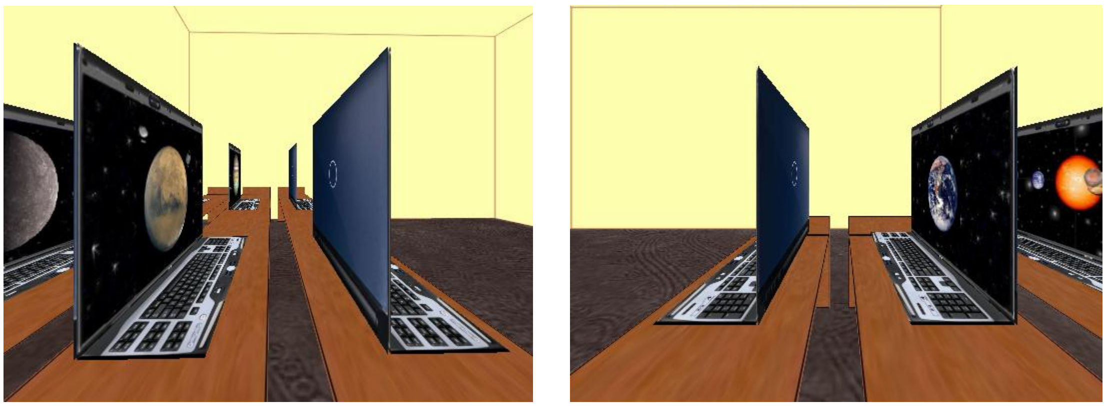

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Figure 6.17 Right and Left view

The last virtual world is a depot; this world contains different sound sources hidden to the viewer in some boxes. Figure 6.18 shows a set of boxes. Although the sound sources are hidden, when the virtual world is navigated the user can find them.

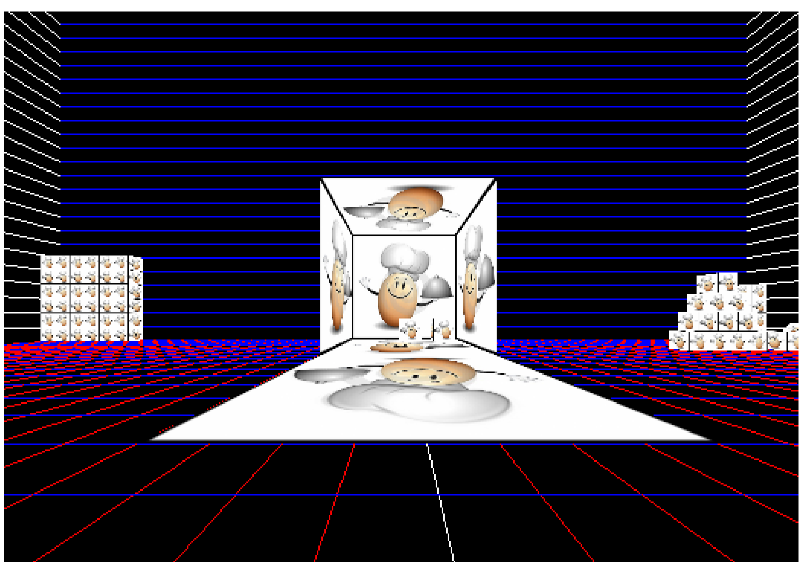

Figure 6.18 Depot

Figure 6.19 shows another view of the depot. In this view two sound sources are shown using black spheres.

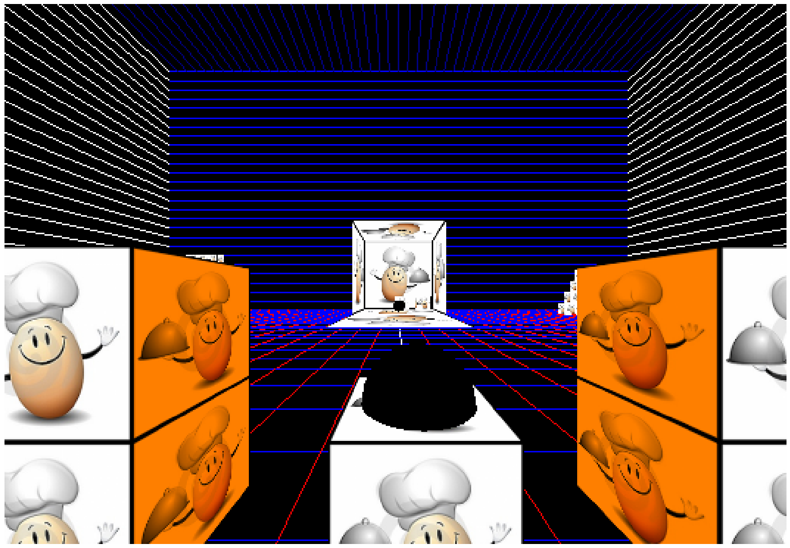

Figure 6.19 Depot and some sound sources

6.10 Problems and solutions on incorporating Sound

Different problems were presented when sound was included in this project. They are mentioned in the following points:

- When different sound sources are used in a virtual world, we should have taken some precautions when placing them. If sound sources are placed near each other it can result in interference and confusion between sounds. However, it also depends on the kind of sound. Music and some other sound source do not have problems, but when the sound is a spoken explanation; they can be mixed and therefore not understood, resulting an annoying noise.

  This problem was found in the computing center, see Figure 6.14, since the size of this virtual world is small and the computers are near, the difference in the sound volume between computers was minimum resulting interference and confusion between dialogues. Therefore an adjustment in the volume of the objects was made, limiting the maximum volume reached in the virtual world.
  The volume of each object (in this case each computer) is V_{obj} and was adjusted with the following equation:

Eq. 6.9
$$V_{obj} = 1 - \frac{d_{obj}}{d_{\max}}$$

  Where d_{obj} is the distance between the viewer position and the object position, d_{max} is the reached maximum distance to hear an object and to avoid interference.

- Every virtual world shown in this chapter can be used with any virtual environment seen in previous chapters, including the environment built with one or more screens, stereoscopic environments described in chapter 5, etc.

  Due to the fact that every environment can display virtual worlds without any modification, this project did not experience any problem when the sound units were included in them. This was true except with the Wheatstone-type digital stereoscope, it produces a laterally inverted virtual world.

  This stereoscope can be built with two monitors or projectors set one in front the other one and a pair of mirrors set in the middle of two monitors, see section 5.2. When the viewer eyes are set in front of the mirrors the virtual world is seen stereoscopically. If the 3D sound is not used, there is no problem seeing the inverted virtual world. When spatial sound was incorporated we had to invert the world beforehand so that it could be seen correctly and coincide with the sounds, see Figure 6.20.

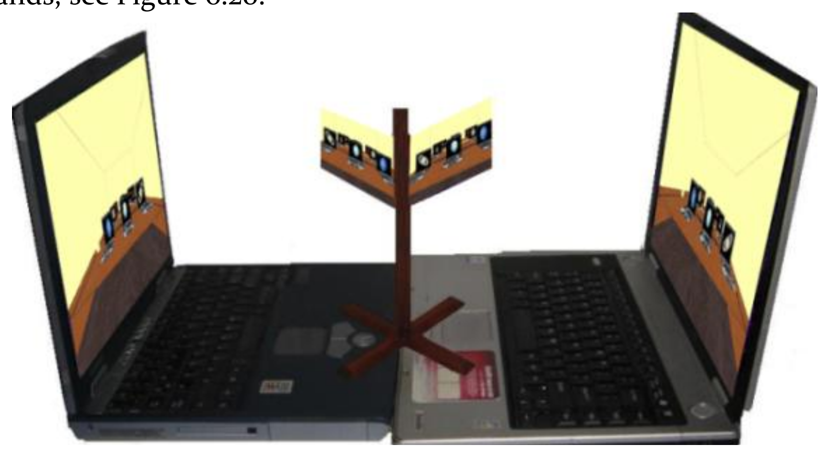

Figure 6.20 Wheatstone-type digital stereoscope

6.11 Summary

This chapter incorporated the use of 3D sound in the building of virtual environments as a complementary tool, because 3D sound allows for the provision of additional information in a graphic world, for instance spatial information such as directions and positions, in addition some explanations, etc. 3D sound allows for having a better interface, which provides realism that other techniques cannot produce.

In this chapter a description about how to combine 3D objects and sound sources was described. Additionally, the combining of 3D sound and navigation was discussed, along with the effects produced by such combination.

The 3D sound in our project was specifically used in two ways:

- As supplement to visual information through:
    - Spatial Information
    - Spoken explanation
- As background sound in two galleries of art.

The incorporation of 3D sound was done in four virtual worlds; they were shown and tested in this chapter. When 3D sound was incorporated in the worlds two problems were found:

- When different sound sources are placed near each other it produces interference and confusion between sounds. Therefore an adjustment in the volume of the objects was made, limiting the maximum volume reached in the virtual world. The solution was the volume adjustment of each object using the Eq. 6.9. In this equation the maximum distance to hear an object is limited.

- The second problem was detected on incorporating 3D sound in the Wheatstone-type digital stereoscope, because it produces a laterally inverted virtual world, the solution was to invert the world beforehand so that it could be seen correctly and coincide with the sounds.