Chapter 7

Proposed model for building adaptable Virtual Environments

7. Proposed model for building adaptable Virtual Environments

This chapter presents two contributions, the first contribution is a proposed model for building adaptable Virtual Environments and the second contribution is the way of manipulating different virtual worlds. Our manipulation technique has been divided into two parts: the first part takes into consideration the viewer´s position in the virtual environment and the second part the navigation of the world. The viewer position is captured by a head-tracker device that allows for the computation of *frustums* involved in the virtual environment, see chapter 3. The navigation allows doing a tour throughout the virtual world.

Furthermore, in this chapter three virtual environments built with two screens are described; they are manipulated in different ways. The results obtained in this chapter are published in the journal CiBIyT (Mora, et al., 2009-1) and in the 20th International Conference on Electronics, Communications and Computers. CONIELECOMP 2009 (Mora, et al., 2009-2).

This chapter is organized in the following way:

Section 7.1 describes a general scheme of the project. The work focuses primarily on the construction of virtual environments that are adaptable to different resources and requirements, meaning they can be constructed with different characteristics, sizes and shapes.

Section 7.2 describes the software used

Section 7.3 presents different configurations using the system characteristics describe in section 7.1.

Section 7.4 describes three ways of manipulating the navigation of our virtual environments. Section 7.4.1 presents the first virtual environment, which uses a remote control for navigation, Section 7.4.2 presents the second virtual environment, which is manipulated using the viewer position and Section 7.4.3 presents the third virtual environment, which is manipulated hands-free using a head-tracker and time as resources.

Section 7.5 describes the evaluation details of a virtual environment built with two monitors forming a 90° angle using different manipulation kinds and 3D sound.

Section 7.6 shows the results of the evaluation described in section 7.5

Section 7.7 presents a comparative analysis with the previous work.

Finally in section 7.8 there is a chapter summary.

7.1 Project scheme for building Virtual Environments

This section describes the general scheme of the project; this project is devised for the building of virtual environments, adaptable to different applications and number of resources. This project has a client-server structure, which allows for the use of a set of devices connected via net. In Figure 7.1 the white squares represent the server and the clients. The gray squares represent the virtual worlds and the manipulation kind.

The server manages one or more clients and is responsible for doing a set of tasks. The server obtains the screen configurations, which refers to their relative position and the angles between them. The server also saves this information (*addScreen*) and returns the four coordinates of its corners to each screen (*calcCoordinates*), see section 3.3. The server also updates the viewer position (*getInputDevice*) through three input devices which include a keyboard, a remote control and a head-tracker. The user can indicate his choice to the server about the virtual world he wants to see (*ChooseVirtualWorld*). There is a virtual world shown by default. The server indicates to the client(s) what virtual world should be displayed and turns on the 3D sound according to the chosen world (*Play3DSound*). The navigation is done through a keyboard, a remote control, a head-tracker and files.

Model_View defines the visualization volume (*setViewPort*) by taking into consideration the screen orientation and viewer position (offAxisProjection).

Each client reads a configuration file (*readConfigFlie*) to know the information about its screen. This information includes the real position, the size, the edge size of the screen and information about whether the virtual world is stereoscopic or not. In the construction of stereoscopic environments half of the clients have to display in the right part of the stereoscopic world and the other half of the clients, the left part. The client establishes communication with the server via messages (*connectToServer*). Then the client sends its screen configuration to the server (*screenInformation*), and the server returns the information necessary to determine the section of the world that corresponds to the display. The client frequently asks the server for the viewer position (*getViewerPosition*) as well as the camera position (*getCameraPosition*) to be able to navigate. The client also receives the choice of the virtual world through the server.
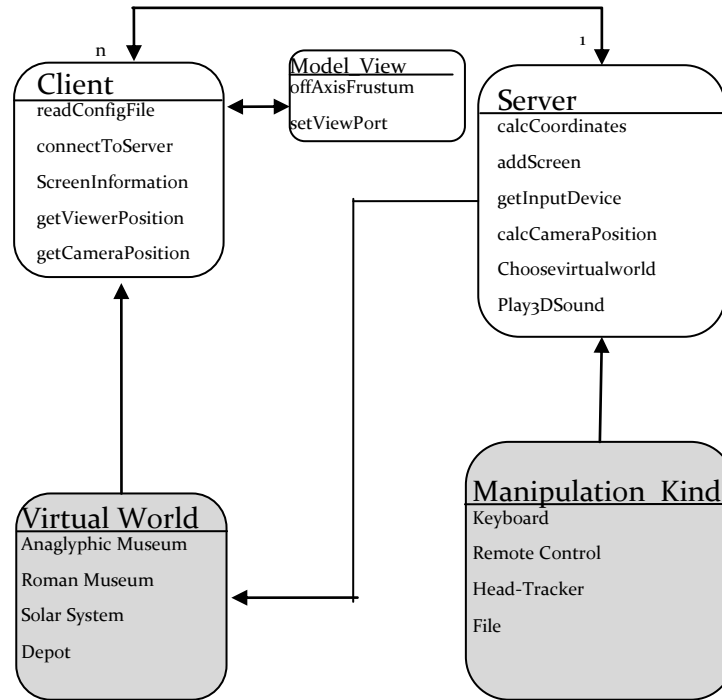
Figure 7.1 General Scheme

Table 7.1 shows the sequence of the system to explain the general scheme.

Table 7.1 System Sequence

Client	Server
Reads the screen configuration from a File (readConfigFile), which also indicates if the virtual world should be stereoscopic.	
Begins the connection with the server (connectToServer)	Establishes the connection
Sends the screen information (screensInformation)	Computes the physical coordinates (calcCoordinates)
	Saves the screen information (addScreen)
	Indicates the virtual world to be displayed (user's choice made through Keyboard or mouse)
	Turns on the 3D sound according to the virtual world chosen (see chapter 6)
Asks for the viewer position (getViewerPosition)	Gets the viewer Position from the input-device (getViewerPosition) and sends it to the client

Asks for the Camera position (getCameraPosition)	Computes the Camera position (compCameraPosition) and sends it.

7.1.1   Communication model

Figure 7.2 shows the communication model using Client-server. Every client connects to the server of a local or remote way using the TCP protocol and the port 9923, it allows connecting one or more computers. The clients and the server communicate via messages. Request/response is a message exchange pattern in which a client sends a request message to a server, which receives and processes the request, ultimately returning a message in response.
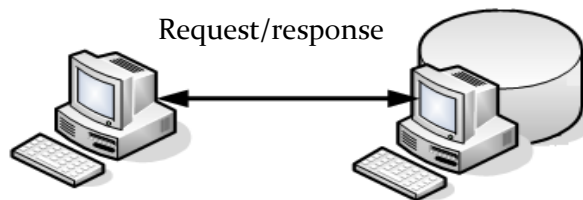

Figure 7.2 Communication model

The request message can be as follows:

-addscreen.- The client sends the screens configuration to the server, containing their relative position and the angles between them. The server saves this information and returns the four coordinates of its corners to the client.

-getViewerPosition. The client frequently requests the server for the viewer position

-getCameraPosition.- The client frequently requests the server for the camera's position to display the correct image on all screens.

There are other request messages, see Figure 7.1.

7.2 Used Software

In this work OpenGL is used for programming the graphic world and OpenAL for programming the 3D Sound.

- OpenGL (Open Graphics Library) was chosen because it is widely used for making graphics and has so many procedures and functions for programming high-quality 3D graphical images.

- OpenAL (Open Audio Library) is an audio API, which can be combined perfectly with OpenGL.

These two libraries (OpenGL and OpenAL) are supported by several Operating Systems including Unix, Linux, Windows and others, unlike DirectX, which runs only on Windows.

Figure 7.3 shows three clients locally connected displaying a virtual world. The three monitors are identical and are being manipulated using a keyboard. The server is not visible in this image.
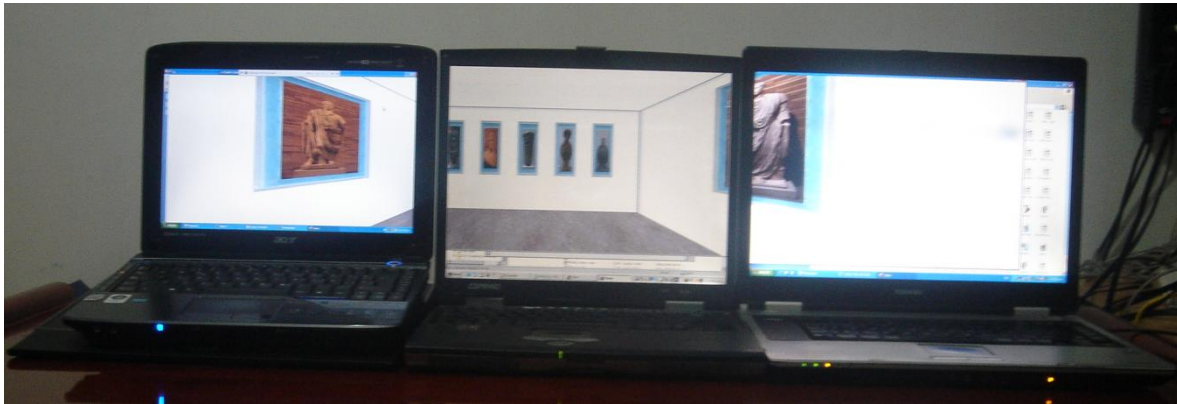

Figure 7.3 Three clients

Figure 7.4 shows a Wheatstone-type stereoscope, this configuration was built with two monitors one in front the other, the monitors are displaying a stereo pair. These images are seen from two slightly different positions. The system knows when an environment is stereoscopic via a configuration file; see Table 7.1. Besides, the file indicates if the monitor will have the left image or the right image.

Figure 7.4 Wheatstone-type stereoscope using two laptops

Figure 7.5 shows a Cazes-type stereoscope, this configuration was built with two monitors, which are displaying a stereo pair. The clients are connected using a wireless network; this environment can be seen using files with a pre-recorded tour.

Figure 7.5 Cazes-type stereoscope using two laptops

7.4 Navigating a Virtual Environment with different Input Devices

In this project first person navigation is applied and three manipulation kinds in virtual environments are used. Sections 7.4.1, 7.4.2 and 7.4.3 describe different environments and the way they are manipulated.

7.4.1   Manipulating the a Virtual World using a Remote Control

Some computers such as laptops include a remote control for manipulating slides, programming DVDs, etc. In this work it has been decided to include the use of a remote control for manipulating the navigation of virtual worlds. Generally, the remote control has enough buttons that allow for the manipulation of a virtual world. This device also has the advantage of providing freedom of movement to the viewer. In section 7.1 is explained that the server is responsible for receiving the instructions of the user through input devices, in this case, manipulation is proposed via the remote control.

A simple and interesting environment can be carried out using two screens, two projectors, one PC, and one remote control. This material is rather common in many Educational Institutions; therefore this environment can be easily constructed without depending on too many resources. See Figure 7.6.

Figure 7.6 virtual environment built with two projections

Figure 7.7 shows the remote control used in this work. It is used sideways so that it can be operated using both thumbs. This tool allows for manipulation of movement and the rotations of navigation; additionally it has buttons for manipulating viewer position.
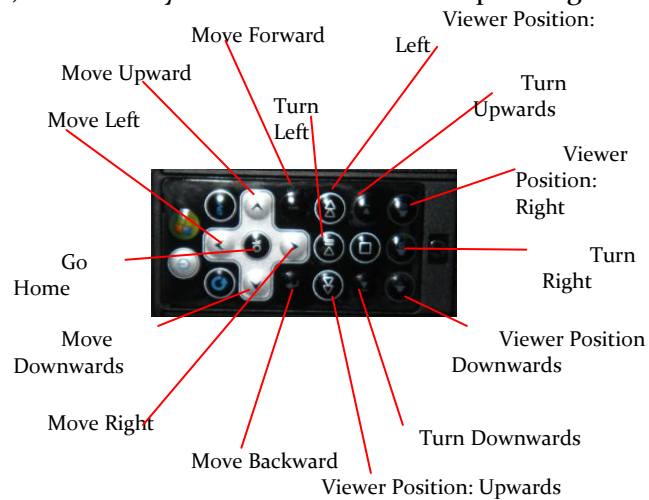

Figure 7.7 Remote Control

The left thumb is placed over the white cross and it is used for the movement in the navigation, while the right thumb is for turning. Although there is no cross for the right thumb, the turning functions are laid out as if there was one. Due to the fact that there are enough buttons, the user is able to have full control over the environment.

7.4.2   Manipulating a Virtual Environment considering of Viewer Position

A common way to manipulate a virtual environment is using a head-tracker to recognize viewer´s position. The head tracker used in this project is shown in Figure 7.8, it is a five-axis game controller that can be manipulated with the head.

Figure 7.8 Head tracker used in this project

Viewer position allows computing the frustums involved, see chapter 3. Besides the same head-tracker allow for navigation of a virtual world. In this section the navigation using a head-tracker is described, then

-If the viewer *turns* his head to his *left, right, up* or *down* direction, the virtual environment will *rotate* the same angle that the viewer turns.

-When the viewer *moves* his head *left, right, upward, downward, forward,* or backward, the frustums used in the environment change according to the new viewer position.

-When the virtual world is used for the first time the user's initial position is located in the central part of the environment.

Figure 7.9 shows a virtual environment built with two screens and using a head-tracker, which composed of a sensor and a headset. In this environment the user can navigate the world upon consideration of his own set of movements.
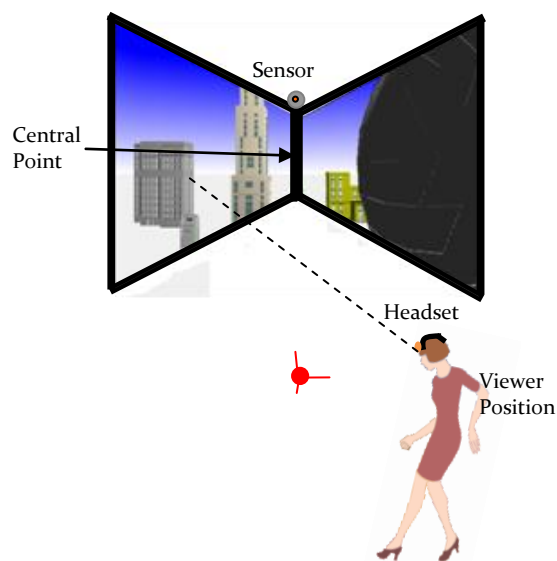

Figure 7.9 Virtual environment that recognizes viewer position

With the same idea as in section 7.4.1 we have tried to build a simple environment, although, it is important to remember that our system is able to have any number of screens.

7.4.3   Head-Tracker for hands-free navigation of a Virtual World using the user's movements in function of time

This environment provides the opportunity for full navigation. This method uses a head-tracker and the movements are produced in a function of time that the user considers suitable. To begin the system, the viewer needs to complete the following steps:

1) Choose a position where the user navigates the environment. This position can be the center of the real environment or in front of the monitors when they are used. When the viewer is in the initial position and is looking towards the front, the virtual world remains static.

2) If the viewer keeps turning his head *P* degrees either *left, right, upward* or *downward* the virtual world will turn to the side where the viewer head is turned as long as the viewer remains with his head turned. When the user returns his head towards the front, the virtual world stops turning.

Figure 7.10 shows a virtual environment and a user using a head-tracker formed of a sensor and a headset. This environment is built with two non-coplanar screens which form a ninety-degree angle. The head-tracker is able to detect viewer rotations on the *x* and *y* axes. The sensor is placed above both screens. An imaginary protractor is drawn on plane *xz*, this protractor shows the angle around the *y* axis. If the viewer is viewing the initial point, then the angle registered by our head-tracker is 90°.
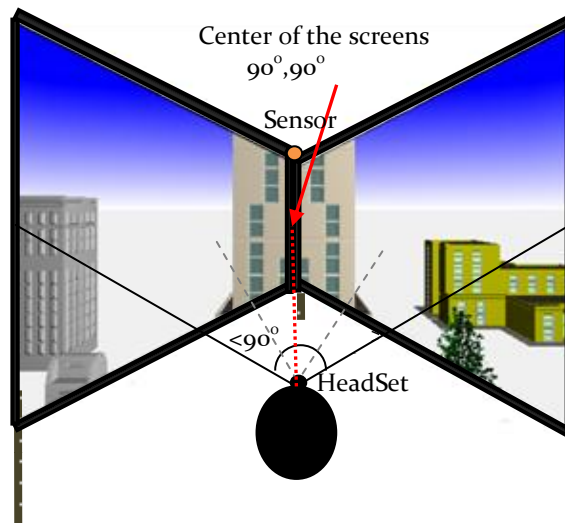

Figure 7.10 A virtual environment formed with two projections

Figure 7.11 shows another imaginary protractor on plane *yz*, to indicate to us the angle around the *x* axis. If the viewer has a view height at the center of the screens, the angle registered by our head-tracker is 90°.
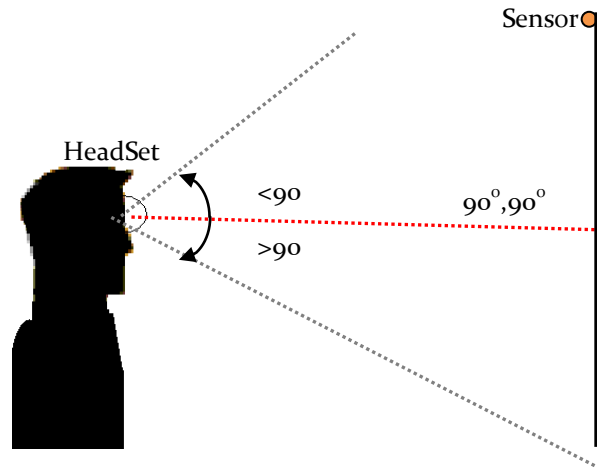

Figure 7.11. **The environment seen from profile**

Therefore, when the viewer turns his head to the *left* the angle registered on the *y* axis will be between 0 and 89°, and if he turns his head to the *right*, the angle registered will be between 91° and 180°.

It is the same situation when the viewer turns his head *upwards* or *downwards*, the angles will be registered between 0° and 180°.

Due to the fact that our system allows for unrestricted virtual navigation, when the viewer moves his head *Q* centimeters to the *left,* to the *right, upwards, downwards forward* or *backwards,* the environment is programmed to move *R* steps to the side where the viewer head moves during the time the viewer remains with his head in the adopted position, and stops when the user returns his head to the initial position.

Several trials have been performed to determine the most comfortable head turns. The results are shown in Figure 7.12.
Figure 7.12.1 shows an environment view as seen from above.
-The black lines represent the screens (which can be monitors or projections).
-The gray point is a sensor.
-The black point represents the head-tracker and it is placed in the ideal position for navigating the environment. In this position the viewer can see virtual environment, displayed through both screens, without problems.

Figure 7.12.2 shows an environment seen by profile. The black line represents both screens (which can be monitors or projection screens).
-The gray point is a sensor.
-The black point represents the head-set.
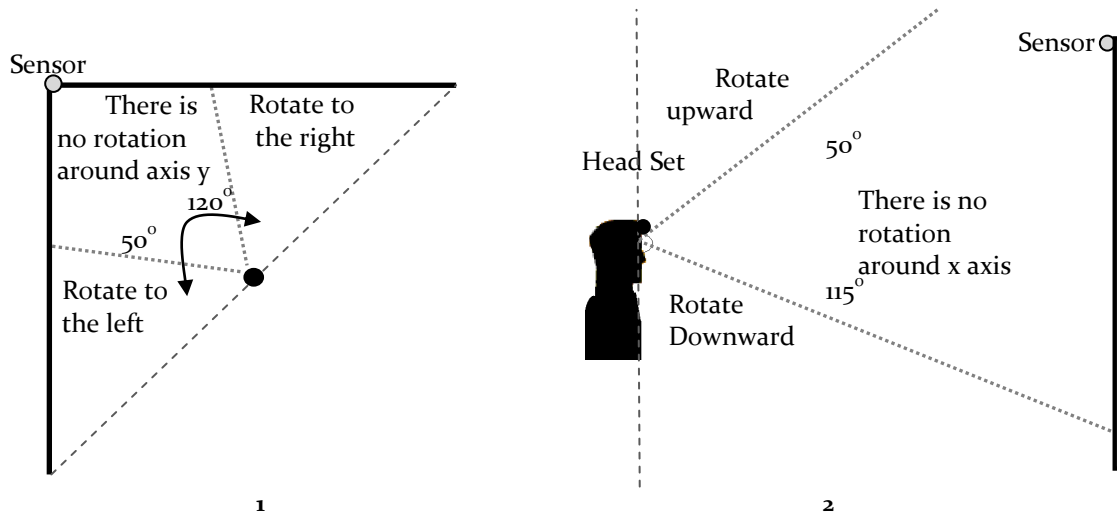Finally, in both figures can be seen the viewer´s turns which allow rotating the virtual world.

Figure 7.12 1)**Environment seen from above. 2)Environment seen by profile**

7.5 Evaluating a Virtual Environment built with two monitors forming a 90° angle

This section shows the evaluation of a virtual environment built with two screens forming a 90 degrees angle between them, this configuration was presented in section 6.3. In this configuration three manipulation kinds are presented. This evaluation also includes the use of keyboard and predefined files for manipulating a virtual world. Each user watched four virtual worlds using sound and the same virtual worlds without sound. The trial duration for every user was 20 minutes. The following input devices were used: Head-tracker, keyboard and remote control. In the trials some topics were focused on the multi-screen display, the manipulation and the sound, see Table 7.2.

Table 7.2 topics for discussion on evaluating a multi-screen virtual environment

Display of multi-screen	Manipulation	3D Sound
Continuity	Ease of use	Improvement of the interaction using sound
Coherence	Practical	Coincidence between sound sources and objects
The screen frames can be considered as simple obstacles in the virtual world.	Coherence between manipulating and results	Improvement of the object location using 3D sound
		3D produces feedback
		3D sound provides extra information

A multi-screen virtual environment was tested by 20 users. The results of the evaluation are shown in this section. The evaluations are separated in three modules: the first module evaluates the displaying. The second module evaluates sound. Finally, the manipulation and different input devices are evaluated.

Figure 7.13 shows the results of the displaying module. 95% of the users could see a continuous virtual worlds, 95% of them appreciated coherence in the virtual world displayed on two screens and 100% of the user evaluated the screen frames as a simple obstacle.
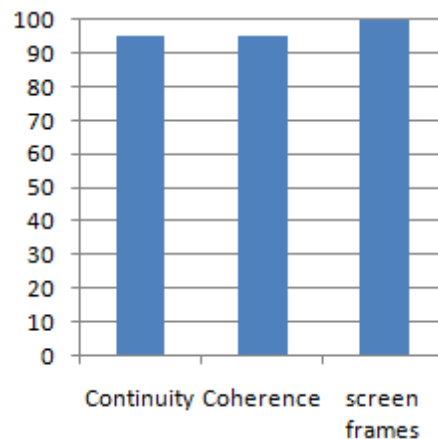
Figure 7.13. Results of the evaluation of displaying of a multi-screen virtual environment

Figure 7.14 shows the results of the sound module. 100% of the users considered an important improvement on using 3D sound in the different virtual worlds. 95% of the users could perceive that the sound sources were emitted from different 3D objects and notice an improvement in the location of 3D objects when the sound sources were incorporated. All the users considered that the sound can be used as feedback and provides extra information.
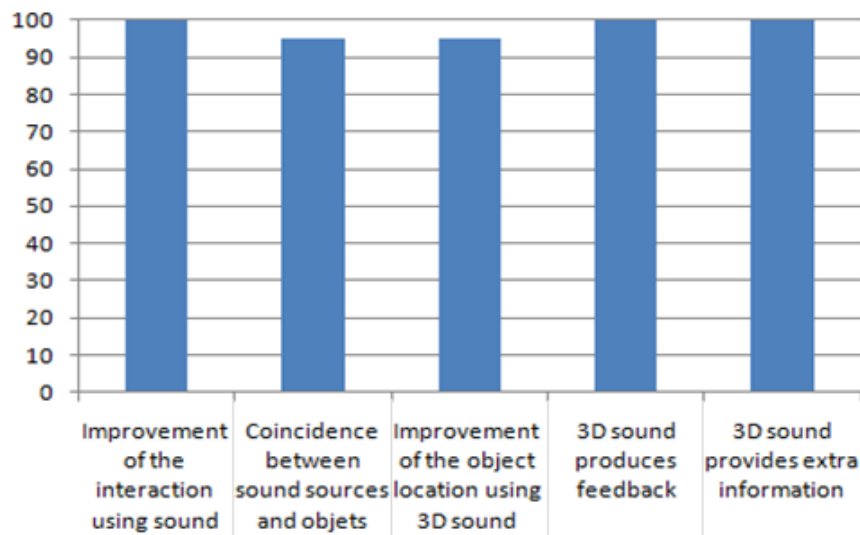
Figure 7.14. Results of the evaluation of sound

Figure 7.15 shows the results of the manipulation module. 100% of the users considered easy to use and practical the different input devices and manipulations.. 100% of users considerate coherent the answer between the manipulation and the effect produced on the screens and the sound.
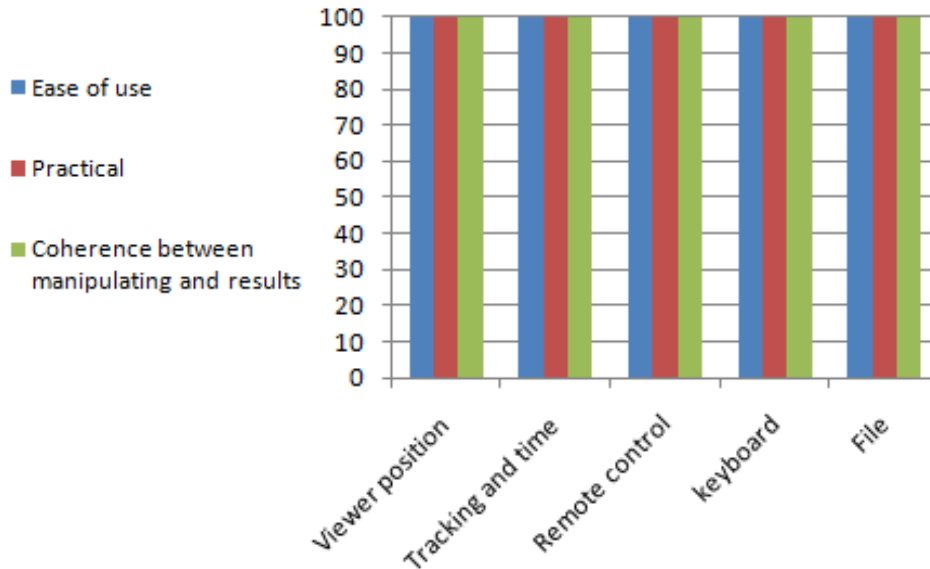

Figure 7.15. Results of the evaluation of manipulation and input devices

After analyzing the charts, it is concluded that the viewers can see a continuous and coherent multi-screen virtual environment. This work considers the frames of the monitors, which the user can see as simple obstacles. Furthermore, the incorporation of 3D sound produces in a general way a better interaction, the 3D sound allows improving the object location and helps to provide extra information, sound also allows feedback the interaction. The manipulation kinds presented in this chapter were evaluated by 20 users and they are considered easy and practical to manipulate a virtual world.

7.7 Comparative analysis with the previous work

Table 7.3 shows a comparative analysis between previous work about display module and the work described in this research. The comparison shows the most important characteristics of this module.
- The Cruz-Neira model uses a fixed number of screens, the structure of this model and the angles between screens are fixed and it does not consider screen frames because only projectors are used.
- Pape presents a mathematical model, which considers the variability of structure and the number of screens, but he does not consider the screen frames.
- Po-Wei, et al does not consider variability of structure and the images look no coherent.
- This work presents a mathematical model, which produces a coherent virtual world and allows variability of screen number and of structure of the virtual environment.. In addition, this dissertation considers the frames of the screens.

Table 7.3 Comparative analysis between other display models and the proposed of this research

	Variability of number of screens	Coherence between screens	Variability of structure of the environment	Variability of angles between screens	Consideration for screen Frames
Cruz-Neira, et al	No	Yes	No	No	No
Pape, et al.	Yes	Yes	Yes	Yes	No
Po-Wei, et al	No	No	No	No	No
Mora	Yes	Yes	Yes	Yes	Yes

Table 7.4 shows a comparative analysis between previous work about projection module and the work described in this document.

- Jalkanen presents a configuration and shows formulae for calculating the distance used from a projector to the screen using mirrors, she does not determine the room size where a CAVE will be placed.
- Aguilera presents four configurations for placing a CAVE. He shows four configuration and the physical requirements, which are computed using a system, but he does not specific a mathematical model.
- Our work present four configurations, every configuration with its mathematical proposed for determining the area of the room where a CAVE will be placed. The fourth proposed model allows determining different configurations, and it considers different distances between the projectors and the mirrors, different angles of the mirrors and different rotations among the CAVE walls and the room walls. In addition a system is presented, which allow calculating different configurations and uses the fourth proposed model.

Table 7.4 Comparative analysis between the previous work of the projection module and the proposed of this research

	Number of configurations	Equations for determining the room size	Determination of room size	System
Jalkanen	1	Yes	No	No
Aguilera	4	No	Yes	Yes
Mora	4	Yes	Yes	Yes

Table 7.5 shows a comparative analysis between three stereoscopes and the work described in this document.

- The Cazes-type stereoscope was built using static and small stereo pairs, which did not use sound.
- In this dissertation a proposed model of a Cazes-type digital stereoscope was described. In addition a mathematical description was offered for determining the size of the mirrors. The result is a stereoscope of variable size, which uses two monitors; the stereo pair is a dynamic virtual world, additionally this model use 3D sound.
- The Wheatstone-type stereoscope was built using static and small stereo pairs, and it did not use sound.
- In this research a proposed model of a Wheatstone-type digital stereoscope was described. In addition a mathematical description was presented for determining the dimensions of the stereoscope. The result is a stereoscope of variable size, which uses two monitors or projectors; the stereo pair can be a dynamic virtual world and this stereoscope incorporate 3D sound.
- The Boxed-type stereoscope was built using static and small stereo pairs.
- In this work a model of a Boxed-type digital stereoscope was proposed. The result is a stereoscope, which shows dynamic and small stereo pairs, which use 3D sound.

Table 7.5 Comparative analysis between three stereoscopes and the proposed of this research

Stereoscope	Size	Static/Dynamic	Stereo Pair	Sound
Cazes- type stereoscope	Small	Static	Cards	No
Cazes- type digital stereoscope	Variable	Dynamic	Monitors	Yes
Wheatstone- type stereoscope	Small	Static	Cards	No
Wheatstone- type digital stereoscope	Variable	Dynamic	Monitors or projectors	Yes
Boxed- type stereoscope	Small	Static	Cards	No
Boxed- type digital stereoscope	Small	Dynamic	Monitor	Yes

Table 7.6 shows a comparative analysis between previous work about sound module and the work described in this document.

- Ying detects collisions between a specific object and the surrounding objects. Ying designs a system for providing visual feedback, and/or 3D auditory feedback during the manipulation.

- Wu uses one sound source changing its position for evaluating the improvement of the location of sound using dynamic movement of the human head.
- Sodnik evaluates the perception and location of 3D sound in a tabletop augmented reality environment. He uses nine sound sources corresponding to airplanes within a small virtual world.
- Our work presents four different virtual worlds. The first is a depot, which contains three sound sources; the second and the third are art galleries with one sound source respectively (background music); and the fourth is a computing center with nine sound sources with spoken explanation. In all these virtual environments the sound sources are used as feedback to some activities, to locate 3D objects, and as background music.

Table 7.6 Comparative analysis between previous work of sound module and the proposed of this research

Title	Number sound sources	Kind of sound	3D sound	Sound is used:
Ying, et al.	No specified	Sounds of a specific object	Yes	As feedback to some activities
Wu, et al.	1	Sound	Yes	To locate objects 3D
Sodnik, et al.	Variable	Sound of airplanes	Yes	To locate objects 3D
Mora	9	Spoken explanation, sounds, music	Yes	As feedback to some activities To locate 3D objects To background music

7.8 Summary

This section describes our system, which has a client-server structure, where the server is responsible of managing one or more clients (screens). Due to its structure, this project allows the construction of different virtual environments. A screen is configured by its position and orientation in the real world, every client sends output information to the screen depending of its position and the navigation of the user, therefore each screen will display a part of a virtual world. This project contains four virtual worlds and the navigation through them is done using a keyboard, a remote control, a head-tracker, or input files.

The kinds of manipulation are discussed in this chapter, and were reviewed using simples virtual environments. The first manipulation was done using a remote control. Currently, many computers include a remote control for manipulating DVDs, moving slides of presentations, etc. In the second manipulation, a head-tracker is used for determining the viewer position and for navigating the virtual world. This manipulation is common in virtual environments; the disadvantage is that when the space is limited, the navigation can also be limited. In the third manipulation, a head-tracker was used and the movements were produced depending of the time that the user maintained his head turned. This manipulation can be useful in limited spaces and is easy to use. Finally, different configurations are shown in section 7.5, these configurations are using the system described in this chapter.

An evaluation of a multi-screen virtual environment using 3D sound and different manipulations was carried out. The results demonstrate that the viewers can see a continuous and coherent virtual world on multiple screens. In addition, the results also indicate that 3D sound improves the interaction, improves the location of the 3D object and improves the feedback in the virtual environment. Finally, the manipulations used were considered by the users as easy and practical for virtual worlds.