Introduction to Virtual Reality

Gilson Giraldi, Rodrigo Silva, Jauvane C. de Oliveira

LNCC–National Laboratory for Scientific Computing
Scientific Visualization and Virtual Reality Laboratory -
`{gilson,rodrigo}@lncc.br`
COMCIDIS Research Group -
`jauvane@lncc.br`

ABSTRACT

In this paper we present an overview of basic aspects of Virtual Reality (VR). We will describe important VR devices and their application when interacting with three dimensional computer generated worlds. In particular, we will discuss VR applied to scientific visualization, medicine and engineering. Finally, we will focus on the perspectives of VR for our projects at the LNCC and present final considerations.

Keywords: Virtual Reality, Virtual Reality Devices, Scientific Visualization

1 INTRODUCTION

Virtual Reality (VR) is a term used for computer-generated 3D environments that allow the user to enter and interact with alternate realities [22, 53]. The users are able to "immerse" themselves to varying degrees in the computers artificial world which may either be a simulation of some form of reality [26] or the simulation of complex data [63, 22].

The term "Virtual Reality" (VR) was initially coined by Jaron Lanier, founder of VPL Research (1989) [14]. Other related terms include "Artificial Reality" [37], "Cyberspace" [33], and, more recently, "Virtual Worlds" and "Virtual Environments".

Today, Virtual Reality is used in a variety of ways and often in a confusing and misleading manner. Originally, the term referred to "Immersive Virtual Reality". In immersive VR, the user becomes fully immersed in an artificial, three-dimensional world that is completely generated by a computer.

When simulating an environment, the focus is on reproducing its aspects as accurately as possible to create the illusion of an alternate reality. This can involve not only 3D images but the incorporation of 3D sound, artificial smell generation and force-feedback (technology that provides the sensation of touch). The resulting digital world may either be representations of real world objects or the imagination of a designer. Examples of this type of simulation would include architectural walkthroughs [10] and VR games [55].

The degree users are "immersed" in the

virtual environment can vary. In the full immersion, the user wears a head mounted display (section 4) that provides 3D visual and audio information, and some form of hand held input device such as data glove, 3D Joysticks etc. Another possibility for full immersion is the CAVE (section 5.1).

Partial levels of immersion can be provided by projecting the computers output into the environment, using large monitors and “head-up” displays [41].

The goal of this report is to present an introduction to VR. We do not intend to be extensive. We start with the Stereographic Projection [49], the basic mathematical model behind VR displays. The extension of field of view coupled with the stereoscopic displays produces the feeling that we are in the place. In some sense, that is the starting point of VR.

Next, we did some consideration about the boundaries between immersive and non-immersive VR (section 3).

In section 4 we describe some VR devices that we are using(see also [34, 29, 53] to complete the material). These devices can be integrated in a computer system. Section 5 shows some examples in this area.

VR systems can be integrated in a collaborative computational environment. Section 6 summarizes some ideas concerning to this systems.

The most common application areas of VR are discussed on Section 7. Architecture, medicine, training and scientific visualization are some of them.

One application area of VR that we are specially interested is the Computational Hemodynamics of the Arterial Human System [22]. In section 8 we discuss the application of VR for visualization and interaction with medical images and numerical data in that context.

Final consideration about VR applications and perspectives are given in section 9.

2 Stereographic Projection

Increasing the perception of three-dimensional depth in a scene is important in many applications.

There are two basic types of depth perception cues used by the eye-brain system: monocular and binocular, depending on whether they are apparent when one or two eyes are used. The principal monocular cues are: Perspective (convergence of parallel lines); movement parallax (when the head is moved laterally; near objects appear to move more against a projection plane than far objects); relative size of known objects; overlap (a closer object overlaps and appears in front of a more distant object); highlights and shadows; Atmospheric attenuation of, and the inability of the eye to resolve, fine detail in distant objects; focusing accommodation (objects at different distances require different tension in the focusing muscles of the eye).

The principal binocular cues are the convergence angles of the optical axes of the eyes and the Retinal disparity (the different location of objects projected on the eye’s retina is interpreted as differences in distance from the eye).

The monocular cues produce only weak perceptions of three-dimensional depth. However, because the eye-brain system fuses the two separate and distinct images produced by each eye into a single image, the binocular cues produce very strong three-dimensional depth perceptions. Stereography attempts to produce an image with characteristics analogous to those for true binocular vision. There are several techniques for generating stereo images. All depend upon supplying the left and right eyes with separate images.

There are two methods, called chromatic anaglyphic and polarized anaglyphic, that use filters to insure reception of correct and separate images by the left and right eyes [49]. Briefly, the chromatic anaglyphic technique creates two images into two different colors, one for the left eye and one for the right eye. When viewed through corresponding filters the left eye sees only the left image and the right eye only the right image. The eye-brain system combines both two-dimensional images into a single three-dimensional image with the correct colors. The polarized anaglyphic method uses polarizing filters instead of color filters.

A third technique uses a flicker system to alternately project a left and a right eye view. An associated viewing device is synchronized to block the light to the opposite eye [19].

All of these techniques require projection of an object onto a plane from two different centers of projection, one for the right eye and on for the left eye. Figure 1 shows a projection of the point P onto the $z = 0$ plane from centers of projection at $E_L(-e, 0, d_e)$ and $E_R(e, 0, d_e)$ corresponding to the left and right eye, respectively.

For convenience, the center of projection for the left eye is translated so that it lies on the z-axis as shown in Figure 2. Using similar triangles then yields

$$\frac{x_L^{*'}}{d_e} = \frac{x'}{d_e - z} \tag{1}$$

and

$$x_L^{*'} = \frac{x'}{1 - \frac{z}{d_e}} = \frac{x'}{1 + rz} \tag{2}$$

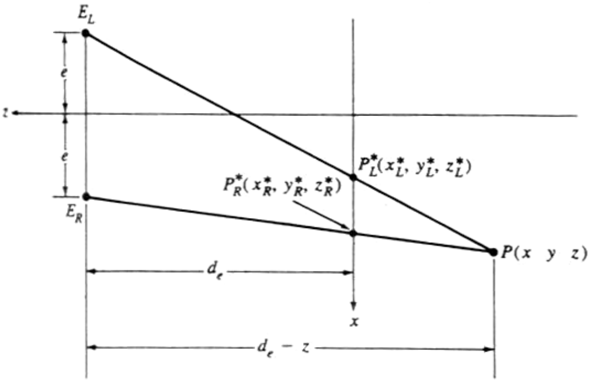

Figure 1: Stereografic projection onto $z = 0$.

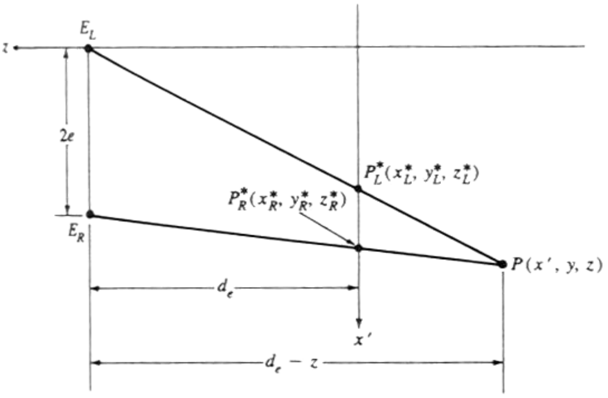

Figure 2: Stereo projection for the left eye.

Similarly, translating the center of projection for the right eye so that it lies on the z-axis as shown in Figure 3, and again using similar triangles, yields

$$\frac{x_R^{*''}}{d_e} = \frac{x''}{d_e - z} \tag{3}$$

and

$$x_R^{*''} = \frac{x''}{1 - \frac{z}{d_e}} = \frac{x''}{1 + rz} \tag{4}$$

Since each eye is at $y = 0$, the projected values of y are both

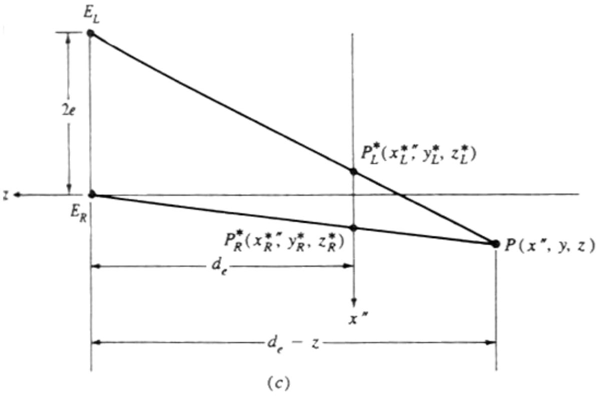

Figure 3: Stereo projection for the right eye.

$$y^* = \frac{y}{1 - \frac{z}{d_e}} = \frac{y}{1 + rz} \tag{5}$$

The equivalent transformations for the left and right eye view, in homogeneous coordinates [49], are given by the following 4×4 matrices:

$$\left[\ S_L\ \right] = \left[\ Tr_{E_L}\ \right] \cdot \left[\ P_{rz}\ \right] =$$

$$= \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ e & 0 & 0 & 1 \end{bmatrix} \cdot \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & \frac{-1}{d_e} \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$$= \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & \frac{-1}{d_e} \\ e & 0 & 0 & 1 \end{bmatrix} \tag{6}$$

and

$$\left[\ S_R\ \right] = \left[\ \ Tr_{E_R}\ \ \right] \cdot \left[\ P_{rz}\ \right] =$$

$$= \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ -e & 0 & 0 & 1 \end{bmatrix} \cdot \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & \frac{-1}{d_e} \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$$= \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & \frac{-1}{d_e} \\ -e & 0 & 0 & 1 \end{bmatrix} \tag{7}$$

where $\left[\ Tr_{E_L}\ \right]$ and $\left[\ Tr_{E_R}\ \right]$ are the translations of the centers of projection E_L and E_R, respectively.

Consequently, a stereographic projection is obtained by transforming the scene using eqs. (6) and (7) and displaying both images.

Stereographic projections are displayed in a number of ways. One technique, which takes a bit of practice, is to first focus the eyes at infinity; then, without changing the focus, gradually move the stereo pairs, held at about arm's length, into view.

3 Immersive and Non-Immersive VR

As already said in the introduction, the term 'Virtual Reality' is also used for applications that are not fully immersive. For instance, we can cite mouse-controlled navigation through a three-dimensional environment on a standard graphics monitor, stereo viewing from the monitor via stereo glasses and stereo projection systems.

Although the boundaries between immersive and non-immersive VR are becoming blurred, the basic characteristics of immersive virtual reality can be summarized as follows [12]:
(a) Head-referenced viewing providing a natural interface for the navigation in virtual environments.

(b) Stereoscopic viewing to enhance the perception of depth and the sense of space.

(c) The virtual world is presented in full scale and relates properly to the human size.

(d) Realistic interactions with virtual objects through data glove or similar devices.

(e) Non-Visual technologies like auditory, haptic and artificial smell to increase the illusion of being fully immersed in an artificial world.

Besides, it is desired that an immersed VR system allows applications and networked users (anywhere in the world) to share a virtual world, see it from their respective points of view communicated with each other, and interact with the virtual environment [22, 45].

It is obvious that such level of sophistication depends on specific devices. In the next section we describe some of these equipments.

4 VR Devices

Humans are experienced in interacting with three-dimensional objects. Traditional computer configuration allows us to interact with virtual worlds through a window (screen), a pointer and a keyboard. However, the digital world resides inside the computer and we are exterior to it.

As we already pointed, the major characteristic of VR is immersion: users experience the felling of being surrounded by an environment [10]. Henceforth, the traditional paradigms for human-computer interaction will change deeply [11, 53]. A new class of devices should be designed to fit the new requirements that come from this change [53].

Basically, we have tracking devices to report 3D position and orientation [39, 13], stereographic devices (glasses or displays), hand measurements devices (data glove) and 3D motion control device (Cyberpuck). The next section describes the basic features of these equipments.

4.1 Tracking Devices

If the user fells to be present in an environment then methods to report 3D position and orientation must be given.

The most important commercial and experimental 3D position tracking devices have used acoustic, electromagnetic, and optical methods for reporting 3D position and orientation [10, 39, 7].

Acoustic systems use the time-of-flight principle to estimate the position of an object in space [10].

For electromagnetic tracking devices (Figure 4) we have a source which generates a low frequency magnetic field detected by sensors [53]. The main problem with this system is that it undergoes interference of any conducting material present in the environment. Besides, the working range might be limited and the update rate may be barely enough for interactive applications.

Recent electromagnetic devices eliminates the problem of signal blocking that limits sonic or laser devices [39]. For those newest devices, there's no need to maintain a clear line-of-sight between the receiver and the transmitter [53].

Figure 4: Electromagnetic tracking system.

Optical tracking systems use visual information to track the user (Figure 5). They are relatively insensitive to environmental distortions and have a large working range [10, 53].

The most common technique is to make use of a video camera that acts as an electronic eye that watches the object or person to be tracked. Computer vision techniques [36] are used to determine the objects position based on the acquired images by the camera. This kind of single sensing device has a limitation that positions can be reported in only two dimensions according to the plane the camera "sees", but without depth information.

Multiple visual input sources can overcomes this limitation. For instance, by using three video cameras in different locations, full 3D position can be reported. Besides, multiple objects can be tracked [53]. However, a limitation of these systems is that the line of sight between the tracked object and the camera must always be clear which limits the range of movement of the participants.

Figure 5: Optical tracking system.

4.2 Head-Mounted Displays

The major aim of a Head-Mounted Display (HMD) is to give the user the sensation of immersion [63, 53]. The actual systems are designed to take the advantage of the human binocular system as well as audio to create the felling of immersion (Figure 6).

Figure 6: HMD.

In general, HMDs present the general following characteristic: (a) Headgear with two small display devices (LCD color screens), each optically channeled to one eye, for binocular vision; (b) A tracking system for precise location of the user's head in real time [13].

Figure (Figure 7) presents the VFX3D HMD and gives a view of its components. VFX3D HMD (7) is a high quality IPD (inter-pupillary distance) system completed with an integrated three degree of freedom tracker for roll, pitch and yaw positioning, standard VGA interface, audio inputs and 360,000 pixel color display [40].

The VFX3D supports design packages such as 3D Studio Max [24], Sense8 [52], Realimation [47] and others.

4.3 VR Glasses

Virtual Reality glasses are stereographic devices. Thus, perception of depth and the sense of space are enhanced when the user observe the virtual world [10, 63, 53].

The technology behind these equipments can vary from chromatic anaglyphic and

(a)

(b)

Figure 7: (a) Front view and (b) Side view of VFX3D Head-Mounted Displays.

(a)

(b)

Figure 8: (a) CrystalEyes Shutter Eyewear (b) Infrared Emitter.

ChromaDepth [9] (encode depth into an image by means of color) to liquid crystal displays (LCD), also called in this paper *shutter glasses*. CrystalEyes and Elsa Revelator Glasses belongs to the LCD technology and are described bellow.

4.3.1 CrystalEyes

CrystalEyes (8) is a lightweight, wireless set of liquid crystal shutter eyewear for Stereo3D imaging in engineering and scientific applications. The product delivers high-definition, stereoscopic 3D images on all major UNIX platforms and Windows 2000/NT workstations in conjunction with compatible software and standard workstation displays. CrystalEyes is activated by an infrared emitter that connects to the users workstation.

CrystalEyes is supported by many professional software applications used in mechanical CAD, molecular modeling, product visualization and simulation, GIS and medical imaging [19, 62, 22, 53].

4.3.2 Elsa Revelator Glasses

The 3D eyewear ELSA 3D REVELATOR (Figure 9) with LCD shutter technology creates an entirely new spatial display in 3D applications [54].

These glasses are designed to work with Nvidia based cards, including cards based on TNT, TNT2, GeForce, GeForce 2, GeForce 3 and GeForce 4 chips. You will need a standard monitor (not an LCD display) that supports a 100 Hz refresh rate, or preferably 120 Hz. Installation is fairly simple and only requires hooking up the glasses externally to your graphics card via the included adapter.

Figure 9: Elsa Revelator Glasses.

4.4 Data Glove

Data Gloves are hand measurements devices with sensors for both the flexion angles of the fingers and the orientation of the wrist [10].

For example, the 5DT Data Glove 5 (Figure 10) has 1 sensor per finger and measures the orientation (pitch and roll) of the user's hand [5]. It can emulate a mouse and can be used as a baseless joystick. The system interfaces with the computer via a cable to the serial port (RS 232 - platform independent).

Figure 10: 5DT Data Glove 5.

It features 8-bit flexure resolution, extreme comfort, low drift and an open architecture. The 5DT Data Glove 5-W is the wireless (untethered) version of the 5DT Data Glove 5. The wireless system interfaces with the computer via a radio link (up to 20m distance) on the serial port (RS 232). Right- and left-handed models are available. One size fits many (stretch lycra).

4.5 Cyberpuck

CYBERPUCK (11) is a six-degrees of freedom, 3D navigation device [4] used to control the user motion in the virtual world . While the normal mouse clicks represents a repetitive and tedious way of designating direction for navigation in 3D space, Cyberpuck allows the user to "fly through" in an intuitive way. Particularly in the field of multi-user graphics applications ("collaborative engineering"), Cyberpuck can improve real-time user interaction.

Figure 11: Cyberpuck.

It features 3D interface (six degrees of freedom) and some modes like "Translation Mode" where only the translation coordinates (X, Y, X) are reported, "Rotation Mode" where only the rotation coordinates (A, B, C) are reported, "Dominant Mode" where only the coordinate with the greatest magnitude is reported.

5 VR Systems

The above devices can be integrated in a computer system which allows one or more users to observe and interact each other when analyzing a scene.

Bellow, we describe examples of these systems which can provide some immersive experiences.

5.1 CAVE

The CAVE [20] was developed to overcome some of the limitations of HMDs, especially for scientific applications. The major goals were to provide high resolution, a large field of view, and a stable display that did not encumber the viewer and would allow multiple people to easily share the VR experience. To achieve this, we surround the viewer with video projection displays, in combination with head tracking and stereoscopy (Figure 12).

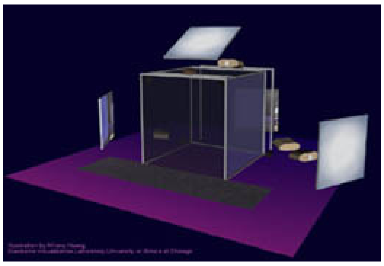

Figure 12: CAVE

The CAVE technology was first developed at the University of Illinois at Chicago. It was built a multi-person 10x10x9 foot theater, with images rear-projected on the walls (screens), and projected down onto the floor. Four projectors, one for each screen, are connected to graphics pipes of one or more high-end workstations (Silicon Graphics Onyx Reality Engine 2 or Infinite Reality).

In the CAVE at Illinois, 1024x768 resolution stereoscopic images are displayed on each screen at 96 Hz. Viewers wear Stereographics' liquid crystal shutter glasses (CristalEyes) to view the stereoscopic images. One user's head is tracked with an 6 degree-of-freedom tracking system, and images are generated from that user's viewpoint. A wand (3D equivalent of a mouse) is also tracked. The wand has three buttons and a small, pressure-sensitive joystick. It is used by viewers to interact with and control CAVE applications.

Graphics Applications are implemented through CAVE library, which controls the display, tracking, and input systems. The CAVE library hides most of the device-specific details, automatically generates the correct, user-centered perspective for each screen, and synchronizes the screens to produce a single, nearly seamless display. The CAVE library also simulates the CAVE, allowing development of VR applications on ordinary graphics workstations. A computer-controlled audio system (the Vanilla Sound Server [42]) with multiple loudspeakers provides sonification capabilities.

5.2 ImmersaDesk

The ImmersaDesk (13) was developed in 1994 at EVL [21]. It is a drafting table format VR display.

The original implementation features a 67x50-inch rear-projected screen at a 45-degree angle. Up to 5 users wear shutter glasses to view high resolution, stereoscopic, head tracked images. The ImmersaDesk screen mostly fills a user's field of view, and at the same time enables the user to look forward and down. One user's head is tracked, allowing an accurate perspective to be generated. A tracked wand is also used, so that the user can interact with the environment. The system is equipped with stereo sound supported by the Vanilla Sound Server [42].

Logistically, ImmersaDesk is simpler and smaller than CAVE. Its cabinet is on wheels, and folds up and fits through doors. It can be deployed in offices, exhibition spaces, galleries or museums.

Besides, it is also portable and self contained. The projector is located in the lower section and a pop-up mirror folds the optics. The original ImmersaDesk uses the same CAVE library software as

Figure 13: ImmersaDesk

is used in the CAVE, to generate accurate perspective projection, and to read tracker and input devices. Therefore, applications developed for the CAVE can be run on the ImmersaDesk, and vice versa, without any code changes.

5.3 Infinity Wall

More recently a larger scale system, called the Infinity Wall (14), was created [21]. The Infinity Wall is designed around the same basic resources as the CAVE, but is intended for presentations to large groups, as in a classroom setting.

It can comprises a single 9 × 12 foot screen, four projectors which tile the display, one or two SGI Onyxes to drive the display, and a tracking system.

Figure 14: Infinity Wall

The stereo display uses shutter glasses, as in the CAVE and ImmersaDesk. The stereo video formats in this case are of lower pixel resolution than the monoscopic video formats; the Infinity Wall has a net resolution of 2048 × 1536 pixels.

Originally, Infinity Wall, like the ImmersaDesk, used the same CAVE library software, to synchronize the displays and to generate accurate perspective projections for each of them.

6 Collaborative VR Systems

In scientific applications, modern research is not conducted alone. Often a team of collaborators works in the same subject, sharing and discussing partial results.

Collaborative VR Systems try to address these necessities [45]. For instance, two (or more) networked users at different locations in the world can meet in the same virtual world by using Head-Mounted Displays. All users see the same virtual environment from their respective points of view. Each user is presented as a virtual human (avatar) to the other participants. The users can see each other, communicated with each other, and interact with the virtual world as a team.

This kind of *collaborative work* is an important consequence of VR development and promises deeply changes in the way people communicate ideas and information.

7 Application Areas

As the technology of virtual reality evolves, new applications of VR appear. In fact, we can assume that VR has been reshaping the interface between humans and information technology by offering new ways for the communication, representation and visualization of processes and data.

Virtual worlds can represent real or abstract three-dimensional environments like buildings, landscapes, underwater shipwrecks, spacecrafts, archaeological excavation sites, human anatomy, sculptures, crime scene reconstructions, solar systems, and so on.

On behalf of our projects at the LNCC, we are specially interested in the visual representation of scalar, vector and tensor fields that are generated in numerical simulations of fluids and mechanical structures [16, 63, 22]. However, the range of VR applications is far beyond these areas.

Bellow we describe some applications of VR. They are examples of the state-of-the-art in VR applications and give a view of the potential of this technology.

7.1 Architecture Walkthrough

The key idea in this case is to explore virtual buildings already designed but not yet constructed [10]. The goal of the computer system is to allow the visualization of the building, to permit the architect to prototype the target and to iterate with clients during the design process of a plant (Figure 15). Using a CAVE, the user (client) would be allowed to walk-through the virtual building and analyze its details as if it was built.

By this way, sales and marketing issues can be also contemplated. In fact, an already designed building can be presented to potential customers [65, 67, 66].

7.2 Medicine

Within the area of medicine and health-care VR is used for training and education as well as surgical simulation for diagnosis, pre-operative planning and treatment (Fig. 16). Further uses include anatomical simulation and psychiatric treatment simulation [1, 62, 59, 30].

Figure 15: VR applied to Building applications.

Figure 16: VR applied to Medicine

7.3 Archeology and Arts

In recent years, a convergence of computer graphics and computer vision has produced a set of techniques collectively known as image-based modeling and rendering (IBMR).

On the other hand, the rapid development of specific hardware makes possible to build low-cost acquisition systems that are increasingly effective.

The emerging technology enables the reconstruction and rendering of three-dimensional objects and environments with subtle real-world effects which are difficult to reproduce with conventional computer graphics techniques. Once this ”virtual world” is generated, a user can visit it and walk-through the environment to appreciate its interior (or exterior).

Arts and Archeology are good examples of areas in which this new technology can be applied. Virtual Museums can be designed and ancient constructions can be available for a user with a VR device like HMD [28, 31, 35].

Figure 17: VR applied to Arts

7.4 Entertainment

For the topic of entertainment, we will focus on computer and video games. Games have had an important role in the development of human-computer interfaces and the divulgation of I/O devices to the public, making then affordable to general users.

UnrealEd [32], for example, uses texture extracted from photographs for the modeling of three-dimensional worlds and provides pseudo look-around and walk-through capabilities on a graphics monitor. The virtual environment so generated can be used to provide new scenarios for game players (Figure 18).

7.5 Simulation and Training

Training is one of the most common applications of interactive visual simulation (Figure 19). Virtual environments can therefore be used to increase safety standards, improve efficiency, and reduce overall training costs [6, 68, 69].

Figure 18: VR applied to Arts

Figure 19: VR used for Training

A safe virtual environment can be used to simulate a real environment that is either too dangerous, complex, or expensive to train in. The most known examples of that kind of VR use are flight simulation, vehicle simulation and battlefield visualization/mission planning in military applications (Fig. 20) [38, 27].

7.6 Engineering

As one would expect, industry plays a major role in the realm of VR applications (Fig. 21). Digital prototyping, collaborative design and engineering, ergonomics and human factors, maintenance analysis, training, education, sales and marketing are areas where VR is more and more being used to enhance quality and improve efficiency [17, 48, 44].

Figure 20: VR applied for training in military issues.

Figure 21: VR applied to Engineering

7.7 Scientific Data Analysis

Scientific research is one area where the use and benefits of VR and visualization have been very much reported in the literature [58, 8, 22] (Figure 22). VR has being used to visualize data that comes from simulations in computational fluid dynamics, physics, molecular modeling among others [25, 46, 15].

Basically, a virtual world representing the data generated during the simulation is created. This digital environment pictures fundamental properties of the interested phenomena. Scientists needs not only fast and efficient displays to analyze the data but also to interact properly with that virtual world. All these requirements are fulfilled by the immersion and input devices (like data gloves) offered by VR systems [63, 11].

The Virtual Wind Tunnel is an interesting example of the pipeline that converts data into pictures for scientific purposes [16]. The Nanomanipulator [58], a user interface for a scanning tunnelling microscope, is another one. These examples give an idea of the power of Scientific Visualization techniques, a special area of interest for our projects, as we shall see next.

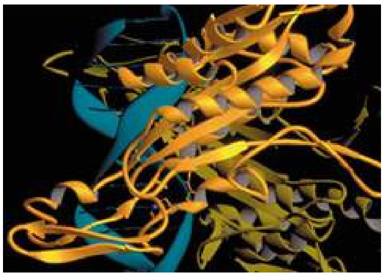

Figure 22: VR applied to Visualization of Scientific Data

8 Virtual Reality at the LNCC

The major interest of VR technology at the LNCC comes from Scientific Visualization. This is a relatively new computer-based field concerned with techniques that allow scientists to create graphical representations from the results of their computations, as well as to visualize features of interest in a data set obtained through imaging instruments [8, 64].

Visualization is essential in interpreting data for many scientific problems and it is such a powerful technique because it exploits the dominance of the human visual channel (more than 50 percent of our neurons are devoted to vision). While computers excel at simulations, data filtering, and data reduction, humans are experts at using their highly developed pattern-recognition skills to look at anomalies. Compared to programs, humans are especially good in seeing unexpected and unanticipated emergent properties [22].

Historically, the LNCC activities was concentrated in numerical methods in engineering, control theory and applied mathematics. The experience obtained by the LNCC staff in numerical methods made it possible to start researches in a broadly variety of problems known as Complex Problems. The activities in this direction was concentrated in the Center for Complex Models [2], which is a virtual center whose activities are centralized at the LNCC. Among the areas encompassed, we have the Computational Hemodynamics of Arterial System and structural analysis.

The numerical simulations involved generate large amount of data which should be properly visualized. To achieve this goal, VR devices have been acquired (HMD, Data Glove, LCD shutter glasses and CyberPuck (all described on section 4)) and we are in charge to get other ones.

Moreover, we aim to explore the LNCC Grid Project [51], developed by the COMCIDIS Research Group, for the development of applications that support collaborative visualization for the exploration of scientific data sets.

The following section describes two projects that encompass VR technology. They have been developed by the Scientific Visualization and Virtual Reality Laboratory team [3] and COMCIDIS Research Group [51], at the LNCC.

8.1 Scientific Visualization

We started using VR to visualize data in computational hemodynamics problems [22]. Then, the acquired knowledge and experience will be used in other areas, like structural analysis and molecular dynamics.

The main goal of the Simulation of the Hemodynamics of the Arterial Human System [61] is to develop a computer system which integrates medical image processing, computational hemodynamics routines and visualization techniques for surgical planning and diagnosis [57, 60, 23, 18].

For instance, once the artery of interest is identified, image processing and segmentation techniques are used to reconstruct the surface that represents the inner (or outer) wall of the artery. Thus, numerical routines start mesh generation. Then, the fluid dynamics of the blood flow is simulated under proper initial and contour conditions. The generated velocity and pressure fields must be visualized to identify anomalies [18].

VR techniques can be used to walk through the reconstructed artery (Figure 23) as well as to immerse the scientists inside the virtual environment created through the generated fields [22].

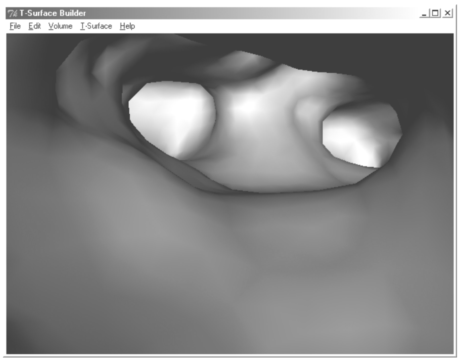

Figure 23: Exploring the interior of an artery.

8.2 Low-Cost CAVE and Collaborative Systems

The goal of this project is to explore immersive virtual environments in fields such as Scientific Visualization and Biotechnology. The first step to achieve such goal is to assemble a low-cost CAVE (see section 5.1), based on a cluster of PCs to drive the rendering process in the CAVE.

A further step will be to integrate the CAVE in a collaborative environment [43] to allow a group of researchers to accomplish a given task collaboratively, even if such users are geographically disperse. By this way, the CAVE facilities will be augmented to allow a user to share his/her view with a remote user using a HMD or even a 2D display.

The existing grid computing facilities at the LNCC [51] will be used to provide a platform for accessing geographically-distributed computational resources to achieve such goal.

Besides, high-performance processing units will be integrated through the Grid allowing to simulate complex systems faster. The generated data could be displayed in the CAVE and shared with users in the system.

9 Final Discussion

As the technologies of virtual reality evolve, the applications of VR become unlimited. It is assumed that VR will reshape the interface between people and information technology by offering new ways for the communication of information, the visualization of processes, and the creative expression of ideas [11, 22]. As a last example, we mention the *Virtual Reality Telecommunication Systems*, a kind of highway for transmitting multimedia information, which is a natural consequence of the VR technology above described [45].

Useful applications of VR include training in a variety of areas (military, medical, equipment operation, etc.), education, design evaluation (virtual prototyping), architectural walk-through, human factors and ergonomic studies, simulation of assembly sequences and maintenance tasks, assistance for the handicapped, study and treatment of phobias (e.g., fear of height), entertainment, and much more.

In our laboratory, we have just started researches in this field. Up to now, we integrated VR facilities to some data visualization applications that we developed [56] through the Visualization Toolkit system [50]

Our perspectives are to expand our applications in order to benefit other areas and projects at the LNCC.

REFERENCES

[1] Special issue of virtual reality on medicine. *IEEE Engineering in Medicine and Biology*, August 1996.

[2] Centro de modelos complexos (http:// 146.134.8.133/ cmc/ projeto/ index.html). 2003.

[3] Scientific visualization and virtual reality laboratory (http:// virtual01.lncc.br). 2003.

[4] 3dconnexion. Cyberpuck (http:// www.3dconnexion.com/). 2003.

[5] 5DT. 5dt data glove 5 (http:// www.5dt.com/ products/ pdataglove5.html). 2002.

[6] H. K. akmak, U. Khnapfel, and G. Bretthauer. Virtual reality techniques for education and training in minimally invasive surgery. In *Proceedings of VDE World Micro Technologies Conference*, 2000.

[7] Ascension. Ascension trackers technical data (http:// www.world.std.com/ ascen). 1995.

[8] Rosemblum at all. *Scientific Visualization: Advances and Challenges.* Academic Press, 1994.

[9] Michael Bailey and Dru Clark. Using ChromaDepth to obtain inexpensive single-image stereovision for scientific visualization. *Journal of Graphics Tools*, 3(3):1–9, 1998.

[10] F. Balaguer and A. Mangili. *New Trends in Animation and Visualization*, chapter 6, "Virtual Environments"., pages 91–105. John Wiley & Sons, Inc, 1991.

[11] J. Balaguer and E. Gobetti. Leaving flatland: From the desktop metaphor to virtual reality. *EUROGRAPHICS'95 Tutorial*, 1995.

[12] K.-P. Beier. Virtual reality: A short introduction (http:// www-vrl.umich.edu/ intro/). 2003.

[13] D. K. Bhatnagar. Position trackers for head mounted display systems: A survey. 1993.

[14] C. Blanchard, S. Burgess, Y. Harvill, J. Lanier, A. Lasko, M. Oberman, and M. Teitel. Reality built for two: a virtual reality tool. In *ACM SIGGRAPH Computer Graphics , Proceedings of the 1990 symposium on Interactive 3D graphics*, 1990.

[15] J.D. Brederson, M. Ikits, C. Johnson, and C. Hansen. A prototype system for synergistic data display. In *IEEE Virtual Reality 2001, Special Topics Workshop, The Future of VR and AR Interfaces: Multi-modal, Humanoid, Adaptive and Intelligent*, 2001.

[16] S. Bryson and C. Levit. The virtual wind tunnel. *IEEE Computer Graphics and Applications*, pages 25–34, July 1992.

[17] H. J. Bullinger, R. Breining, and W. Bauer. Virtual prototyping - state of the art in product design. *Proceedings of the 26th International Conference on Computers and Industrial Engineering. Melbourne, December*, 1999.

[18] J. Behr. S. M. Choi, S. Groszkopf, H. Hong, S. A. Nam, Y. Peng, A. Hildebrand, M. H. Kim, and G. Sakas. Modelling, visualization and interaction techniques for diagnosis and treatment planning in cardiology. *Computers and Graphics*, 24(5):741–753, 2000.

[19] StereoGraphics Corporation. Crystaleyes (http:// www.stereographics.com/). 1999.

[20] C. Cruz-Neira, D. Sandin, T. DeFanti, R. Kenyon, and J. Hart. The cave - audio visual experience automatic virtual environment. *Communications of the ACM 35*, pages 65–72, 1992.

[21] M. Czernuszenko, D. Pape, D. Sandin, T. DeFanti, G. Dawe, and

M. Brown. The immersadesk and infinity wall projection-based virtual reality displays. *Computer Graphics*, 1997.

[22] A. Van Dam, A. Forsberg, D. Laidlaw, J. LaViola, and R. Simpson. Immersive vr for scientific visualization: A progress report. *IEEE Computer Graphics and Applications*, pages 26–52, November 2000.

[23] E. A. Dari, M. I. Cantero, and R. A. Feijóo. Computational arterial flow modeling using a parallel navier-stokes solver. In *Proceedings of ECCOMAS 2000*, September, 2000.

[24] Discreet. 3ds max (http://www.discreet.com/products/3dsmax/). 2002.

[25] M. A. Disnard, B. Ozell, and C. Pic. Vuvoice: A speech recognition interface for scientific visualization in immersive environments. In *International Journal of Speech Technology*, 2002.

[26] P. du Pont. Building complex virtual worlds without programming. *EUROGRAPHICS'95 State Of The Art Reports*, pages 61–70, 1995.

[27] S. Ellis. Virtual environment research and applications at nasa ames research center. *Virtual Reality Universe*, 1997.

[28] C. Park et all. The making of kyongju vr theatre. *IEEE Virtual Reality Conference 2002*, 2002.

[29] C. Faisstnauer and T. Mazuryk. Tracker library: Handling VR input devices. *Technical Report TR-186-2-95-18, Vienna University of Technology , Austria*, 1995.

[30] H.M. Fenlon and J.T. Ferrucci. Virtual colonoscopy: what will the issues be? *American Journal of Roentgenology*, pages 169:453–458, 1996.

[31] A. Gaitatzes, D. Christopoulos, and M. Roussou. Immersive vr theatres and rendering for edutainment: Reviving the past: cultural heritage meets virtual reality. *Proceedings of the 2001 conference on Virtual reality, archeology, and cultural heritage*, 2001.

[32] Epic Games. Unreal universe (http:// www.unreal.com). 2003.

[33] W. Gibson. Neuromancer. *New York: Ace Books*, pages 208–217, 1984.

[34] T. He and A. Kaufman. Virtual input devices for 3D systems. *Proceedings of IEEE Visualization'93*, pages 142–148, 1993.

[35] Z. Hendricks, J. Tangkuampien, and K. Malan. Applications in vr: Virtual galleries: is 3d better? *Proceedings of the 2nd international conference on Computer graphics, virtual Reality, visualisation and interaction in Africa*, 2003.

[36] B. Horn. *Robot Vision*. MIT Press, 1986.

[37] M. W. Krueger. Artificial reality. *(2nd ed.). Reading, MA: Addison-Wesley*, pages 208–217, 1991.

[38] M. Macedonia. Games soldiers play. *IEEE Spectrum Online*, 2000.

[39] K. Meyer, H. Applewhite, and F. Biocca. A survey of position trackers. *Presence*, 1(2):173–200, 1992.

[40] Mindflux. Vfx3d (http:// www.mindflux.com.au/ products/ iis/ vfx3d.html). 2002.

[41] M.L. Moroze and J.M. Koonce. A comparison of analog and digital scales for use in heads-up displays.

In *Proceedings of the Human Factors Society 27th Annual Meeting, 938-940*, 1983.

[42] NCSA. Sonification at ncsa (http:// access.ncsa.uiuc.edu/ stories/ sonification/ sonifpage4.html). 1998.

[43] J. C. Oliveira and N. D. Georganas. Velvet: An adaptive hybrid architecture for very large virtual environments. In *Proceedings of IEEE International Conference on Communications*, 2002.

[44] J.H. Oliver, J.M. Vance, G. Luecke, and C. Cruz-Neira. Virtual prototyping for concurrent engineering. In *1st International Immersive Projection Technology Workshop*, 1997.

[45] A. Pakstas and R. Komiya, editors. *Virtual Reality Technologies for Future Telecommunications Systems.* John Wiley & Sons, LTD, 2002.

[46] A. Plouznikoff, B. Ozell, C. E. Aubin, and V. Goussev. Virtual reality scoliosis surgery simulator. In *3rd BioInformatics and BioEngineering Conference*, 2002.

[47] Realimation. Realimation (http:// www.realimation.com/). 2002.

[48] O. Riedel, R. Breining, U. Hfner, and R. Blach. Use of immersive projection environments for engineering tasks. In *Proceedings of the 25th SIGGRAPH 98, course Applied Virtual Reality*, 1998.

[49] D. F. Rogers and J. A. Adams. *Mathematical elements for computer graphics (2nd ed.).* McGraw-Hill, Inc., 1990.

[50] W. Schroeder, K. Martin, and B. Lorensen. *The Visualization Toolkit: An Object-Oriented Approach To 3D Graphics.* Prentice Hall PTR, 1998.

[51] B. R. Schulze. Projeto grid lncc (http:// netra01.lncc.br). 2003.

[52] Sense8. (http:// www.sense8.com/index.html). 2000.

[53] W. Sherman and A. Craig. *Understanding Virtual Reality: Interface, Applications and Design.* Morgan Kaufmann Publishers, 2003.

[54] Stereo3d. Elsa 3d revelator (http:// www.stereo3d.com/ 3dhome.htm). 2002.

[55] Stereo3d. Stereoscopic 3d games (http:// www.stereo3d.com/ 3dhome.htm). 2002.

[56] SVVRL. Scivis 1.2.3 documentation page (http:// virtual01.lncc.br/ vrodrigo/ document/). 2003.

[57] C. A. Taylor, T. J. R. Hughes, and C. K. Zarins. Finite element modeling of blood flow in arteries. *Comput. Methods Appl. Mech. Engrg.*, pages 155–196, 1998.

[58] Russell M. Taylor, II, Warren Robinett, Vernon L. Chi, Frederick P. Brooks, Jr., William V. Wright, R. Stanley Williams, and Eric J. Snyder. The nanomanipulator: A virtual reality interface for a scanning tunnelling microscope. In James T. Kajiya, editor, *Computer Graphics (SIGGRAPH '93 Proceedings)*, volume 27, pages 127–134, 1993.

[59] M. Vannier and J. Marsh. Three-dimensional imaging, surgical planning, and image-guided therapy. *Radiologic Clinics of North America 34:3*, pages 545–563, 1996.

[60] M. Vénere, R. A. Feijóo, and A. C. S. Guimar aes. Finite element mesh generation from 3d digital images. In *Proceedings of ECCOMAS 2000*, September, 2000.

[61] "Scientific Visualization and Virtual Reality Laboratory". "scientific visualization for hemodynamics (http:// virtual01.lncc.br/ monografia/)". "2002".

[62] J. A. Waterworth. Virtual reality in medicine: A survey of the state of the art. *Department of Informatics - Ume University*, 1999.

[63] D. Weimer. *Frontiers of Scientific Visualization*, chapter 9, "Brave New Virtual Worlds"., pages 245–278. John Wiley & Sons, Inc., 1994.

[64] D. Weimer. *Frontiers of Scientific Visualization*, pages 245–278. John Wiley & Sons, Inc., 1994.

[65] S. Woksepp and O. Tullberg. Virtual reality at the building site: Investigating how the vr model is experienced and its practical applicability. *Journal of Automation in Construction*, 2001.

[66] S. Woksepp and O. Tullberg. Virtual reality in construction: A state of the art report. *Department of Structural Mechanics, Chalmers University of Technology*, 2001.

[67] S. Woksepp and O. Tullberg. Vr modeling in building construction: Some experiences and directions. *20th CIB W78 2003 conference on Information Technology in Construction Conference in Auckland*, 2003.

[68] Y. Zhang, L. Guo, and N. D. Georganas. Collaborative virtual environment for industrial training and e-commerce. In *Proc. Workshop on Application of Virtual Reality Technologies for Future Telecommunication Systems IEEE Globecom Conference*, 2000.

[69] X. Zhong, P.Liu, N.D.Georganas, and P.Boulanger. Designing a vision based collaborative augmented reality application for industrial training. In *Informationstechnik und Technische Informatik*, 2003.