THE WORLD'S LARGEST VR-DOME FOR COLLABORATIVE DESIGN

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Abstract. This paper reports on the development of a new VR (Virtual Reality) system with the world's largest hemispherical screen, which can display high immersive, life-size scale, stereoscopic images. A cluster of PCs is used in master-slave architecture, with 18 slave PCs for rendering left eye and right eye images, and the master for synchronizing the images for stereo view. Contents can be shared with a VR system operating on a notebook with a new VR system developed as part of the same VR toolkit. We apply the system to a real, collaborative architectural design project.

1. Introduction

Life-size scale indicates a state in which the image displayed is the same size as the real thing. In the case of an architectural or an urban design review and presentation, a life-size scale model is often needed. In the case of a physical model, it is limited to the scale of an interior or a house size because of limitations of space and time in which to build. In the case of a digital model such as 3DCAD (3-Dimensional Computer Aided Design), 3D CG (3-Dimensional Computer Graphics), and VR (Virtual Reality), it is possible to apply an architectural or an urban design if the display system is developed because the internal definition in the computer can be life-size scale.

Therefore, various kinds of life-size scale display system have been designed. For instance, CAVE (Cruz-Neira et al., 1992; 1993) and CABIN (Hirose et al., 1998) are displayed on some flat screens in the shape of a cube. Ensphered Vision (Hashimoto and Iwata, 1999) and Vision Station (Elumens Corporation, 2005) are displayed on a curved screen. The advantage of curved screen type systems over the flat type is that there is no picture edge effect at the screen boundaries, making it possible to have better immersion due to the seamless image. We have developed a VR system with a hemispherical screen and reported to CAADRIA 2000 (Fukuda et al., 2000) This system can display a life-size, undistorted image with a wide field of view. However, various problems have become clear both with hardware and software after applying the system to real projects.

The paper is organized as follows. Section 2 clarifies the problems of the previous VR system. Section 3 describes the development of the new VR system intended to solve these problems. Section 4 evaluates the new system through application to real projects. The paper is concluded in Section 5.

2. Problem of the Previous VR System with Hemispherical Screen

2.1. SUMMARY OF THE PREVIOUS SYSTEM

The previous VR system, as depicted in Figure 1, consisted of a hemispherical screen (6.8 metres in the horizontal direction and 5.4 metres in the vertical direction), six front projection type CRT projectors, a high-end super graphics computer (Silicon Graphics ONYX Infinite Reality2 using 3 processors and 640MB RAM), LCD shuttering stereo glasses, an I.R. emitter, and input devices. For the stereoscopic image, the graphics computer generated right-eye view images and left-eye ones up to 120 times a second reciprocally. A maximum of 15 participants could experience a life-size scale stereo image at the same time. The field of view from the centre position was 180 degrees in the horizontal direction, 90 degrees in the vertical direction, and the immersive sense was high. Moreover, participants could walk-through or fly-through from various viewpoints, and compare two or more alternatives in the 3-D virtual space interactively with an input device such as a mouse or a joystick.

Figure 1. The previous VR system with hemispherical screen.

However, various hardware and software problems became apparent through application to real projects.

2.2. ARRANGEMENT OF PROBLEMS

First, there were hardware problems. It was difficult to display an image of realistic brightness although the projector used was one of the best available at the time (about maximum 17 lx on a screen with a stereoscopic image). For instance, a difficult case was the design review of the night view. Moreover, the real-time rendering performance of the graphics computer at that time was inferior to that of the system of clustered PCs used in recent years. Moreover, a VR image cuts into the verge between the screen and the floor, and it cannot secure a sufficiently low field of view for reviewers standing on the floor.

Next, were software problems. We developed a VR system that operated on a notebook computer, using it together with the previous VR system with a hemispherical screen. Data formats and setting environments of geometry, colour, texture, lighting, and viewpoint were different between both systems, which raised issues with interchangeable data. When both systems were used, data conversion and settings had to be carried out individually. Moreover, VR authoring work taking one day or more was required because an easy-to-use authoring system had not been developed. When the design proposal was reviewed immediately before the design meeting, it was sometimes not possible to produce the VR contents in time. Moreover, necessary basic functions for the design review were insufficient. For instance, it was impossible to walk-through while staying at eye-level along stairs and terrain.

3. Development of the New VR System with Hemispherical Screen

To solve the problems described in Section 2, a new VR system with hemispherical screen was developed, as depicted in Figure 2.

3.1. HARDWARE

The new VR system, as seen in Figure 3, consists of a hemispherical screen (8.5 metres in the horizontal direction and 7.5 metres in the vertical direction), 18 front projection type liquid crystal projectors, 19 PCs, polarized 3D glasses, and input devices. All PCs are connected on a 1GB-LAN. For rendering a stereoscopic image we use a cluster of PCs in master-slave architecture, as seen in Figure 4, with 18 slave PCs for rendering left eye and right eye images and the master for synchronizing the images for stereo view. A maximum of 30 participants can experience life-size scale image at the same time.

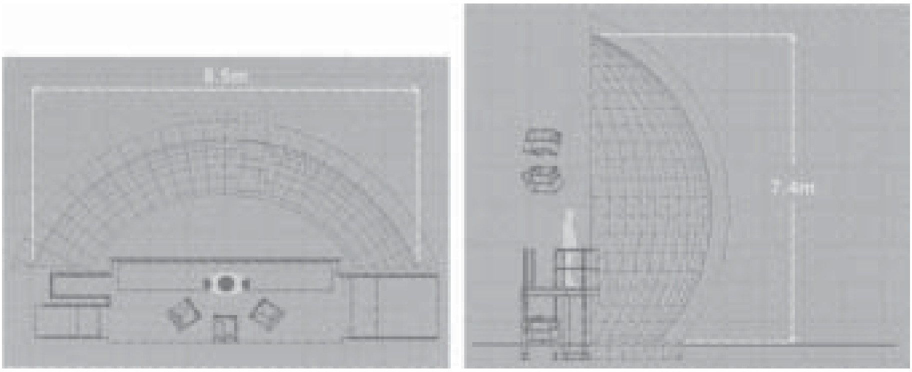

Figure 2. Elevation view (left) and plan view (right).

Figure 3. Overview of the new VR system with hemispherical screen.

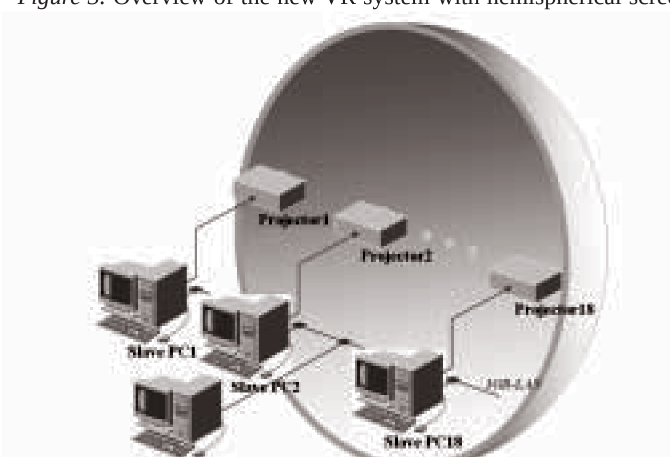

Figure 4. System configuration: A cluster of PCs in master-slave architecture and projectors.

The hemispherical screen is divided into nine sections, in a 3-by-3 pattern in length and width areas. Each image for both eyes is projected from 18 projectors on to the screen in each area. As a result, a high resolution and a very bright image can be generated. The number of pixels is increased 6.4 times and brightness is increased 20.5 times compared with the previous system. Moreover, a viewing stand is installed on the floor side at a height of 1.3m, and participants review a design plan standing on that. The field of view is 180 degrees in the horizontal direction and 150 degrees in the vertical direction. It is wider compared to the previous system. In a word, the new system can be reviewed in a wider field of view and with a higher immersive sense.

Distortion correction has been developed for displaying the image on a hemispherical screen. Brightness levels are increased in the area where two or more projector images come together. An edge-blending technique has also been developed.

Figure 5. The image of each camera divided into nine before distortion correction (Left: left eye image; Right: right eye image).

3.2. SOFTWARE

Actually, the toolkit of the VR system that operates on the notebook computer is Virtools™ Dev, as seen in Figure 6. This was selected because its data loading time and rendering time are very fast compared with VRML (Virtual Reality Modeling Language). It uses the latest Microsoft Direct3D-API technology. It has a binary data format and its data structure is always optimized. Because it can be developed by visual programming, rapid development according to the design contents is also possible.

Virtools™ Dev is designed to render with one PC. By installing it in 18 PCs, a gap is caused in the timing of rendering, and the image divided into 18 pieces for both eyes cannot render one image synchronized with real time. Therefore, an enhanced system was developed including an algorithm enabling rendering with a total of 19 PCs, including 18 slave PCs for rendering and a master PC for synchronizing the images on the network. The details of the developed synchronous algorithm are shown below:

1. By walk-through operation, etc. the camera of the Virtools contents on master PC is moved.
2. The viewpoint position of a movement place is defined as Point A.
3. Point A information is notified to all slave PCs from master PC.
4. The contents of a rendering of Point A are calculated by each slave PC.
5. The contents of a rendering can be calculated and the notice of the completion of preparation is performed to master PC from order and slave PC.
6. If the notice of completion arrives from all slave PCs, master PC directs a rendering to all slave PC.
7. Master PC and each slave PC perform a rendering.

Using the Virtools™ Dev camera setting, a life-size scale display is produced when viewing from the centre of the viewing stand (at a position 4m away from the screen).

As a result, the life-size scale image can be displayed in real time. Consequently, it became possible to show the hemispherical screen the contents which work on a notebook PC for a short time.

Figure 6. VR authoring interface on Virtools™ Dev.

TABLE 1. Comparison between previous system and new system

	Previous system	New system
Screen size (m)	(H) 6.8 (V) 5.4	(H) 8.5 (V) 7.5
Maximum no. of persons	15	30
Hardware	6 CRT projectors, Onyx2 Infinite Reality, LCD shuttering stereo glasses, I.R. emitter, Distortion correction, Edge blending	18 liquid crystal projectors, 19 clustrered PCs, 1GB-LAN, Polarized 3D glasses, Distortion correction, Edge blending
VR toolkit	Real Master	Virtools™ DEV
Stereoscopic method	Liquid crystal shutter	Polarized light
Luminous flux of projectors (lm)	1,200	36,000
Brightness on screen (lx)	17	341
Resolution (pixel)	(H) 1920 (V) 960	(H) 3840 (V) 3072
Field of view (degree)	(H) 180 (V) 90	(H) 180 (V) 150

4. Application to the International Architectural Design Collaboration

4.1. SUMMARY OF THE PROJECT

We applied the new VR system to the architectural building and art museum in National Chaio Tung University (NCTU) in Taiwan. The main participants_@were the president and dean of the college of architecture of NCTU (client), and the Japanese architect (schematic designer). The president was not a professional in the field of architecture. The participants were very busy and it was very difficult for them all to travel frequently between Taiwan and Japan. Such a situation is not limited to this project and happens often. After establishing mutual trust between participants, it was necessary to engage in sharing and consensus building regarding the concrete image of the schematic design, and this had to be done immediately due to the pressure of the completion schedule.

4.2. PRESENTATION

The presentation was held at the end of January in 2004. There were 25 participants including 9 clients, a schematic designer, an execution designer, a coordinator, 7 VR engineers, an interpreter, and 6 reporters.

Before presentation of the VR system, the outline as depicted in Figure 8, was explained in the meeting room, and participants shared the content of the design and the review route. The review route had about 30 main standing viewpoints and continuous viewpoints such as a bird's-eye view, an approach road, an entrance, a round plaza, an internal space, etc. Then the presentation was made in the VR room along the review route, (Figure 9) and all the participants reviewed the schematic design. After a fly-through and walk-through along the route, the design was reviewed, and participants were able to check freely from any viewpoint they wished to use.

Because the 3-D VR image of the wide field of view was displayed at a life-size scale, many aspects of design, such as the arrangement of architectural buildings, museum, and complex terrain, an appearance of a well hole in the building space, a round plaza extension, and a view from the top floor, could be reviewed with a sense of actually being in the place. Such a review is impossible in the notebook computer VR system because of the limits of the display field of view and cutting of the image. Moreover, even a slight expression of concrete became possible by improving the brightness function of the projector. The basic functions contributing to the design review were developed by Virtools™ Dev in a short time. For instance, there was high-quality expression of shadow and walk-through operation while staying at eye-level along the stairs and terrains.

The meeting was closed by the handshake of the president and the architect. This was the moment when architect's concept was exactly conveyed to the client,

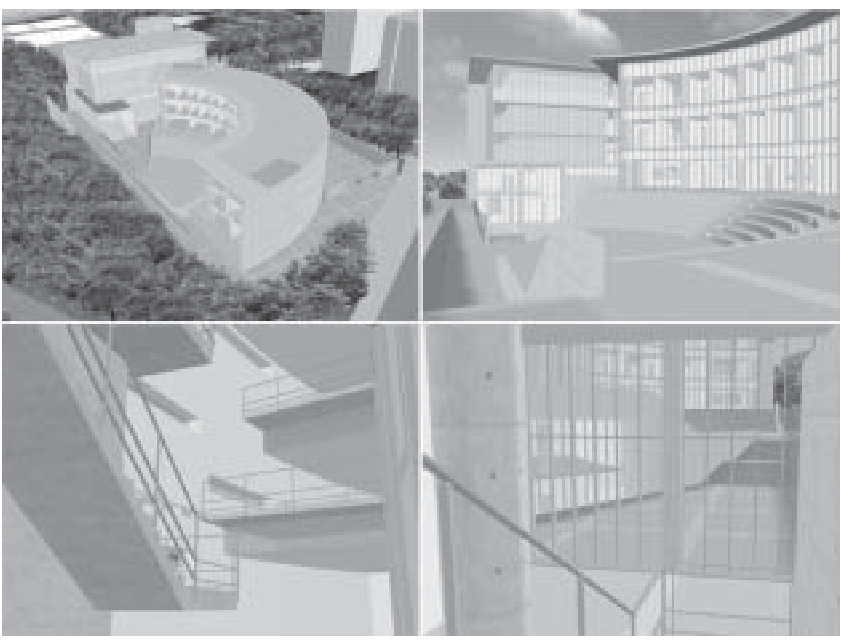

Figure 7. VR image of schematic design.

Figure 8. Outline explanation.

Figure 9. Presentation with the new VR system.

Figure 10. Moment of consensus building between client and architect.

and consensus building was carried out regarding final execution (Figure 10). The participants' evaluations using the system were as follows:

The client said, "We understood, to an incredible degree, the designers' concept for the future outdoor and indoor spaces of the building in the virtual environment. Seeing this, I knew that we are now indeed one more step closer toward ubiquitous digitization of architecture."

The architect said, "Because it is possible to review the design at life-size scale, it is possible to check that the user's view coincides with the architect's view. To date, this has not been possible until construction is completed, and it has not been possible on a small screen either."

5. Conclusion and Future Work

*T*he new VR system is not limited to the NCTU project taken up by this paper, and has also been used at presentations of plural urban renewal projects in Japan. This system is an installation type, and has the drawback that it is necessary for participants to meet in Tokyo. The VR system using a life-size scale and wide field of view displays can be seen to be very effective as a design review and presentation tool.

As a result of adopting Virtools™ Dev as the new VR system, the contents creator became unnecessary to carry out a conversion and each setup of data in VR room in which VR system is installed. Previous VR system had to do much work with the supercomputer in VR room. What is necessary is to make contents with one's PC, and just to only see a final result in VR room. This leads also to UP work efficiency while mitigating a creator's stress.

On the other hand, when fly-through, walk-through and rotation at a speed faster than reality are employed, VR sickness is experienced by some viewers. It is necessary to note this for operation purposes although the problem arises only because the system is too immersive.

This paper describes how a life-size scale display system was developed by enhancing Virtools™ Dev used on notebook computers. In new VR system, the design proposal displayed on the life-size scale can be reviewed now. In addition, the function which displays during examination the idea which comes into the persons concerned's mind, the function to investigate an unknown point immediately, and the function in which the persons concerned who are in remoteness can participate in an examination meeting are also needed. Moreover, the effectiveness was evaluated by an actual architectural design project. We want to advance development connecting to database system to correspond to the design change in a 3-D virtual space in the near future.

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