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Portable distortion-free Back Projected VR Dome for Environmental Design: an Application Research

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1. Introduction

Background

Recently, many researchers have used various media to represent environmental designs. However, lacking of an affordable system, most simulations such as still frame, animation and real-time projections can only be displayed on 2D flat screens. No matter how realistic they can be presented, it cannot provide the audience with a realistic sense of space. A tool that is able to represent both the sense of space and immersion is our expected goal.

Previously, many pioneers of virtual reality had invented certain devices with a desire to immerse human being in believable virtual spaces. The most famous products are CAVE, developed by EVL (Electronic Visualization Laboratory, University of Illinois at Chicago), HMD by MIT (Massachusetts Institute of Technology), and front projection VR dome which is made by MEW (Matsushita electric works, ltd.). All of them are expensive, heavy, and unwieldy. For example, the sizes of CAVE and front projection VR dome are large. Therefore they need a large space to setup. CAVE is burdened with the obvious corner-edge conditions between screens. HMD is heavy for the viewer, because one has to wear a big helmet with wires. At the same time, the field of view of HMD isn't wide enough to represent the sense of immersion. These are the reasons why none of them could become popular. This research aims at avoiding the shortcomings of all these systems, and hopes to develop a friendly system for normal user.

The Power of GPU

GPU (Graphic Processing Unit)—special unit aimed at real-time 3D rendering in PC systems. Recently, performance values of GPUs have been enhanced dramatically. Even consumer levels GPUs have overtaken the supercomputers that processes very complicated 3D scene, which is shown in Table 1. On the other hand GPU can compose and transform images with width band graphic memory. This paper will explain that at the following chapter. Through the advantage of GPU, this research can be very easy to get over the bottleneck of real-time graphic processing.

Table 1: Performance comparison between three systems

	Athlon K7 1.2GHz with nVidia Geforce 2 Ultra GPU	Onyx 2 Infinites reality	Onyx Reality engine
Triangle drawing speed (polygons per second)	31.25 million	11million	2million
Anti-aliasing triangle drawing speed (polygons per second)	31.25 million	N/A	0.6million
Pixel fill	2000 million	200 million	80 million
CPU	Athlon K7 1.2GHz	MIPS R10000	MIPS R4400

2. Back Projection VR Dome System

Concept

The installation is very simple, as shown in Figure 1 it is made by a LCD projector and a plastic hollow hemisphere with a special coating. Viewers move their viewpoints in the center of the dome. The warping image would be projected on the other side of the dome. Through the screen the image would be restored to the original condition. Therefore, the viewer would be immersed in the semi-enclosed space.

Figure 1: VR dome setup

Method

The VR-dome projection process is very similar to the method of creating an environment map. Traditionally, the scene or the data is rendered six times from a single vantage point but with six different viewing directions, as seen in Figure 2. The production of the images is based on a cube. Images are generated from the center of the cube looking at the six different faces of the cube. These six images are used as texture maps to generate a spherical projection by projecting them onto the dome.

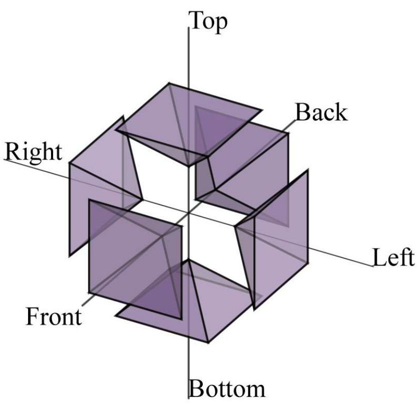

Figure 2: The image was generated by six different viewing directions

This approach would require rendering six images to create one spherical image. All objects in the scene would have to be rendered six times, one for each face of the cube. This would significantly impact the performance of the application. The approach is created by three warping meshes, which are optimized for the screen shape of the dome. A 180-degree field of view (FOV) is required, not a full 360-degree FOV. Since objects behind the camera/viewer are not visible, the "Back" face of the cube does not need to be rendered.

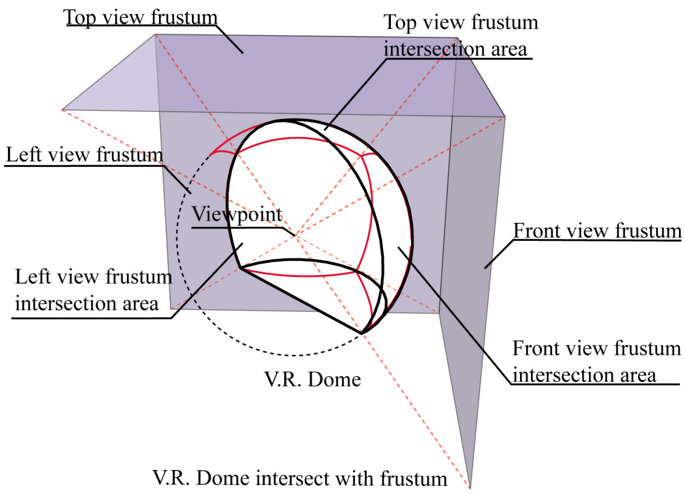

Figure 3: This is the view of VR-dome screen and the virtual cube.

Since only the front 180-degree FOV is required. Except the front side, only half of the each cube's surface images will be utilized. By orienting the cube, as shown in Figure 3, the number of rendered cube faces is reduced to four. While complete images of both the left and front cube faces will be used in the dome projection, only half of the top cube face image will be utilized. The screen shape for VR-Dome is a hemisphere. The bottom quarter of the hemisphere was removed, because the shape that consists of three sides could occupy the screen area larger than the complete circle, which consists of four sides. Figure 3 identifies the exact portion where the image is not displayed. It also shows that the left and front cube faces completely cover the visible portion of the screen and the bottom face of the cube is not required for the final projection. Thus we need only three cube faces to generate a hemispherical projection with a 180-degree horizontal FOV. This improves the rendering speed significantly as the data is rendered only three times. Also, the number of texture objects required for creating a spherical projection is significantly reduced.

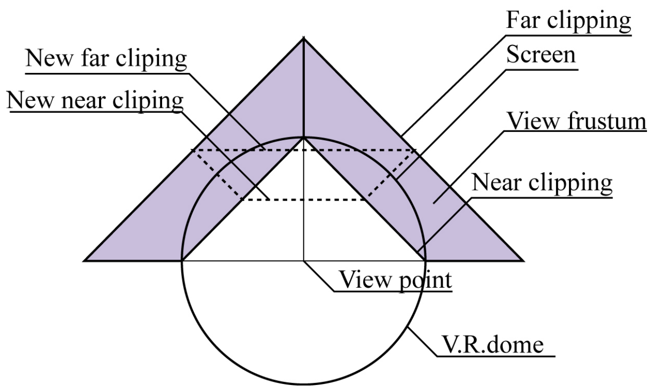

Figure 4: Top view of optimized approach to generate spherical projections.

Since three faces are being rendered, these faces have to be arranged for a projection screen. The projection screen consists of the warping images of the left, front and half of the top side images. The warping images would be constructed as a 180-degree fisheye shot. The warping process is shown in Figure 5. After the projection screen is made, the image can then be projected to the dome with a seamless screen.

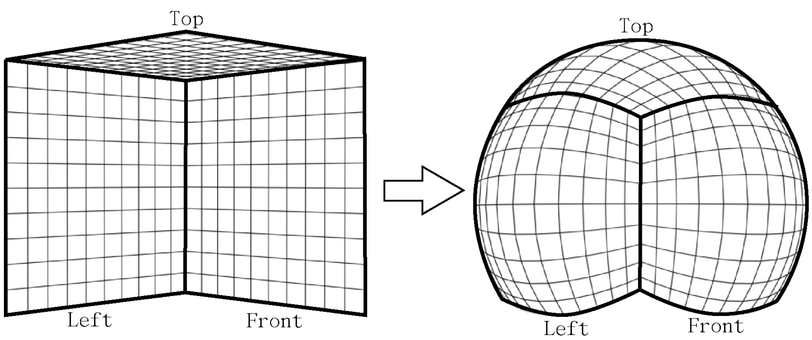

Figure 5: The 180-degree fisheye shot is composed of left, front and top images

Hardware Issues

A two-step process has been developed for generating real-time dome projections based on methods that have been discussed above. In the first step, three 90-degree FOV planar projection frustums are rendered on the back buffer or on any accelerated off-screen pbuffer. These are copied via a high-speed bus to the texture memory. In the second step, the textures are decaled on to a static mesh pre-projected for a spherical projection. For a final output resolution of 1024x768, the individual texture sizes must be at least 512x512 pixels for both the left and right cube faces. This amounts to 1.8 MB of color-buffer data. Every frame rendered thus requires a large amount of data to be copied from the frame buffer to texture memory. This requires a graphics card with a large amount of internal texture memory, and with a very high bandwidth bus connecting the texture buffer and the frame buffer.

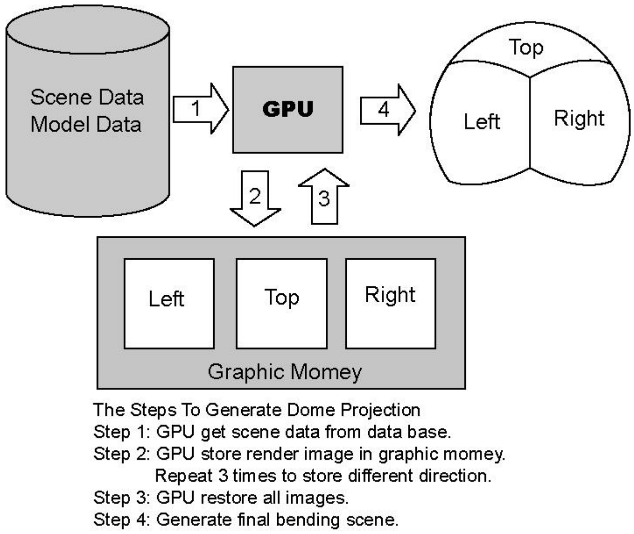

Figure 6: Process flow of generate dome projection

3. Applications in Real Project

Jong Jeng Road, Hsinchu, Taiwan

Since 1980, the Science Park, known as Taiwan's Silicon Valley, has attracted many high technology factories. Each year waves of young people with high academic backgrounds flood into the small city and make it even more crowded. These newcomers bring fresh values to the city and also create a new tide of "culture shock.”

In this case, the city government had plans to turn the streets of Hsinchu into a Museum of Culture which would present the life style of Hsinchu’s citizens. In this case, Hsinchu government decided to use VR-dome as an environmental checking tool.

Interface feature

This research project utilized Virtools® Dev 2.0 to create the interface prototype. The features are as follows:

1. Controllable viewpoints—viewers can change their viewpoints to any position inside the scene.
2. Real-time rendering—all screens in this simulation are produced in real-time,

there isn't any pre-rendered animation sequence.

3. Changeable elements—certain elements inside the scene can be changed. Viewers can change the elements and switch them on and off.
4. Collision detection—this function is activated in order to keep the viewer from straying beyond the street area, and to prevent access to awkward environmental moments.
5. Gravity—keeps the subject's viewpoint at an average height.

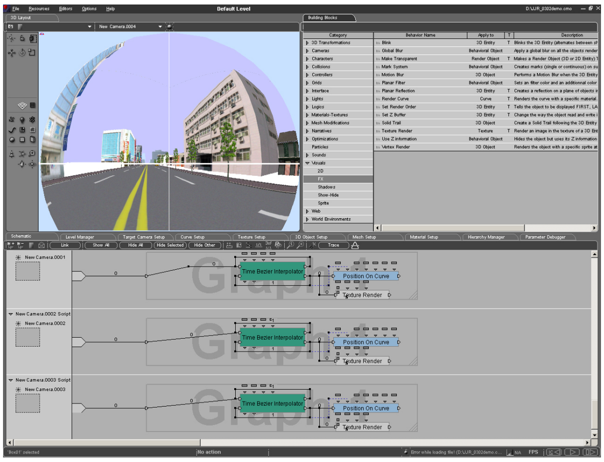

Figure 7:Jong Jeng Road model under editing in Virtools® Dev 2.0

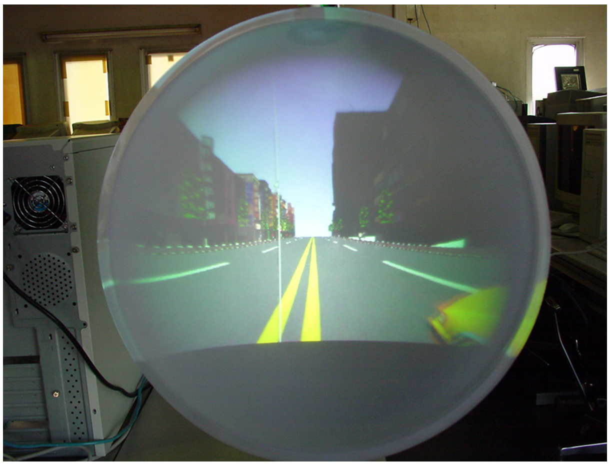

Figure 8: Jong Jeng Road real-time simulation display on VR dome.

4. Conclusions

Benefits

-Immersible system is able to enhance the sense of space and interaction

-Viewer can experience accurate scale in VR dome, reducing design errors.
-The cost of hardware is low. Affordable prices will make the VR dome a popular tool for environmental design.
-The dome is portable. The weight of this system is light. VR dome can practically display in any place according to the needs of designers and clients.
-This system can be setup easily anywhere.

CAVE, HMD, front projection VR-dome and our system

CAVE and HMD are rather old systems. But some researchers still use them as their VR develop platforms. Table 2 is a comparison between CAVE, HMD, front projection VR-dome and our system.

Table 2: Comparison between VR-dome and CAVE

	Back projection VR-dome	HMD	CAVE	Front projection VR-dome
Display device	One projector	Two small LCD panel	3 or more projectors	6 projectors
Distortion-free	Yes	Yes	No	Yes
Shape	Spherical	2D flat panel	Cubic	Spherical
Size	small	small	Large	Large
GPU performance require	High	High	Lower	High
Synchronize processed	No	Yes two	Yes, 3 or more	Yes, 2 or more
Easy to carry	Yes	Yes	No	No
Seamless	Yes	Yes	No	No
Immersible	Yes	No, because the FOV of HMD is narrow	Yes	Yes
Value	6,000 USD (1024x768 LCD projector output)	8,000USD(800 x600 stereo output)	800,000 USD(5 high resolution projectors)	1 million USD(6 high resolution projectors)

Feature study

-Improve the projection angle and projection area.

-Apply the system to different cases in environment design.

-Enhance the rendering speed of scenes.

-Friendly interface is required when designing with dome projection kits.

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