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CyberDome: PC Clustered Hemi Spherical Immersive Projection Display

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Abstract

This paper aims at introducing 'CyberDome', a PC-Clustered Projection Based VR Display, where the illusion of immersion is realized by projecting stereo images into a hemi-spherical screen. With the help of our developed distortion correction software, the system is capable of displaying life size, stereoscopic, distortion free images on the screen with a wide field of view. Dome software is designed such that it could take positions of projectors, eye point of user, and diameter of hemi-spherical screen as parameters, which in turn makes it possible to have 'Scalable CyberDome Systems' with arbitrary size of hemi-spherical screens. Focus of the paper is the description of two such developed Systems, CyberDome1800 and CyberDome8500

Key words: Immersive Projection Technology, VR, Distortion Correction, Edge Blending, Hemi Spherical Screen

1. Introduction

VR Techniques have been receiving wide spread use as interactive information visualization aids. Immersive Projection Technology has been playing a key role for visual data mining. Compare to the “traditional” IPT systems such as HMD and BOOM, CAVE [1,2] has been a more successful immersive virtual environment and many clone installations of CAVE have been made world-wide for the past several years. Some among them are three- and five-sided CAVEs at Fraunhofer-IGD at Darmstadt, Germany [3] the “CUBE” at the university of Stuttgart, Germany [4], the “CABIN” and the “CoCABIN” at the universities of Tokyo and Tsukuba, Japan [5], COSMOS at Technoplaza, Gifu, Japan [6] the six-surface, fully immersive CAVE at the Royal Institute of Technology, Sweden [7], six-sided “CABANA” at HRL laboratories at Malibu, CA [8]. Another recent addition to CAVE family is desk-like responsive workbenches (RWBs) such as the “PanoramaBench” [9] and the “ErgoDesk” [10]. IPD family also includes Curved Screen surrounding systems such as Ensphered Vision [11] and Vision Station [12]. Advantage of curved screen type systems over flat type is that of no picture edge effect at the screen boundaries making it possible to have better immersion due to seamless image. Concurrent advances in visualization and computational capabilities along with high performance PC hardware have spurred the creation and use of PC-based three-dimensional virtual environments. Recent trend has been PC-driven, cost effective, projection based VR displays. For example, a recent addition to the CAVE family is a PC-based CAVE known as NAVE [13]. While all these existing IPD systems have its own pros and cons, the required features of the system are highly dependent on the user and the simulation application.

Briefly put, recent trend regarding the demanding features of IPD systems for visual data mining from the user’s point of view can be summarized in four terms a) High image quality b) Affordability for the masses c) Compatibility with existing systems and d) General purpose. CyberDome is an attempt to meet the all above-mentioned four requirements. The paper is organized as follows. Section 2 details the design considerations of CyberDome, section 3 describes the developed CyberDome systems, section 4 briefs the possibilities of using CyberDomes and the paper is concluded in section 5.

2. Design Considerations of CyberDome

The design target of CyberDome can be summarized as follows

“ To make an optimal design to have high quality, high resolution, distortion less, life-size, cost effective and scalable Immersive Projection Display for Real Time Interactive Visualization of many kinds of applications”

To start with, let us broadly classify CyberDome in to two types; Small Dome and Big Dome. Small Dome is the one whose projectors rendering area covers the complete Dome Screen, while in the case of Big Dome, only one portion of the screen will be rendered by each projector. The steps taken to achieve the design targets for each type are briefly described below.

Small Dome

Having decided to have spherical screen for better immersion by displaying seamless image, the first issue is to have a technique to generate non-distorted image on spherically curved screen.

a) Distortion Correction Technique

In the case of CyberDome, image distortion has to be handled in two cases.

Case 1. Distortion due to spherical screen

Case 2. Distortion due to projector's position.

In case 1, as shown in figure 1, a plane image is distorted when projected on to a spherical surface. A distortion free image can be displayed on a spherical surface by projecting a pre-distorted image, making the process as an inverse problem, as shown in figure 2. Generation of such pre-distorted image is achieved by distortion correction function as shown in figure 3. Detailed description can be found at Hatanaka et al [14] and Nomura et al [15]. The whole process can be summarized as below.

- Define the view volume
- Map the rectangled image on to spherical configuration as texture data
- Extract the distorted rectangle area by projecting it parallel. Which would be the pre-distorted image from the computer.

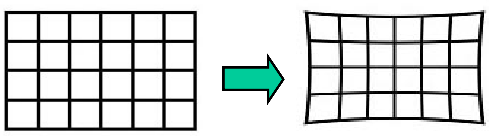

Fig 1. Plane image presented on a spherical screen

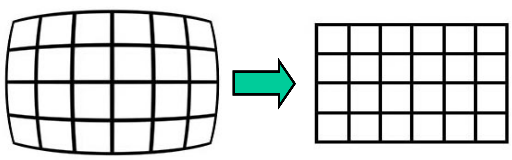

Fig 2. Presentation of pre-distorted image

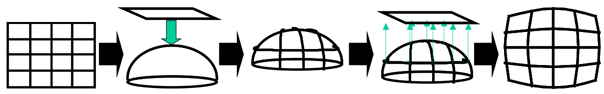

Fig 3. Generation of pre-distorted image using distortion correction function

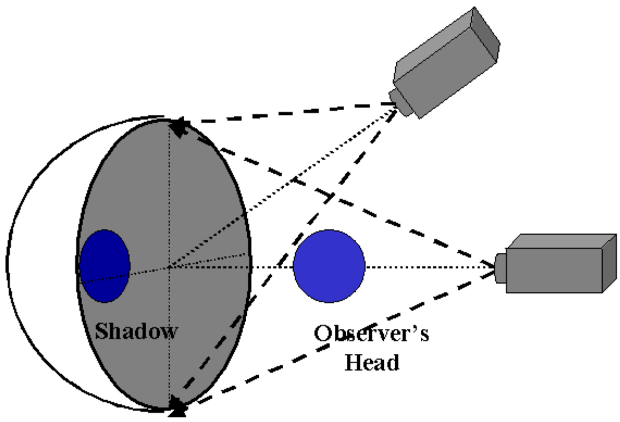

Fig. 4 Projector Configuration Test

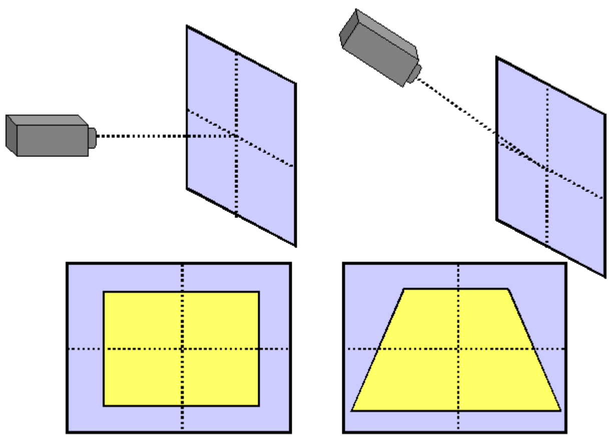

Fig. 5 Image Distortion due to projector's position

Ideally, high quality bright image can be viewed if the projector placement is along the center of the screen. That would result user's shadow on the screen and can be avoided by shifting the projector up as shown in figure 4. The image distortion caused by the projector shift (as shown in figure.5) could be corrected using lens shift feature of the projector. But, not all the projector has this feature and our distortion correction software had to take care of this feature

The distortion correction function is designed such that a pre-distorted image can be generated for any size of viewing volume, by setting the parameters such as size of the screen, projector position and user's position. All the system components settings can be fine-tuned by the software. By measuring the actual distances between projector, screen and the user's position, the software calculates the correction needed and could be fine-tuned manually by adjusting the parameters with reference to an ideal reference point on the screen. The final version of the corrected arrangement can be evaluated by displaying grids on to the whole screen as shown in figure 6. The same method is applied for both left and right projectors and the GUI as shown in figure 7 can set up all the viewing parameters.

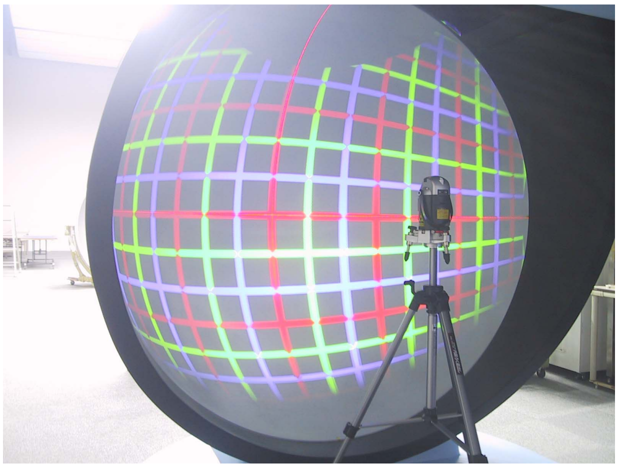

Fig. 6 Evaluation of Distortion Correction

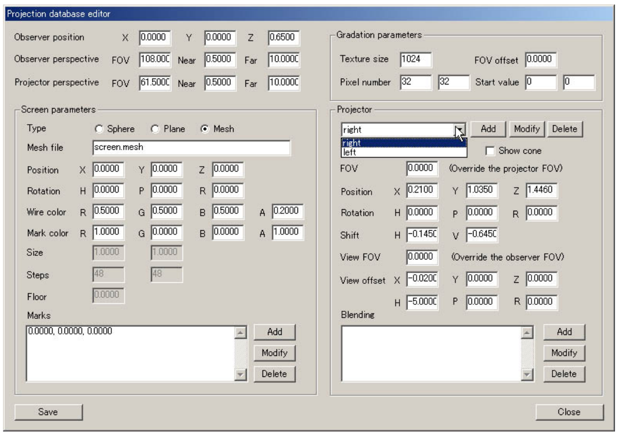

Fig 7. gui for parameter setting

b) Stereo View and Data Synchronization

For almost any visualization application, there is data that changes from frame to frame, for example, the viewpoint. A visual simulation application may also have moving models, animations, special effects and other data that is updating in the scene. On single system architecture, the data is simply updated in a shared memory segment and all processes using this data simply update their respective tasks with this shared information. Though the PC based architecture is becoming better and better due to high performance 3D graphics rendering techniques, considering the need of good frame rate and high quality visualization for real time interactive stereo viewing applications, single system architecture is not a good choice. For rendering a stereoscopic image we use cluster of PCs as master-slaves architecture, with 2 slave PCs for rendering left eye and right eye images and the master for synchronizing the images for stereo view. The configuration is shown in figure 8. Stereo synchronization is achieved by time synchronized refreshing of swap buffers on vertical retrace from the master PC.

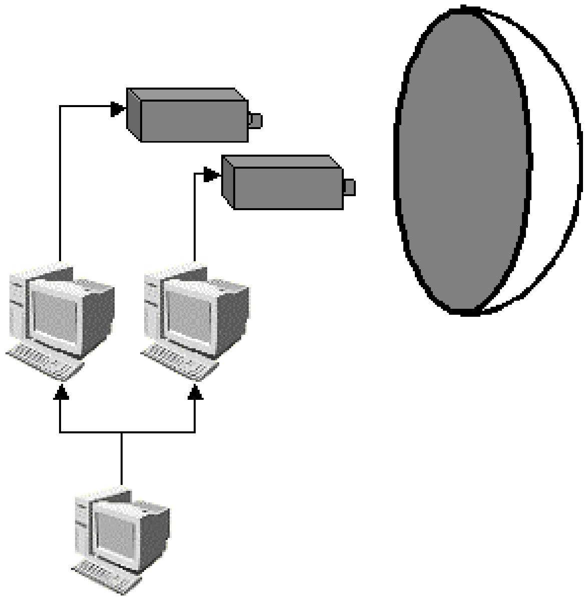

Fig. 8 Configuration for stereo view

c) Functions for Real Time Interaction

Having completed the design considerations for the Dome configuration, the next issue is to have modules for interactive real time visualization. Dome software is designed such that any walk through device can be added to the system easily. Couple of PCs can be networked with the Dome System for both application and device management.

Big Dome

Big Dome can be considered as an extension of small dome. In the case of small dome, each projector renders whole image. When the display size increases, the sharpness and the resolution of rendering image decrease. To keep high-resolution high quality display, multiple channel output has long been a requirement for an immersive environment. Rather than using high-end super graphics computers, our architecture use PC based multi channel architecture. The total display has to be divided in to many areas and a well-arranged set of projectors cast the restrictedly defined part of the scene. Total image will be the combination of all the rendered image portion of individual projectors. This requires further mechanism of blending near the boundary of each projected image to have seamless image.

Blending Technique

Consider a situation as shown in figure 9, where there are 4 projectors A,B,C and D. Each projector is restricted to render only one portion of the whole image and there obviously will be an overlap at the boundary of each rendered portion. Smooth blending near these boundaries has to be achieved by software. The steps to achieve smooth blending can be summarized as below

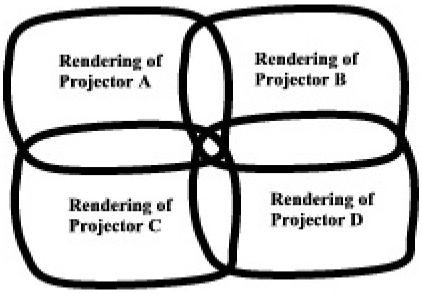

Figure 9. 4 portion of the total image are rendered by respective projectors

- Align the projectors such that all the individual display portion is covered completely the total image space, meaning there is no hole or separation between image portions.
- Adjust the parameters such that a continuous grid can be achieved in all the rendered portion
- Find the image portions which had rendered 2 times, 3 times and 4 times and store it separately
- Interpolate and calculate the pixel values required near the boundary from the stored pixel information

Configuration of each rendered portion is similar to that of small dome for stereo view, which is rendered by 2 PCs and 2 projectors. Same process is repeated for all the 4 portions of the image making the system configuration as 8 Projectors and 8 PCs controlled by one Master PC.

With the above-mentioned developed software for distortion correction and smooth blending, any arbitrary size of the hemi spherical display system is possible. Next section of the paper describes our developed Cyber Domes using the concept described in this section.

3. Developed Systems

As of now, developed CyberDome family includes 3. CyberDome1800 and CyberDome3700 under small dome configuration (in which the latter one is a system based on SGI workstations) and CyberDome8500 under big dome. This section briefs the characteristics of each system.

CyberDome1800:

This hemi-spherical display is 1.8 m in diameter. Using 2 liquid crystal type projectors, the system generates a stereoscopic image as wide as 140-degrees in horizontal direction and 90 degrees in vertical. The system configuration is shown in figure 10. To have a compact

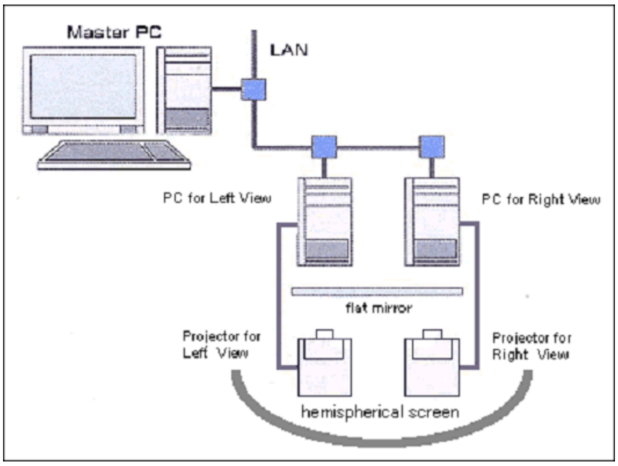

Fig. 10 System Configuration of CyberDome 1800

Fig. 11.a CyberDome1800

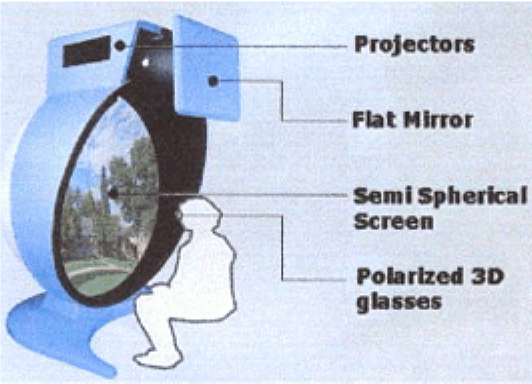

Fig. 11.b CyberDome1800 Components and the screen size.

design, best positions for the projectors had to be considered and it is achieved by using a flat mirror in front of the projectors as shown in figure10. While calculating the distortion using the distortion correction software, the positions of the virtual projectors are used. For detailed description, readers are requested to refer shibano et al [16][17]. Figure 11 shows the over all view of CyberDome1800.

CyberDome 3700 : While we focus on PC clustered IPD, it is to be noted that our developed distortion correction software is independent of the Operating Systems. Shown below in figure 12 is SGI work station based CyberDome, whose screen size is 3.7 m in diameter. Using SGI Onyx and Barco's Galaxy projector, we have succeeded to display distortion free images on the Spherical Screen

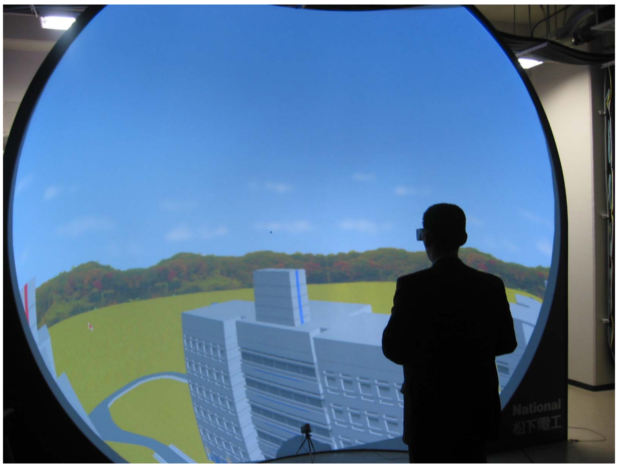

Fig. 12 CyberDome 3700

Cyber Dome 8500

This Dome could be the largest multi-pc controlled 3D display in the world. Components of the system include hemi-spherical screen of 8.5 m diameter, 18 liquid crystal projectors, 18 personal computers to generate rendering images for the respective projectors and few couple of computers for managing simulation database and interactive devices. The total system configuration is shown in the figure 13. The whole image is divided in to 9 portions. Each pair of projectors cast the each scene portion. Process of distortion correction and blending techniques as mentioned in section 1 is carried out. Evaluation of the distortion correction is made using grid test as shown in figure 14. Step by step calculation for smooth blending near the boundary of the projected image is also carried out as shown in figures 15. Figure 16 and 17 show the final image after distortion correction and smooth blending. With a bright, high-resolution life size stereo image projected on to the screen, having a wide field of view of 180 degrees in horizontal direction and 150 degrees in vertical, the audience can experience total immersion in this virtual environment.

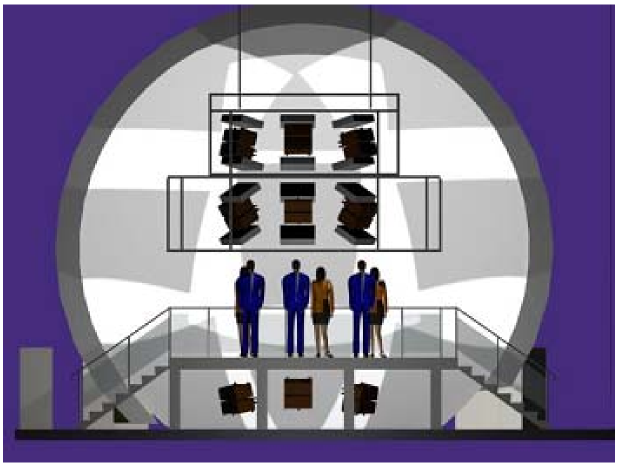

Fig. 13 over all view of CyberDome8500

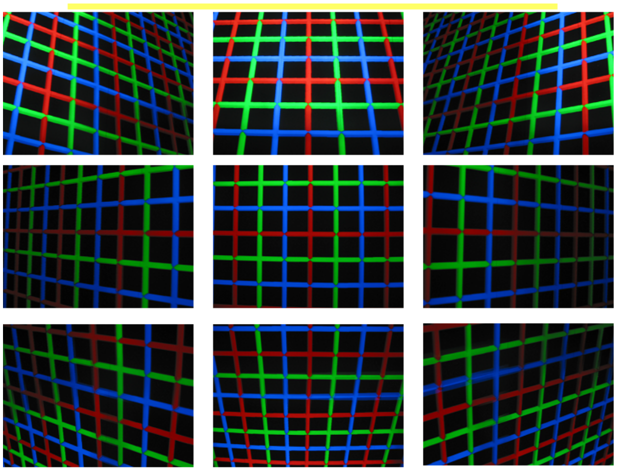

Fig. 14 Evaluation Method of Distortion Correction of CyberDome8500

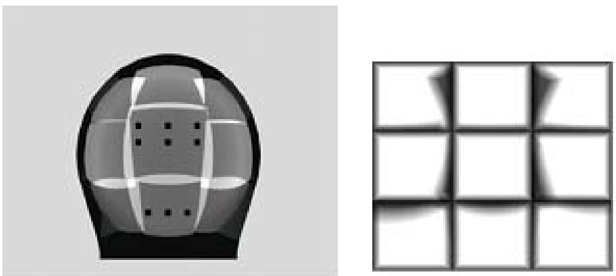

Fig. 15 Image showing the need for smooth blending near the boundaries of each projected image portions

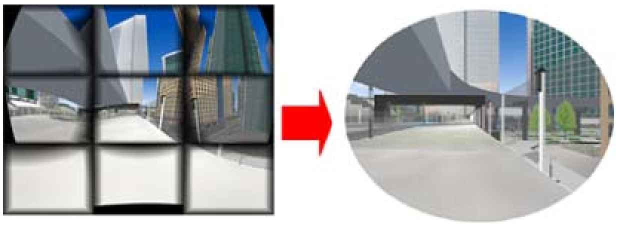

Fig. 16 the whole image on CyberDome, before and after blending

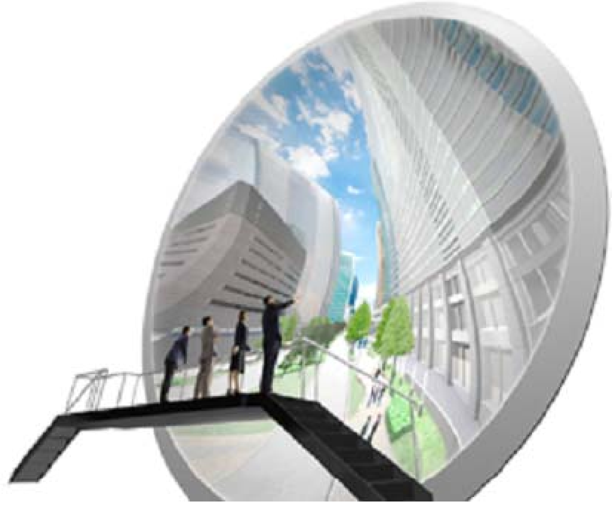

Fig. 17 CyberDome8500

4. Realtime Interactive Visualization in CyberDome

For achieving real time performance data has been completely separated from the rendering PCs. Apart from 18 rendering PCs, a few couple of PCs is used for managing simulation database and interactive devices. A special device has been developed called “Track Ball” to use with CyberDome8500. The characteristics of this device are shown in figure 18. Figure 19 shows the default interactive devices of both small and big dome respectively. Other interactive devices such as moving chair, room runner etc are also can be merged with the system easily and figure 20 shows few such examples

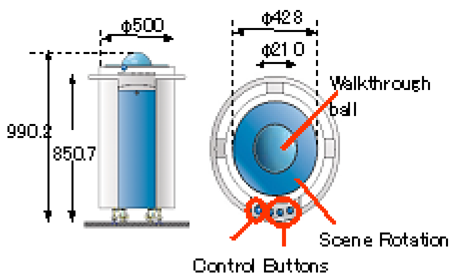

Fig. 18 Features of TrackBall

Fig. 19 Standard Interaction devices to use with CyberDomes: Trackball for Big Domes and joysticks for small domes.

Fig. 20 Images to show that many devices can be plugged with CyberDome view easily.

Dome software is designed such that many kinds of simulations can be easily merged in as plug ins. One of the main services with CybeDome has been Urban Design. Apart from visualizing standard 3D contents, developed software modules include interaction functions for urban design, lighting simulation, evacuation simulation, digital prototyping etc, making it possible for a user to have his required interactive data visualization in a short time. Some of the developed modules are shown in figure 21.

Fig. 21 Some of the developed add on plug ins for Dome System (Lighting simulation, Digital Prototyping, Evacuation Simulation, Age changing for barrier free design)

4. Conclusion

PC Clustered Projection based Immersive Display, CyberDome, has been introduced. Design considerations for the system to have convincing real scale visualization has been briefed. Developed systems include a compact design CyberDome1800 and the largest PC-Clustered Dome CyberDome8500. Using the developed distortion correction and smooth blending techniques CyberDomes with any arbitrary screen size can be developed and it is possible to have high resolution distortion free life size immersive visualization for many interactive real time applications.

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