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Short Papers

Elbe Dom: 360 Degree Full Immersive Laser Projection System

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Abstract

The immersive visualization of virtual interactive environments presents an immense challenge to current representation techniques, especially multi-user applications. This paper presents a new solution to meet the drastically increasing demand for greater degrees of realism and immersion in representation techniques: Full 360 degree continuous projection in the Elbe Dom. Moreover, this solution points toward other potentially widespread uses from multi-user and mixed reality applications through detailed user tracking. These applications are discussed and interaction paradigms are presented with initial examples of applications employing this new display system are presented.

Categories and Subject Descriptors (according to ACM CCS): H.5.1 [Information Interfaces and Presentation]: Multimedia Information Systems - Artificial, augmented and virtual reality; I.3.7 [Computer Graphics]: Three-Dimensional Graphics and Realism - Virtual Reality

1. Motivation

Immersive representation devices such as CAVEs, which primarily focus on single user applications, are subject to spatial limitations. Tremendous demand exists for representations of virtual contents in larger spaces. Fields for which virtual contents are of interest range from urban or architectural visualization to multidimensional data representation, e.g. hurricane visualization, through specific training simulations and far more. Design review of virtual models, especially in collaboration with clients, is predestined for immersive and realistic (virtual) environments and is becoming more important than ever. New approaches must be developed to increase the level of realism and obtain a greater degree of immersion. In particular, high contrast, depth sharpness and a color space more suitable for humans than the sRGB-color space can produce better visualizations and consequently added value for users. Such a technique could be offered to small and medium-sized enterprises as a service that would make immersive VR solution financially attractive to them.

2. Related Display System Techniques

A number of immersive representation devices exist. Bernd [Ber04] defines three basic categories of VR representation techniques based on their degrees of immersion. These are gone into in more detail below. This paper concentrates on the category of immersive VR, which completely integrates a user in a virtual environment, e.g. CAVE^{TM} [CNSD*92], [CNSD93] or head-mounted display [Sut68].

Referred to as semi-immersive devices, output devices such as the vision station [Liu01], stereoscopic wall screen, 3-D display [Fra], workbench [KF94], Reachin-Display (www.reachin.se), or the PI-casso-System [SHP04] are employed to fill most of a user's field of vision. Lately, these devices have become more interesting for companies as hardware costs decrease and the cost-value ratio increases.

The third category is desktop VR (DVR). Desktop VR presentations only cover a certain area of a user's field of vision less than 60 degrees. This variant is very cost effective since existing hardware components can be used. The degree of immersion is considerably limited though.

One project comparable to the Elbe Dom in terms of size and resolution is the HEyeWall [KS04], [KRK03] implemented by the Fraunhofer Institute for Computer Graphics IGD in Darmstadt. The HEyeWall has a resolution of 18 megapixels, a height of 2.5 meters and a width of 5 meters. 48 projectors and 48 PCs generate a seamlessly blended backprojected image. Figure 1 shows an example.

Figure 1: *Design review using the HEyeWall®(©IGD-Darmstadt)*

The i-Cone™(see [SG02]) is a 4 channel 240 degree display system with a resolution of 8000*x*1460 pixels. The screen is 2.80 m high and has a diameter of 6.60 m on the top (see Figure 2).

Figure 2: *Setup of the i-Cone™(©Fraunhofer IAIS)*

The PanoLab [MPI] is a wide-area cylindrical/spherical frontal projection system measuring 7 meters in diameter and 3.2 meters in height. With a resolution of approximately 3500x1800 pixels and a field of view of 230x125 degrees, it is based on a concept quite similar to the one presented here. Figure 3 shows the setup of the PanoLab.

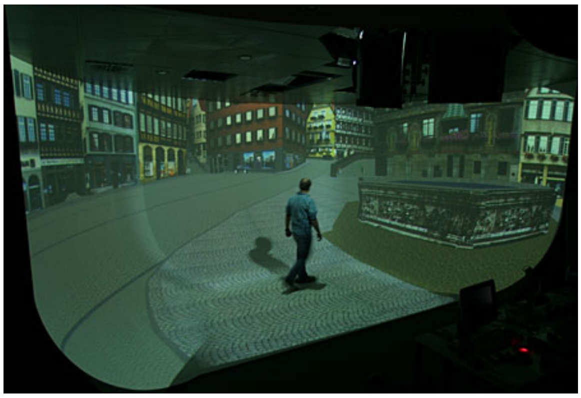

Figure 3: *Setup of the PanoLab (©MPI-Tübingen)*

A collaborative project between Carl Zeiss Jena GmbH and Jenoptik LDT GmbH, the All Dome Laser Image Projection system (ADLIP) with a surface area of more than 800 square meters was completed in 2006 for the planetarium in Jena. This was the second laser planetarium constructed after the one in Beijing in 2003 and has the same resolution of XGA (1024x768 pixel) and 6 channels too. Figure 4 shows the ADLIP in operation.

Figure 4: *ADLIP system in the Jena Planetarium (©Sternevent GmbH)*

A number of other projects such as the CyberDom [SHH*03] or La Cueva Grande with 43 megapixels [CHK*06] for example could be referred to but the scope of this paper precludes going into all of them in detail.

A number of different display technologies and techniques exist that are geared toward specific objectives (and represent special solutions in part). Their distinctive features are the coverage of the field of view and the relative resolution, contrast and multi-user capability (multi-user interac-

	Possible Field of view [*degree*]	Relative resolution [*percent*]	Contrast
6 sided cave in active stereo mode	+∞ / -∞ h +∞ / -∞ v	12.33 h 13.24 v	30000:1
Digital workbench "Baron"	+30 / -30 h +17 / -17 v	30.82 h 50.20 v	20000:1
Workplace system "PI-casso"	+22 / -22 h +16 / -16 v	36.47 h 36.72 v	800:1
24" LCD display	+20 / -20 h +13 / -13 v	75.47 h 75.42 v	3000:1
i-Cone display	+65 / -65 h +18 / -28 v	41.82 h 48.54 v	30000:1
HEyeWall	+59 / -59 h +27 / -49 v	53.62 h 53.62 v	800:1

Table 1: *Comparision of selected projection systems*

tion). Table 1 provides an overview of important design parameters for the aforementioned display technologies. The relative resolution is expressed in percent of the maximum resolution of the human eye and is more significant than the absolute resolution in pixels [Hof05].

3. The Elbe Dom

The increasing demand for interactive fully immersive virtual environments for more than only one active user was the impetus behind the development of the Elbe Dom. The Elbe Dom's physical dimensions and construction are crucial for a user's degree of immersion. The projection screen was specially made by Astrotec Inc. (www.astro-tec.com).

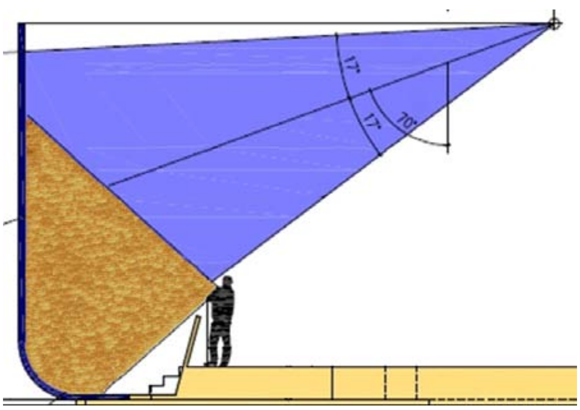

Figure 5: *Schematic overview of the Elbe Dom design*

It is a cylindrical perforated wall, 16 meters in diameter and 6.5 meters high. The entire screen is aluminum and spans a surface area of approximately 330 m^2. The screen is not a perfect cylinder however. The diameter of the lower portion of the screen is slightly constricted to create the illusion of ground projection since users look at the screen from a circular platform in the center of the setup (cf. Figure 5 and Figure 6). Since the laser beams are hazardous to eyes

Figure 6: *Aluminum screen wall Elbe Dom with entry*

and skin, standing in the projection area itself is prohibited. A PC cluster consisting of 7 high-end PCs is used for image generation. Each PC is responsible for generating the image for one projector. The seventh PC supplies the geometry and kinematics data for the other nodes and synchronizes them. The software running on each computer must support synchronization with the other nodes either by itself or by using suitable libraries, e.g. CAVELib (www.vrco.com). Other computers in the system preprocess the tracking data delivered by the tracking system or control the lasers and security systems.

The projection system consists of 6 G2 laser projectors developed and manufactured by Jenoptik LDT GmbH (www.jenoptik.de). Each laser projector has its own laser generator unit that generates one 55 W UV laser beam and converts it with complex optics into three laser beams of different wavelengths (red, green, blue) and intensities. The three base colors of red, green and blue have intensities of approximately 1.5, 1.5, 1.0 watts respectively. The maximum resolution of the projectors is $UXGA$ with $1600x1200$ pixels at a refresh rate of 60 Hz. Since their laser beams write an image line by line, a special feature of the laser projectors is their extremely high depth of sharpness. Thus, the projected image is always completely sharp regardless of the shape of the screen and the distance to it. This is a huge advantage of this setup since the distance between different points on the screen and the projector varies because of the special shape of the screen and the position of the projectors. Each projector handles approximately 68 degrees of the 360 degree projection. The overlapping sections of the images are used for soft edge blending. The rendered VR objects are subject to distortion generated by the construction of the cylindrical aluminum projection plane. 3 combiner boxes regulate the two processes of blending and distortion. Another advantage of this setup is its capability to blend additional information into the VR scenario by means of a "picture in picture" functionality. A netpix box distributes the incoming signals to the appropriate combiner box. The configuration from OpenWARP®(www.openwarp.com) is diagrammed in Figure 7.

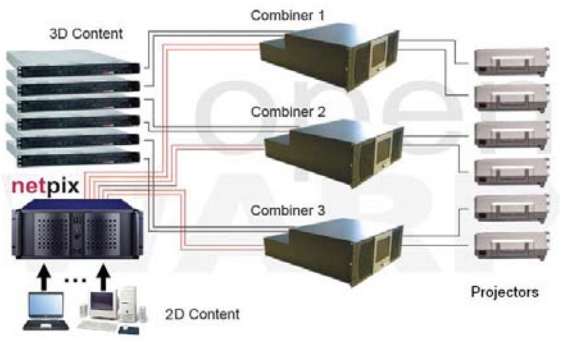

Figure 7: *Distortion correction for 2-D and 3-D contents (©Eyevis OpenWARP)*

Many tracking systems are available, e.g. magnetic tracking, gyroscopic tracking, ultrasonic tracking, and optical tracking (see [Hof05]). The tracking system used here is a commercial optical solution from Vicon Inc. (www.vicon.com). It was selected because of its extremely high accuracy and speed. This system also supports complex tracking procedures. The tracking system consists of twelve MX-13 IR cameras made by Vicon, each with a maximum frame rate of 484 Hz and resolution of 1.3 megapixels. The location and orientation of objects (users, controllers, etc.) can easily be determined in real time in the whole Elbe Dom with an accuracy of less than 1 mm. Full body motion of up to eight persons can be captured (with over 500 trackable markers) simultaneously.

At least two devices are needed to provide users a minimum of interaction with the virtual environment. The first is used to track a user's position and resembles a collar-like ring or a badge with three passive IR markers mounted on the front. Additionally, a control device is used to simulate a user's hand in virtual reality. This control device supports six degrees of freedom and is outfitted with a mini joystick and multiple buttons for advanced interaction. It also allows users to do things like press buttons on virtual machine controls, grasp and move objects or move through a virtual environment. Furthermore, a remote interface such as a PDA or tablet PC enables users to more generally modify a scene for specific applications. More information on input devices for VR environments is provided in [BKLP04].

Safety is another important aspect of such a construction. Special safety restrictions apply to the class 4 lasers. In the case of an emergency, the laser projection system must shut off automatically to protect users on the platform. The platform is surrounded by an active infrared LED band. If a user enters the off limits projection zone by leaning over the railing for example, at least one of the security band's LEDs, which are monitored by two redundant working cameras, will be partially or fully obstructed. The laser system responds directly by shutting down.

As a standard output device, the Elbe Dom must support different software applications. The Elbe Dom supports the IVS_VDT platform for virtual training [SMR06], the PTC DIVISION MockUp (www.ptc.com) to improve communication and collaboration in the design process by making realistic, interactive digital mock-ups available at an early stage and a cluster enabled version of Bitmanagement's VRML/X3D Viewer (www.bitmanagement.de). Moreover, various 2-D contents such as movies, 360 degree pictures or PowerPoint slides are also supported on multiple channels without synchronization. To this end, a special computer called Netpix maintains a Windows desktop about 10000 pixels in width, which is superimposed over the 3-D content.

4. Discussion and Results

Laser safety regulations limit interaction since users must remain in the safe area, which is quite far away from the projection surface. This slightly disturbs a user's sense of immersion. Additional floor projection could eliminate this minor drawback. Users have verified that the level of immersion is outstanding in part because of the realistic relation between virtual world and users themselves. In addition, the depth contrast of 50000:1 and a relative resolution of 42 percent horizontally and 43 percent vertically give users a quasi 3-D sensation. The 360 degree projection (+30 / -20 degrees vertical field of view) also enhances this impression because an entire scene completely surrounds users even when they randomly move their heads or bodies (as happens naturally).

Urban visualization of the Lutherstadt Eisleben, a UNESCO World Cultural Heritage site, presents different design concepts for the particular buildings, which can then be interactively discussed and reviewed (see Figure 8, top, with one alternative design, middle). Another application is the preflight check pilots must perform (see Figure 8 bottom). This training scenario instructs pilots how to perform a preflight check and can completed entirely in a virtual environment without a real plane.

5. Conclusion and Future Directions

The Elbe Dom is a novel 360 degree laser projection system. Its dimensions, resolution and color luminosity make it a unique construction. The advantage of this system is it supports collaborative interaction in a full immersive virtual environment with extremely high visual quality. The setup may be used for numerous applications. Real equipment such as a driver's cabin in combination with the MotionLab platform [vdH00], may also be integrated on the platform to increase the level of realism (mixed reality).

Raytracing rendering techniques will be used for realistic high definition VR environments. A cluster of 36 PCs, each with multiple quad-core processors, will do this in real time. To take full advantage of the features of laser projection, multiuser counteractions in collaborative working environments will be developed further. Finally, a variety of research is being done on real 3-D environments. For example, Benk's approach [Ben03] to stereo round view applications, which reduces computational costs and produces good results for static scenes, could be extended for dynamic scenes. A laser projector generates an image line by line in two half images produced by two integrated lasers. It is technically possible to produce a dynamic stereo picture with a resolution of 1600x600. The problem with passive anaglyphic stereo is the channel separation. In laser projection using standard color-anaglyphic stereo methods, one eye receives two of the three intensity (color) channels, which reinforces the impression of different levels of brightness.

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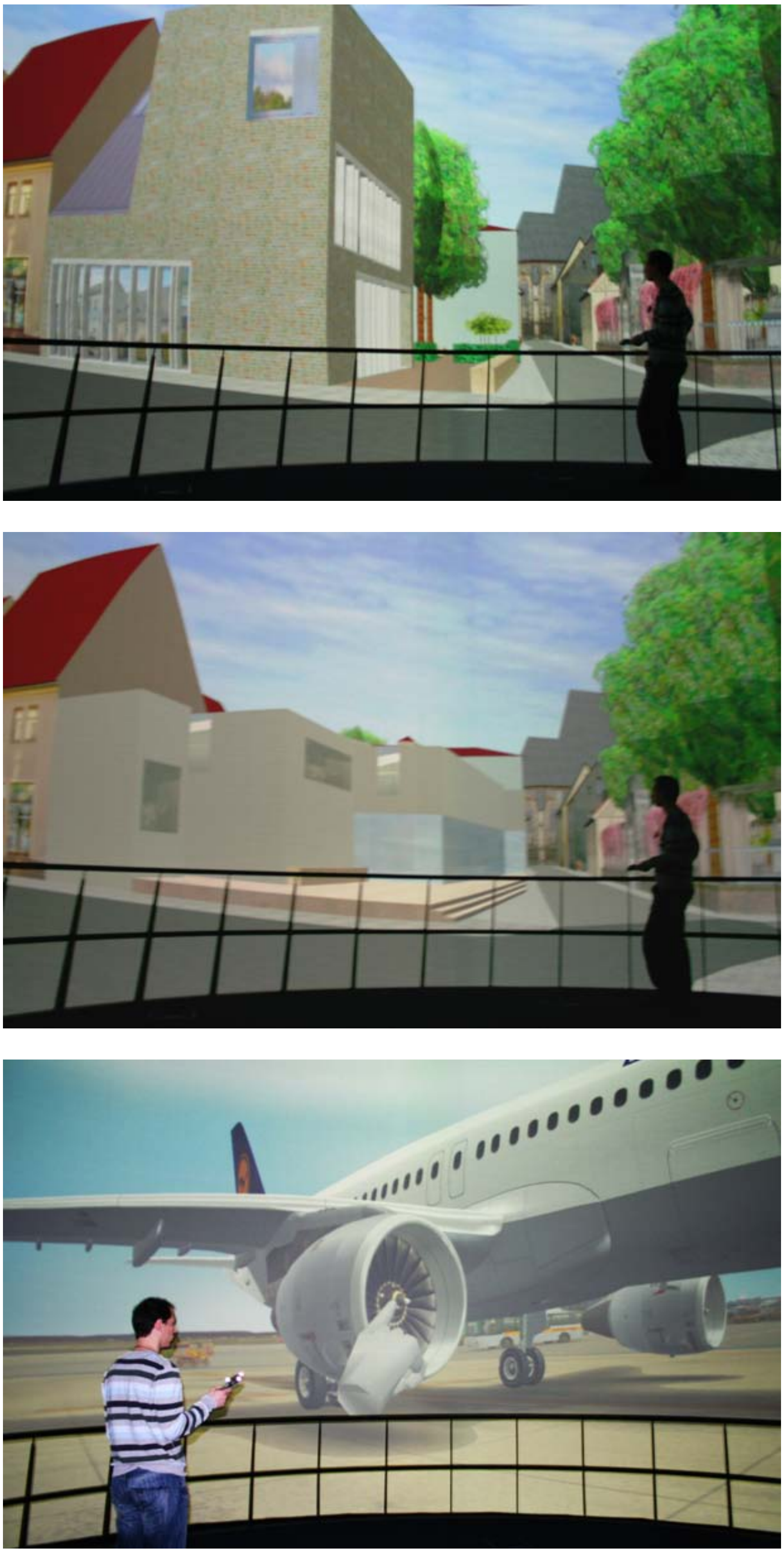

Figure 8: *Virtual interactive scenarios in the Elbe Dom: Urban visualization of Lutherstadt Eisleben (top and middle) and pilot flight training sequence (bottom)*