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IVY: Basic Design and Construction Details

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Abstract

Six-sided projective immersive displays present complex design and engineering constraints, especially if physical construction space is at a premium. Here we describe the physical construction of IVY (Immersive Visual environment at York), a six-sided projective immersive environment operating at York University, Toronto, Canada. IVY is a fully immersive (six-sided), projective, stereo visual environment that can be used for a range of tasks from space structure visualization to studying issues related to human perception in real and virtual environments.

Key words: Immersive displays

1. Introduction and Motivation

Projective Immersive Environments have become a popular technology for the display of large-field virtual environments. The gamut of devices runs the range from large single wall projections (e.g., the PowerWall at the University of Minnesota[1]), to three-wall (e.g., the Immersion Square at Fachhochschule Bonn-Rhein-Sieg [2]), four-wall (e.g., the original CAVE™[3]), five-wall (e.g., the CABIN at the University of Tokyo[4]), and more recently six-sided environments (e.g., the COSMOS – Cosmic Multimedia of Six Screens[5]) have begun to appear. Indeed, companies such as TAN Projektionstechnologie GmbH and FakeSpace™, have emerged who will construct Immersive Projective Displays essentially to one's specification. As the number of walls increase, the design constraints and complexities that face the designer also increase. In a restricted space there become fewer and fewer places to place projectors, screens, trackers, and other necessary technology associated with the device. Given the increased complexity, why would one want to build a six-sided projective immersive environment?

Each site has its own motivation for building more complex projective environments. At York University, the interest in building a six-sided projective environment has been driven by an interest in exploring human perception of self-orientation in real and virtual environments. It has been known for a number of years that our perception of the direction of gravity can be manipulated in a number of ways. At York University, A "Tumbling Room"[6] has been developed that has proven extremely effective at generating a perceived up direction that is not aligned with the true gravity vector (see Figure 1a).

Various experiments conducted within the room have demonstrated that subjects' perception of the direction of up can be manipulated through the presentation of an appropriately polarized visual display. Although the tumbling room is an effective tool for generating a perceived direction of up that does not agree with the normal gravity direction, it has a number of limitations. As the Tumbling Room is a real room, it takes large and powerful motors to rotate it. It is also very time consuming to change the internal visual texture of the room.

Given the complexities associated with the Tumbling Room, a "Tilted Room"[7] (see Figure 1b) has also been constructed. This again is a six-sided physical room that is used to influence the subject's perceived direction of gravity. Unlike the Tumbling Room, the Tilted Room is a static room, but it has been built rotated by ninety degrees. It too has been found to influence the perceived direction of up[7].

Although the Tilted Room is somewhat easier to use than is the Tumbling Room, it is still extremely time consuming to change the layout or texture of the room. In order to simplify the process of changing the structure of the room – and in particular the visual patterns (wallpaper) that can be displayed – we have embarked on the construction of a fully enclosed (e.g., 6-sided) immersive visual environment. This environment – known as IVY – is a virtual Tilted Room and is being used to examine fundamental issues related to human perception, and issues related to perception in virtual environments.

IVY is an enclosed cube 8' on a side. Each of the sides, including the ceiling and floor, are rear-projected surfaces

(a) Tumbling Room

(b) Tilted Room

Figure 1. The Tumbling and Tilted Room. (a) The Tumbling room is an 8' cube mounted on a horizontal axis. The room can be rotated about this axis under computer control. (b) The Tilted room is an 8' cube built rotated by 90 degrees. The left panel shows what the subject sees (the subject is actually lying right side down on the floor), the right panel shows the true situation.

capable of presenting stereo visual displays to the observer inside of the cube at 48hz. This paper summarizes the construction details of IVY, and describes in detail a number of the design and construction decision that were made during its construction.

2. A Short Survey of Six-Sided Projective Virtual Reality Environments

Before setting out to build a 6-sided projective virtual reality environment, it is worthwhile reviewing the handful of such environments that exist in the literature. Each of the existing 6-sided projective VR environments have been built for different functions, and have been built to be housed within different physical enclosures. These constraints have lead to a number of different designs and constructions.

2.1 COSMOS

COSMOS --- Cosmic Multimedia of Six Screens --- was perhaps the first 6-sided projective VR environment[5] (see also [8]). Built in 1998 at the VR Techno Centre, in Gifu, Japan, COSMOS was constructed in an extremely large space that provided considerable simplifications in terms of construction. The throw distance to the walls was sufficiently large that the wall surfaces could be projected directly, Given the tall height of the physical enclosure, ceiling and floor were projected via a single reflected mirror. No special treatment seems to have been used at the seams, and 6-10mm seams were introduced.

Each surface consisted of a $9m^2$ vinyl film, with the floor supported by a sandwich of three acrylic panels. Each projection surface was projected by two projectors in order to enhance the brightness of the display. Video was generated at 1024x768 at 96Hz, and stereo viewing was available through CrystalEyes LCD shutter glasses. Head tracking was performed via a Polhemus head tracker. Given the sensitivity of this tracker to the presence of metal, much of the construction was of wood. An SGI Onyx2 was used for video generation.

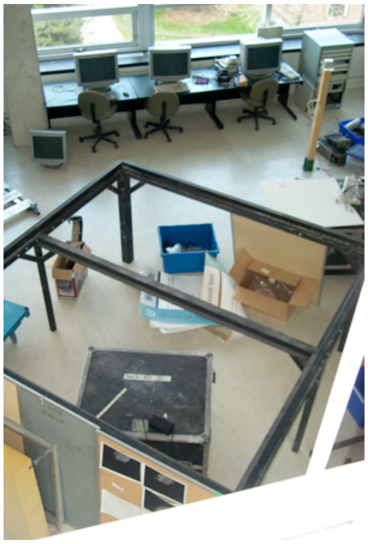

Figure 2. View of the floor support taken from the 2nd story of the VGR lab. A catwalk around the space provides access to the projectors and mirrors. Note that IVY's floor is located 4' above the physical floor of the lab.

2.2 PDC VR-CUBE

At almost the same time as COSMOS was being built in Japan, the VR-CUBE was constructed at the Centre for Parallel Computers at the Royal Institute of Technology in Stockholm[9]. The VR-CUBE was built by TAN Projektionstechnolgie and is 3m (w) x 3m (d) x 2.25m (h).

Fabric projection surfaces were used, with a 40mm acrylic glass surface used to provide structural support on the floor. The fabric projection surface was stretched above this glass surface. As with COSMOS, the PDC VR-CUBE was also built in an extremely large physical space, and this provides a number of simplifications in terms of construction and video projection. A large wooden structure provides physical support for the screens and mirrors. Most surfaces are projected via mirrors in order to reduce the total physical volume of the device. The wooden structure permits the use of standard magnetic tracker technology for head tracking.

The floor and ceiling were configured to run with a resolution of 1024 x 1024 pixels at a frequency of 96Hz (i.e. 48Hz per eye, due to stereo projection). The walls run at 1024 x 852 to keep the pixels square and to keep the resolution constant along the edges. An SGI Onyx2 is used to generate content and Barco projectors with CrytstalEyes glasses complete the video generation process. The door to the VR-CUBE is hinged, unlike the COSMOS in which the door slides into place.

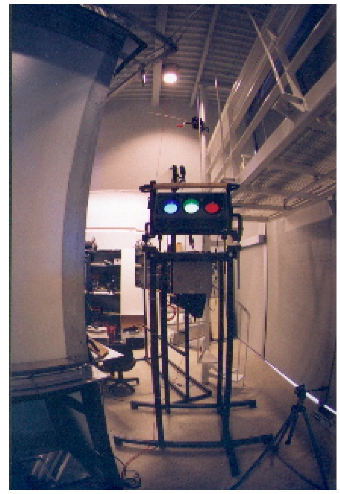

Figure 3. Projector stand

2.3 ALICE

Alice is a VR cube being constructed at the Beckman's Integrated Systems Laboratory, University of Illinois at Urbana Champaign[10]. As with the VR-CUBE, ALICE is being built by TAN Projektionstechnolgie. To reduce the total physical footprint, all surfaces are displayed via a single bounce mirror with one projector per wall.

Physical construction of ALICE is of non-metal materials, permitting the use of standard magnetic trackers within the virtual environment. Perhaps the most unique feature of ALICE is the use of solid, rather than fabric walls, as a display surface. Although this introduces seam complexity, it does reduce issues related to fabric sag. A sliding, as opposed to hinged door is being used.

2.4 HyPI-6

Fraunhofer Institute for Industrial Engineering IAO HyPI-6 was the first 6-walled projective environment to work with standard PC's[11,12]. Completed in May 2001, HyPI-6 operates in one of two modes. Using 12 Barco 909 projectors, and driven by 12 PC's, a passive stereo system using polarization filters is used. An active stereo system driven by an SGI Onyx2 is also available. The environment is 29m (w) x 2.9m (d) x 2.7m (h).

Fabric screens are used for projection surfaces. Mirrors are used for each surface in order to reduce the total physical footprint of the device.

2.5 C6

The C6 at Iowa State University's Virtual Reality Applications Center became operational in 2000. The C6 relies on Barco 909 projectors at 1024x1024 and 96hz. Ascension Technology's wireless Motionstar system is used for headtracking. Floor and ceiling surfaces are displayed using single bounce mirrors while the walls are direct projections.

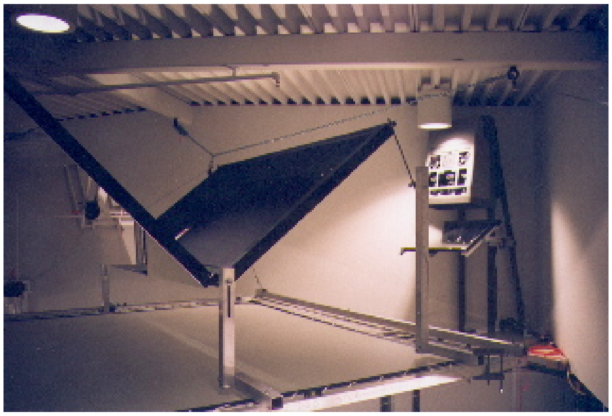 

Figure 4. Details of the ceiling (left) and floor (right). The ceiling is suspended from the ceiling of the laboratory on cables that permits the ceiling to be raised slightly above the walls to provide better air flow, and lowered (when the walls are removed) to permit servicing. The mirrors are mounted on adjustable rods to permit adjustment of the projection angle. The floor mirror is mounted to the floor support. You can see the projector reflected in the floor mirror. On the right hand side of the ceiling mirror you can see the vertically placed projector.

2.6 VR-CAVE
The VR-CAVE at the VR-CENTER NORD at Aalborg University is a six-sided cube measuring 2.5m x 2.5m x 2.5m. Electro-magnetic tracking is used to maintain the user's viewpoint, and video is generated using an SGI Onyx2. The VR-CAVE was built to study the interplay between a user and their 3D environment.

2.7 Summary
There are now about half a dozen six-sided projective immersive environments worldwide. Each of these devices have been built with differing goals and within radically different physical enclosures. However, a number of common construction and design problems have emerged that are more or less unique for six-sided environments.

- **Getting the video to the wall.** For fewer than six-sided projective environments, there is at least one open wall, and corresponding physical space within which the projectors, mirrors, trackers, etc., can be placed. For six-sided environments within restrictive physical environments, actually getting the video to the projective walls is a complex design issue.

- **Wall, and especially floor construction.** For projective immersive environments, there are a number of different competing constraints. The projection surface should maintain the polarization of light (if polarization is to be used to generate stereo cues), the surface should be isotropic, should not reflect other surfaces, and should not attenuate the video signal any more than is absolutely necessary. Walls and ceiling are not necessarily load bearing, although the floor must be.

- **The entrance**. Projective immersive environments with fewer than four walls can be entered by just walking through the missing wall. Once this fourth wall is added, it becomes necessary to consider how to open and close this wall in a controlled manner to permit entrance and exit, while at the same time ensuring that when the wall is closed, the entire device does not have to be recalibrated.

- **Tracking**. The relatively large size of most six-sided projective immersion environments presents difficulties for many tracking technologies. As the entire environment is enclosed, trackers that require either transmitters or base stations must have the base unit brought into the environment – which may interfere with other uses of the environment – or it must be placed close to the edge of the environment in such a manner as to not block the required light paths to the projection surfaces.

3. IVY Design and Construction Details
IVY is situated within the two-story Vision, Graphics and Robotics Laboratory at York University, Canada. Total effective ceiling height is approximately 16'. With the goal being the construction of an 8'x8'x8' cube, this leaves approximately 4' above and below IVY for the projection of the video for the floor and ceiling. Given the limited horizontal physical space for IVY, each of the four walls must be projected using mirrors to bend the light path within the available footprint within the VGR. Figure 2 shows the empty lab (with just the framework for the floor in place).

IVY's floor is located four feet above the ground. This means that the mirrors, projectors, and wall surfaces must be positioned well above the ground. Ideally this means

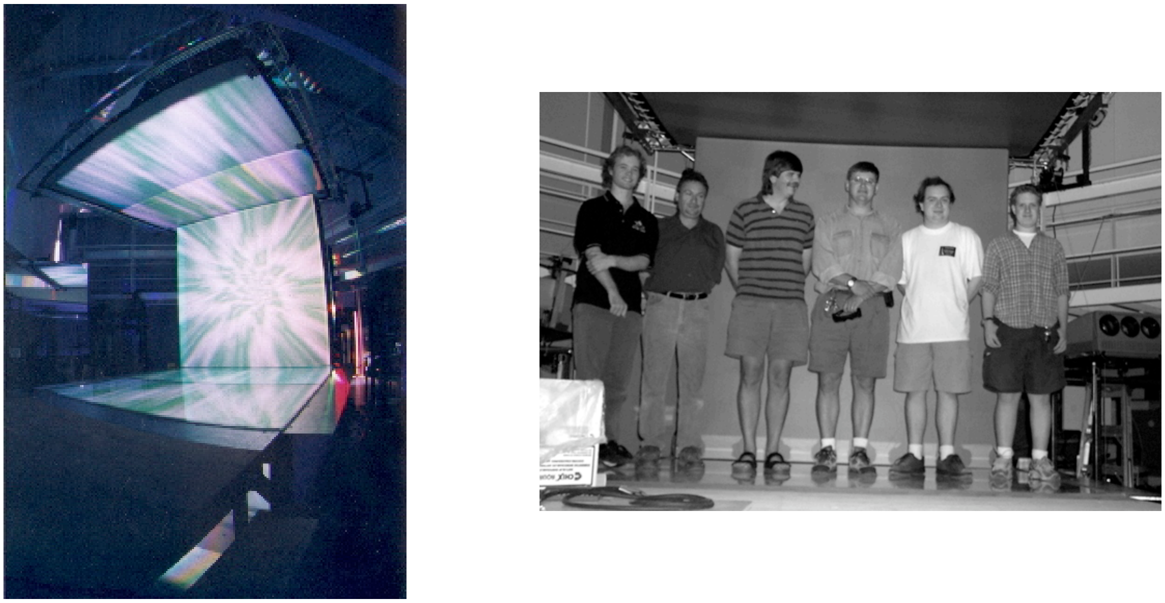

Figure 5. IVY is shown in action (left) with the floor, ceiling and one wall in place. The right panel shows the Implementers(from left to right, Andrew Hogue, Jeff Laurence, Michael Jenkin, Jim Zacher, Matt Robinson, Andrew German) standing in the partially completed IVY.

that the projectors are mounted approximately 8' above the surface of the floor of the lab (in line with the centre of the wall surfaces) with mirrors mounted in a similar fashion. In order to simplify construction, we mounted our wall projectors on separate "projector mounts" that locate the projectors 8' in the air (see Figure 3). Each projector is mounted on an adjustable table that permits fine adjustment of the projection orientation of the projector. Three of the four walls require mirrors to extend the path length to the walls. Featherlight front surface mirrors were mounted with centres 8' above the floor. Each mirror has three mounting points to permit fine adjustment of the mirror – and hence the light beam – with respect to the projector stand and the projection surface.

Fabric rear-projection screens are hung in frames attached to IVY's floor outside of the projective environment. The same material is used for the floor and ceiling, although different techniques are required in order to deal with the need for physical support (floor) and for the limited spacing above the ceiling and below the floor.

Figure 4 provides details of the ceiling and floor. Given the limited vertical space between the floor of the lab and IVY's floor, and between the ceiling of the lab and IVY's ceiling, the floor and ceiling are projected by two separate projectors, each responsible for displaying one half of the surface. Mirrors direct the video onto the appropriate half of the display. The projectors for the floor halves are mounted on the physical floor of the lab. The projectors for the ceiling are much more complex. One is located on a catwalk 12' above the floor. The second is mounted vertically, and a second mirror is used to direct the video towards one of the ceiling mirrors. This use of two video signals for each of the floor and ceiling results in a total of eight video signals to project the six sided of IVY.

The floor is a sandwich of a thick (4") glass panel which provides physical support so that users can walk within IVY, a fabric projection screen, and a thin glass layer on the top to protect the projection screen. The floor is held within a steel support cradle that also provides support for the walls.

Entry and exit to IVY is via one of the walls that can be slid back away from the interior of the cube. With this wall slid back, people and equipment can enter and exit IVY. With this wall in place, a user within IVY cannot distinguish between the opening/closing wall and the other three fixed walls.

Due to the high bandwidth of the video display (96hz video at 1024x768) and the physical separation between the video generation computer --- an SGI Onyx2 --- it is necessary to convert the eight video signals from the SGI to a digital signal that runs over on optical fibre cable and then reconstitute the video signal at the projection site. This physical separation has implications for input devices, and an input device server has been built to allow standard input devices to be used with IVY.

Stereo imagery is presented on IVY's six walls and decoding using CrystalEyes glasses. Long range emitters

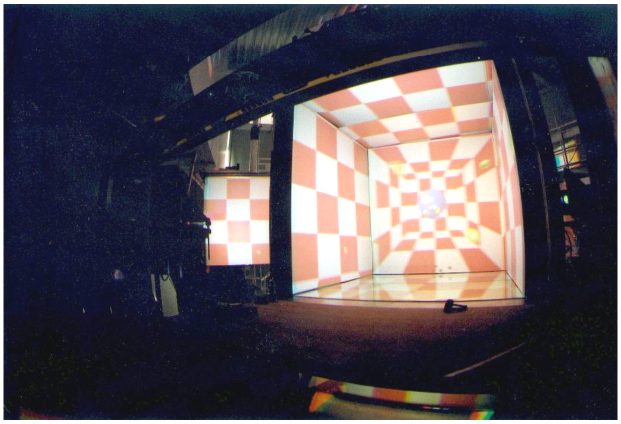

Figure 6: IVY with 3 walls and floor and ceiling in place. The reflection from one of the mirrors is also visible.

have been found to be sufficiently powerful to be detectable through the walls, floor and ceiling

Tracking within IVY is accomplished via a novel hybrid tracking system (see [14]). This system integrates an inertial tracker worn by the user, with a laser/vision system that corrects drift in the inertial tracking system. Communication between the worn inertial system and the laser/vision system is accomplished via a wireless 802.11 network connection. Thus the user within IVY is completely untethered.

Applications for IVY can be written in any graphical software package that runs on the SGI. In order to simplify software development a package has been built which abstracts the various display and input technologies required by applications that wish to make full use of the tracking and display systems. This package, known as VE, is described in [14].

Figure 5(left) shows IVY in action, with video projected on the floor, ceiling and one of the walls. The left and right walls are generally not removed and are now permanently in place. The far wall (upon which video is being projected in Figure 5) is also a permanent wall. The near wall (not shown) can be slid in and out to provide entry and exit to IVY. Figure 5(right) shows the Implementors standing on IVY's floor (and hence demonstrating that it can take significant static load). Figure 6 shows IVY with the back wall removed.

4. Summary

IVY is an immersive visual environment currently under construction at York University, Canada. IVY is a 6-sided cube in which all of the walls of the cube are rear-projected video surfaces, including the ceiling and floor. IVY became operational in August 2002.

IVY is being constructed to be a virtual Tumbling or Tilted Room. As such it will be used to enable researchers at York to investigate the factors that influence the perceived direction of gravity.

Completely surrounding the user with visual displays, requires a tracking technology which does not interfere with the user within the environment and which does not require a physical tether of any form between the user and the hardware. IVY utilizes a wireless inertial tracker coupled with a video-based tracker to accomplish this.

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