

Enclosed Five-Wall Immersive Cabin

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Abstract. We present a novel custom-built 3D immersive environment, called the Immersive Cabin (IC). The IC is fully enclosed with an automatic door on the rear screen, and thus very different from existing CAVE environments. Our IC, the construction of the projection screens and stereo projectors as well as the calibration procedure are explained in details. The projectors are driven by our Visual Computing cluster for computation and rendering. Three applications that have been developed on the IC are described, 3D virtual colonoscopy, dispersion simulation for urban security, and 3D imagery and artistic creations.

1 Introduction

Visual immersive exploration can be an immensely valuable tool in enhancing the comprehensibility of raw and derived data in a diverse set of applications, such as battle-field simulation, health care, engineering design, and scientific discovery. It exploits the brain's remarkable abilities to detect patterns and features in 3D visuals and draw inferences from these. As a result, human interaction with 3D visual support is central to the analysis and understanding of complex data, and this requirement is only escalated by the current trend toward increasingly large datasets and complexities.

In light of this fact, there is an urgent need for visualization technologies more powerful than those in existence today, and this was also pointed out in a seminal report entitled "Data and Visualization Corridors", cosponsored by DOE and NSF [1]. In their executive summary, they state "There is a real need for design of effective human interfaces for 3D immersive environments, where conventional keyboards and mice are ineffective". In response to this challenge, we established a novel 3D immersive environment, called the Immersive Cabin (IC) inspired by the Fakespace Immersive Workbench with Crystal River Engineering 3D sound with SensAble Technologies haptic Phantoms and a pair of PINCH Gloves as input devices, and three Ascension trackers [2]. It embraces a visualization paradigm known as 'Spatially Augmented Reality' (SAR), in which any object in the physical environment can double as a passive display surface. The user is free to roam around in this environment and interact with these physical objects in a multitude of ways. We strongly believe that the concepts implemented in our IC will set new trends and will create new opportunities for a wide range of domain applications for which the growth of current visualization technologies has started to level off. However, at the same time, it will also put in place a new platform and visual interface for education, training, simulation, engineering, industrial and architectural design, homeland security, and the arts.

2 Equipment and Construction

The IC is an active stereo projection system that consists of three groups of components: projection screens and projection floor; active stereo projector pairs; and computers to drive the projectors. It is a fully enclosed system with a 29" wide door on the rear projection screen. The door is operated by an Otodor automatic door opener from Skylink, Inc. Augmented reality capabilities inside the IC are implemented through the use of a foldable wood table with projection table top.

2.1 Projection Screens and Projection Floor

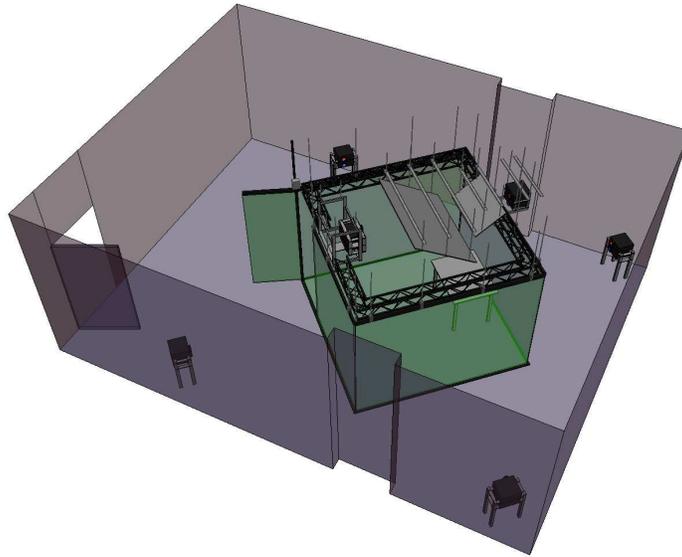


Fig. 1. Computer model of the IC with the rear door open

To optimally utilize the available 21×28 ft lab space, we placed the IC diagonally in a 21×21 ft region of the lab with the four projector pairs in the four corners (see Fig. 1). To preserve the native 4:3 aspect ratio of the Hitachi CP-SX1350 SXGA+ (1400×1050) multimedia projectors, the maximum size of the front, right, left, and back projection screen is 9.67×7.25 ft when wide angle lenses (0.8:1) are used with the four projector pairs. Therefore, the floor projection area is 9.67×9.67 ft, and Zoom lenses (1.1-1.5:1) are used with the floor projector pairs. The height of the four projection screens is lower than 3 meter walls of many existing CAVE system. However, due to the relatively small size of the IC and the pure black background, users have not complained or looked over the screens. The distance from the lens of a wall projector to its corresponding projection screen is 7.72 ft. The mirror for floor projection is 55×45 " and is hung 8.67 ft above the ground. The floor projector is placed 2 ft away from the mirror.

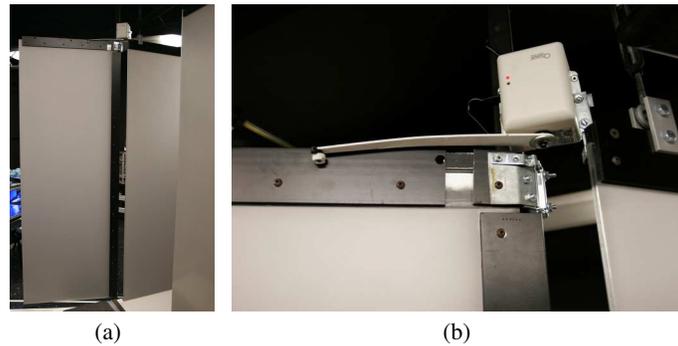


Fig. 2. (a) Rear projection door shown in open position, and (b) Otodor automatic door opener

The TekPlex 100 acrylic rear projection screen from Stewart Filmscreen Corporation is used to construct the front, right, left, and back projection walls. A major difference between our IC and existing CAVE systems is that the IC is entirely enclosed by the four projection screens. To allow accessing, one of the projection screen has an automatic door (see in Fig. 2). The door is made of the same acrylic material and its frame has a vertical rotating spindle. The spindle is carefully installed several inches away from the corner so that the automatic door does not rotate around the corner. Therefore, the distance between the door and the two neighboring walls is minimal when the door is closed. Fig. 3 shows the projection screen with the door closed and open. The four vertical screens are suspended from the ceiling onto a wooden front projection platform to form the IC, (see Fig. 4). To suspend and stabilize the four vertical projection screens, steel bars are cut and mounted to the concrete ceiling so that 15 screen hanging cables and aluminum trusses could be mounted. The aluminum trusses are used to mount cameras, lights, trackers, and speakers. Then the floor in the center of an area sized 21×21 ft is leveled with epoxy flooring, a wooden front projection platform is installed, and front, right, and left projection screens are attached to the hanging cables.

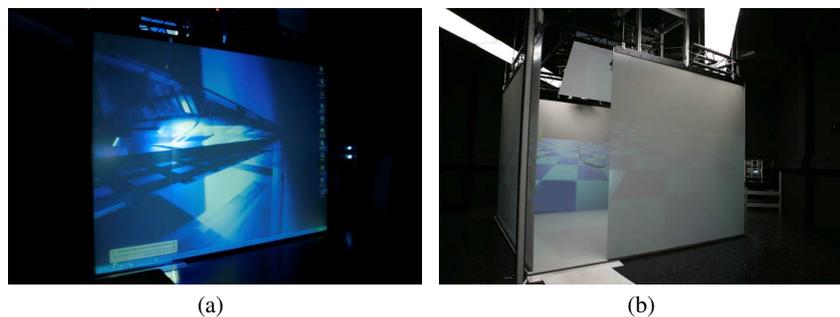


Fig. 3. (a) The door of the rear screen in closed position, and (b) the door shown in open position



Fig. 4. (a) Screen hanging cables, aluminum trusses mounted to the ceiling, and (b) aluminum trusses painted in black to minimize light reflection and the floor projection mirror

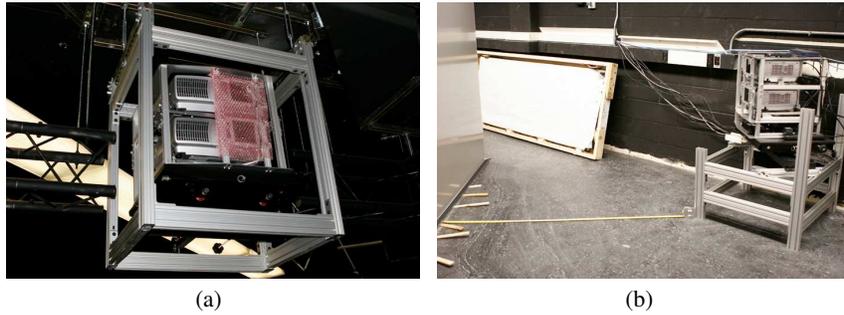


Fig. 5. (a) Floor Beacon system, and (b) a rear Beacon system on the ground

2.2 Active Stereo Projector Pairs

Five SX+ Beacon Active Stereo Synchronization systems from Fakespace are used to project images onto the walls and the floor. Each Beacon system contains one pair of Hitachi CP-SX1350 SXGA+ projectors installed on Fakespace 5 DOF projection alignment platform, Stereographics EXXR IR Emitter, and a control system from Crestron Electronics, Inc. Fig. 5 shows the floor beacon system and a rear beacon system for a wall. Stereographics Crystal Eyes 3 LCD stereo glasses and NuVision 60GX LCD stereo glasses are used with the Beacon systems to provide stereo.

2.3 Computers to Drive the Projector Pairs

The five Beacon Systems are driven by 10 display nodes from our Visual Computing cluster (see Fig. 6), which contains 66 high-end Linux/Windows dual boot workstations, a gigabit Ethernet frontend network, and each computing/display node is connected to

an InfiniBand network. Each projector is connected to the DVI port of a display node via Gefen HDTV DVI-D fiber optic cable.

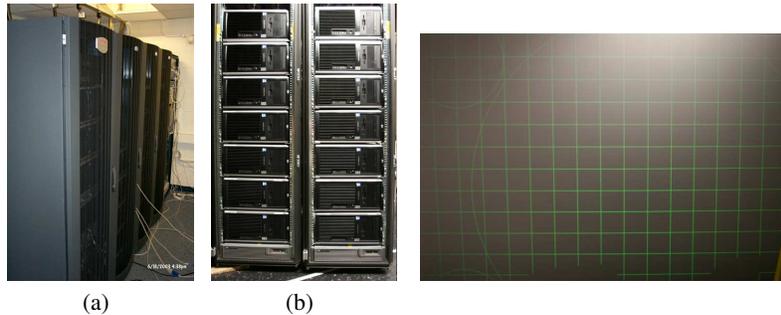


Fig. 6. (a) Our Visual Computing Cluster, and (b) display nodes of our Visual Computing Cluster to drive the IC

Fig. 7. The calibration pattern

Each of the first 34 nodes of our Visual Computing Cluster contains dual-Intel Xeon CPUs, 2.5GB memory, 160GB hard disk, nVidia Geforce FX5800 Ultra graphics, an onboard Intel gigabit network interface card, a Terarecon VolumePro 1000 volume rendering board with 1GB memory, and an InfiniBand network card. Each of the other 32 nodes contains dual-Intel Xeon CPUs, 2GB memory, 160GB hard disk, nVidia Quadro FX4400 graphics, and gigabit and InfiniBand network cards.

2.4 Integration and Calibration

To install and integrate the projection screens and projection floor portion of our IC, we pursued the following workflow: install mounts to the concrete ceiling; install and paint aluminum trusses; install floor projection enclosure; install screen hanging cables; level floor projection area; install wooden floor projection platform; install front, right, and left projection screens; install floor Beacon system onto floor projection enclosure; install fixed portion of rear projection screen; and install and align the rear screen door and wireless door opener. To set up the Beacon systems, we first installed the floor Beacon system onto a floor projection enclosure; set up front, right, left, and rear Beacon systems onto the projection stands and finally connected each projector to its driving computer using the Gefen HDTV DVI-D fiber optic cable.

Fig. 7 shows the pattern used to calibrate the projectors. We have manually adjusted projector settings including keystone, focus, zoom, brightness and position (minor lens position) until: (1) lines in the pattern images are straight, evenly distributed, and either parallel or perpendicular; (2) pattern images of each projector pair are aligned; (3) pattern images of any two neighboring screens are aligned and continuous; and (4) the brightness of five projection screens is uniform.

A foldable table is installed inside the IC to facilitate additional display and user interaction, specifically with haptic devices, as shown in Fig. 8.

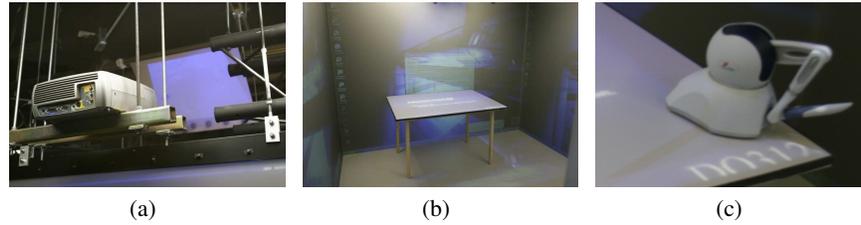


Fig. 8. (a) Projector for the table, (b) folding wood table; and (c) haptic device on the table

3 Applications

3.1 3D Virtual Colonoscopy

The 3D Virtual Colonoscopy (VC) is a non-invasive computerized medical procedure for examining the entire colon to detect polyps, the precursor of colon cancer [3, 4]. While the patient is holding his or her breath, a helical CT scan of the patient's abdomen is taken, capturing a sequence of 2D slices which covers the entire range of the colon. This scan takes 30-45 seconds and produces many hundred transaxial slices of 512×512 pixels, which are subsequently reconstructed into a 3D volume of 100-250 MB. Then, the colonic surface is extracted, and the physician virtually navigates inside the colon to examine the surface for polyps.

Interactive 3D virtual colonoscopy is comprised of two primary components: camera control and interactive rendering. Camera control essentially defines how the physician navigates inside the colon. A desirable camera control should enable the physician to examine the surface easily and intuitively, and prevent the camera from penetrating through the colon wall. In our system, the centerline of the colon lumen is defined as the default camera path. During the navigation, the colon interior is displayed using volume rendering methods. Volume rendering provides more accurate mucosa display and other rendering effects such as using translucent transfer function for electronic biopsy images. One important requirement in VC is that the physician must inspect the entire colon surface during navigation. However, due to the bends and haustral folds on the colon surface, the physician needs to navigate from the rectum to the cecum, and then in the reverse direction for full coverage. VC typically uses a perspective projection with 89 degree field of view. It only covers about 77% of colon surface area in retrograde direction [5]. In comparison, our IC provides a 360 degree panoramic view inside the colon that substantially improves the colon surface coverage and investigation performance. The physician may use the five walls, especially the rear screen, to inspect the entire colon surface in a single navigation pass.

3.2 Dispersion Simulation for Urban Security

Efficient response to airborne hazardous releases in urban environments requires the availability of the dispersion distribution in real time. We have developed such a system for simulation and visualization of dispersed contaminants in dense urban environments on the IC. Our simulations are based on a computational fluid dynamics model,

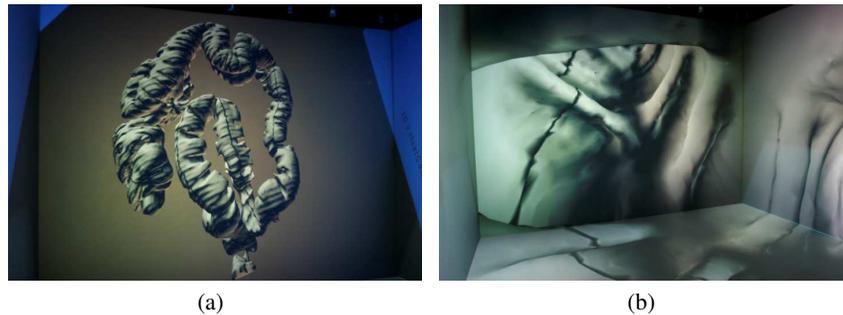


Fig. 9. (a) 3D colon model displayed in the IC, (b) navigation inside a colon in the IC

the Lattice Boltzmann Method (LBM) [6]. The LBM simulates the fluid dynamics by microscopic collisions and propagations of fluid particle distributions on a discrete set of lattice nodes and links. These local distributions model the global behavior of the fluid and solve the Navier-Stokes equations in the incompressible limit. Lattice-based simulations have recently emerged as efficient and easy way to implement an alternative to simulations using finite elements. One advantage is the simple handling of boundary conditions for complex and dynamic objects inside the flow field. Also, the highly local computations allow for efficient implementations on parallel architectures. These advantages position the LBM as the ideal method for simulating dispersion in dense urban environments and accelerating the computations on the GPU to achieve high simulation performance and interactive visualization of the evolving system.

In practice, the simulation domains needed for open urban environments are too large for the local memory of a single GPU. In addition, rendering to the walls of our IC at interactive rates can be a challenge for even the fastest GPU, especially when advanced smoke rendering techniques are employed. Therefore, we have implemented our LBM simulation and visualization using 16 nodes of the Visual Computing GPU cluster. The algorithm for partitioning and distributing the simulation data is based on the work of Fan et al. [7]. Visualization is also performed on the cluster nodes since the simulation results already reside on the local GPU memory. We render the density volumes using volumetric ray tracing with single scattering and composite the resulting images from each node. The final image is overlaid on a mesh-based rendering of the urban environment. Buildings in this rendering pass are textured with memory-efficient synthetic facades that exhibit high level of perceived detail.

We demonstrate our simulation and visualization system with the Times Square area data-set which covers New York City from 8th Avenue to Park Avenue and from 42nd Street to 60th Street. This region is approximately 1.46×1.19 km and contains 75 blocks and more than 900 buildings. Fig. 10 shows the rendering of smoke at different states of the simulation. By effectively utilizing the computational power of our GPU cluster, our system can achieve highly interactive framerates, as well as 360 degree immersive visualization of complex dynamic flow in a dense urban setting.

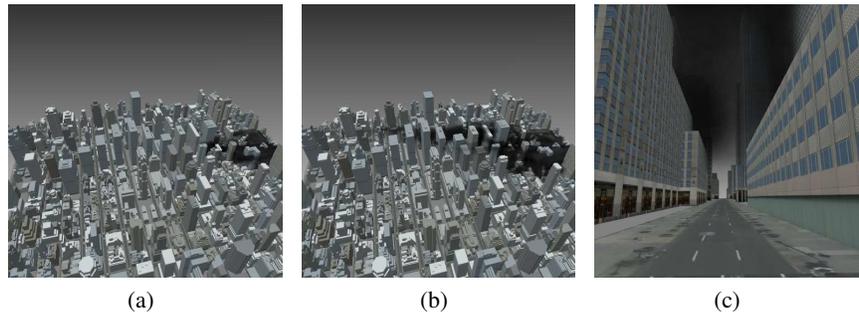


Fig. 10. Smoke dispersion simulated in the Times Square Area of New York City, (a) and (b) bird-eye views, the wind is blowing from the right to the left, (c) a snapshot during navigation.

3.3 3D Imagery Research and Artistic Creations

The IC is further used to explore scientific research on 3D image generation and artistic expression in virtual space. However, our effort not only assists academic efforts and communication in scientific research but also in other areas, especially the humanities. We designed the stereo image gallery as an expandable forest, divided into sections according to the contents and the archival time of the virtual specimen. The gallery navigation is conceived to follow a 3D map of a virtual landscape, and a 4th dimension "timeline" is in sync with the "growth" of the gallery forest.

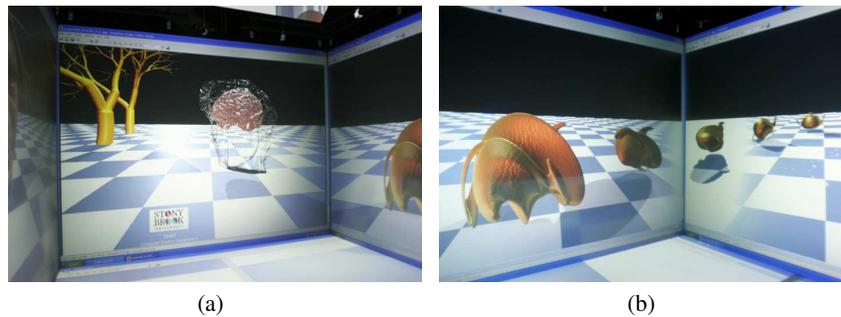


Fig. 11. (a) Conformal brain mapping, and (b) deformation of a teapot

The first stage of the development has included 3D image representations of conformal brain mapping. A human brain cortex surface features complicated geometries. In order to register and compare different brain cortex surfaces, we have developed a novel conformal brain mapping method. Following principles from differential geometry theory, brain cortex surfaces can be mapped to the unit sphere preserving all angles. Such kind of angle-preserving (conformal) maps form a six dimensional Mobius transformation group. By mapping the brain to the canonical sphere, different brains can

be registered and compared directly. We use the method proposed by Gu et al. [8], which is sufficiently general for registering other deformable shapes, and fuse medical imaging data sets with different modalities. Shape registrations and comparison can be directly visualized, evaluated and adjusted in the IC, and the manipulation is intuitive and efficient.

Stereoscopic photography has been utilized to document the architecture of our campus buildings as well as its permanent art display. The IC is also an ideal media to plan and showcase the future developments of our campus. The high-tech center of Excellence in Wireless and Information Technology (CEWIT) building is the first building being built in our new R&D campus. The IC is being used as the perfect media to display 3D models and animations of this new building to visualize and facilitate the planning of the building architecture, interior design, as well as the purchasing and installation of scientific research facilities. The immersive IC has been indispensable in visualizing and planning the extremely complicated special relationship and electromagnetic and optical influences between various devices for wireless and electromagnetic technologies.



Fig. 12. (a) User manipulation of virtual images through a wireless tablet PC, and (b) virtual representation of chariots displayed on our campus

4 Future Work

The calibration procedure described in Sec. 2.4 currently relies on manual adjustments to projection parameters with the help of a set of test patterns. We are developing a system for automatic calibration using high resolution static cameras which will greatly simplify the tasks of color and brightness matching and geometry correction. On the hardware side, we are also extending our IC with a wireless tracking system, surround sound, cameras and lighting systems. With these additions, automatic calibration would become even more important.

One of the challenges in programming an immersive visualization system such as our IC is that existing tools and applications may require significant code base changes. We are currently investigating the use of a unified rendering pipeline based on a scene

graph model, which will ease the development of our urban modeling and simulation projects. The visualization aspect can be handled by this framework, while the developers remain oblivious to the underlying hardware architecture of the immersive visualization system. We are currently developing a pipeline based on the OpenSceneGraph library [9] with COLLADA files [10] as the main format for asset management and interfaces for advanced shading and cluster based simulations and rendering.

As we continue developing both the hardware and software aspects of our IC, it is important to also study the usability of our applications. In particular, the 3D virtual colonoscopy application described in Sec. 3.1 is of interest to the medical community and usability studies of the IC implementation will allow for further refinement of our techniques.

Acknowledgements

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