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AVIE: A Versatile Multi-User Stereo 360° Interactive VR Theatre

Advanced Visualization and Interaction Environment (AVIE)

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Abstract

The iCinema Centre for Interactive Cinema Research at UNSW has created a versatile virtual reality theatre that, by combining real-time 360-degree omnistereo projection with surround audio and marker-less motion tracking, provides a highly immersive and interactive environment for up to 20 users. The theatre, codenamed AVIE, serves as the Centre's principal platform for experiments in interactive and emergent narrative, artificial intelligence, human-computer interfaces, virtual heritage, panoramic video and real-time computer graphics, as well as our primary platform for public exhibition of iCinema projects.

This paper briefly discusses the design of the system, technical challenges, novel features and current and future applications of the system. We believe our system to be the first and only 360 degree cylindrical stereo virtual reality theatre constructed to date.

Keywords: virtual reality, omnistereo, stereo projection, interactive narrative, vision-based body tracking,

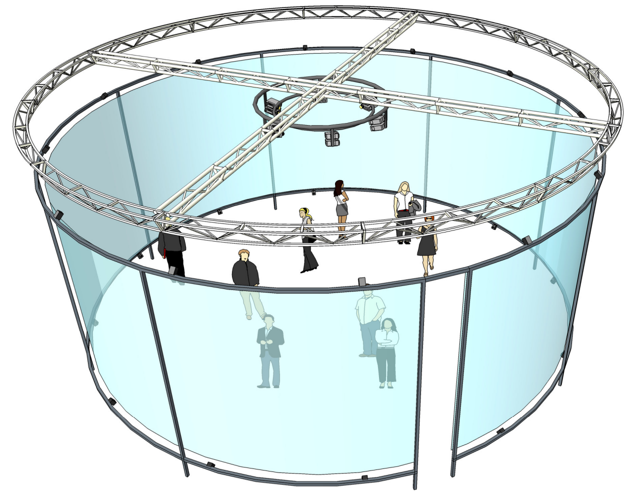
1. Introduction

The iCinema Centre for Interactive Cinema Research is principally concerned with the development of interactive immersive narrative experiences. In 2004, work was begun on a virtual reality theatre that would allow us to perform practical experiments with multi-user interactive immersive narrative systems, and which had the following features: high level of immersion; up to 20 simultaneous users; non-invasive multi-user interface (users may walk in and out of the space without interrupting the experience); an interface that encourages (and space enough to accommodate) physical activity and group interaction; fit in existing laboratory (12m x 12m x 5m); low cost; portable and, finally, easy to create or import new interactive content.

2. System Design

In order to provide a sense of immersion for a large number of users, a cylindrical screen design was adopted as it lends itself readily to the projection of omnistereo images. Omnistereo is described in more detail below. The concept of a cylindrical screen also builds on previous iCinema projects [1][2].

The AVIE screen is a 10 metre diameter cylinder, standing 3.6 metres high. A narrow (80 cm) doorway provides entry. These dimensions lead to a vertical field of view of 40 degrees for a centrally located viewer.



12 SXGA+ projectors with 1:1 throw are mounted in pairs so as to illuminate the entire cylinder, resulting in a total circumferential resolution of around 7500 pixels (with approximately 180 pixel wide blend regions). The pixel resolution for a viewer standing in the centre is 168 arcseconds per pixel. This is comparable to viewing a 17” SXGA monitor from a distance of 32 cm. Left/right eye channel separation is achieved using polarising filters. A custom screen was constructed using a silver material chosen firstly for its ability to preserve the polarisation of the projected light and secondly for its robustness and portability.

A cluster of six dual Xeon Windows PC's is used to drive the 12 projectors. DVI cables are used for maximum signal quality. We do not use genlock. Another PC acts as the master computer, communicating with the audio system, the tracking system and any other peripheral devices.

A ‘control centre’ application was developed for remote control of all projectors, lights and computers. It also allows, by remote control of a video matrix and USB matrix, instantaneous switching of monitors/mouse/keyboards to any of the computers in the facility.

24 high-quality loud speakers, distributed evenly around the top and bottom screen, provide real-time spatial audio. The system is driven using a spatial renderer written in the SuperCollider [3] programming language. Both VBAP [Pulkki 1997] and ambisonic [Fellgett 1975] spatialisation algorithms have been implemented. For long audio-visual tracks, temporal drift is avoided by using timecode generated by the audio engine to synchronise video playback.

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2.1 Tracking

Twelve infra-red cameras, distributed at various locations overhead, provide coverage of the entire AVIE arena. 20 infra-red flood lights provide illumination. Running on a cluster of 4 Linux PC's, two very different tracking algorithms are run in parallel, together providing real-time unencumbered tracking of audience movement and gesture. This hybrid system acts as the primary human-computer interface for AVIE.

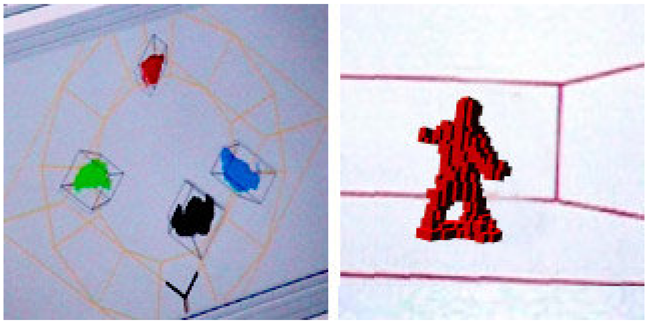

Figure 1 . Real-time voxel construction

The first system uses images from all 12 cameras to construct a voxel representation of all entities inside the theatre [Penny et al. 1999]. A maximum voxel resolution of 4.2 cm per voxel is possible, which is sufficient for capturing limbs and head. From this data we are able to keep track of individuals, detect when people come in to contact with one another and estimate head position.

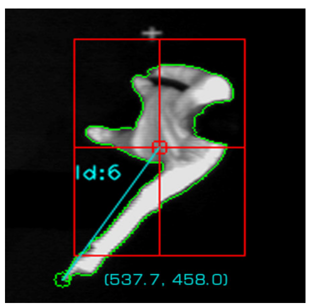

Figure 2 . Finger tracking

The second system employs only the subset of cameras that are angled perpendicular to the ground. The resolution is sufficient to distinguish features such as individual fingers, which can be found by detecting local maxima of curvature in silhouette contours.

When extremely accurate control is required, we use one or more Intersense InertiaCube3 orientation sensors. These can be used in concert with the visual tracking system to provide both positional and directional information.

2.2 Software

When designing the software, or *engine*, to drive the system, three critical requirements were identified. First, the engine must be capable of compelling immersive and interactive content; a benchmark presently set by computer games. Second, the platform must serve as unifying framework for integration of various technologies which is core to our research. Finally, it is vital that people other than virtual reality software engineers are able to rapidly and easily generate interactive content for AVIE. For a VR theatre, we see this as the key to a long and fruitful life.

In view of these requirements, the commercial package *Virtools* [4] was selected as the basis for the software platform. With minimal preparation, any Virtools composition can be experienced in AVIE, opening content development up to 3rd parties such as architects and city planners, simulation developers, archaeologists, game developers and artists.

3. Image generation

3.1 Image Distortion Correction and Blending

In order to create a seamless, distortion-free image across the entire surface of the cylinder, we adopt the common two pass technique of mapping the desired imagery on to a suitably shaped *distortion mesh*, and then modulating this image with a suitable *blend texture*. A unique mesh and blend texture is required for each projector. AVIEConfig, an interactive calibration tool, was developed to allow easy calibration of a parametric model of the system, with particular attention given to choosing parameters that could be intuitively tweaked by hand.

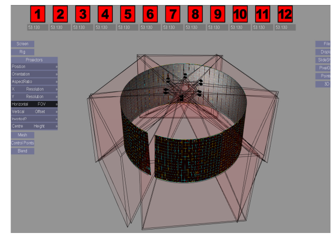

Figure 3 . AVIEConfig

First, real world measurements of the theatre are fed into a simple parametric model that captures the salient features of the theatre. The screen is modelled as a cylinder, with a gap for the door and each projector is described by its position, orientation, throw & vertical shift. From this, we construct a first approximation of the distortion meshes. Second, discrepancies between this basic model and the real-world (for example, the real screen is not a true cylinder), are then accommodated by transforming the meshes in 'screen space'. We apply horizontal and vertical scaling and translation, parabolic keystone, as well as 3 separate parabolic curves for vertical displacement of the top, middle and bottom of the mesh. Finally, for pixel accurate alignment, a 9 control point quadratic Bezier patch is used to fine-tune the mesh.

The blend textures are generated using a simple model that defines the start and end points of each blend region, plus a power function and gamma correction, according to Bourke [2004]. In our case, however, the start and end points are defined using a pair of vertical parabolic curves, in place of straight lines.

3.2 Omnistereo Rendering

Stereoscopy is a powerful means of enhancing immersion. Conventional stereo projection demands that a viewer's position and orientation accurately match the position and orientation from which the imagery was rendered or captured. This is often achieved by tracking the users head orientation and position, and rendering images in real-time for this particular view. This approach, however, precludes construction of a multi-user environment where people are free to move and look wherever they choose, as it is unable to produce correct images for everyone. To overcome this problem, we turn to a method known as *omnistereo*.

Omnistereo assumes a view point at the centre of the cylinder and a view direction perpendicular to the screen surface. This method produces perceptually correct stereoscopic depth over the full 360º viewing circle [Simon et al. 2004]l, providing all viewers with a valid stereo image.

Strictly speaking, this method only produces correct imagery for viewers located at the centre of the cylinder. Despite this, and importantly for AVIE, we observe that *omnistereo images can be viewed comfortably from any position inside the theatre.* This is the principal advantage of a cylindrical screen over composite planar systems – it has no corners. Any image distortions induced by the discrepancies between viewer position and the image viewpoint are continuous over the whole screen, and consequently less perceptible. These observations are based on the experiences of the many hundreds of visitors AVIE has already received.

3.3 Omnistereo Real-time Computer Graphics

Simon et al. [2004] describe two methods for rendering real-time omnistereo images: the 'multi-view' method and the 'object warping' method. We have implemented both, including both CPU and GPU versions of the latter. When integrated with our graphics engine, these methods exhibit varying degrees of efficiency and versatility.

The multi-view method is the most versatile, as it will correctly render any Virtools composition without any modification of the render pipeline. However, to achieve an acceptable level of continuity between views, each view must have a horizontal field of view no larger than 11°. Conversely, anywhere below 8.25° per view produces no discernable improvement in visual quality. For AVIE, where each projector covers 66°, this implies rendering between 6 and 8 views per eye, per projector. The effect this has on the frame-rate very much depends on the content of the rendered scene. For example, at 6 views per eye, we observe anywhere between a 5% and 40% decrease in frame-rate, depending on the nature of the scene.

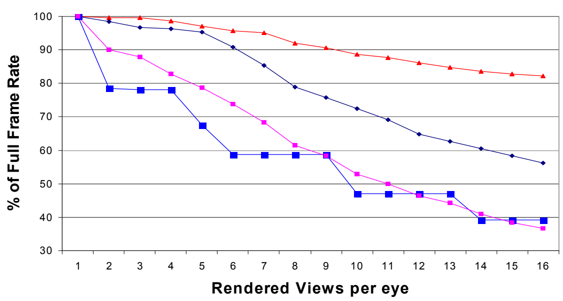

Figure 4. Multi-view method. Decrease in frame-rate vs number of views for 4 scenes of varying complexity.

CPU object-warping reduces the number of render passes to one per eye per projector, and therefore is more efficient, but in order to meet the requirement that any Virtools composition can be rendered in AVIE, careful attention must be paid to phenomena such as particle systems or objects with vertex-shaders. This is further exasperated when employing the even more efficient GPU-object warp method, as it requires a means of automatically combining the object warp vertex shader with any vertex shaders that may exist in the scene. Therefore, at the time of writing, we employ the multi-view method for its ability to correctly render any Virtools composition, while work is underway on a *shader management system* that will allow the use of the GPU-object warp method with arbitrary scenes.

4. Discussion

The relatively small vertical field of view offered by AVIE at the centre, diminishes the sensation of immersion. A greater vertical field of view is possible by simply reducing the radius of the cylinder, but this would compromise the number of users the theatre could accommodate.

The front-projection configuration of projectors leads to a shadow-free play area of 6.5 metre diameter, assuming an adult of 1.75 metre height. However, in practice, we have found that casting shadows on the screen is seldom a problem, even when viewers do wander beyond the shadow-free zone.

We have noticed a certain amount of de-polarisation towards the bottom of the screen, due to the high angle of incidence of the incoming light at the bottom of the screen. This could be overcome by using wavelength interference filters, such as INFITEC filters [Jorke and Fritz 2006], in place of polarisation filters, however this would incur additional costs.

Omnistereo methods employed here only produce strictly correct images for viewers located in the centre. Despite this, we have found that the images can be viewed comfortably from any position inside the theatre. However, when the viewer moves while viewing a scene, the apparent lack of motion parallax causes the viewer to perceive motion in the image where there is none. This effect is most evident in scenes with distinct foreground and background objects.

5. Applications

Described here are a number of different projects to be implemented in AVIE that, taken together, demonstrate the versatility of the system.

5.1 Stereo panoramic still images

We have developed a simple stereo panoramic slide show application. Using the commercially available Roundshot 220 VR [5], a stereo panoramic still camera, a series of very high resolution stereo panoramas were captured at various locations of archaeological importance.

5.2 Panoramic video

The iCinema *SphereCam* [6], a high-definiton 24 mega-pixel panoramic video camera. SphereCam comprises a re-configurable array of 12 high-definition UXGA 12-bit colour CCD cameras and a hard-disk recording system capable of capturing all 12 streams, at 25 fps, of uncompressed video. SphereCam is capable of producing panoramic videos of sufficient resolution for projection in AVIE.

The first SphereCam film to be produced for AVIE takes the audience on a virtual tour of Sydney (colour plate 5). The film was made by mounting the camera on a flat-bed utility vehicle. Playback of 8k x 1k resolution video is achieved using mpeg2.

5.3 Stereo panoramic video - Hampi

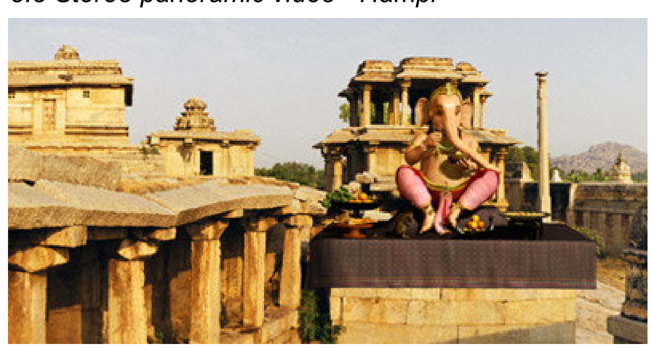

Figure 5 . Hampi panoramic video: Ganesha feeds his rat.

By compositing computer generated stereo images on still panoramic photographs, we produce stereo panoramic video.

Hampi [7] is the first project to employ this method. A selection of panoramas featuring the most significant archaeological, historical and sacred locations at the site of the World Heritage of Vijayanagar in Hampi, southern India are brought to life by embedding computer graphic renderings of mythological characters sacred to the site. The next stage in the Hampi project involves replacing the pre-rendered CG characters with real-time CG characters that, via the tracking system, can sense and react to the presence and actions of the audience.

Figure 6 . TVisionarium

5.4 TVisionarium

TVisionarium [8] is a prototype immersive televisual datamining application. 24 hours of television was automatically segmented into 22500 shots, each of which was then tagged with meaningful keywords. In addition, key frames for each shot were automatically extracted, along with colour descriptors. A metric for measuring the similarity between shots was developed, with parametric weights allowing the user to adjust the importance given to different categories of keywords. The user is immersed in a three dimensional constellation of images. Using a pointing device, the user navigates through this database, following threads of semantic similarity or disparity between clips. TVisionarium is capable of rendering over 200 windows of video simultaneously.

5.5 Mining Training Simulator

Figure 7 . Mining training simulation

The UNSW School Of Mining Engineering is actively involved in developing and delivering virtual reality training systems to the coal mining industry. The VR simulations developed at UNSW encompass scenarios such as unaided self-escape, pre-shift truck inspections, hazard awareness, isolation procedures, outburst management and spontaneous combustion. In the past, these simulations had been deployed on monoscopic wide-screen systems. However, by ensuring that both iCinema and the School of Mining Engineering shared a common software platform, we have been able to present the simulations in AVIE. The results have been so successful, that the deployment of four AVIE systems to mining industry clients is now underway.

5.6 CharacterLab

iCinema's principle concern is the development of interactive immersive narrative experiences. We believe in notions of interaction and immersion that are intrinsically interwoven with the narrative context within which they occur. *CharacterLab* will be a virtual laboratory for constructing experiments concerning autonomous virtual agents, narrative scenarios and real people. Integrating the tracking system with an autonomous agent architecture and animation and behaviour engine, *CharacterLab* will allow us to study the phenomena of immersion, presence, perceived intelligence, group behaviour and emergent and evolutionary narratives.

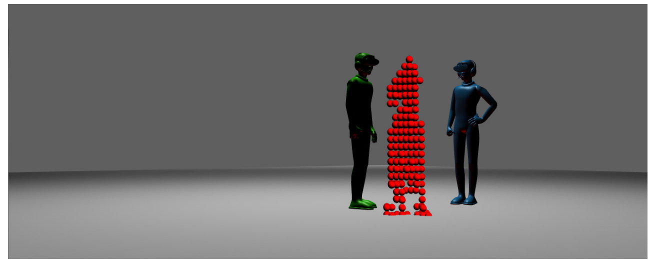

Figure 8 . Two virtual autonomous agents fix their gaze on a user, represented here by a voxel model generated the tracking system.

6. Conclusions

In AVIE we have successfully developed an VR theatre that meets all our requirements; it permits a truly immersive, interactive multi-user experience and it is relatively low cost and portable. By building our software engine on a commercially available game engine, it is relatively easy to create or import new interactive content.

7. Acknowledgements

The tracking system has been developed by Anuraag Sridhar and Andre Bernhardt. Balint Seeber created the video engine used in TVisionarium. Tim Kreger developed the Supercollider scripts for spatial rendering of audio. *SphereCam* is funded by an ARC Linkage Infrastructure grant, *Hampi* is funded by an ARC Linkage grant and *TVisionarium* and *Scenario* are funded by separate ARC Discovery grants. AVIE itself is funded by the UNSW University Capital Infrastructure Grants Scheme.

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Web Links

[1] www.icinema.unsw.edu.au/projects/prj_placeurb.html
[2] www.icinema.unsw.edu.au/projects/prj_eavesdrop.html
[3] supercollider.sourceforge.net
[4] www.virtools.com
[5] www.roundshot.ch
[6] www.icinema.unsw.edu.au/projects/infra_spherecam_1.html
[7] www.icinema.unsw.edu.au/projects/prj_hampi.html
[8] www.icinema.unsw.edu.au/projects/prj_tvis_II.html

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Figure 1 . TVisionarium in AVIE

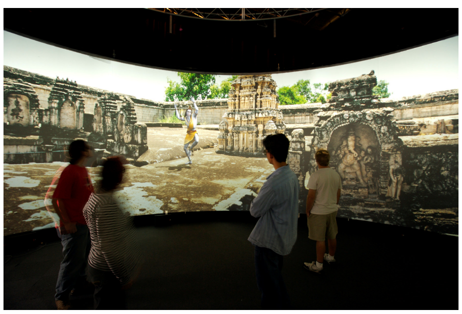

Figure 2 . Hampi Stereo Panoramic Video

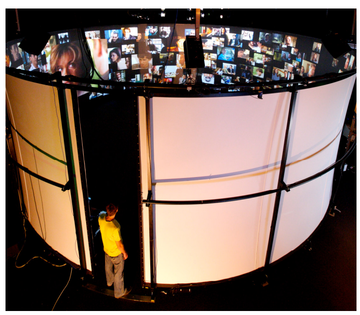

Figure 3 . AVIE screen structure

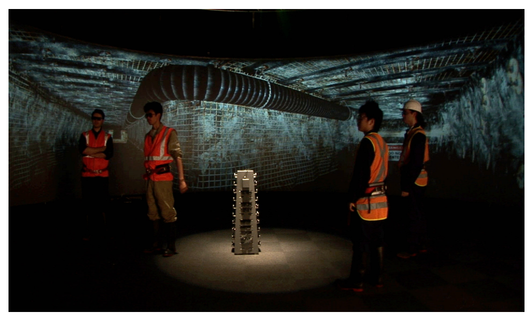

Figure 4 . Mining Training Simulation

Figure 5 . SphereCam footage. 360° digital video.