Lower Cost Modular Spatially Immersive Visualization

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Abstract. The development of lower cost modular spatially immersive visualization systems based on commodity components and faceted display surfaces is described. Commodity computers are networked to form graphics computing clusters. Commodity digital projectors are used to form surrounding rear projected faceted display surfaces based on polyhedral shapes. The use of these systems in the design and evaluation of human environments is discussed.

Keywords: spatially immersive visualization, modular visualization systems, lower cost visualization, graphics computing clusters.

1 Introduction

Access to computer simulation and computer based visualization has dramatically impacted our ability to understand data and design complex systems and environments. Immersive visualization, with its ability to present high quality interactive three-dimensional representations of complex systems, is the next step in this evolution. While standard visualization techniques provide 'windows' into virtual environments, immersive visualization provides the sense of being 'within' and experiencing the environments. However, immersive visualization has, until recently, been associated with complex, expensive, specialized systems used in applications such as scientific visualization, flight training and petroleum exploration where the benefits clearly justified the expense.

This paper explores the development, characteristics and potential of lower cost *modular* immersive visualization systems. We see the development and use of these systems as one way to extend and augment our ability to understand complex systems and complex data and to design and evaluate complex environments.

1.1 Impediments

While immersive visualization facilities are still relatively rare, they are becoming key facilitators for many research and industrial projects. Impediments to the broad use of immersive visualization have been:

1. high system cost – these systems, both hardware and software, have been expensive,
2. high cost of operation – specialist support staff and ongoing maintenance have been required,
3. accessibility – only a few systems are in place for a relative small number of users,

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4. software complexity – there are only a few 'off-the-shelf' applications; custom application software development is required for most new applications,
5. ease of use issues – special effort is needed to use these systems; they are not well integrated into workflows except for a few specialized problem domains, and
6. human factors issues – user fatigue, 'simulator sickness,' and the need to wear special viewing apparatus are a few of these issues.

Our goal, aimed at mitigating high system costs and limited accessibility, has been to develop very capable lower cost immersive visualization systems that are useful, cost effective and widely accessible. Such lower cost systems promise to enable much broader use in many disciplines.

2 Prototype Development

Technology now available enables spatially immersive visualization systems created using off the shelf components including high performance, relatively inexpensive, commodity computers and inexpensive commodity digital projectors. Flexible modular configurations utilizing polyhedral display surfaces with many identical modular components and networked visual computer clusters is one approach to such systems. This is the approach we have been pursuing.

Work is underway at the Texas A&M College of Architecture focused on developing and evaluating several prototypes of this class of systems to determine their practicality and effectiveness. Underlying concepts and issues related to the design and development of these systems are presented.

2.1 Spatially Immersive Systems

A spatially immersive visualization system consists of three major elements: computational infrastructure, surrounding display surfaces, and viewer tracking and interaction elements. We are exploring approaches to both the computational infrastructure and the display surface geometries used.

Current and near future technologies and computational economics allow the development of better and more cost effective spatially immersive visualization systems. In recent years, low cost commodity projectors have been replacing expensive projectors and commodity PC based graphics systems have been replacing expensive graphics systems.

A very compelling concept is collections or clusters of commodity computers networked to form powerful, inexpensive distributed parallel computing engines. This concept has been extended into visual computing with the development *tiled* display systems formed by dividing a two-dimensional display area into an array of adjacent regions or tiles [1]. Each of these regions is projected by one of an array of image projectors. This approach can support large, very high aggregate resolution displays.

2.2 Faceted Immersive Displays

Taking this approach one step further, spatially immersive systems are created by arranging the display tiles or *facets* into a surrounding three-dimensional display surface and creating a commodity based computational architecture optimized to support such immersive systems [2]. The computational infrastructure used is, as in the tiled display concept, a visual computing extension of the commodity computer cluster concept [3]. In such configurations, each facet need only display a relatively small portion of the total virtual environment. We have focused on faceted systems that are based on portions of the 24 face trapezoidal icositetrahedron shown in Figure 1. To date we have developed three, four, and five facet operational prototypes. A seven facet prototype is currently being developed. Figure 2 shows an early three facet prototype system and a current test-bed system using five display screens.

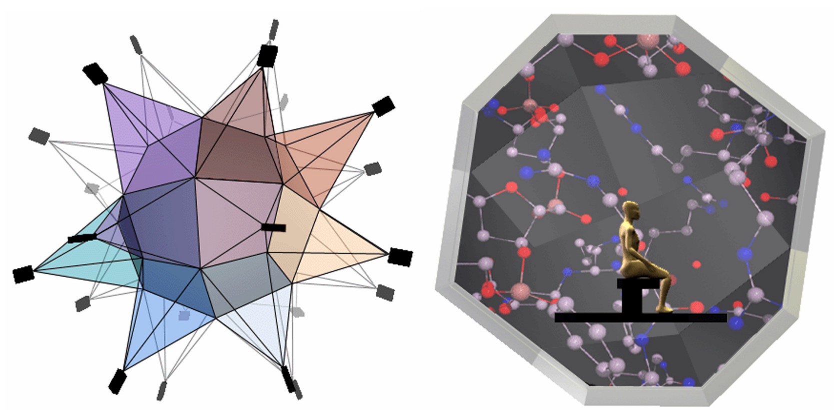

Fig. 1. On the left, a conceptual view of a 24 facet immersive system based on the trapezoidal icositetrahedron is shown. Also shown are the rear projector placements. On the right is a cross-section of a simulated 5 meter diameter 24 facet system.

2.3 Image Compensation

Since the display surfaces of immersive systems have often been curved and often required blending multiple projected images, expensive high light output CRT based projectors coupled with specialized optical image blending techniques have been the norm. These projectors allowed electronic warping of the projected images to compensate for various optical distortions.

The advent of commodity projectors based on solid-state light modulators such as DLP technology invite the development of immersive systems based on these lower cost devices. However, since the use of optical or electronic image correction with these projectors is very limited, the use of curved projection surfaces, especially rear projected surfaces, is difficult. This is one motivation for using faceted planar projection surfaces. The less than ideal optics used in commodity projectors coupled with the difficulty of precisely positioning the projectors has required the development of software based, primarily GPU based, approaches to compensating for geometric, intensity and color distortions in the projected images. This software image compensation has been informed by the work of Raskar [4] and Majumder [5].

2.4 Stereo Image Display

The use of commodity projectors also limits the available approaches to displaying stereo images. The active stereo imaging techniques usually employed in high-end systems require very high frame rates that only expensive projection systems can support. In addition, commodity graphics processors do not typically support tight frame synchronization across multiple systems. This tight synchronization is required for active frame sequential stereo techniques in multi-screen systems.

The frame rate limitations of commodity projectors and the lack of tight image synchronization in commodity graphics processors limit us to passive stereo display techniques. Anaglyphic stereo depends on separating the stereo images based on color. Polarization based stereo depends on separating the stereo images using polarizing filters. Anaglyphic stereo can be done with a single projector for each display facet. Polarization based stereo requires two projectors for each display facet. Both approaches require that the user wear glasses with color or polarizing filters to present each eye with the appropriate images.

Fig. 2. On the left is a view of an early three facet prototype system in operation. On the right is a rear view of an operational five screen immersive system showing the backside of the display screens, projectors, computers and optical path folding mirrors.

3 Integration into Work Flows

As listed above, two of the impediments to using immersive systems are software complexity and lack of integration into workflows. While a number of software development libraries are available, only a few 'off-the-shelf' applications exist. The potential user is most often confronted with the daunting task of developing specialized software to support her tasks.

Our location in a college of architecture tends to focus our attention on the integration of these immersive systems into the design and evaluation of human environments. An approach we have been pursing is to develop 'bridging' software that allows users to make use of familiar design tools. The bridging software then facilitates easy translation of data and designs to the immersive systems.

Uses of our prototype systems have included the visualization of a nautical archeology site, the visualization of a currently inaccessible a historic cliff dwelling site and the interactive exploration of an underground leafcutter ant colony.

4 Future Modular Systems

Immersive systems based on rear projection technology have inherent difficulties including the need for large, usually high ceiling spaces, to accommodate the projection throw distances and the need for periodic calibration to maintain image alignment. Advances in large-scale flat panel image display technology promise effective alternatives to rear projection. Faceted display configurations could enable truly modular systems where the immersive environment is created by literally bolting together mass replicated modules. Each module would contain the required structural, computational, and display elements. The display surfaces of these modules might eventually utilize flat panel display technology such as organic LEDs. Our vision is that such truly modular systems would allow the widespread use of spatially immersive systems assembled where needed in modest sized spaces at relatively low costs.

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