ImmersaDesk-4 : A High Resolution, High Visual Acuity Desktop Virtual Reality System

Jason Leigh (spiff@uic.edu), Cristian Luciano, Andrew Johnson, Robert Kooima,
Greg Dawe, Luc Renambot, Thomas A. DeFanti

Electronic Visualization Laboratory (EVL), University of Illinois at Chicago

ABSTRACT

In this paper we discuss the design and implementation of a desktop virtual reality system that offers high-resolution and high-visual-acuity passive-stereo visualization on a single-computer-driven system. Present commercial desktop VR systems are limited to a maximum resolution of 1600x1200 pixels. The ImmersaDesk-4 uses two 4 mega-pixel LCD displays and a novel polarization technique to create stereo of uncompromised resolution. A head and hand tracking system is integrated to provide a fully interactive VR environment that can render viewer-centered perspective.

CR Categories and Subject Descriptors: VR displays, flat panel

1 INTRODUCTION

Following the development of the CAVE in 1992 [1], EVL has developed a number of display systems with the goal of creating higher resolution and lower cost desktop displays. In 1994, EVL developed a projection-based system resembling a drafting table, called the ImmersaDesk-1 (IDesk-1) [2]. IDesk-1 used a CRT projector to create field-sequential stereoscopic images at 120Hz onto a screen that was angled at 45 degrees. This angle was specifically chosen to facilitate the viewing of small 3D CAD models and data-sets. The second generation of the system, the IDesk-2 (Figure 1), used a system of hydraulics to allow the user to arbitrarily choose a tilt angle between 0 and 45 degrees. This allowed it to be used both for the viewing and manipulation of small objects, and for applications that required users to navigate through a 3D space. ImmersaDesk-3 (Figure 2) explored the use of plasma displays to generate field-sequential stereo[4]. At the time (1998) plasma screens were just emerging on the market and given their brightness, size, and cost compared to CRT projectors, seemed an attractive technology for creating a VR display. In practice plasma screens were found to be one of the most incompatible technologies for VR. Firstly they were electromagnetically noisy making them incompatible with electromagnetic trackers; secondly the displays refreshed at 60 Hz which meant that the stereo images refreshed at a mere 30 Hz-resulting in considerable eye-strain for viewers; and lastly the red and green phosphors do not decay as quickly as the blue resulting in considerable cross-talk in the left and right-eye images [4].

The ImmersaDesk-4 (IDesk-4) is a result of our on-going effort to develop a cost-effective, high-resolution, high-visual-acuity, immersive desktop virtual reality system. IDesk-4 is a 4 mega-pixel LCD-based display that provides viewer-centered passive stereoscopic computer graphics.

2 PRIOR WORK

A number of autostereoscopic displays have recently emerged on the market to take advantage of the low cost of LCD monitors (e.g. StereoGraphics' SynthaGram, Sharp LL-151-3D, SeeReal). While these displays are suitable for viewing stereoscopic images, they are not well suited for viewing viewer-centered stereoscopic images because they require that the viewer keep their head stationary and straight in order to see the correct pairs of vertically interleaved images. Furthermore, even though many of these displays boasted a resolution of 1600x1200, the interleaving techniques used to create the stereo effect meant that each eye's image had only a maximum resolution of 800x1200.

Figure 1: The ImmersaDesk-2.

To attempt to address some of the current limitations of autostereo displays, we developed the Varrier system [6], a barrier-strip autostereo display that uses a moving virtual line screen synchronized with viewer-centered perspective to enable the viewer to move their head and to tilt it slightly during viewing. While successful, 3/4 of the screen's native resolution is used to reduce moiré effects since 4 pixels are rendered for each anti-aliased stereo pixel. Furthermore, precise low-latency head tracking is needed to ensure that the stereo images are perfectly aligned with the viewer at all times.

While autostereo displays hold considerable promise for the future, there is an immediate need for low-cost, wide field-of-view, high-resolution desktop displays in application areas such as the Geosciences (www.geowall.org). Therefore, concurrent with our efforts to develop autostereo displays, we began exploring an alternative approach using more conventional augmented reality and passive stereographics techniques. The IDesk-4 provides an uncompromised 4 mega-pixels (2560x1600) of resolution for each eye, and allows the user to comfortably move, tilt and turn their head while maintaining correct viewer-centered stereo with a wide field of view. The IDesk-4 achieves stereo using two 30" Apple Cinema Displays bisected by a half-silvered mirror to reverse the polarization of the polarized light emerging from one of the LCD screens. The viewer then wears polarized glasses to resolve the stereo images. An electromagnetic tracking system is used to track the orientation and position of the viewer's head to properly render the correct viewer-centered perspective images. An additional 3D pointing device (such as a Wanda or SpaceGrip) enables 3-space interaction.

Figure 2: The ImmersaDesk-3.

The display device that most closely resembles the IDesk-4 is the commercially available 15-inch Planar SD1300 system (PSD) [5]. The PSD, however, has a number of limitations: it only provides a resolution of 1024x768; it does not provide correct viewer-centered stereo; has a considerably smaller display area making the visual experience less immersive; and the technique used to achieve stereo on the PSD display cannot be immediately applied to larger high-resolution displays.

3 DESIGN OF THE IMMERSADESK-4

3.1 Achieving Passive Stereo

Figure 3 shows a schematic of the IDesk-4. Two 30-inch Apple Cinema Displays are mounted above and in-front of the viewer. Given that the 30-inch screen is 25 inches wide, when viewed from a comfortable distance (approximately 24 inches), the user's field of view is atan (25/2 * 1/24) * 2 = 55°. Given that the visual acuity of a display can be computed as 20/(FOV*1200/resolution) [7], therefore, the visual acuity of the IDesk-4 is 20/(55°*1200/2560), which is approximately 20/26[1]. The original concept was to use the IBM T221 9.2 mega-pixel (also known as the Big Bertha) display. But since these displays have been discontinued it seemed more practical to use the widely available Apple displays. Also the larger Apple displays helped produce a wider field-of-view than the smaller 22.2-inch IBM displays.

[1] In the United States 20/40 is considered the limit at which automobile drivers are permitted to drive without the need to wear corrective eyewear; and 20/30 is the limit for emergency vehicle drivers.

To achieve passive stereo, a quarter-wave plate with the fast axis oriented at 45 degrees is laminated between two polarization-preserving acrylic sheets (for rigidity) and then velcroed onto the LCD screens. Since the light from large LCD screens is polarized vertically, the addition of the quarter-wave plate creates circularly polarized light. While the light passing through the half-silvered mirror is polarized in one circular direction, the light from the top LCD screen reflecting on the mirror is polarized in the opposite direction. The viewer then wears a pair of circularly polarized glasses to resolve the stereo image.

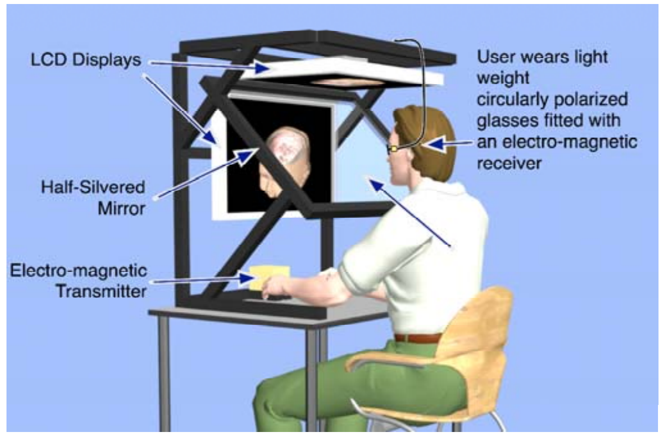

Figure 3: Schematic of the ImmersaDesk-4.

The PSD on the other-hand takes advantage of the 45 degree polarization that is naturally emitted from smaller (less than 17-inch) LCD screens. This polarization is therefore reversed with a mirror and so the user can wear linear polarized glasses to resolve the stereo. In the case of the IDesk-4, this technique will not work because larger LCD screens emit linearly polarized light in the vertical direction (rather than at 45 degrees), and the reflection of polarized light in the vertical direction will not re-orient the light at 90 degrees.

A 6mm half-silvered glass mirror with 40% refractivity and 60% reflectivity was used to bisect the screens (manufacturers often refer to this as a mirror with a 40/60 coating). A thinner mirror would probably have sufficed, but since the mirror we built was rather large we wanted to ensure that it was strong enough to withstand accidental knocks. A polarization-preserving half-silvered acrylic mirror would have been an ideal solution, but we were unable to identify any manufacturers who could make one. While the PSD uses a mirror of the same width as the LCD display, the IDesk-4 instead uses a mirror that is much wider than the display. It was discovered that a wider mirror afforded the viewer a wider range of head motion without the frame of the mirror interfering with the image- this is particularly important for achieving a good sense of immersion in VR.

3.2 The Physical Structure

The frame for the IDesk-4 was built using extruded aluminum (80/20) parts. The use of a thick mirror necessitated the building of a thicker frame to guarantee stability and rigidity of the overall structure. We had, in fact, prototyped an earlier version of this display (see Figure 4) using a design that enabled the system to open and close like a clam-shell while keeping the mirror correctly bisecting the two displays. The advantage of the design was that a foldable system was easier to transport. Furthermore, by opening the screens further apart, one could more easily accommodate taller users. And by attaching a potentiometer to measure the angle of the two screens, one could adjust the graphics in software to account for the new projection planes. Alas, this "dream" system was ultimately found to be structurally unstable resulting in poor alignment of images between the two screens.

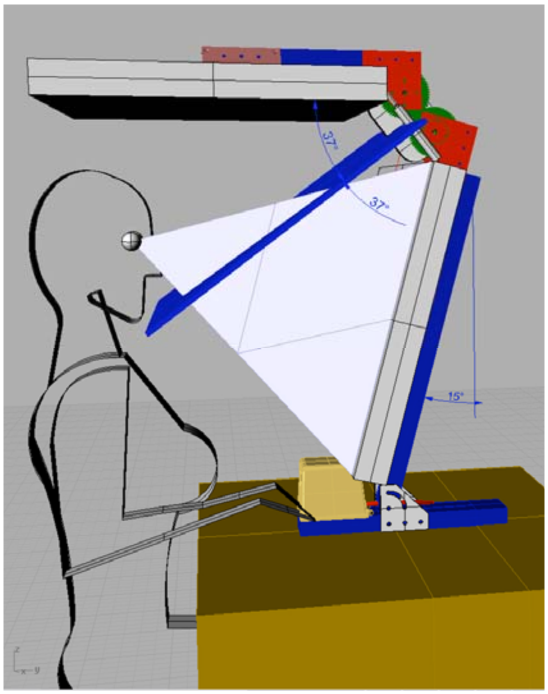

Figure 4: An Early Prototype Design of the ImmersaDesk-4. This version was actually built but was found to be structurally unstable.

3.3 Generating Viewer-Centered Stereographics

A high-end graphics card with two dual-link DVI outputs, such as the nVidia Quadro FX 4400, was required to display at the maximum resolution on both LCDs in clone mode. We have also tested two nVidia Quadro FX 3400 synchronized by a SLI connector. The latter option required an extremely powerful power supply to drive both cards. In addition, it allowed us to get full resolution on both displays, but not in clone mode. Therefore, the former configuration was recommended.

Viewer-centered perspective was achieved by using the Flock of Birds electromagnetic tracker to acquire the viewer's head position and orientation information and then draw the left and right eye images using the standard stereo off-axis projection calculations [3]. However, one final problem that had to be resolved was the need to flip the image on the top screen so that the reflected image would not appear reversed. The latest nVidia ForceWare stereo drivers (version 77.77) allows applications showing full-screen clone-mode stereo to flip the orientation of one of the images. This allows fixed-viewpoint applications such as DirectX games or OpenGL CAD applications to work in stereo without any modification. However, this cannot be used for viewer-centered perspective because the driver does not support user head position and orientation tracking. It assumes a fixed head position with horizontal eye alignment and a constant inter-ocular distance.

A more general implementation of viewer-centered perspective may be implemented in software. However, this places the responsibility of flipping the image on the software as well. In general, any projection matrix may be vertically flipped simply by swapping the *top* and *bottom* parameters used to specify the projection. In OpenGL code, for example, this amounts to swapping the 3rd and 4th parameters to glFrustum or glOrtho.

Flipping the projection in this manner has one side effect that must be corrected. It results in the reversal of the winding of all polygons. Back-face culling commonly uses winding to distinguish back from front facing polygons, thus a flipped projection will invert the effect of the back-face culling mechanism. In OpenGL code, the front-face winding can be reversed with a call to glFrontFace(GL_CW) prior to the rendering of the flipped view.

Depending on the installed orientation of the displays, the flip may be either vertical or horizontal. A horizontal flip behaves just as a vertical flip, but requires the swapping of the left and right projection parameters. The polygon rewinding requirement remains the same. In the event that both a horizontal and a vertical flip is necessary, no polygon rewinding is necessary, as the rewindings of the flips cancel out. A generalized display configuration mechanism should include flags to enable a horizontal or vertical projection swap, and should enable polygon rewinding on the exclusive-or of these flags.

We have implemented application development middleware, named Electro (www.evl.uic.edu/rlk/electro), that uses such a mechanism. Electro provides a comprehensive display configuration system that encompasses the requirements of IDesk-4 in addition to those of passive stereo projected displays (GeoWalls), tiled displays, and the Varrier. The embedded programming language Lua forms the core of Electro's rapid-prototyping capability, which enables interactive development of cross-platform 3D applications. Electro's easy-to-use scripting language allows content for IDesk4 to be created quickly, without concern for the details of the display.

4 CONCLUSION

We have developed a complete high-visual-acuity VR system that provides flicker-free, viewer-centered high-resolution stereo at 4 Mega-pixels. The final built system is shown in Figure 5. The technique used to achieve circular polarization can easily be applied to support higher resolution LCD screens such as the 9.2 mega-pixel IBM T221 display, or a tiling of LCD screens to achieve even higher resolutions.

A key advantage of using LCD panels as VR displays is that they are extremely bright making them usable under normal office lighting conditions. However since circular polarizers do not block light as completely as linear polarizers, some cross-talk is visible when viewing high contrast images. One solution to mitigate this effect is to reduce the intensity of the LCD displays. However, despite this limitation, the images are stunningly "crisp" as compared to other desktop VR display currently available on the market.

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Figure 5: The Final Fully Constructed ImmersaDesk-4.

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