Personal Tele-Immersion Devices

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Abstract

The Electronic Visualization Laboratory (EVL) at the University of Illinois at Chicago (UIC) has partnered with dozens of computational scientists and engineers to create visualization and virtual reality (VR) devices and applications for collaborative exploration of scientific and engineering data. Since 1995, our research and development activities have incorporated emerging high bandwidth networks like the vBNS and the Internet2 in an effort now called Tele-Immersion.

As a result of our six years' experience in building first and second-generation VR devices to support these applications, we consider third-generation VR devices that will provide desktop / office-sized displays. Since no current technology is yet configurable with ideal resolution and size, we will first simulate these devices with available parts, and then build more advanced prototypes. We believe that the devices we propose to build using the new display technologies form a set of desirable human/computer interface requirements for successful Tele- Immersion adoption. A goal of this research is to develop clearly compelling prototypes so that these devices can be improved and reproduced by the private sector.

1. Introduction

In 1991, we conceived and over several years developed the CAVE virtual reality theater, a room-sized, high-resolution, projection-based system that enables users to experience excellent immersion in full 3D imagery. We exhibited the CAVE at SIGGRAPH 92, 94 and 97, Supercomputing 92, 93 and 95, as well as several other major conferences, enabling over 15,000 people to have immersive CAVE experiences of applied computational science or design engineering. Substantial NSF and DARPA and DoE funds were received for these efforts. NIST and NSF support then allowed us to develop the ImmersaDesk, a smaller, software-compatible, drafting-table-format version of the CAVE. The ImmersaDesk has been deployed to dozens of locations in the US government, national laboratories, universities, and companies, both here and abroad.

We are partners in the NSF Partnership for Advanced Computational Infrastructure (PACI) program; we are specifically charged with deploying our VR/Tele-Immersion technology to scientists and schools throughout the US. We are developing a family of prototypes and products to evolve over time as technology improves and needs become more demanding, and that are all compatible. Our VR software has been designed to be networked, portable, and easy to use; the hardware now needs to be made smaller, higher resolution and more adaptable to the human and his/her workspace.

2. Background

The Electronic Visualization Laboratory (EVL) at the University of Illinois at Chicago (UIC) have developed several virtual reality (VR) projection-based displays to date, notably the CAVE, the ImmersaDesk, and the Infinity Wall.

The CAVE is a multi-person, room-sized, high-resolution, 3D video and audio environment. Graphics are projected in stereo onto three walls and the floor, and viewed with stereo glasses. As a viewer wearing a location sensor moves within its display boundaries, the correct

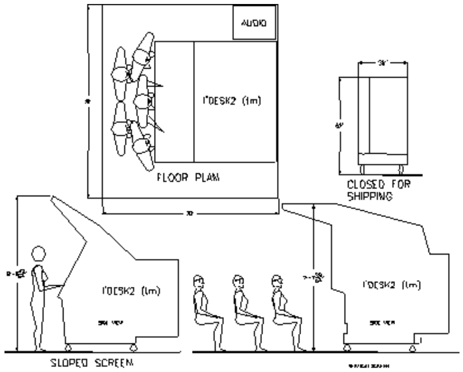

Figure 1. Immersadesk 2

In the tradition of computer hardware development, we followed the plan of first making the CAVE work, then making it faster, and then making it smaller and cheaper. The ImmersaDesk, described above, is a drafting-table format version of the CAVE. [3] The ImmersaDesk2 (see Figure 1) is a second-generation projection VR device ruggedized and packaged for shipping via air or truck. It is ideal for desimulation, and imaging. Connect with networking as good as direct memory access. Provide software and hardware to track gaze, gesture, facial expression, and body position. Offer it as a built-in feature on all personal computers and workstations.

Obviously, we are far from achieving ubiquitous Tele-Immersion. Let us consider the situation with human voice and audio in general. There is a worldwide network optimized for speech (the telephone system) that supports 2-way and multi-way interactions. Computers and other equipment one can purchase in shopping malls can completely record, edit, playback, and duplicate audio to near perfection. Real-time speech synthesis is close at hand with gigaflop desktop machines. Similarly, for video recording, editing, playback, global teleconferencing, and broadcast, mature and optimized systems exist, at much higher cost. No such consumer/corporate demand exists yet for Tele-Immersion; however, the near-term ubiquity of 3D graphics engines, expected implosion of telecommunications costs, and emergence of new display technologies are reasons for timely experimental development of integrated systems. We hope to inspire private sector products by developing prototypes of fully integrated Tele-Immersion hardware and software, as we have thus far with projection-based VR systems. Many of the barriers are market-based, but several are true technical research issues. Below, we identify a set of these research issues.

The Tele-Immersion system of 2008 would ideally:

1. Support one or more flat panels/projectors with ultra-high color resolution (say 5000 x 5000)
2. Be stereo capable without special glasses
3. Have several built-in micro-cameras and microphones, and other sensors
4. Have tether-less, low-latency, high-accuracy tracking
5. Network to teraflop computing via multi-gigabit networking with low latency
6. Have exquisite directional sound capability
7. Be available in a range of compatible hardware and software configurations
8. Have gaze-directed or gesture-directed variable resolution and quality of rendering
9. Incorporate AI-based predictive models to compensate for latency and anticipate user transitions
10. Use a range of sophisticated haptic devices to couple to human movement and touch
11. Accommodate disabled and fatigued users in the spirit of the Every Citizen Interface to the NII

What we have as parts to integrate into 1998 systems are:

1. Heavy, moderately expensive 3-tube projectors as the only straightforward stereo-capable projection devices
2. Large projection distances needed for rear projection
3. Medium resolution (1280 x 1024 pixel) displays with barely sufficient brightness
4. Moderately awkward stereo glasses
5. Graphics hardware that integrates poorly with non-stereo camera input
6. Imprecise electromagnetic tethered tracking with significant latency
7. Best effort networking with random latency
8. Expensive multi-processor workstations and rendering engines ($300,000 / screen for multi-screen systems)
9. Primitive software models of user interactions within VR and Tele-Immersive systems
10. Very primitive hardware devices for haptic interaction

The computing and networking hardware needed as the base for Tele-Immersion applications is fortunately coming along nicely through open market competition. The integration of these technologies with emerging visual displays is deeply challenging work, however.

5. Personal Tele-Immersion Devices: Rationale, Design Concepts, and Development Methods

To construct the Tele-Immersive office workspace, one would want affordable wall-sized high-resolution borderless displays with low lag and undiminished image intensity when viewed at an angle. Given that such a display does not exist today, we must start by assembling new VR systems from available components. [2]

We intend to build several devices, each of which addresses different major issues in the Tele-Immersion / VR human computer interface:

1. ImmersaDesk3
2. Personal Augmented Reality Immersive System (PARIS)
3. Personal Penta Panel (P3)
4. Totally Active Workspace (TAWS)
5. CAVEscope

New projection and display technologies are showing promise, but the winning technology of the future is not at all evident. Rather than place our bets on one particular type of device, we specify below a set of display technologies. In the context of building new VR devices, we shall investigate the viability, flexibility of operation and breadth of application of the following new display technologies as compared to current 3-tube projector systems:

[2] Several companies, like Panoram and VRex, [23] offer well-designed, non-tracked displays for the office and showroom. Barco and Fakespace have products similar to the ImmersaDesk. The goal of EVLs research is not to compete with the commercial sector, but to investigate and inspire new display and tracker technologies for the human-centered interface to Tele-Immersion.

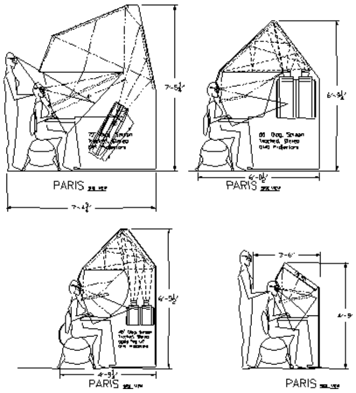

Figure 3. PARIS

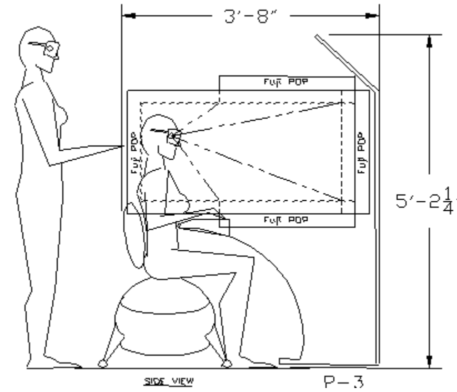

Figure 4. P3

1. Liquid Crystal Display (LCD) projectors and panels. These are achieving better resolution now (1280 x 1024), but have too high lag to be used for stereo unless two projectors are used with shutters. [23]

2. Digital Micro-mirror Displays (DMDs). These are medium resolution (1024 x 768), and theoretically fast enough for stereo, but the hardware does not permit stereo yet. [23]

3. Plasma panel displays. These are low-medium resolution (800x480) but probably fast enough to do stereo with the proper driver electronics. These displays have electronics mounted around their edges so border-less multi-screen configurations are a challenge to construct. [23]

4. Light Emitting Diode (LED) displays. These are low resolution right now (e.g., 208 x 272 and 320x192) but bright and borderless, in principle. [23]

5. Ferro-electric Liquid Crystal (FLCs) displays. These have the benefits of LCDs with very low lag, but are just now appearing in developer kits. These are fast enough to produce stereo images, theoretically. [23]

6. The Five Devices

6.1. ImmersaDesk3

As noted earlier, the ImmersaDesk and its more flexible, more easily deployable derivative, the ImmersaDesk2 (see Figure 1), have achieved penetration in their niche market, computational science and engineering VR. The ImmersaDesks are large because we wanted to present a wide angle of view, but also because the available projection technology has a limit to how small the screen can get (approximately 6’ diagonal). Rear projection distances are significant, even when folded with mirrors, and the projector itself is quite large and heavy. Both of these devices are sized for a laboratory, and are too large for a typical faculty office or cubicle. We wish to develop ImmersaDesk-compatible technology for the scientist’s desktop using flat-panel technology, assuming it can be made to work, eventually, in stereo.

The ImmersaDesk3 (see Figure 2) will be configured so a user can position the screen at any angle from horizontal to vertical, forward or back, on the desk. The angle will be measured automatically and passed to the CAVE library so that the correct perspective view of the computer-generated images for the tracked user will be presented. Cameras will be added to this configuration to make image/gesture recognition, tether-less tracking and Tele-Immersion experiments possible. Given its configuration flexibility, the ImmersaDesk3 will also be amenable to the integration of haptic (tactile input/output) devices.

The ImmersaDesk3 will be prototyped with color plasma panel technology. We are working with various manufacturers to discover how to drive panels in stereo, building pro-

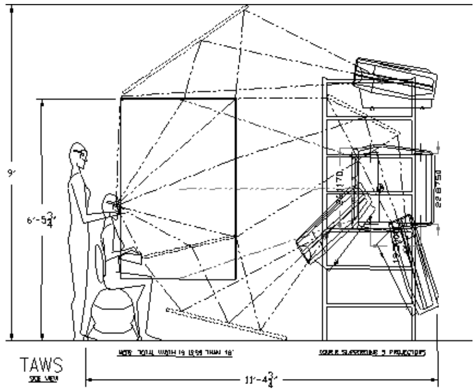

Figure 5. TAWS

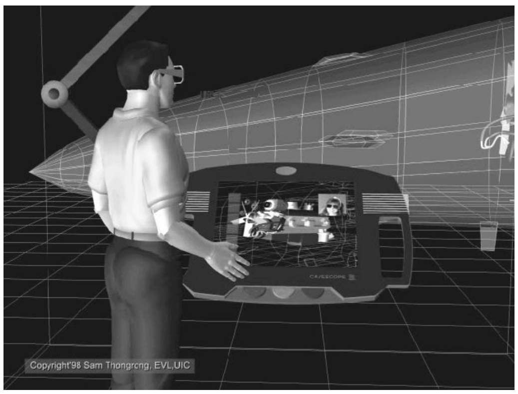

Figure 6. CAVEscope

6.2. Personal Augmented Reality Immersive System (PARIS)

Twenty years ago, Ken Knowlton created a see-through display for Bell Labs using a half-silvered mirror mounted at an angle in front of a telephone operator. The monitor driving the display was positioned above the desk facing down so that its image of a virtual keyboard could be superimposed on the operator's hands working under the mirror. The keycaps on the operator's physical keyboard could be dynamically relabeled to match the task of completing a call as it progressed. Devices that align computer imagery with the users viewable environment, like Knowlton's, are examples of augmented reality, or see-through VR. More recently, researchers at the National University of Singapore's Institute of Systems Science built a stereo device of similar concept using a Silicon Graphics' monitor, a well-executed configuration for working with small parts in high-resolution VR [15]. Neither of these systems provides tracking, but rather assume the user to be in a fixed and seated position.

We want to use projection technology to prototype a desktop VR device, the Personal Augmented Reality Immersive System (PARIS, see Figure 3.) We will insure that a keyboard is integrated, and that tracking cameras looking through the half-silvered mirror can capture facial expressions and head position. Gesture recognition can come

VR Device	Equipment
ImmersaDesk3	1 custom desktop enclosure 1 desktop Octane 1 42" plasma panel on a custom fram e 1 television camera on a flexible mount
PARIS	1 custom desk and superstructure 1 deskside Onyx 2 LCD projectors or possibly one DMD/FLC projector, or a stereo 42" panel 2 television cameras for gesture and facial recognition, and Tele-Immersion
P3	1 desktop workstation 1 3-5 pipe Onyx Rack 5 42 plasma panels
TAWS	400 sq. ft. room with normal ceilings 1 3-5 pipe Onyx Rack 5 Electrohome 3-tube projectors, DMDs or 5 very large panels, possibly hi-res laser displays
CAVEscope	An existing CAVE or Power/Infinity Wall An extra pipe in the SGI Onyx rack 1 LCD panel w/ touch screen and mini camera

Figure 7. Summary of Technical Description of Instrumentation Parts

from tracking, as well as the top and front views from the mirror. PARIS is also an excellent device for integrating various haptic (touch) displays.

Since we are committed to stereo in general, and would like as high as possible resolution, we cannot initially use a plasma panel display. Instead, we will use two 1280x1024 LCD projectors with electronic shutters compatible with active glasses to achieve stereo separation. [3] We will keep the design flexible so that we can test panel configurations as well.

We can also use PARIS to prototype passive (polarized) stereo since we can polarize the two projector outputs, allowing very inexpensive and lightweight glasses to be incorporated, an important feature for use in museums and schools., We can also use DMDs in pairs to achieve very bright displays. If plasma or LED panel displays ever achieve excellent brightness, stereo speeds, and high-resolution, these would be preferable devices for PARIS.

A potentially important emerging technology is the FLC display, a product of Displaytech Corp. This technology is used to make high-speed shutters and high-speed, high-

Display Technology	Resolution	Lag	Cost	Stereo Possible?	Proposed Device(s)
LCD Panel	1280 x 1024	High	Medium	No	CAVEscope
LCD Projector	1280 x 1024	High	Medium	In Pairs only	PARIS
DMD Projector	1024 x 768	Low	Med-Hi	In theory	PARIS, TAWS
Plasma Panel	800 x 600	Low	Med-Hi	Unknown	P3, ImmersaDesk3, TAWS
LED Panel	320 x 192, tiled	Low	High	Maybe	P3, TAWS
FLC Projector	640 x 480, then 1280 x 1024	Very Low	Unknown	In pairs, possibly with 1 only	PARIS
3-Tube Projector	1280 x 1024	Low	Medium	Yes	TAWS (initially)

Lag is the time for the image to decay; it if is high, stereo cannot be achieved by time multiplexing
Cost: High means >$35,000 / high-resolution screen; Medium means approx $15,000 / screen; Low would be <$5,000 / screen

Figure 8. Summary of Experimental Display Technologies Compared to Current 3-Tube Projection Technology

a stereo image, without shutters as needed with LCDs or DMDs. With assistance from the manufacturer, it is possible that stereo speeds could be achieved since lag is not deemed to be an issue.

6.3. Personal Penta Panel (P3)

The Personal Penta Panel (P3, see Figure 4) is a open box made out of five 42” diagonal plasma panels. The user places his/her tracked head and hands into the box of screens and is presented with a surround (initially non-stereo) view. Since each panel has a frame around it, this creates seams between screens that are difficult to eliminate. There are, however, optical methods to relay an image a few inches forward, which could be used to (mostly) eliminate the effects of the frames. Such a device would be useful for all but very close viewing, even in non-stereo, as we wait for the needed technological progress in panels.

Another promising technology for consideration is the color LED screen, which could be manufactured to any size without borders and easily built into a cube. Eventual resolution is unpredictable at this point, but LED technology has great potential and lag is not theoretically a problem. Human/computer interface problems like claustrophobia and simulator sickness will be interesting to monitor with users of the P3.

6.4. Totally Active Work Space (TAWS)

We intend to build screens into a cubicle-sized 7 x 7 x 7 CAVE-like structure such that the user works on a glass desk surface. Much care will be needed in the choice and position of the desktop surface so that reflection is not a problem (for instance, it may have to be angled). A variable-position desktop is very desirable for designers and the Every Citizen Interface work we want to do as part of our research. Since we would skip the floor projection in this model and its size is much smaller than the CAVE, we would also be free to add a top-projected ceiling. We can also experiment with rigid wall screen materials given the smaller size. Perhaps this concept can be realized with huge high-resolution plasma panels (being developed for HDTV) or tiled LED panels, thus eliminating the need for rear projection and its huge consumption of space in an office environment. In the future years, we expect 70” or larger high-resolution plasma panels to be available. Laser projectors are also potentially promising technology for the future.

The TAWS configuration (see Figure 5) is topologically and computationally equivalent to a CAVE, so it is equally demanding of graphics resources. TAWS is large enough for two colleagues to share the workspace when need be. EVL has been running its LCD shutter glasses at 160Hz, so that four lenses (in two sets of glasses) can operate almost flicker-free at 40Hz each. This capability, called duo-view, allows two tracked users of the same display to see the image in correct perspective and size, important for sharing a workspace. Research into screen materials is needed because the de-polarization that comes from looking at screens at very oblique angles creates ghosting that is more an issue with duo-view than normal stereo.

6.5. CAVEscope: Simulating Variable Resolution Displays

Both the CAVE and the ImmersaDesk trade off wide angle of view for resolution. Human vision, though, is acute only for a very narrow angle, the approx. 5 degrees of vision falling on the fovea. It would be desirable, therefore, to have adaptive resolution displays that, given eye tracking, could match human visual acuity in the area of the screen in this five-degree angle of view. In stereo, graphics engines currently achieve a resolution of 1280 x 1024 spread across 5 to 10 feet, a rather less-than-crisp display. Software techniques can be used to render more detail in the area of interest, but resolution in terms of pixels per square foot does not improve. The projectors now available cannot handle the dynamic horizontal scanning fluctuations needed for variable resolution display. CAVEscope (see Figure 6) , however, provides a way to approximate variable resolution in a CAVE setting.

Some flight simulators have elaborate mechanisms to inset high-resolution images at the pilot’s center of interest by using a second projector inset at higher resolution. Since CAVE users have much more freedom than a pilot to move and look around, this technique will not work well since the inset projector, whose image is positioned by a moving mirror, has a limited range of motion and focus. Instead, we are providing a high resolution (e.g., 1024 x 768 or 1280 x 1024) LCD display that one can move into the area of detailed interest. Such a display would be like a portal into a higher-resolution space. It will be suspended in the CAVE by a counterweighted mechanism, much like an X-ray machine in a dentist’s office. One would navigate in the CAVE as normal, with surround vision, but pull the CAVEscope into place when high resolution is needed. The

VR Device	Size	Display	Cost	Enhanced Performance Features
ImmersaDesk3	Desktop	42” Plasma panel	Low	Desktop VR, variable angle of use, 42” display gives wide angle of view; more reliable, user-friendly, flexible, easily acquired, operated, maintained
PARIS	Desk and Above	2 LCD or DMD projectors, later large stereo panel	Medium	Integrates gesture, facial recognition, hands-in display, good for Tele-Immersion, desktop stereo VR. Very bright, large screen. Passive stereo and lightweight glasses possible and desirable.
P3	Desktop	5 Plasma or LED panels, possibly LCDs	High, but much less than CAVE	Very immersive if in stereo and if perfectly executed. Small version of CAVE. Brighter, more reliable, user-friendly, easily operated and maintained
TAWS	Cubicle in 20’x20’ room	4 or 5 DMD projectors, possibly large panels, or laser	High, but much less space than CAVE	Dilbert’s Dream. Simulates capabilities of cubicle made of large high-resolution panels. Can include ceiling display. Very bright,very immersive. Intriguing conceptual model for for the future workspace
CAVEscope	In CAVE	LCD mono panel, with touch, later stereo panels	Medium, enhances CAVE	Simulates variable resolution large display. Improves accuracy, resolving power, user-friendliness. Can be used alone or with any projection VR device. Can incorporate touch panel for input

Cost: High means $>$\$500,000 w/computer, Medium means approx \$150,000 w/computer, Low means $<$\$50,000 w/computer. A four- screen CAVE with newest Onyx rack lists for approx \$1,500,000. With compromises, one can build a very usable CAVE for approx \$350,000.

Figure 9. Summary of Proposed VR Instrumentation Features

CAVEscope will be tracked so that it can present the proper projection. Touch screen technology could also be available for user input. A miniature television camera mounted on the CAVEscope will assist in Tele-Immersion implementation studies. Users can see and talk to each other using CAVEscopes, or position their devices for coverage relevant to the task at hand. CAVEscope combines the intuitive navigational capabilities of the CAVE with the detailed view of the LCD portal, all under user control.

Since LCD panel technology does not permit stereo (due to high lag) at this point, we will work with a mono image. We hope that plasma or LED technology will provide

VR Device	Minimum Graphics Computer Requirements	Research and Development Efforts
ImmersaDesk3	Desktop SGI or any NT PC with single stereo pipe*	Plasma panels are not stereo (yet). Resolution is low currently, although size (42”) is fine. Will have to work with manufacturers.
PARIS	Deskside SGI with multi-screen option** or dual-pipe PC (e.g., Intergraph)	Achieving stereo this way is new for EVL. The structure holding the projectors will be a design challenge. Integrating video cameras and gesture/facial recognition with stereo displays needs R&D.
P3	SGI Onyx rack*** with 3-5 pipes	Border-less display difficult to achieve. Not stereo (yet). Video camera placement problematic. Resolution currently low to medium.
TAWS	SGI Onyx rack with 3-5 pipes	Desk surface material must be transparent but not reflective. Desk position and angle needs to be variable. Needs room for rear projection until hi-res stereo 70” plasma panels available.
CAVEscope	Extra pipe in CAVE Rack SGI or PC with stereo pipe	Construction is a challenge. Choice of right size/resolution LCD panel is critical. Stereo is desirable but difficult.

* Pipe is shorthand for ‘pipe-line’ and refers to the graphics engine.

* A high-end SGI pipe can drive two screens with this option.

** A rack (as opposed to deskside or desktop) configuration is currently required for >1 pipe/2 screens.

Figure 10. Summary of Proposed VR Instrumentation R&D Efforts

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[23] Web Addresses

ANS	www.advanced.org/teleimmersion.html
Alliance	alliance.ncsa.uiuc.edu
CAVERNUS	www.ncsa.uiuc.edu/VR/cavernus
DMD	www.electrohome.com
	store.infocus.com/lp420/index.htm
	www.ti.com/dlp/docs/business/
EVL	www.evl.uic.edu
FLC	www.displaytech.com
Internet2	www.internet2.edu
LCD	www.nec.com
	www.angleview.com
	www.electrohome.com
LED	www.lumagraph.com/lumatile.html
	www.daktronics.com/PAGES/Prostar.HTM
	www.microweb.com/kwu/fdisplay.html
Next Gen. Internet	www.ngi.gov
Panoram	www.panoramtech.com/
Plasma panels	www.nec.com
	www.fujitsu.com
Pyramid Sys.	www.pyramidsystems.com
STAR TAP	www.startap.net
Tele-Immersion	www.evl.uic.edu/spiff/ti
VRex	www.vrex.com