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Abstract. The emergence of inexpensive 3D-TVs, affordable input and rendering hardware and open-source software has created a yeasty atmosphere for the development of low-cost immersive systems. A low cost system (here dubbed an *IQ-station*), fashioned from commercial off-the-shelf technology (COTS), coupled with targeted immersive applications can be a viable laboratory instrument for enhancing scientific workflow for exploration and analysis. The use of an IQ-station in a laboratory setting also has the potential of quickening the adoption of a more sophisticated immersive environment as a critical enabler in modern scientific and engineering workflows. Prior work in immersive environments generally required special purpose display systems, such as a head mounted display (HMD) or a large projector-based implementation, which have limitations in terms of cost, usability, or space requirements. The alternative platform presented here effectively addresses those limitations. This work brings together the needed hardware and software components to create a fully integrated immersive display and interface system that can be readily deployed in laboratories and common workspaces. By doing so, it is now feasible for immersive technologies to be included in researchers' day-to-day workflows. The IQ-station sets the stage for much wider adoption of immersive interfaces outside the small communities of virtual reality centers. In spite of this technical progress, the long-term success of these systems depends on resolving several important issues related to users and support. Key among these issues are: to what degree should hardware and software be customized; what applications and content are available; and how can a community be developed?

1 Introduction

Immersive environment (IE) systems, also known as virtual reality (VR) systems are a unique medium that offers the opportunity for natural interactions with a simulated world. The potential for natural interaction stems from taking into account the physical movements of the user when rendering the simulated, or virtual, world. This feature is referred to as "*physical immersion*" [1].

Since the early 1990's, immersive environment systems have closely followed the predicted path defined by Gartner's Hype Cycle for new technology [2] depicted in Figure 1. The technology trigger was the 1989 release of commercially

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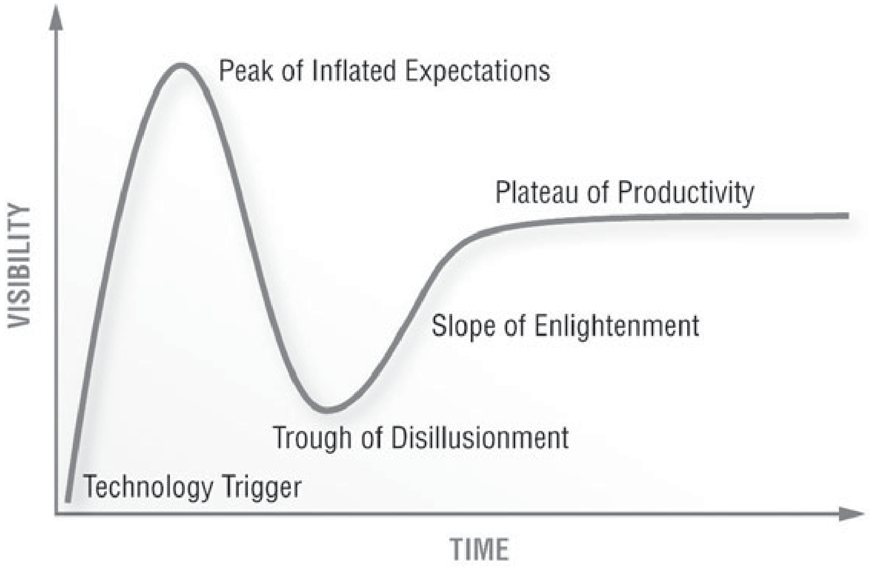

Fig. 1. Gartner's Hype Curve for new technology. Immersive technologies (aka VR) have moved beyond the *Trough of Disillusionment* onto the *Slope of Enlightenment*.

produced equipment enabling virtual reality — such as stereoscopic displays, glasses and three-dimensional position tracking systems. By the mid 1990's, immersive environments reached the peak of inflated expectations, where the technology was, and still is, frequently compared to Star Trek's Holodeck. Predictably unable to live up to these expectations, immersive environments fell into the trough of disillusionment. Weaknesses in the technology of the time included insufficient networking, rendering and computational power. Improvement in these areas was inevitable according to Moore's Law, but the computer gaming market and industry further accelerated advancements. The resulting improvements pushed the technology up the slope of enlightenment creating an "immersive environments renaissance" by the end of the 2000–2010 decade. One can argue that there is a substantial amount of work ahead to reach immersive environments' plateau of productivity for scientific and engineering workflows, but the technology seems to have turned the corner, putting it on the right side of Gartner's Hype Cycle.

1.1 Demonstrated Usefulness of Immersive Environments

Successes in using immersive environments to enhance scientific and engineering workflows have been demonstrated at several laboratories. Researchers at Brown University explored the effectiveness of microbiologists (graduate students, research associates and professors) in performing practical workflow tasks [3]. Their study compared the use of a CAVE^{TM}, an immersive fishtank display and a standard desktop environment in analyzing three-dimensional confocal microscopy data. The testing of common tasks for microbiologists exhibited a statistically significant improvement as immersion increased, moving from a desktop up through a CAVE.

Atmospheric researcher Gil Bohrer reports that the CAVE at Duke University was instrumental in aiding his research by acting as the catalyst for a discussion on how forest canopies affect local atmospheric air flow [4]. Once the initial insight was obtained, the CAVE had served its purpose and the workflow returned to traditional desktop visualization tools.

These efforts extend earlier work from the National Center for Supercomputing Applications (NCSA) where the Crumbs project used a CAVE as a visualization tool for a variety of volumetric datasets, including MRI and confocal instruments [5]. This early effort clearly revealed that for some data analysis, the immersive system provided both crucial insights and significant time savings in analyzing the data, and became a part of the research workflow.

1.2 Missing Links

The need for more natural and effective interfaces for immersive environments is real and growing. As described in the 2006 NIH/NSF report on visualization research challenges [6], “Fluid interaction requires that we create user interfaces that are less visible to the user, create fewer disruptive distractions, and allow faster interaction without sacrificing robustness.” What Johnson et al. were calling for is in fact the essence of immersive interfaces. This is the “missing link” that immersive environments provide. This need was echoed in an NSF sponsored workshop by presenters and attendees alike [7].

Another critical “missing link” is the availability of immersive displays. Low-cost VR workstations can bring immersion to the masses almost like the advent of the personal computer made computing available to the broad public. Projector-based immersive environments are generally costly and require a large amount of space. HMDs are often cumbersome, small, and focused on an individual. The 3D-TV based IQ-station represents a middle ground that provides a solution available and usable by a much wider audience.

2 Development of Low Cost Immersive Systems

The Desert Research Institute (DRI) was among the first to implement a low-cost VR workstation using the first generation of commodity 3D-TV screens. (Similar efforts were also taking place at the University of California, Davis.) Development of this system evolved over the course of the past three years. The earliest prototypes began as systems that would augment DRI’s primary immersive facilities that included a 4-sided FLEX/CAVE^{TM}with a 6-sided system in the works. The ability to purchase a large stereoscopic display at a local retail outlet was the catalyst around which the system was created. Combined with a reasonably priced turnkey 3D position tracking system, low-cost immersive systems were made viable. Indiana University (IU) built upon these initial experiences at DRI. Subsequently the system has been dubbed the Inexpensive Interactive Immersive Interface (*I-quaded-*, or *IQ-*) *station.*

The IQ-station is an instantiation of fishtank-style VR — a stereoscopic single screen display with head tracking. Our implementation of the IQ-station also derives from the community building aspect of the early CAVELib and GeoWall communities [8]. Our project brings together the combined benefits of the larger screen size and community of the GeoWall, and the physical immersion of VR. By building on the larger 3D-TV screens, more users can gather around the IQ-station, enabling more collaborative discussions. By fostering a community around a particular recipe the IQ-station further differentiates itself from a generic fishtank system that any individual might construct. Providing a specific recipe enables the concept to proliferate more quickly by allowing new groups to benefit from the testing and analysis of individual components without duplicating these efforts. Thus, the Idaho National Laboratory[1] (INL) leveraged the IU design to deploy the technology in a research engineering environment. Of course, tweaking a recipe for local requirements or tastes is appropriate. For example, the default screen orientation for an IQ-station is vertical, but when using flat-screen displays, other choices are possible — such as drafting style (ala the ImmersaDesk™) or table-top (Responsive WorkBench™). Thus the advance, is both in form and increased functionality through community.

Integrating a turnkey system benefits from a formal prescription for hardware assembly, middleware software, and end-user applications. In the following subsections, we describe some of the available options, and choices made as an evolutionary outcome of usage, experience, and technology improvements of the past two years.

2.1 Hardware Recipes

There is a wide range of hardware options possible, depending on the desired ergonomics and budget constraints. On the very low-end, many home users may be able to assemble a VR system with hardware components already at home (the you-pick-it recipe). Stepping up from there, the next tier is at about \$10K–\$15K (the home-style recipe), and for the gourmand, \$25K is sufficient to produce a highly-capable, beefier system.

Given that physical immersion is a necessary feature of a VR workstation, the 3D position tracking system is crucial. This is the component that gives the system the ability to render the virtual world from the changing perspective of a user as they move. A visual display is also required of course, and usually for immersive experiences a stereoscopic display is preferred. For fixed-screen displays (such as monitors and projectors), the stereo effect usually requires a pair of specialized glasses for each viewer. Finally, a computing system capable of simulating and rendering the virtual world is needed. Of course, a way to mount or position the system is handy, so our recipes include this as a component as well.

There are a number of ways to produce low-cost 3D position tracking. A method popularized by CMU researcher Johnny Lee [9] uses the internal camera and software of a Nintendo Wii™game controller (aka "Wiimote") to calculate

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[1] References herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the U.S. Government, any agency thereof, or any company affiliated with Idaho National Laboratory.

the translational offset between a pair of infrared LEDs and the Wiimote. Similarly, one can take a video camera connected to a computer and use a software toolkit to analyze the view and make a position calculation. One freely available toolkit that uses fiducial markers to accomplish this is the ARToolkit [10] [11]. A third option that also makes use of video technology is the OptiTrack™system from NaturalPoint that uses multiple infrared cameras to track clusters of retro-reflective markers. Marker reflections are used to calculate the location and orientation values. This is the most expensive of the listed technologies, but at about $5K for a 6-camera set, it is still quite reasonable — a $3K, 3-camera option is also available, but is less robust, working better in a ceiling mounted configuration, thus sacrificing mobility. As this software is restricted to Microsoft Windows, users of other operating systems should either add approximately $1K to the cost of this system for a separate tracking PC, or allow some of their primary compute cycles to be used as a virtual machine for this software.

There are tracking technologies other than those using video, but they do not quite match the needs of a large screen-based VR station. For example, inertial devices can calculate relative movements and rotations, but while an HMD-based immersive system can tolerate the inexactness of these devices, the IQ-station cannot. Electromagnetic tracking systems are capable of producing sufficient position tracking, but are somewhat higher in cost for a comparable tracking volume. For a complete discussion on available tracking technologies, an introductory textbook on VR is recommended [1].

In the 2007/2008 time frame, commercial television manufacturers, in particular Samsung and Mitsubishi, began releasing models featuring stereoscopic output using Digital Light Processing™(DLP®) projection technology. These systems functioned well, though were 16-24” deep to accommodate their projection nature. By the outset of 2010, it was quickly evident that 3D-TV technology had truly come of age. The Consumer Electronics Show in Las Vegas was awash with 3D. This explosion of new models and technologies aimed at the consumer 3D market has been driven by the re-invasion of the 3D theatrical movie. The result is a large selection of 3D-TVs to choose from, with the predictable price decreases and improvements in form factor, such as going from ∼18” deep projection to only 3” deep plasma, and 1” LCD and LED devices. As these are not “auto-stereo” displays, stereo-glasses are still required. Fortunately, the cost of these glasses has also fallen from $700 or more to under $150 to accommodate the mass market.

The last major component of the system then is the simulation and rendering computer. Depending on the complexity of the virtual world, the cost for this system could feasibly range from $1.5K to $10K. A typical system will include a professional level GPU card (such as the nVidia Quadro™), which puts the cost of the computer in the $5K range. But for graphically simple worlds this might be overkill.

Finally, there is the physical positioning and securing of all the components. This could be as simple as a TV display table or wall-mounting bracket. On the more elaborate end of the scale, one could consider a rolling flat-panel mount, or perhaps two, with a second mount for a display for the tracking

Fig. 2. The IQ-station, a mobile integrated immersive display system. This model uses two PCs, one for tracking and one for rendering.

computer which might also include other inputs, perhaps even screen-touch inputs. Another option is a multi-tiered or even a motorized elevating table, such as available from Anthro^{TM}. Whatever the choice, if one chooses to use video technology for the position tracking, then a means of mounting the camera(s) must also be incorporated. By directly mounting the cameras to the platform, the system is made mobile. Accurate software-hardware calibration is essential for immersive environments and requires a stable physical relationship between the display screen and the tracking system. Table 1 presents the costs of the standard (IU), advanced (INL) and minimal IQ-station systems. All cases use an OptiTrack^{TM}tracking system, however the minimal case uses fewer cameras. IU selected a 67" Samsung DLP, whereas INL opted for the 73" Mitsubishi DLP. On the computing side, INL has included a multi-CPU system with a robustly sized RAM. To accommodate larger audiences, INL also opted to include ten pair of the more robust style of stereoscopic glasses. This is all combined on the multi-tiered Anthro^{TM}table (Figure 2).

2.2 Software Systems

Frequently, the selection of the underlying software will be made in conjunction with the system's hardware. The decision is intertwined because one must choose hardware that will operate with the selected software. Furthermore, the application software will often dictate what middleware libraries and device drivers are required. Here we describe the two VR integration libraries commonly used with the IQ-station. These two libraries are Vrui [12] developed at the University of California, Davis, and FreeVR [13].

As mentioned, our systems use the NaturalPoint OptiTrack^{TM}system. OptiTrack includes a software suite that generates tracking data in common VR

Table 1. Approximate IQ-Station costs in USD

Component	IU	INL	Minimal
Optical tracking system	\$5,000	\$5,000	\$3,000
Optical tracking computer	\$1,000	\$1,000	\$500
3D TV display	\$2,000	\$2,000	\$2,000
3D glasses	\$500	\$3,000	\$500
Visualization computer	\$5,000	\$10,000	\$1,500
Table and mounting hardware	\$1,500	\$4,000	\$1,500
Total	\$15,000	\$25,000	\$9,000

protocols (VRPN and trackd™), so from the VR library perspective, it receives a standard input stream.

Both the FreeVR and Vrui libraries are full-featured virtual reality integration libraries. That is to say, both handle the interface to the input and output systems, make the perspective rendering calculations, and then allow the end-user application to simulate and render the virtual world. Both required special adaptation to handle the "checkerboard" style of left-right eye renderings. There are pros and cons to each library, but fortunately both can peacefully coexist on the same system. Both work on Unix-style operating systems, including Linux and OS-X. One benefit of Vrui is that it includes a set of 3D widgets that can transition from a desktop interface to an immersive interface. Vrui also includes a specialized interface to the Wiimote. FreeVR allows for the quick porting of many existing VR applications. FreeVR also has a full-featured and formally defined configuration system.

In the end, one only needs to choose one or the other when developing a new application. For deploying an existing application, the choice will have been made by the application developer.

3 Applications

An integrated low-cost hardware scheme, and middleware software are necessary, but not sufficient to be a tool useful for the scientist, engineer, or other end-users. To complete the package, end-user applications must be included. Representative applications include a pre-existing volume visualization tool ("*Toirt Samhlaigh*"), and a world walk-through application suitable for training workers who need to become familiar with real-world physical operations.

3.1 Volume Visualization

Toirt Samhlaigh, our volume visualization tool, is built upon the virtual reality user-interface (Vrui) toolkit. Vrui enables visualization in an immersive environment by providing a collection of classes to facilitate the development of immersive applications. To meet the unique performance constraints required for implementation in an immersive environment, we utilize an approach to accelerate GPU-based volume visualization, using a heterogeneous data structure [14]. Visualization of large volumes is facilitated through an empty-space leaping data structure traversal using tailored termination criteria.

The resulting application has been used in several imaging-based laboratories. Toirt Samhlaigh has been used successfully in a geology laboratory examining Green River shale for composition in oil-shale using data from an electron microscope; in a microbiology laboratory for examining micro organism ecosystems in a Tunicate from a confocal microscope; and has been used to manipulate medical imaging data from MRI and CT imaging equipment as depicted in Figure 3 (a).

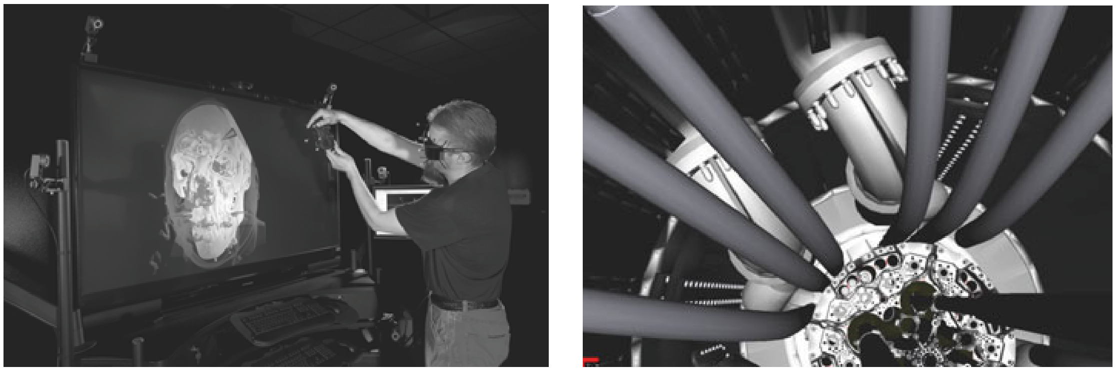

Fig. 3. Left: (a) Here a user manipulates a clipping-plane through computer tomography (CT) data using the Toirt Samhlaigh immersive application. Right: (b) A view looking downward in the ATR reactor vessel. Details shown include: serpentine reactor core, channels and tubes for experiments and large pipes for cooling water.

3.2 Training via World Walk-Through

INL's Advanced Test Reactor (ATR) operates a water cooled, high flux test reactor for scientific purposes. To support engineering, training, and the National Scientific User Facility mission of the ATR, a VR application was developed to use 3D CAD drawings of the facility and present a virtual tour, which is based on Delta3D[15] combined with either Vrui or FreeVR (Figure 3 (b)). The immersive environment provided by the IQ-station, coupled with this application, creates an effective training medium that communicates important technical information much more quickly and accurately than simply reviewing paper drawings or computer images with a typical 2D user interface.

Engineers, maintenance staff, subcontractors, and operators use the virtual ATR application running on an IQ-station for interactive exploration of the ATR components and facility. The combination of a portable immersive workstation and the easy-to-use application, create an ideal environment for discussion of features, design, and operating characteristics without the access and scheduling limitations of visiting the real facility. New staff paired with experienced staff in front of an IQ-station are able to engage in highly effective knowledge transfer that might not be possible by traditional means. This project has been very successful and generates numerous requests for enhancements and additional immersive environment interactions such as interactive component change-out and reactor physics overlays.

4 Experiences

The value of even a relatively low-cost VR system can only be realized when the end-users find the system sufficiently useful that they are willing to overcome the barriers of an existing workflow and actively exploit it. On the flip-side, without a workable development environment (which includes a support community), the costs of maintaining and upgrading systems with low-cost hardware can outweigh the benefits.

4.1 The User Experience

One benefit of the VR libraries used by our applications is that both were designed to scale between large and small immersive display systems. Thus, users do not have to become familiar with new user interfaces as they transition between an IQ-station or a CAVE, for example. The Vrui-based applications also run reasonably well on traditional desktop workstations (though most users will likely be migrating from other analysis tools). We might consider the range of interface systems to be a “pyramid” ranging from the highly immersive but rare 6-sided CAVE all the way down to the non-immersive but ubiquitous desktop, with the IQ-station a step or two above the desktop. This ability to move up and down the pyramid can be beneficial in both directions — allowing sites with existing high-end immersive systems to spread their wealth and promote their immersive applications to a wider community; and for sites just entering the fray, an IQ-station can be a gentle introduction to the benefits of the physically immersive interface.

4.2 Development Experiences

There are many trade-offs to evaluate in determining a suitable system for one’s user community. By sharing the lessons learned through this process, we help others avoid rediscovering these same trade-offs and more quickly find the right technologies for them.

Hardware Development. Riding the wave of consumer technology certainly can bring us to the point where we can deliver functional immersive systems that improve our ability to work with large collections of data. However, there are hazards when we rely too much on technology that has a short model-life and targets general users rather than the special-purpose needs for immersive displays. Thus, the whims of the consumer-driven marketplace means that manufacturers of 3D display hardware no longer need to focus on the issues of whether the systems will be more or less usable in a research setting. Whether for ease of use, or locking customers into proprietary environments (for repairs/replacement, or expansion) consumer options often mean less flexibility and in some cases less usability for systems aimed at improving scientific workflow. The flux of the consumer display models suggests that if there is a desire for a fleet of similar units, it is prudent to purchase a sufficient quantity of displays from the outset, whereas the tracking and computing technologies are less susceptible to the whims of the consumer marketplace.

Thus, during this period of great flux, there are many considerations to take into account when choosing a display technology. The DLP technology uses projection systems, resulting in deeper units that cannot be tilted. The positive side of DLP systems is that they are available in larger sizes (up to 82”) and suffer less from stereo-separation interference (ghosting) and burn-in. LCD and Plasma systems can be very thin, opening up a variety of mounting options, including drafting or table-top styles, and are also somewhat more mobile. However LCD and Plasma systems are limited in size (up to 62”) and do suffer from ghosting, and more noticeable burn-in effects. Unlike computer monitors, the modern HDTV specifications (1.4) require that the TV itself generate the stereo synchronization signal. The result of this requirement is that it becomes impossible to synchronize multiple screens together. Whether there is a problem with vendor lock-in is on a model by model basis. Overall, the DLP solutions are still the best options, but at least one manufacturer (Samsung) has already discontinued their line of DLP displays. A third option is the “pro-sumer” stereoscopic display from JVC (model GD463D10) which provides stereo separation through polarizing filter technologies (dubbed Xpol®). The benefits come from requiring only inexpensive glasses, and not suffering from the multi-screen synchronization problem. The problem with the display is that 46” is the only size available, and thus larger displays require the extra complications of tiling[16].

Software Development. Benefits of using highly-customized software include the ability to adapt for new hardware, such as when 3D-TVs and “Wiimotes” were hitting the marketplace, plus the ability to adapt to requests that arise from the user community. On the other hand, tools developed for a wide audience (i.e. “generic tools”) benefit from their ability to be more widely deployed and therefore generate a larger user base. If a community is supported, then generic tools can become self-supporting through a user community that helps it’s own.

The questions are: is there a middle ground, and does aiming at the middle ground reduce the potential user base? Perhaps some of the generic tools can be adopted to work with off-the-shelf components. This possibility is increased when the hardware vendors choose to make use of existing standards. For example, many of the early 3D-TVs worked with existing stereoscopic glasses and emitters. Also, some OpenGL drivers (such as the nVidia Quadro$^{\text{TM}}$) were adapted to convert the traditional left and right rendering buffers into a checkerboard stereo format. Both of these aspects eased the development process of the IQ-station.

Another example includes the use of the existing VRPN and trackd^{TM}position tracking protocols by the OptiTrack^{TM}rigid body tracking suite.

Application Development. Software plays an important role in the success of an IQ-station. The most significant predictor of project success with the IQ-station is the quality of the applications that are developed to utilize the immersive display.

Understanding user requirements and proper implementation of immersive user interfaces should be the priority of any organization considering deployment of an IQ-station. Of course, if the purpose of the IQ-station is to jump-start IE development then this system is an ideal place to start.

5 Conclusion

A new plateau has been reached in the realm of immersive interface technologies by taking advantage of recent product developments to produce an integrated system that performs as a useful tool, not merely a research prototype. Beyond integrating disparate hardware components, existing immersive software tools were adjusted to ensure their usability on these smaller-scale immersive systems. Ultimately, the achievement that is important is that there is now a fully functional immersive system that can be deployed where the research is taking place. By moving the equipment out of the computer science research lab and into the domain science labs, domain researchers have begun to fully incorporate this technology into their day-to-day operations.

Not all computing needs are met by portable smart phones and not all applications require a supercomputer. A desktop computer is a good compromise that serves the needs of a large segment of computer users. In a similar manner, the IQ-station has the potential to serve the needs of a large segment of users. As immersive environments grow in popularity and expand into everyday activities, a solution such as the one presented in this paper, effectively fills the need for many users. As a laboratory instrument, an architecture evaluation system, or as a scientific discovery tool, the use of these systems will quickly expand and support the next generation of immersive environment applications.

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References

1. Sherman, W., Craig, A.: Understanding Virtual Reality. Morgan Kaufmann Publishers, San Francisco (2003)
2. Fenn, J., Raskino, M.: Mastering the Hype Cycle: How to Choose the Right Innovation at the Right Time. Harvard Business School, Boston (2008)
3. Prabhat, F.A., Katzourin, M., Wharton, K., Slater, M.: A Comparative Study of Desktop, Fishtank, and Cave Systems for the Exploration of Volume Rendered Confocal Data Sets. IEEE Transactions on Visualization and Computer Graphics 14, 551–563 (2008)
4. Bohrer, G., Longo, M., Zielinski, D., Brady, R.: VR Visualisation as an Interdisciplinary Collaborative Data Exploration Tool for Large Eddy Simulations of Biosphere-Atmosphere Interactions. In: Bebis, G., Boyle, R., Parvin, B., Koracin, D., Remagnino, P., Porikli, F., Peters, J., Klosowski, J., Arns, L., Chun, Y.K., Rhyne, T.-M., Monroe, L. (eds.) ISVC 2008, Part I. LNCS, vol. 5358, pp. 856–866. Springer, Heidelberg (2008)
5. Brady, R., Pixton, J., Baxter, G., Moran, P., Potter, C., Carragher, B., Belmont, A.: Crumbs: a virtual environment tracking tool for biological imaging. Biomedical Visualization 82, 18–25 (1995)
6. Johnson, C., Moorhead, R., Munzner, T., Pfister, H., Rheingans, P., Yoo, T. (eds.): NIH/NSF Visualization Research Challenges Report. IEEE Press, Los Alamitos (2006)
7. Sherman, W.R., O'Leary, P., Kreylos, O., Brady, R.: IEEE Visualization 2008 Conference Workshop on Scientific Workflow with Immersive Interfaces for Visualization. In: Sherman, W.R., O'Leary, P., Kreylos, O., Brady, R. (eds.) Proceedings of the IEEE Visualization 2008 Conference. IEEE Press, Columbus, OH (2008)
8. Johnson, A., Leigh, J., Morin, P., Van Keken, P.: GeoWall: Stereoscopic Visualization for Geoscience Research and Education. IEEE Computer Graphics and Applications 26, 10–14 (2006)
9. Lee, J.: Head Tracking for Desktop VR Displays using the WiiRemote (2007), `http://www.youtube.com/watch?v=Jd3-eiid-Uw`
10. Kato, H., Billinghurst, M.: Marker Tracking and HMD Calibration for a Video-Based Augmented Reality Conferencing System. In: IWAR 1999: Proceedings of the 2nd IEEE and ACM International Workshop on Augmented Reality, Washington, DC, USA, p. 85. IEEE Computer Society, Los Alamitos (1999)
11. Kato, H.: ARToolKit (1999), `http://www.hitl.washington.edu/artoolkit`
12. Kreylos, O.: Environment-Independent VR Development. In: Bebis, G., Boyle, R., Parvin, B., Koracin, D., Remagnino, P., Porikli, F., Peters, J., Klosowski, J., Arns, L., Chun, Y.K., Rhyne, T.-M., Monroe, L. (eds.) ISVC 2008, Part I. LNCS, vol. 5358, pp. 901–912. Springer, Heidelberg (2008)
13. Sherman, W.: Commodity-Based Projection VR: Software for Virtual Reality. In: SIGGRAPH 2004: ACM SIGGRAPH 2004 Course Notes. ACM, New York (2004), `http://freevr.org/`
14. O'Leary, P., Sherman, W., Murray, A., Riesenfeld, C., Peng, V.: Enabling Scientific Workflows Using Immersive Microbiology. In: Sherman, W., O'Leary, P., Kreylos, O., Brady, R. (eds.) Proceedings of the IEEE Visualization 2008 Conference. IEEE Press, Columbus (2008), DVD
15. Darken, R., McDowell, P., Johnson, E.: Projects in VR: The Delta3D open source game engine. IEEE Computer Graphics and Applications 25, 10–12 (2005)
16. DeFanti, T., et al.: The Future of the CAVE. Central European Journal of Engineering (to appear, 2010)