Army Research Laboratory

An Augmented Virtuality Scientific Data Center

by Jerry Clarke, John Vines, and Eric Mark

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Jerry Clarke, John Vines, and Eric Mark
Computational and Information Sciences Directorate, ARL

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14. ABSTRACT

Augmented Virtuality can be effective in the analysis of physics-based computational simulations. By providing context and additional detail not always available in purely virtual systems, the effective addition of physical objects into a virtual scene greatly enhances the intuitive objective of the original calculation.

The U.S. Army Research Laboratory has developed an Augmented Virtuality system for the investigation of physics-based simulations. Constructed from commodity components, unique projection screen material, and custom software, this system provides a novel approach to the investigation of results from a multitude of computational areas.

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1. Introduction

Physics-based simulation codes regularly focus on some detailed aspect of an entire system. For example, a computational structural mechanics simulation of a kinetic energy penetrator impacting a tank might only concentrate on a portion of the armor instead of the entire vehicle. To effectively analyze and present the results, it is imperative to put the simulation in context.

In addition, the computational simulation might be run with a simplified version of the complete system that only incorporates the detail that is germane to the calculation.

It can therefore be beneficial to incorporate Augmented Virtuality techniques into the analysis in order to provide context and provide additional detail not always available from the virtual model.

Paul Miligram[1] is credited with the term "Augmented Virtuality," which identified systems which were primarily synthetic with some real-world imagery added to the virtual objects, as shown in figure 1.

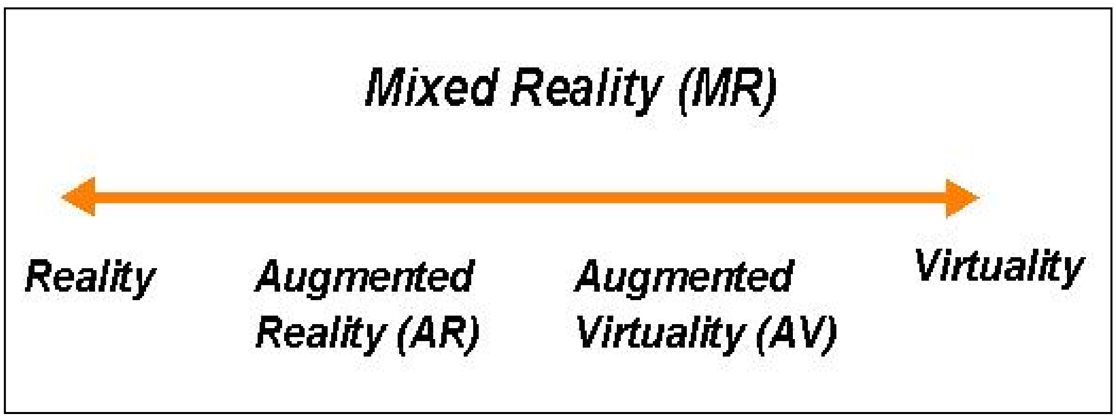

Figure 1. Miligram's reality-virtuality continuum.

Commodity-based virtual reality systems have recently blossomed primarily due to the increased computational and graphical capability of cost-effective PC systems. Combined with relatively low-cost bright projectors, a single rear-projection stereoscopic system can be built for under $15,000. Impressive systems like the FlatWorld project at the University of Southern California's Institute for Creative Technology,[2] combine these rear-projected screens with modular theatrical components and three-dimensional (3-D) spatial audio in order to deliver a scalable, reconfigurable training and simulation environment.

[1] Miligram, P. *The 23rd Army Science Conference*, Orlando, FL, 2–5 December 2002.

[2] Flatworld: *A Mixed Reality Environment for Simulation and Training.* University of California Institute for Creative Technology.

Systems like FlatWorld, the CAVE (CAVE Automatic Virtual Environment), and the NAVE (Nonexpensive Automatic Virtual Environment), etc., have advantages over head-mounted displays (HMDs). The main advantage is the "shared experience" of a group. This is a major contribution to the success of many theme park attractions, like those found in Orlando, FL. Using "mixed reality" techniques to combine real and virtual objects with spatial audio systems, they demonstrate the ability to convince a group to collectively "suspend reality" for some purpose, like entertainment or training.

But the application of these mixed reality techniques to physics-based simulations is not obvious. Exactly how would adding sound to a molecular visualization increase the insight of the user? What real object could one add to an electromagnetic wave simulation to better explain the demonstrated phenomenon?

2. The Reality Sandwich

An inherent aspect of traditional projection screens is that even with stereoscopic projection, real objects can never be in front of virtual objects, they would block the projection of the virtual image. Using a unique transparent material called "TransFilm," however, we are able to project stereoscopic images that appear to be in front of real objects. TransFilm[3] has the special property of preserving the polarization of light, a property not shared by other transparent screen materials. By adding a traditional rear projection system, we can create a "reality sandwich," consisting of Virtual-Real-Virtual objects sandwiched together as shown in figure 2. Naturally, additional configurations are now possible (Real-Virtual-Real, etc.).

The transparent screen approach differs from other efforts like the "Being There" project[4] where synthetic textures are projected onto real objects. With a transparent screen, virtual objects are not visually limited to the surface of the object.

We have observed that one must pay great attention to proper lighting. While real objects must be brightly lit, ambient light on the TransFilm ruins the apparent "holographic" effect.

The effect of semi-transparent objects that appear to hover in mid air is not new. In fact, there is a well-known technique called "Pepper's Ghost" that is used in such places as the Haunted Mansion at Walt Disney World in Orlando, FL. The name is taken from Professor John Henry Pepper, who amazed audiences in the late 1800s with the illusion of a transparent ghost that seemed to hover in mid air above the stage. It's a simple technique that consists of nothing more than the reflection on an angled piece of glass.

[3] TransFilm. Laser Magic Productions, Los Angeles, CA; http://www.laser-magic.com/transscreen.html.

[4] Kok-Lim, L.; Welch, G.; Lastra, A.; Fuchs, H. Life-sized Projector-Based Dioramas. *Proceedings of ACM Symposium on Virtual Reality, Software and Technology (VRST 2001)*, Banft Calgary, Canada, November 2001.

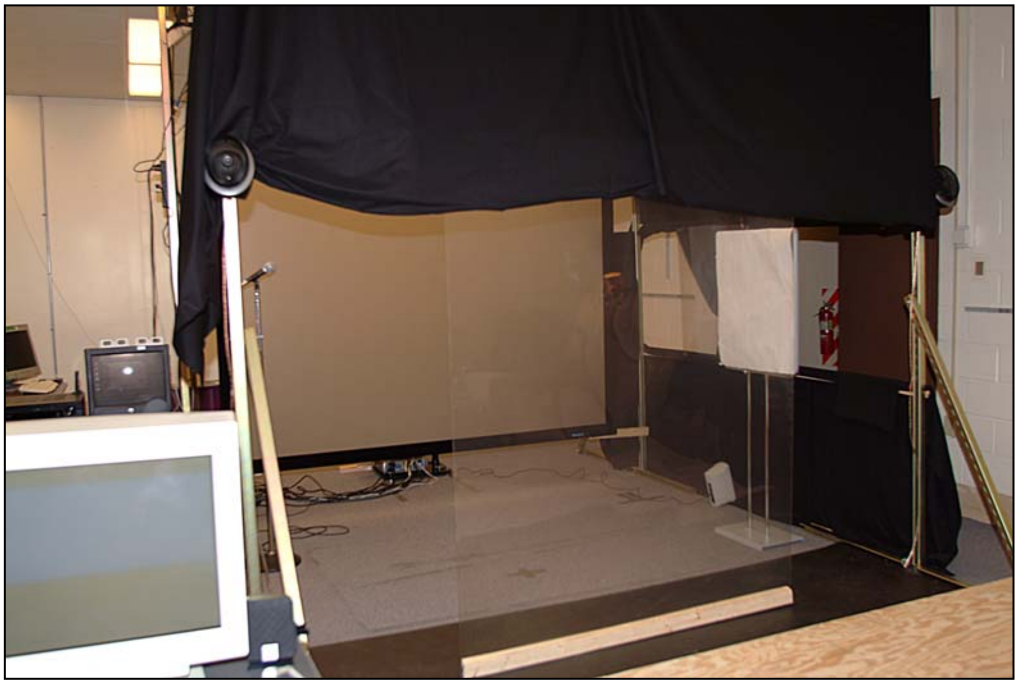

Figure 2. Augmented Virtuality prototype system at ARL.

3. Data Sonification

But visual representation is only part of the puzzle. For a total immersion into simulation, the Scientific Visualization (Sci Vis) team is using established "data sonification" techniques to place 3-D spatial sounds in the environment. This allows for more dimensions of data to be simultaneously experienced than would be possible with visual techniques alone.

According to H. G. Kaper[5] of the Scientific Sonification Project at Argonne National Laboratory, "Sound, alone or in combination with visual imaging techniques, offers a powerful means of transmitting information. It can significantly increase the bandwidth of the human/computer interface."

For example, if one were to launch a data probe into a volumetric dataset, the probe could change color in response to a scalar field. If the pitch of a sound were additionally varied in response to another scalar field, the user could intuitively glean the relationship between the two attributes.

The hardware to drive the sound is an Audigy 2 card from Creative Labs, which provides 6.1 surround-sound capability. A commodity audio/visual (A/V) receiver outfitted with a powered subwoofer and omnidirectional speakers are mounted around the audience.

[5]Kaper, H. G. MCS Division, Argonne National Laboratory: Argonne, IL; http://www.unix.mcs.anl.gov/~kaper /sonification.

Additionally, we have constructed a viewing platform and installed a device that isolates low-frequency audio signals and transforms them into tactile vibrations with a powerful piston. This allows the third sense of “feel” to convey additional data. Incidentally, the viewing platform performs the additional function of eliminating the “hot spot” from the audience’s view created by the TransFilm’s rear projectors.

4. Passive Stereoscopic Graphics

In addition to being less expensive than active systems, passive stereo has the advantage being more scalable in a distributed environment because multiple screens do not need to sync the video signal.

Currently, we are using dual InFocus LP650 Digital Micromirror Devices (DLP) projectors driven by a single NVIDIA GeForce 4 dual display graphics card.

For passive stereo, polarizing filters are placed over the projectors at right angles as shown in figure 3. Glasses with the same filter material are worn to pass the proper projected image to the correct eye.

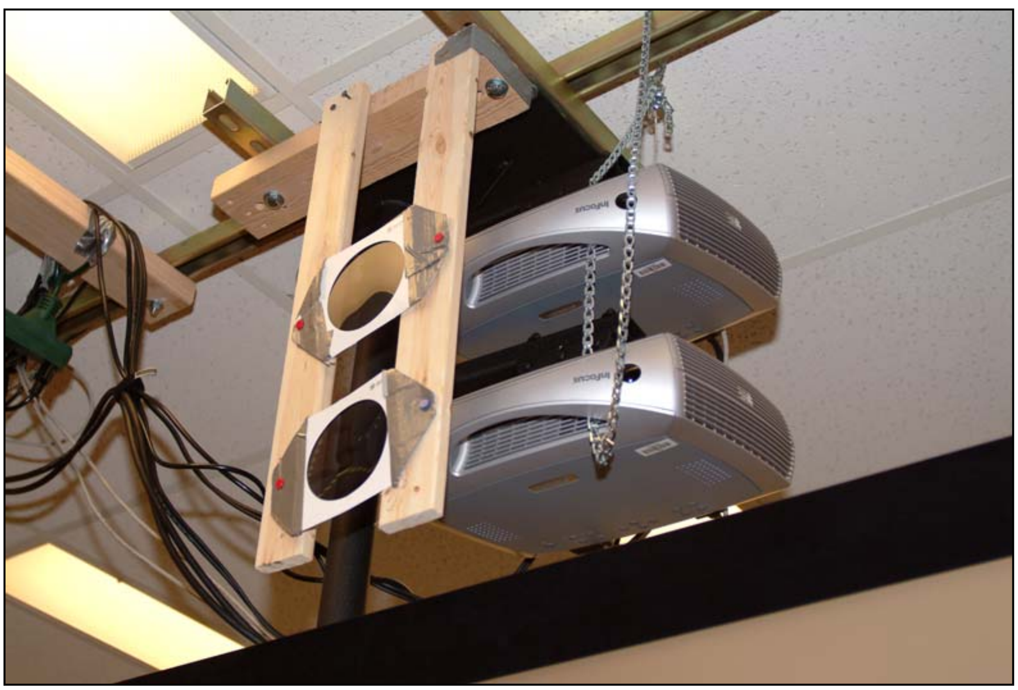

Figure 3. Dual DLP projectors with polarizing filters.

Because the projectors that the Sci Vis team are using require a 15-ft “throw” distance, they project the image onto an ordinary, but good quality, bathroom mirror. The image is then directed to the screen. Both the TransFilm and the traditional rear-projection screen must preserve the polarization of the light.

5. Nothing but Net

A major problem with systems composed of many individual parts is control. To assist in this area, great care has been taken to ensure that all parts are controllable via software. The projectors have a network interface and are controlled via a custom Python layer. Other electrical devices are controlled via an X10 interface that sends control signals across the standard electrical wiring. The Sci Vis team has developed a Python interface to the X10 controller so that applications can set the necessary lighting conditions without user intervention. Finally, hardware services that are only found on certain PCs, like the sound and speech on the node with the Audigy 2 card, are made available to other nodes via transmission control protocol/Internet protocol (TCP/IP) socket-based servers and listed in a common XML system description.

6. Software Integration

From the outset, an integrated system was envisioned. A PC-based Augmented Virtuality scientific data center is of little use without a scalable software interface.

Data from physics-based simulations come into the system via a common data model and format. We are using the "eXtensible Data Model and Format" (XDMF) developed at the U.S. Army Research Laboratory (ARL) to provide a common data interface for the development of scalable codes and tools on high-performance computing systems. XDMF combines XML and HDF5 from the National Center for Supercomputing Applications (NCSA) with a custom heterogeneous shared memory system to provide a common method to exchange data during runtime or for post-processing.

The visualization toolkit (VTK) is an enormous collection of visualization algorithms and graphics facilities. VTK has an XDMF reader which allows us to import data from many different codes into the VTK visualization pipeline.

The Sci Vis team is using a platform-independent software layer called OpenAL to place various sounds in 3-D space. OpenAL allows for the placement of multiple objects in 3-D space and for effects such as reverb and Doppler shift. An additional layer, EAX, allows for additional effects.

The Sci Vis team has added an additional, object-oriented convenience layer on top of OpenAL in order to easily place sounds in our environment and synchronize their movement with the graphical output.

Additionally, the team has developed another object-oriented convenience layer in order to interface with the Microsoft "Speech" facility to provide both a text to speech and speech recognition capability. This allows the entire complex system to be controlled via simple voice commands. For example, "Front Projectors On" and "Ceiling Lights Off" are two of the more useful commands of the system.

All of the various layers have been "wrapped" to provide an interface to the Python scripting language. Thus, all applications are developed at a high level of abstraction without sacrificing much performance.

7. Current Prototype System

The Sci Vis team currently has a prototype system consisting of three 2.6-GHz Pentium 4 systems with NVIDIA GeForce 4 dual display graphics cards. One of the systems incorporates an Audigy 2 Platinum sound card connected to a Yamaha A/V receiver/switcher. For speech recognition, a dynamic microphone is also connected to the Audigy 2. The Yamaha drives six Mirage OmniSat speakers and a 150-W powered subwoofer.

The Sci Vis team constructed a frame made from electrical conduit structural steel known as "channel strut." The frame holds a traditional rear projection screen and a TransFilm screen. Additionally, the frames support two InFocus LP650 projectors for each screen.

An 8- × 8-ft viewing platform sits 3 ft from the frame and is outfitted with the "shaker" (commercially available as the "ButtKicker II" from The Guitammer Company Inc.), which is driven by a 1000-W amplifier. Because the Sci Vis team built the prototype on the second floor of their building, they have certainly "got the attention" of their downstairs neighbors when the sound system is at full volume.

The Sci Vis team used the system to explore electromagnetic pulses over various geometries of interest and to explore penetrator-armor interaction. The sound systems allow the team to map scalar fields to sounds and to probe the datasets both visually and acoustically. The TransFilm allows for the team to place representative objects in the middle of computed isosurfaces and volume visualizations.[*]

[*]The Sci Vis team used the system to explore electromagnetic pulses over various geometries of interest, to explore penetrator-armor interaction, and guntube dynamics. The sound system allows them to map scalar fields to sounds and probe the datasets both visually and acoustically. For example, the XM1002, a training round for the M1A1 Abrams Main Battle Tank, was studied in the system through sonification of scalar values representing guntube pressure. Areas of high pressure within the guntube were represented by louder, high-pitch sounds, while low-pressure areas were represented with softer, low-pitch sounds.

8. Future Configuration

Each of the frames, with projectors, mirrors, sound, and computer system is known as a mixed reality pod or "MrPod." From these scalable units, the Sci Vis team has begun to construct a multipod facility. Small pods with 8- × 6-ft screens and large pods with 12- × 9-ft screens will be combined to provide a scalable data center that can be reconfigured as needed.

The team's current tracking needs are modest. The accuracy of the magnetic systems like those from Polhemus Inc. is not necessary in most of our applications. The Sci Vis team is currently exploring the use of infrared image-based tracking for objects inside the pods.

9. Conclusion

Physics-based simulations provide important insight into the behavior of complex systems. A unique application of Augmented Reality techniques to the analysis of these simulations provides an intuitive understanding of the complex relationships between computed values. In addition, the use of commodity components and a little imagination makes for a cost-effective solution for presenting complex phenomena.

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