Toward the Comparison of Different VR Devices for Visualization

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Figure 1: Anatomic visualization in a CAVE-type display system.

Abstract

Immersive display systems in the form of head-mounted displays or full-size, walkable display systems can provide a very intuitive environment for a multitude of applications. Such applications include exploration, simulation for training, experimental studies to learn about people's behavior and many more. Similarly, large-scale high-resolution display systems can also be very effective in data exploration and visualization. These systems can also be fully immersive. This paper describes the infrastructure available at Wright State University with its advantages and disadvantages to explore the benefits and applicability of each system comparatively.

Index Terms: Computing methodologies—Computer graphics—Graphics systems and interfaces—Virtual reality; Computing methodologies—Computer graphics—Graphics systems and interfaces—Mixed / augmented reality

1 Introduction

Visualization can be a great tool to explore and better understand a variety of types of data. Interacting with the data is typically one of the key elements of the exploratory process. Virtual reality display systems and devices provide a great way to interact with content. While not all types of data sets lend themselves to be explored in a virtual reality setting, many benefit from these more advanced display paradigms. There is a wide variety of delivery options for display data in a virtual reality setting that range from head-mounted displays to full-scale walkable display systems.

This paper outlines the various display systems and environments available at Wright State University to provide a wide variety of different display technologies. This enables us to explore the benefits of each system and choose the most suitable one for each application.

The visualization and simulation infrastructure at Wright State University is supported by the Appenzeller Visualization Laboratory and the Immersive Visualization and Animation Theater. These two laboratories serve the common goal of making a variety of display systems available to the university. The Appenzeller Visualization Laboratory is more focused on the research side with some teaching components whereas the Immersive Visualization and Animation Theater provides students with 24/7 access to fully immersive display capabilities.

Right from the inception of this infrastructure, it was important to provide access to a variety of diverse display systems as different applications require different parameters. This diverse configuration also allows for direct comparison of different display environments to identify the most suitable one for a specific application or to interconnect display systems for a collaborative environment [11]. Cavallo et al. even envision a hybrid collaborative setup that combines AR and VR [2].

The remaining sections discuss our experience with these display

Figure 2: Students using an HTC Vive Eye head-mounted display with their custom-developed software also showing on the screen in the back.

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Figure 3: User exploring a vascular structure on a mobile projection-based VR display (left) and passive projector configuration for the display (right).

Figure 4: High-resolution tiled display system showing a GIS application based on OpenStreetMap.

systems and their applicability to different visualization applications. Insight into their advantages and disadvantages is provided based on that experience.

2 Hardware Environments

To support the various activities in our laboratories, a diverse variety of display systems are installed. This ranges from desktop systems and head-mounted displays to large wall displays and walkable CAVE-type systems. Some systems are using large TVs for the display system. However, 3D TVs were discontinued a few years ago and are therefore no longer available.

Head-mounted displays (HMDs) provide a cost-effective way to provide immersive display technologies to students and researchers. In our laboratories, multiple HTC Vive Eye HMDs and HP mixed reality devices are available. Figure 2 shows students exploring their custom-developed software using one of the head-mounted displays. We also utilize the Magic Leap One augmented reality devices. These stand-alone devices, similar to the Microsoft Hololens, provide an overlay image on top of the real world suitable for augmented reality applications. We have successfully used these devices for nursing education in which overlay images of fully animated organs and other internal structures are displayed on the traditional manekins [14, 16]. Another application was for assisting surgeons to visualize fractured ribs through the skin based on a CT scan during corrective surgery [15, 19].

Different projector-based display systems are available, such as a Barco CADwall, a dual-projector large-screen display, and a mobile projection screen with support for passive stereo. For the mobile screen, the focus was on low-cost off-the-shelf components to make it affordable and account for items being lost or damaged during transport or use. This configuration comprises a set of two standard projectors that are mounted on top of each other within a custom-built mount using threaded rods to allow for full articulation of the projectors as depicted in figure 3 (right). Passive polarization filters were installed in front of the lenses. The projectors are used in a rear-projection setup so that the user does not block any of the projected images. Since passive stereo is based on polarization, a special polarization-preserving projection screen is required, such as the Da-Lite 3D Virtual Black.

For tracking, a very cost-effective setup was chosen based on Microsoft's Kinect. Another option would be a lighthouse sensor. The Kinect sensor provides full 6DoF data, albeit the directional information is not overly accurate. However, the positional data provided by the Kinect is fairly precise. A dedicated computer running FAAST [22] captures the data from the Kinect sensor and transmits it to the rendering computer via the VRPN protocol. This provides head tracking and tracking of an input device, a Logitech F710 wireless gamepad. Since the directional information is not reliable enough, only positional tracking is used in combination with the input device. However, this still provides for a very intuitive user experience with full immersion as shown in figure 3 (left).

For applications that require higher-resolution display environments, tiled configurations are a common way of supporting those applications. One of our configurations uses a 2-by-3 setup comprising Sony's 50-inch 4K TVs [25]. The entire system is driven by a single computer with two graphics cards to allow an easy deployment of standard software packages. To provide intuitive input modalities, this system uses a Logitech touchpad T650 to enable smartphone-style interaction metaphors.

An in-house built system, the Display Infrastructre for Virtual Environments (DIVE) [26], utilizes 27 55-inch full-HD LED-backlit displays with small bezels. Specifically, we used Samsung's UA55E large-format displays as those are commercial-grade displays. Arranged in a 3-by-3 configuration per wall using three walls, the system provides a 12-by-12 foot walkable footprint with a height of 87 inches. Each wall is driven by a single computer with three graphics cards running each of the Samsung displays in the side-by-side HDMI stereo mode. Since active stereo glasses are used for this system, all graphics cards are frame-looked using AMD's FirePro S400 sync cards. This provides a high-resolution display system bright enough to be used in an environment with the lights fully turned on. To interact with the system, a NaturalPoint OptiTrack optical tracking system is used as well as a Logitech wireless gamepad. In addition, our custom pinch glove uses the electronic components of a wireless mouse with contacts on the fingers and thumb wired to where the mouse buttons had been connected. These pinch gloves

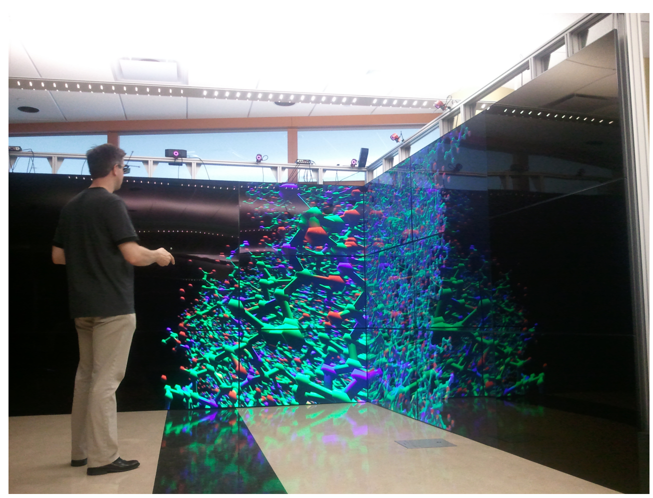

Figure 5: Molecular visualization using the DIVE system.

are also fully tracked in 3D space using the optical tracking system.

To provide access to a fully immersive walkable display system, we chose the Virtalis ActiveCube to upgrade from the previous Barco I-Space. Our configuration includes a typical 10-by-10 foot footprint with projections on three walls and the floor. Figure 1 shows this system depicting an anatomical model of the rib cage and multiple organs. The system uses Barco's F80 series projectors which are laser-based projectors to avoid continuous bulb replacements. Each side wall uses two projectors resulting in about 2716 by 2716 pixels per wall. The system is combined with an A.R.T optical tracking system with a flystick2 for input.

3 Software Environments

Many of the display systems are powered by Linux or support a dual-boot environment in which Linux and Windows are installed side-by-side. Additional software is used to realize different virtual environments as outlined in the following sections. We have a variety of software packages installed, including ParaView [1] and FreeVR [20].

We have had great success with VRUI [12] due to its flexibility both in terms of configuring it for a variety of display systems as well as integrating it with different OpenGL-based applications. VRUI can also be integrated with VTK to render into the provided OpenGL context to support any display system configured for VRUI to support devices beyond the HTC Vive which is supported natively by VTK. This allowed us to support a wide variety of visualization algorithms with all of our display systems.

The game engine Unity can also be used in traditional CAVE-type configurations. MiddleVR provides a commercially available integration for using Unity with CAVE-type displays [13]. An open-source integration was developed at the University of Wisconsin, Madison by Tredinnick et al. [24] that is freely available called Uni-CAVE. Since Uni-CAVE may require more configuration compared to MiddleVR, Davis et al. provide additional tutorials for setting up Uni-CAVE [7].

Another software we use for some applications is Visionary Renderer. Visionary Renderer is a commercial software package provided by Virtalis. Visionary Renderer can be run on a standard desktop computer or within a CAVE-type environment. It also supports head-mounted VR displays. Visionary Renderer is capable of ingesting a variety of different CAD formats natively. The models can be fully animated through lua [9] scripting.

In our experience, running virtual reality displays with VRUI has been very successful due to the fact that VRUI makes it very easy to run software on various types of displays without the need for changing the software code. Visualizing various data sets with the VTK integration supports a large variety of visualization approaches. The CAVE support that is now available in Paraview [21] will be a great toolkit for data visualization as well. Obviously, this highly depends on the application as some software environments are better suited for specific applications. For example, Unity works well for running a virtual simulation as a serious game, especially if a previous version was already developed for other devices, such as HMDs. When exploring mechanical designs, the VisionaryRenderer has worked well. This is why we support a variety of software environments, including dual-boot systems on some of our displays.

4 Comparison

When comparing different VR display systems, there are various parameters one can select to analyze the difference between these systems. As outlined in table 6 there obviously is a great variation in price. Full-size CAVE-type systems tend to be significantly more expensive compared to HMDs whereas some single-screen configurations can at least come closer to the price range of HMDs.

Other comparisons focus on different perceptual issues. For example, the estimation of short distances was investigated by Combe et al. [4] who found no significant difference in the ability to estimate short distances when comparing HMDs and CAVE-type systems. However, they confirmed that distances were typically underestimated confirming previous results, such as [3]. Juan and Pérez report an increase in presence and anxiety in an acrophobic environment when using a CAVE-type system compared to an HMD suggesting a higher level of realism in a CAVE-type system. Tcha-Tokey [23] found similar results with higher scores for presence, engagement, and immersion when using a CAVE-type system for an educational virtual environment. Pala et al. [17] on the other hand report a higher level of presence when running a pedestrian simulator on HMDs compared to a four-sided CAVE when using these systems for studying pedestrian behavior.

Cordeil et al. [6] determined that when using CAVE2 and HMD for collaborative analysis of network connectivity, participants using HMDs tended to be faster. However, there was no difference observed in accuracy. In an extensive study comparing CAVE and HMD systems, Combe et al. [5] deployed two different types of virtual scenarios: a complex virtual environment participants had to navigate and a guided walk through a virtual environment. In the former scenario, no difference in cybersickness was observed. However, participants experienced a higher heart rate when using an HMD. They also observed shorter completion times when using HMDs similar to the previous study. In the second environment, an increase in cybersickness and postural stability was noted when using an HMD.

Jadhav and Kaufman [10] proposed MD-Cave, a virtual reality solution for medical data sets. They point to the higher effort when cleaning HMDs compared to shutter glasses as one of the reasons for not using HMDs. Another disadvantage they pointed to was the strain HMDs can put on the user after prolonged use. CAVE-type systems were ruled out due to their large footprint. Instead, they opted for a tiled-screen configuration. While no quantitative results were presented in the evaluation of this system, the domain experts provided positive feedback in a qualitative analysis.

In addition to these findings, our practical experience with the variety of VR-capable display systems available in our laboratory environment supports some of these findings. HMDs can provide a great tool for virtual environments used for exposing participants to a virtual world or for data visualization. However, these devices can be strenuous for a user when used for prolonged periods of time.

Display systems that use passive or active stereo glasses impose less strain on the user due to these being light weight similar to conventional glasses. This also makes these easier for the user to put on compared to an HMD which can be a significant advantage when dealing with novice users. For this reason, we typically prefer using our CAVE-type displays and large-screen displays for tours that are open to the public. This allows a visitor to easily put on the glasses and similarly take them off again when issues, such as cybersickness, occur. Due to the nature of HMDs which remove the user more from the real world compared to many CAVE-type systems, with the exception of six-sided CAVEs, cybersickness seems to be less of an issue with CAVE-type systems. Another advantage of CAVE-type systems and large-screen systems is that outside spectators can still get a glimpse of the content and observe the participant's performance in the virtual world. An HMD would require some sort of mirroring on a monitor or TV in order to obtain a similar effect.

Some of the experiments we ran in our laboratory environments [8, 18] required the display system to support the full range of the human visual system. Humans typically can perceive up to 178 degrees when including the full range of the peripheral vision. As listed in table 6, HMDs typically can go only up to 140 degrees. This left only the CAVE-type systems, such as the DIVE and ActiveCube, to support these types of experiments.

While HMDs support collaborative environments, they typically rely on the use of avatars. This is the only viable approach for re-

Display system	Size	Resolution (per eye)	Field of View	Tracking system	Input capabilities	Price (including computers)
3D TV	49 inch diagonal	4 Megapixels	position dependent	Kinect	position tracked, 2 joysticks 14 buttons	$3,200
3D TV	65 inch diagonal	4 Megapixels	position dependent	optical (2 cameras)	fully tracked, 2 joysticks 14 buttons	$5,300
Passive screen	102 inch diagonal	2 Megapixels	position dependent	Kinect	position tracked, 2 joysticks, 14 buttons	$6,000
4K tiled screen	150 inch diagonal	24 Megapixels	position dependent	Kinect	position tracked, 2 joysticks, 14 buttons	$10,000
HTVC Vive Eye	N/A	2.3 Megapixels	110 degrees	lighthouse	fully tracked, 1 trackpad, 4 buttons	$4,000
HP Mixed Reality	N/A	2 Megapixels	100 degrees	optical (2 cameras inside-out)	fully tracked, 1 trackpad, 4 buttons	$2,800
D.I.V.E.	$144\times144\times87\text{inch}^3$	27 Megapixels	up to 180 degrees	optical (11 cameras)	fully tracked, 2 joysticks, 14 buttons	$120,000
Virtalis ActiveCube	$120\times120\times90\text{inch}^3$	26.5 Megapixels	up to 180 degrees	optical (4 cameras)	fully tracked, 1 joystick, 5 buttons	$500,000

Figure 6: This table lists the capabilities of the display setups and their tracking systems.

mote collaborations. However, CAVE-type and large-screen systems work well in a collaborative setting by simply using multiple sets of glasses. Some systems even support multi-view projection configurations. This then does not require the use of an avatar as one can still see the other person. This makes pointing to features in a data set significantly more intuitive in our experience.

5 Conclusion

In conclusion, the visualization and simulation environment at Wright State University has been very successful in supporting a variety of visualization and experimental applications. The broad variety of different technologies available allows us to utilize the best-fit system for each application as there are clear advantages of these individual systems. Similarly, experiments can be conducted to compare display systems for an application if multiple candidates appear to suit that use case. The choice of system depends on various factors, such as cost, mobility, ease of use, need for a collaborative environment, or display fidelity. Neither system excels in all of these categories and as such analysis and discussions of the advantages and disadvantages of these systems in comparison are important.

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