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Immersive Visualization Lab at Idaho National Laboratory

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Changing the World's Energy Future

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Idaho National Laboratory

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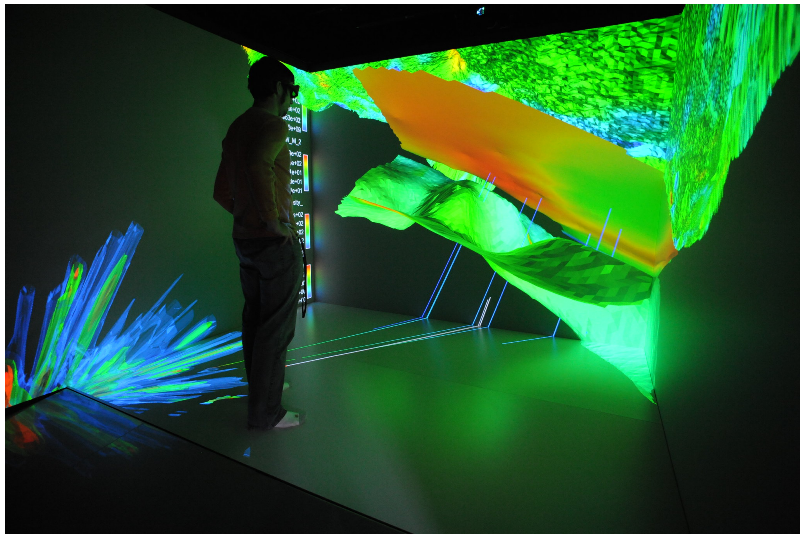

Figure 1: A researcher using the CAVE at INL's Center for Advanced Energy Studies to view and analyze their data in a new way.

ABSTRACT

This article introduces the Applied Visualization Laboratory at Idaho National Laboratory, including the lab's success and challenges as an immersive visualization laboratory. Also, it discusses the future direction of the immersive virtual environment and visualization.

Index Terms: Human-centered computing—Visualization—Visualization systems and tools—Visualization toolkits

1 INTRODUCTION

Immersive virtual environments (IVE) are an instance of a virtual worlds presented in an interactive medium such as virtual reality that allow users to experience and interact with a virtual world as if they were physically in it [7]. In an IVE, users typically wear a headset or use a device that tracks their movements and allows them to move around and interact with the virtual world. They may also use handheld controllers or other input devices to interact with the environment and objects. IVEs can be highly realistic, with detailed graphics and realistic physics, or they can be more abstract, with simple graphics and exaggerated physics. Regardless of their style, IVE allows users to explore and interact with virtual spaces in a way that is impossible in the physical world [6]. IVEs have gained widespread attention and adoption in recent years across various industries and fields, including education, training, research, entertainment, and product design. One key driver of this growth has been the development of increasingly sophisticated and realistic IVEs, thanks to computer hardware and software advances. This has made it possible to create more immersive and engaging virtual experiences, which in turn has led to increased demand for IVEs. Another factor contributing to the growth of IVEs is the increasing accessibility of IVE technology. Many IVEs can now be accessed via relatively inexpensive hardware such as headsets and controllers, making them more accessible to a broader range of users.

In terms of usage, IVEs are being used for a wide range of applications, including training, education, research, engineering, entertainment, and product design. For example, IVEs are being used to train pilots, surgeons, and other professionals, to study human behavior and cognition, to create virtual worlds for entertainment, and to design and test new products.

Overall, the current state of IVEs is one of rapid growth and development, with increasing demand and usage across various industries and fields. This trend will likely continue in the coming years as IVE technology advances and becomes more widely available.

With the ease of access and decreasing cost of commercial off-the-shelf (COTS) VR devices there is an on-going discussion between researchers and users on how these COTS would compare against the usability with the large immersive displays (like CAVEs). The immersive visualization requirements of researchers could be satisfied using COTS VR devices used in their offices. However, it is also essential to consider the specific needs and goals of the research, as well as the limitations of COTS VR devices.

One potential advantage of COTS VR devices is that they are often more portable and convenient than large immersive display systems, such as CAVEs. This can make them well-suited for use in smaller office environments or for researchers who need to take their visualization setup with them when traveling.

However, there are also several potential limitations to consider when using COTS VR devices for immersive visualization. For example:

- Visual quality: COTS VR devices may not offer the same level of visual quality as larger, more specialized immersive display systems.

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- Multiple users: COTS VR devices are typically designed for use by a single user, whereas large immersive display systems can support multiple users at the same time.

- Computing resources: COTS VR devices may have limited computing power and may require a powerful computer to run demanding visualization applications.

Overall, it is important to carefully evaluate the specific requirements and goals of the research, as well as the limitations of COTS VR devices and large-immersive systems, to determine if they are suitable for satisfying the immersive visualization needs of researchers.

Applied Visualization Laboratory at Idaho National Laboratory houses a virtual environment from non-immersive to full-immersive. This lab was established in 2010 to support researchers, scientists, students, educators, and individuals from diverse backgrounds with a vested interest in the field of 2D/3D Visualization. Since its founding, the lab has consistently fulfilled this mission, offering a range of resources and services to aid in developing and advancing knowledge in the field of visualization.

This paper will present an overview of the Applied Visualization Laboratory at Idaho National Laboratory, including its current state, successes and a few challenges we have encountered.

2 Accomplishments

2.1 Engineering Designs

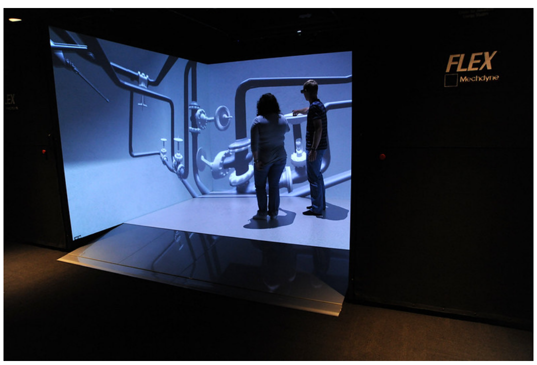

Figure 2: Users using large-immersive systems to inspect the engineering prototype design

For engineering design and prototyping, an IVE can be used to create a simulated world in which engineers and designers can test and iterate on their concepts without the need for physical prototypes. It can be more effective in the areas of aerospace, automotive, nuclear, and manufacturing, where construction of a physical prototype can be expensive and time-consuming.

Engineers in one of the our source recovery projects were initially reluctant to use the IVE for prototyping. For early design evaluation and review, they relied on traditional CAD software. We developed a virtual prototype to visualize the entire instruments for radioactive source recovery and process in the IVE. We invited them to view and interact with the virtual environment for radioactive source recovery process. They found several design imperfections and things to be considered for developing the prototype while being in the virtual prototype and interact. As a result of the immersive experience, the engineers went back and modified the design of the prototype with a better understanding of the spatial and physical limitations of their design. The use of IVE provided a reliable and trustworthy platform to conduct engineering design and prototype while saving time, cost, and increasing reliability.

2.2 Training

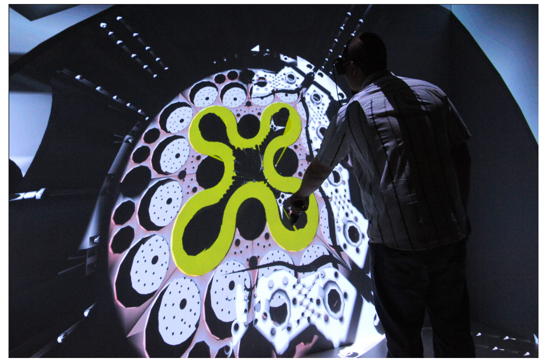

Figure 3: A user interacting with ATR core to understand its design.

Training is an essential component in the field of the nuclear industry. Firstly, the handling and operating of nuclear materials and facilities require a high level of technical expertise and knowledge. As a result, researchers and technical operators working in the nuclear industry must continue training to guarantee their job safety and efficiency. This includes training in nuclear reactor design, nuclear physics, radiation protection, and emergency response.

Advanced Test Reactor (ATR), the world's premier nuclear test reactor, provides nuclear fuel and materials testing capabilities for military, federal, university, and industry partners and customers. It periodically undergoes a maintenance overhaul. We have converted the 3D Computer Aided Design (CAD) model into an environment in our CAVE and developed interactions that allow us to virtually look inside the reactor and remove components or sections of the reactor for better viewing. This ATR virtual environment provides a co-located collaboration opportunity for the engineers performing maintenance work to train and understand the design and working mechanism of the ATR. We have received feedback that the use of large-immersive display systems for ATR visualization is far more effective than recorded videos and printed documents that have been used in the past.

2.3 Scientific Visualization

Our lab is dedicated to supporting the scientific community in its efforts to uncover new knowledge and advance their fields of study. By helping researchers to visualize and analyze their data effectively, we aim to enable them to make more informed and accurate conclusions about their research.

In one of our scientific visualization projects, we visualized graphite billet to analyze and understand the density, variation, and properties. The researchers had previously used a non-immersive 3D environment for visualization. They asked us to develop a 3D model using large-immersive display system to allow multiple people view the model collaboratively. They informed us that visualizing the graphite billet using the large-immersive display system provided a new dimension in understanding the essential components of graphite billet to conclude the experiments. They were able to navigate and be inside the graphite billet and conduct in-depth analysis. They also informed us that it would not be possible to do so using traditional tools for visualization.

2.4 Lidar Visualization

LIDAR (Light Detection and Ranging) is a remote sensing technology that uses laser pulses to measure the distance to an object or surface [2]. LIDAR data can be used create 3D models of real-world objects that can be further developed into a virtual environment. It

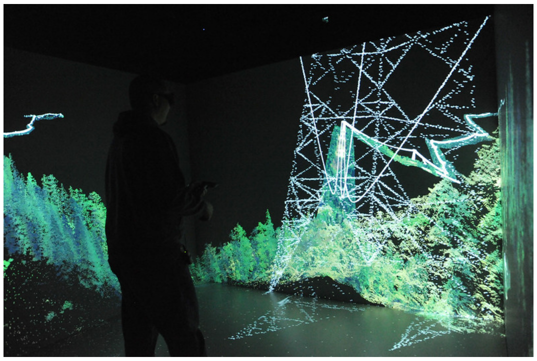

Figure 4: A user viewing a LiDAR scan of electric power grid.

can create highly detailed 3D models of real-world objects and environments that are utilized in decision-making, training, engineering, and education applications.

We have conducted LiDAR scans of buildings, rooms, outdoor environments, and equipment. In one particular project we were asked to scan and develop a 3D model of a portion of building that had been constructed in the early 40s and the blueprints for this part of the building could not be located. The scan was used to develop a 3D model that could be added to the engineering drawings of the rest of the building. This scan was then used to precisely locate and measure rooms, ducting, electrical conduit, and water lines for a proposed remodel project. After we combined the existing digital building model with the scan, we developed an environment that we displayed in our CAVE for project managers to view for better planning.

2.5 Education and Outreach

Figure 5: A group of users using large-immersive system for visualization.

IVE can be a valuable tool for education and outreach programs. In a way that traditional visualization approaches might not be able to, these technologies can offer immersive and interactive experiences that captivate audiences and impart knowledge.

Our lab regularly provides demos to students for experiential learning opportunities and also excites them toward a STEM career. These demos are designed to be engaging and interactive, providing a dynamic and immersive experience to the students. We have experienced that these demos increase students' curiosity and encourage questions about their careers, projects, and opportunities. We provided demos to over 1300 viewers in fiscal year 2022. This volume of viewers provides us the opportunities to interact and engage with diverse groups of individuals for potential collaboration and support.

3 IVE at Idaho National Laboratory

Applied Visualization Laboratory (AVL) is located at the Center for Advanced Energy Studies (CAES) [1]. AVL has eight team members to develop and maintain the lab. AVL hardware and software is mostly core-funded, occasionally a Principal Investigator will purchase hardware or software that stays with the computer lab. The environments that we create are through research projects that aim to utilize the hardware and software capabilities.

3.1 Hardware

AVL has a four-panel Mechdyne CAVE system as a large-scale immersive visualization system (12ft X 12ft X 9ft). It uses ART system's DTrack eight-camera system to track a user's head and joystick movement. This CAVE system was refreshed in 2017 and can run both Linux and Windows. There are three IQ-Stations as a single-panel immersive display system in AVL. This IQ-Station was designed and developed in collaboration with Indiana University to provide a low-cost and immersive mobile system [8]. AVL also houses HTC Vive Pro VR and Oculus Quest virtual reality headsets as a fully immersive display systems. We have Microsoft Hololens II, Magic Leap, and tablets to support the need for augmented reality visualization. We also have an Omni Treadmill as a tool to provide users with walking capabilities while training and interacting with the environments. AVL also has leap motion and haptic gloves as additional interaction tools to support user needs for immersive virtual environments.

3.2 Software

We utilize a variety of software to meet our client's needs and requirements. Currently, we use VRUI software [3] for scientific and LiDAR visualization in CAVE systems. We also work with Paraview and VTK for scientific visualization for non and full immersive-display systems (HTC Vive). We also use the Unity3D and UNREAL engines to develop engineering prototypes and training simulations. Furthermore, we use Blender for 3D modeling, ArcGIS for geographic data visualization, Meshlab for editing and processing 3D triangular meshes, and three.js/Aframe for 3D web-based visualization.

4 Challenges

4.1 Unfamiliar / Unaccustomed

Although the usage of an immersive virtual environment using virtual reality (VR) technology has increased, some individuals are still afraid to utilize VR devices for visualization. This hesitation may be due to various factors, such as the expense of VR equipment, the chance of feeling motion sickness or other undesirable consequences, or a lack of awareness about how VR might be utilized for visualization. Furthermore, some people may be apprehensive about privacy or feel uneasy when wearing a VR headset or gadget. Addressing these issues and educating people about the benefits and applications of VR technology may be beneficial in encouraging more usage of VR for visualization.

4.2 Standard Software in CAVE Systems

The CAVE VR system has numerous advantages, but because of the difficulties in running software on the system, scientists and researchers could be unwilling to utilize it. These issues could have to do with the system's incompatibility with particular programs or its difficulty being properly set up. Therefore, researchers and scientists may think about utilizing different VR systems that offer a more streamlined software experience. It's crucial to remember that the designers of the CAVE VR system are always striving to enhance the user experience and resolve any issues.

4.3 Cost and Maintenance

Virtual reality systems might be difficult to deploy widely due to their high cost. Due to the unique hardware and software requirements, as well as the requirement for training and support, these systems sometimes have a high price tag. As regular updates and upgrades are required to keep the system operating effectively and to assure compatibility with the newest software and technology, maintaining a virtual reality system may also be expensive. For people and organizations, especially smaller ones with tighter finances, these fees can be difficult. Despite these financial obstacles, virtual reality systems are growing in popularity as the technology advances and their costs come down.

5 Trends in Immersive Virtual Environment

5.1 Market for VR and AR

It is anticipated that the VR and AR markets will expand in the upcoming years. The VR industry is anticipated to reach 20.9 billion by 2025, while the AR market is anticipated to reach 88.4 billion dollars by 2026, per a survey by MarketandMarket [4, 5]. These trends show that there will be an increasing number of users in research and academics. VR and AR will increase their usage in many industries including healthcare, education, retail, and entertainment. For example, VR is used to train surgeons and provide rich educational experiences. In contrast, augmented reality is used to enhance the shopping experience and provide interactive entertainment. Immersive virtual worlds are used more frequently in education to deliver dynamic and exciting learning experiences. This trend is anticipated to continue as teachers look for fresh approaches to teaching and engaging pupils. As designers and developers of VR/AR environments, we should be prepared to develop rich, interactive, and enhanced virtual environments to meet their requirements.

5.2 Adaptation

Immersive virtual environments are becoming more popular across various areas, including healthcare, education, the military, architecture, etc. As more business areas learn the advantages of employing immersive virtual worlds for training, simulation, and other uses, this trend is anticipated to continue. We may anticipate visual, haptic feedback, and artificial intelligence innovations as immersive virtual worlds get more advanced. The COVID-19 epidemic has increased the trend toward remote work, and immersive virtual environments provide a mechanism for distant teams to collaborate and communicate in a more immersive and dynamic way. Although virtual reality (VR) and augmented reality (AR) are sometimes grouped, we anticipate an increase in the use of AR, which integrates the actual world with digital aspects.

5.3 AI/ML and IVE

There has been an increasing movement toward using artificial intelligence (AI) and machine learning (ML) in 3D visualization for pattern recognition, predictive analysis, and automated user interface support. The automated production of 3D models and visualizations using AI is one instance of this. By doing this, time can be saved, and analysts can concentrate on higher-level duties like evaluating the data and providing recommendations based on the findings. Another trend is utilizing ML techniques to find patterns in data that may not be immediately obvious when represented in 3D. These algorithms can also be used to forecast outcomes for the future using data from the past. Additionally, there has been a increasing interest towards the use of natural language processing (NLP) to enable analysts to communicate with 3D visualization tools orally or in writing. Analysts may find it simpler to query the data and draw conclusions. In general, the application of AI and machine learning in 3D visualization aids analysts in more rapidly and precisely deriving insights from data and producing more accurate forecasts of future events.

6 Final Thoughts

It is likely that large immersive display systems and virtual reality headsets will continue to coexist in the market to meet users' diverse needs and preferences. Large immersive display systems, such as CAVEs (Cave Automatic Virtual Environment) and other projection-based systems, offer a high-quality, immersive experience for groups of users. These systems are often used for training, simulation, and visualization applications, where the ability to see and interact with digital content in a large, shared space is important.

On the other hand, virtual reality headsets, such as the Oculus Rift and HTC Vive, offer a more personal, portable immersive experience for individual users. These devices are often used for gaming and entertainment, as well as for various other applications, including visualization, healthcare, education, and design.

Overall, both large immersive display systems and virtual reality headsets have their own unique strengths and limitations, and it is likely that they will continue to be used in parallel to meet the needs of different groups of users and applications.

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