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The Emerging Technology of Virtual Environments

Carolina Cruz-Neira*
Iowa State University, Ames, Iowa 50011

I. Introduction

From pioneering groups in the early 90s to current practices today, research groups and industry have been following and accepting virtual environments (VE) technology as a tool that enables them to respond to today's global market opportunities and competitive pressure. Virtual reality (VR) technology and VEs have the potential to provide an integrated environment for the design, analysis, test, and evaluation of products and processes. Such an environment opens new and exciting modes of communication within a research and development team,[1] which is critical to successfully conceive, complete and deploy new products and processes. However, as with many other emerging technologies, VE technology has not quite reached its full potential. This editorial reflects my personal assessment of what are VEs, their benefits and promises, and the challenges that need to be addressed to reach those promises.

II. What are Virtual Environments?

VEs are primarily interactive visual simulation environments that immerse the user in a responsive virtual world. The initial idea originated from Ivan's Sutherland vision for an "Ultimate Display":[2]

> "The ultimate display would, of course, be a room within which the computer can control the existence of matter. A chair displayed in such a room would be good enough to sit in. Handcuffs displayed in such a room would be confining, and a bullet displayed in such room would be fatal. With appropriate programming such a display could literally be the Wonderland into which Alice walked." -- Ivan Sutherland, 1965

Thus, the main feature of these environments is their ability to provide dynamic control of the viewpoint based on the user's location and direction of sight. Interactivity allows not only for dynamic viewing of the space, but also the ability to grab, move and manipulate objects and the space. To enhance the experience, virtual environments can also include simulations reflecting the behavior of the different components of the virtual world. For example, there could be physics simulations, so objects can fall following gravity laws if a user releases them in midair, or bounce if they collide with the floor or other objects. More complex simulations can show the flow of air over an airplane wing, or the stresses on the surface of a metal piece supporting some weight.

To immerse users in virtual environments, a set of technologies is integrated to create a virtual reality system.[3] The core technologies are visuals displays, audio systems, user tracking systems, and a graphics computer system, which provide the basic framework for VEs. There are a variety of commercially available products on those core technologies as well as several "system integrators" companies, which provide the services to design and install a complete VR system. Additional technologies in VEs include interactive devices, such as gloves and custom-devices, and devices to feel virtual objects (haptics).

One of the most popular VE systems is the CAVE,[4] shown in Figure 1 and its derivatives, such as workbenches, shown in Figure 2, and theaters, shown in Figure 3. Basically a CAVE is a projection room in which three of the vertical walls and the floor are rear-projected stereo displays. Multiple users can enter a CAVE-like system sharing the experience of the virtual world, thus enabling group discussions while exploring and manipulating the virtual space.

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*JACIC Associate Editor, Stanley Chair for Interdisciplinary Engineering; cruz@iastate.edu.

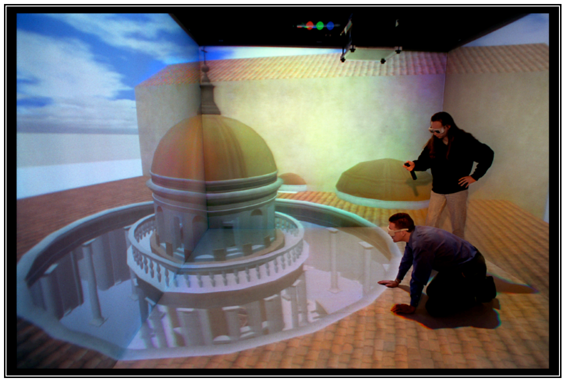

Fig. 1 CAVE-like virtual environment.

Fig. 2 Users working on a Workbench.

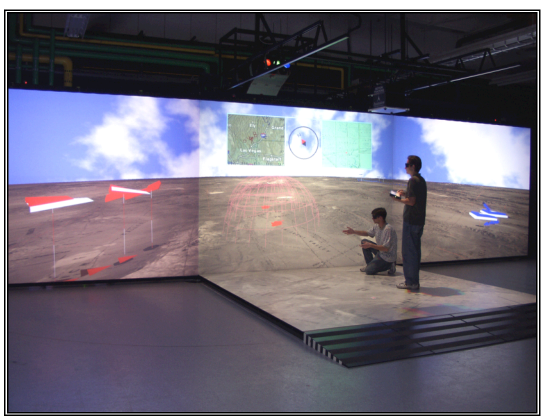

Fig. 3 An immersive theater.

Head-mounted displays (HMD), shown in Figure 4, are another type of VR systems, and historically the earliest type of VR devices implemented, with the Sword of Damocles[5] built in 1968. Obviously, these are single user devices, limiting how the virtual environment can be shared among multiple users.

The video segments accompanying this editorial show users working in these environments. Video 1 shows two users interacting in a six-sided CAVE-like device. They are completely surrounded by imagery, being able to navigate and interact with the space. Video 2 shows a workbench, a movable projection surface. This device is interesting for applications that may require look at them as if in a table, such as a medical student training on a virtual patient lying on an examination table. Video 3 shows two kinds of HMDs. From the video, it is clear to see that only the wearer of the display gets to experience the virtual world. Video 4 shows a variation of an HMD called the BOOM. In A BOOM, the display is mounted in an articulated mechanical arm that carries its weight and serves as the user-tracking interface. Video 5 shows the lowest level of VEs, in what it is called "Fishtank VR". This is an enhanced desktop system including a stereo capable monitor and user's head tracking.

Fig. 4 Head-mounted display virtual environment.

III. Benefits of Virtual Environments

In the early 1990s, the graphics and computational science community widely acknowledged the promise and potential of large-scale virtual environments. We envisioned a myriad of opportunities to use VR to transform the ways in which we visualize and interact with complex information. Two key years, 1992 and 1993, clearly marked the acceptance of immersive environments, with the introduction and embrace of the Virtual Portal,[6] CAVE,[4] and Responsive Workbench.[7] These systems helped establish the field of virtual reality by introducing the novel yet pragmatic use of proven, familiar projection systems to create immersive displays.

The key aspect of VEs is that the line between data, computations, and user are blurred. The user is active part of the system, entering the computational territory occupied by the research problem at hand. VEs give a full digital representation of the problem space enabling users to create interactive "what if" scenarios as if they were truly "there". "There" can be an aircraft's cockpit, an assembly line at a factory, a molecular system, or the Universe. Figure 5 shows several examples of these VEs.

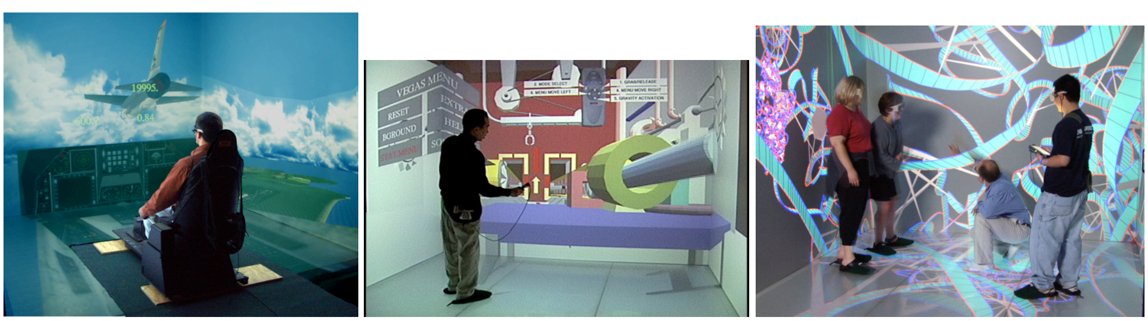

Fig. 5 Uses of VEs: a) Flight simulation, b) Assembly planning, and c) Bioinformatics.

Being "there" opens new and unexplored opportunities to better understand and gain insight in the three-dimensional world we live in. Imagine being able to stand in a virtual environment representing a wind tunnel. A designer could observe the changes on the airflow pattern over the airplane's wing as he make changes to its shape, size and position. Or, imagine being able to evaluate different concepts for aircraft cockpit configurations while including ergonomic considerations from actual pilots virtually flying the aircraft. These scenarios highlight the potential benefits that VEs provide to the engineering community:

Shorter time for product development: VEs enable concurrent work by placing the product being designed in the context in which it will operate. Multiple design stages can be performed simultaneously to identify potential interdependencies and conflicts, as well as their impact in the overall product design.

Wider range of testing/evaluation: VEs make possible the use of fully functional digital prototypes, thus reducing the time and cost of developing physical mockups for testing and evaluation. Furthermore, digital prototypes enable to do radically new designs instead of incremental designs based in pre-existing products or models.

Safety: Testing and training on digital prototypes significantly reduce the risks of human lives and environmental effects. Although the VEs can be a faithful representation of a design scenario, the possible dangers, such as a vehicle crash due to engine malfunction, are also virtual, therefore not placing the human operator in any immediate danger.

Enhanced communications: VEs facilitate the communications among different engineering team members by providing a common language for understanding: the visual, auditory and other sensory representations of the problem, product, or idea being discussed. Furthermore, end users can be brought very early in the discussions and get their input as the project progresses. For example, a user may not understand traditional sketches of the interior of a new car, but will immediate understand and be able to give feedback, such as leg room, location of controls, and visibility from driver's seat, if he can virtual sit in a virtual prototype of that car and virtually drive it.

Accelerated decision-making: Because of the enhanced communications afforded by VEs, groups can reach consensus faster and with more information at their fingertips.

Reduced costs: Ultimately, being able to have VEs of a wide range of digital scenarios reduces the cost of engineering activities. The elimination of physical prototypes, the ability of combining multiple design stages and the integration of the end user much early in the process is expected to have an impact on the overall budget for new products.

IV. Challenges Using Virtual Environments

The emerging technology of VEs promises significant benefits in the world of engineering. Yet, VE systems comprise not only an integration of advanced hardware technologies. They demand a new paradigm for interaction with information, with our colleagues, and with audiences in research, production, and entertainment activities. Since 1995, the number of immersive display facilities has grown at a fast pace. In 1999 alone, some 200 new installations were set up worldwide. Today there are well over 2000 VE systems around the world. These installations can be found in academic, research, industrial, and public sites. Applications include engineering design, medical training, architectural walkthroughs, military simulations, entertainment rides and remote meetings.

However, while the hardware technologies have significantly evolved in the last 10 years and a business infrastructure has emerged to support them, there is not a single integrated set of commercial or research software tools to effectively and elegantly build and run virtual environments. Large-scale immersive environments integrate varied hardware and low-level software technologies that simply are not hidden from application developers in today's VR development environments. Currently, every VR facility relies on its own set of customized tools, typically home-grown and incompatible with any other set of tools.[8-10] This creates duplication of efforts, frustrations on the user's end, and delays in accepting this new technology, since it means considerable effort to get started. This is a limitation that the VE research community is well aware of and significant efforts are underway to develop software tools to standardize and facilitate the development of applications.[11-13]

The second challenge in VEs is the lack of a good world representation and interaction standard; we do not yet have discovered the virtual reality equivalent to the desktop WIMP paradigm. Most applications are developed "ad-hoc" and with little attention to the design of a good interface. Application developers tend to map (and often overload) actions to the devices available. For example, pressing a button on a wand may mean grab the object intersecting it in one application and may mean fly forward in another. In this way, applications are hard to use and very non-intuitive for users other than the developer. We are starting to see that at least most VE sites are developing their own internal interaction guidelines to help all the users of the same facility have a base for their applications. The VE research community is aware of this issue, giving it top priority. Today we are seeing an increasing number of research efforts in this area, integrating computer scientists, psychologists, graphics designers and application users.

V. Summary

VE technology is emerging from research to routine tool. Although there are still major challenges for its transparent use and integration in engineering activities, its potential benefits open unique opportunities for the

JACIC community. The growing computational capabilities combined with VEs allow for the development of virtual scenarios, testbeds, prototyping environments and many other situations to create, analyze, evaluate and deploy new concepts, theories and products.

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