Desktop VR Centered Project Based Learning in ET Courses Using a Low-cost Portable VR System

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In this paper desktop VR is used as a medium to deliver Project-based Learning (PBL) curricula to Engineering and technology students. Recently, several courses in engineering and technology education seem to be focusing more on proprietary software tools for modeling, visualization, and animation. While learning a software tool surely will add to the skill sets of students, this cannot replace theoretical knowledge. A strong understanding of the fundamental mathematical, geometric, trigonometric, and physics fundamentals plays a crucial role in determining the career-success of students. Students, especially those at the beginner's level, typically tend to associate theoretical knowledge with 'textual information' involving substantial reading. Hence, this paper puts forth a novel PBL-based approach wherein an interactive portable desktop Virtual (pdVR) framework is used to methodically organize and present such foundational information. The application is being built using web-friendly XML-based technologies such as VRML/X3D and Java/JavaScript to facilitate online dissemination. This is presented using a low-cost portable VR system so that the overall system remains cost-effective. This way, technology and engineering schools that would like to implement such a system for teaching fundamental Engineering & Technology (ET) theory to students will not be deterred by the high costs of immersive facilities (e.g. CAVE). This framework can be included in the form of PBL-based exercises or within course curriculum in ET departments/schools. PBL involves efforts on part of the students that involves active learning and solving real-world like problems. The proposed prototype framework can be used for such PBL exercises as demonstrated with examples in this paper.

Introduction

The effectiveness of the use of non-traditional instructional methods in aiding student learning has been demonstrated by several notable authors. Driscoll (2005) recommends using context-sensitive material in courses and states that the material must inspire the students to succeed in accomplishing their course objectives. This study employs a portable desktop Virtual Reality (pdVR) based visualization to facilitate Project-Based Learning (PBL) in engineering and technological (ET) literature. The visual presentation of the information presented enhances students’ interest and enables better understanding. Active learning methods including problem-solving and project-based learning enable students to better understand the subject material and more importantly, help them to apply the skills learned in classroom in the workplace (Mills & Treagust, 2003, Newby, Stepich, Lehman, & Russell, 2010, Prince & Felder, 2006). Especially, in today’s interdisciplinary educational scenario, several engineering and technology disciplines collaborate with various other schools and departments. Hence, this paper presents a prototype pdVR framework that uses a portable desktop VR system for case-study scenarios for ET courses. Virtual reality based visualization not only facilitates viewing complex and information, but also enables comprehending even hidden or ineffable information (Chandramouli & Huang, 2008). The 3D virtual worlds facilitate navigation and offer a sense of immersion; the users can position themselves within the scenes and explore the virtual world. This study capitalizes on the potential of dVR and reduces the overall set-up components to make it more portable.
3D Virtual worlds can be visualized using a wide range of UI including desktop VR, CAVE, HMD, and augmented VR etc. Each of the aforementioned platforms offers unique functionalities which may or may not be available in others. For instance, CAVEs offer high end fidelity, immersion and navigation. However, CAVEs involve large spaces and cumbersome installation procedures. Besides, CAVEs also entails significance caused with respect to installation, operation and maintenance. On the other hand dVR (desktop Virtual Reality) systems offer good functionalities for online dissemination and dynamic interaction (real-time). However, the level of immersion and navigation offered by such systems remains questionable. A utopian system (ideal) would incorporate all desired characteristics in a VR platform including immersion, navigation, dissemination, fidelity and portability. The last mentioned characteristic, portability is one area where significant and concerted efforts are lacking. The advantages of a portable VR system are manifold. While VR scene built for a CAVE system can be modified for display on a dVR, this would come at the cost of compromising immersion and navigation capabilities. A meticulously designed VR scene with emphasis on immersion and navigation would lose much of the intended benefits when shown to a client on an alternative UI/platform devoid of I/N (Immersion/Navigation) capabilities. For instance A dVR system can neither appropriately capture nor display a visualization originally designed for a CAVE system in its entirety, while laptops are used for dVR, portability is a notable advantage while I/N are compromised. Hence in this paper we design and implement a pdVR system that represents an optimal trade off while offering portability. Also, this system, to a reasonable extent facilitates Immersion/Navigation/Interaction (I/N/I).

As a compromise between these two systems, a Head Mounted Display (HMD) offers an immersive context that constantly displays content no matter which direction one looks, yet sacrifices telepresence when an individual cannot see their own body within the virtual environment. Commercial HMDs have a broad range of capabilities based on the specifications: resolution, field of view (both for horizontal/vertical), optics quality and cost. With some of these HMDs, a wider field of view can be achieved than a dVR or pVR, however may sacrifice resolution fidelity, while still not covering as much peripheral vision as a multi sided CAVE. However, because the focused view on an HMD is in front of one’s eyes, it provides a homogeneous view with no creases or corners and provides consistent display capabilities regardless of where a user is looking. The need for visualization in solving practical problems has been emphasized in numerous works by authors from diverse fields. 3D information visualization and exploration is being used in multifarious engineering fields such as electrical, mechanical, civil, and also in diverse disciplines such as demographics, medicine, hydrology, land-use, and various other applications. Visualization enables getting a better insight into the data and also aids effective presentation of the results of the analytical process. Visualization is also a very powerful tool that motivates students. In ET courses, especially in the introductory courses that teach core foundational aspects and principles of engineering and technology to students, motivation is an important factor to be considered. Talton and Fitzpatrick (2007) stated: “A long-standing difficulty in the development of introductory courses in computer graphics is balancing the educational necessity of ensuring mastery of fundamental graphics concepts with the highly desirable goal of exciting and inspiring students to further study by enabling them to produce visually interesting programming projects.”
Related Work

Teaching foundational concepts to ET students in various disciplines of engineering and technology is a challenging task. The difficulty of successfully completing courses at the freshman level can lead to an increase in the dropout rates. This is another important issue of concern to engineering and technology schools across the nation and probably around the globe. Educators in these ET disciplines have come up with various innovative ways to enhance the learning of foundational concepts in ET courses. One of the popular methods used is gaming or game-development that is used to effectively impart discipline-specific skills to students. (Hernandez, Silva, Segura, Schimiguel, Paradela, and Bezerra, 2010,).

In an effort to take these a step further, this paper combines active learning and PBL (Project-Based learning) using a pdVR interface that allows students to learn by interacting with dynamic virtual worlds. While any pictorial or graphical representation can be considered a visual tool, a term that has been, of late, quite frequently used in visualization circles is ‘Virtual Reality’ (VR). In VR, the 3D visualization is created in a virtual space and these models (or 3D representations) are also known as ‘virtual worlds’. These virtual worlds enable user-navigation and interaction with the 3D scene objects and more importantly, provide a sense of immersion. Connolly (2005) describes virtual reality as the application of an artificial environment generated by computer technology to simulate some targeted activity. Mohler (2000) stated: “Virtual reality (VR) technologies provide a unique method for enhancing user visualization of complex three-dimensional objects and environments. By experience and environmental interaction, users can more readily perceive the dimensional relationships of objects typically portrayed through static multiview or pictorial representations. (p. 151)”

The advantages of such display systems for 3D Visualizations

• Multiple scenarios can be evaluated
• Infinite viewpoints can be generated
• Decision-makers can view the finished product before hand
• Virtual models are extremely time-saving and economical
• Setting up this pdVR system is relatively simpler compared to cumbersome setup processes for a portable CAVE system
• Consumer-friendly nature of the components facilitates easier operation, calibration, and maintenance

In an attempt to describe these different display techniques, the authors provide a brief overview to compare and contrast the pros and cons of the various methods. In a CAVE environment the system displays a virtual environment surrounding the user which places the individual into a virtual context. However with a dVR, pVR, and HMD, the individual (and what they can see of their own body) falls outside of this visual context.

The use of pdVR framework for ET instruction has immense potential for the advancement of PBL (Project-Based Learning) and AL/PS (Active Learning/ Problem Solving). This proposed pdVR framework can be used to facilitate designing and implementing innovative and unorthodox teaching/learning practices. There is also another tremendous advantage this
framework offers over the use of commercial proprietary software. Currently, there is significant use of proprietary commercial software in technology education. The use of such tools for teaching introductory graphics principles to students has resulted in a heavy dependence on commercial software, which in turn has financial implications for the educational institution. On the other hand, open-source platforms and programming languages (PL) reduce the financial burden for both institutions and students. This proposed pdVR framework can be used to facilitate and encourage the use of such OS language and platforms.

Methodology

**Development of Virtual Worlds for ET Courses: Virtual Objects and Customizable Nodes**

Virtual world objects are described as shapes with geometry and appearance. Different ET disciplines have varying course work requirements. Invariably, most ET departments have basic concepts that need to be covered as part of the curricula. PBL is a very effective means of imparting such fundamental knowledge to students. All features within a virtual world (scene components) such as mechanical components, or architectural elements such as buildings, rooms, artifacts, etc. can be modeled as shapes which can be grouped together.
Smaller or less complex objects are grouped in a hierarchical structure to form more complex shapes. VR objects can be programmed or generated using the basic shape geometry with the principal aspects of geometry and appearance. The virtual worlds in this study are built using web-friendly technologies such as VRML/X3D and Java/JavaScript to facilitate online dissemination. Figure 1 below illustrates the virtual objects representing machine tool components, built using customizable components called nodes. Such custom-built (user-defined) shapes are defined as PROTOS (prototypes) that are also reusable software objects. These can be built once and accessed later using the EXTERNPROTOS (external prototypes). More importantly, as will be seen later, these can be used for creating dynamic virtual worlds that are interactive in nature.

Figure 2 illustrates the virtual worlds generated for a construction/interior design project. By way of creating custom-made PROTOS and EXTERNPROTOS, the behavior of the scene components can be manipulated to facilitate dynamic interaction. Movements within a VR world are brought about by animating position, orientation, or scale of the coordinate systems in which the objects exist. The scene is defined by "nodes" (X3D/VRML). A visualization scene can be considered to be composed of objects with properties. Considering a sample scene, say an interior design as considered in this study. If further broken down into smaller fragments, the elements that result include tables, chairs, lamps, washrooms, etc. The furniture may be of a particular material, color, and dimensions. All these are the attributes of the furniture. Similarly, each element has its own characteristic features or attributes. A scene can be viewed as being composed of elements or objects, each of which has its own properties or attributes. A parent object can include any number of children, which can be grouped or assembled to function as one single entity. This sort of hierarchical arrangement helps in the step-by-step design of the object and also understanding the framework at any later stage. A scene-tree construction is used in Virtual Scene Renderings. The root or the parent object consists of whole scene grouped together and all the other components are grouped under this parent object using ‘parent-child’ relationships. Individual scene elements corresponding to each floor type were created and positioned according to their corresponding positions as per the Pareto plan obtained in the previous step. For complex objects including multiple parts, various object parts are grouped to form parent objects, leading to complete objects that are combined and re-positioned to create the final 3D scene. Another advanced way of customizing the virtual objects is by the use of PROTO nodes, which the following section addresses.

**Hardware Component**

The hardware used in this research consists of the following major components

- HP Z800 machine,
- Samsung C7000 46inch 3D TV,
- Razer Hydra, and
- Microsoft Kinect

The HP Z800 uses a Quadra 5000 graphics card. (Polygon capability) The HP Z800 is a recognized workstation for high performance graphics. The Samsung display is an active stereo 120 Hz system that uses its own proprietary glasses for binocular vision. The Razer Hydra is built specifically for the game industry. OF late, there has been a surge in interest in the use of
the Hydra for DIY-VR applications. (DIY – do it yourself). These DIY includes a gamut of applications such as applications for mechanical engineering, civil engineering, construction, interior design (Figure 1 and Figure 2) as well as for research, entertainment, video games, etc. There is also an emerging interest in industry-oriented applications. MS Kinect is a gaming interface designed to function with MS Xbox; however, owing to the possibility of Kinect being extended (without Xbox), this research uses Kinect as the tracking interface. More specifically, we use Kinect for head-tracking of the users. If the Portable VR system used in this research is compared with high-end VR systems (e.g. CAVE), the pVR can still provide reasonable immersion and navigation capabilities to the user, but at extremely low costs (when compared to CAVEs). This is accomplished at the cost of resolution and tracking-fidelity. But, it needs to be noted that not all applications that use CAVE necessarily require such high specifications. Quite frequently, the ultimate objective of an application can be attained using the system proposed in this research without resorting to CAVE. For instance, let us consider the usage of an industrial tool e.g. A VR simulator for flight UI training. There are very specific controls for manipulating specific operations. These just need a simple display (e.g. monitor), as the UI that the personnel are being trained for is a simple ‘flat’ display panel. In such a case, a 3D or immersive facility does not offer any significant advantage over a flat 2D display (like a monitor). The application does not require high-end output, then the user might be able to further bring down the cost of the equipment. This can be done by using a desktop instead of a high-end workstation. That could possibly bring the cost down by one-fifth (2k). The display system can also use a HD Monitor instead of a HDTV (as commercially there is a significant difference between TV vs monitor). Such monitor can be procured for anywhere around 500$.
Programming Objects for Interaction

When the user clicks within the perimeter/boundary of the pixel/voxel, the position (geometric center) is highlighted. (In reality, the highlighted object always exists in the scene. However, initially in the un-activated state (when the user has not clicked), it remains hidden as its visibility is set to complete transparency. Later using JavaScript functions, the user click event is used to activate the object (by modifying the material node’s transparency value). In order to facilitate the user clicking, a buffer is provided whereby the user can click within a radius of the geometric center of the grid and the object is still selected. Different types of mouse actions that can be used include mouse Cursor Click, cursor movement (hover), and mouse click / drag.

Results and Discussion

The virtual scenarios are developed using x3D/VRML and Unity platform. Unity3D is a game engine built to be capable of rendering through either through OpenGL or DirectX depending on end platform and is capable of exporting to a variety of platforms including: web embedded, iOS, Android, Windows, Mac, and also with the usage of some middleware applications, it can also be used in CAVE environments. The Unity3D environment is empowered by the client’s machine and can extend PhysX for achieving better looking graphics as well as functionalities of DirectX 11 like dynamic geometry tessellation, complex particle effects and even provide functionalities for dynamic lighting as well as static light baking. By combining these capabilities with the previously mentioned devices, one can mimic the functionality of a CAVE system by incorporating devices that can perform head-tracking, stereoscopic 3D visualization and input devices that allow interaction using physical movement. When using Unity, a 3D graphics engine, all they would need is the Unity Web plugin which functions with all major browsers and will give immediate access to the complete 3D environment.

Fig 4a. Interior Design Visualization
Fig 4b. View with a standard VR plug-in
Fig 4c. Visualization in Unity Web Player
Images below depict a sample restaurant scenario generated in x3D/VRML and visualized in three different settings
- Using a standard web-browser and a VR plug-in (Figure.4a)
- As a 3ds Max© Rendering (Figure.4a b)
- View inside Unity Web Player (Figure.4a c)

Table 1: Comprehensive Table Comparing Cost Vs Benefits of the Various Display Systems

<table>
<thead>
<tr>
<th>Display</th>
<th>pdVR (Proposed System)</th>
<th>4-Sided CAVE * (Details based on a standard CAVE )</th>
<th>Full-Fledged CAVE - 6 sided, HR Multi-Projection Screens, Cluster(s)</th>
<th>Consumer VR HMD system:</th>
<th>Desktop VR</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Samsung 7000C 46” 3D LED TV 1920x1080 @ 60hz (120hz after interpolation) Active stereo shutter glasses (by Samsung)</td>
<td>Barco NW7 projector at 1356x1080 per display @ 120hz Each projection - 8’ by 10’ (300k) +Installation + Structure (1M)</td>
<td>- Rear Projected Optically Blended MP system (&gt; 2 million, minimum) - Resolution (1920 by 1920 per screen 120Hz Active Stereo)</td>
<td>Oculus Rift: 1200x800 (600x800 per eye) at 60hz. Stereo provided by side-by-side 300</td>
<td>Standard LCD Monitor</td>
</tr>
<tr>
<td>FOV (Hori)</td>
<td>45-90 degrees (approx.)</td>
<td>270 degrees (max.)</td>
<td>360 degrees</td>
<td>&lt; 110 degrees</td>
<td>At a distance of 20” from screen, approx.. 60 deg for a 20” Screen</td>
</tr>
<tr>
<td>Machine</td>
<td>HP Z800 workstation + Quadro 5000 (5k)</td>
<td>HP Z800 workstation + Quadro plex d2 (30k)</td>
<td>Cluster-driven Between 6 – 12 machines (WS) Min. Req. WS with Quadro VC(50-100k) Approx.</td>
<td>HP Z800 workstation + Quadro 5000 (A Std gaming pc/laptop &lt; 2k)</td>
<td>Standard Gaming PC/ WS</td>
</tr>
<tr>
<td>Tracking</td>
<td>YES (Microsoft Kinect with primesense drivers)</td>
<td>YES Intersense – 100k</td>
<td>Yes. Wide Range Possible Magnetic Tracking / Optical Tracking (OT) (OT – 25k/Intersense-100k)</td>
<td>YES Display &amp; rotational tracking</td>
<td>NO</td>
</tr>
<tr>
<td>Real-time Interaction</td>
<td>YES</td>
<td>YES</td>
<td>YES</td>
<td>YES</td>
<td>YES</td>
</tr>
<tr>
<td>Immersion</td>
<td>Medium*</td>
<td>High</td>
<td>Very High</td>
<td>Medium High</td>
<td>Low</td>
</tr>
<tr>
<td>Equipment + Installation Cost</td>
<td>Approx. 8k TV (2k) + HP W/s (5k) + Tracking (250$)+ (Hydra+Kinect) (Low Inst. Costs)</td>
<td>1.5 M Approx</td>
<td>2,100,000 (Approx.)</td>
<td>2500 $</td>
<td>2k</td>
</tr>
<tr>
<td>Op/Maintenance Cost</td>
<td>Negligible</td>
<td>Per Year 30 k Maintenance 50 k Operation</td>
<td>50 k /annum (Maint.) 100 k /annum (Operation)</td>
<td>Negligible</td>
<td>Negligible</td>
</tr>
<tr>
<td>Simulator Sickness</td>
<td>Low</td>
<td>Medium</td>
<td>Medium</td>
<td>Medium High</td>
<td>Low</td>
</tr>
</tbody>
</table>
Clean-Room Study

The cleanroom project is a virtual simulation (Figure 5) designed to give Pharmacy students an opportunity to have a hands-on experience with IV medication preparation as well as learning the concepts behind the United States Pharmacopeia Convention (USP) 797 code for sterile environments. This simulation is incorporated into the 2nd and 3rd professional year within the pharmacy curriculum, and is administered to small groups consisting of 5-8 students. Figure 5 below illustrates the Cleanroom simulation being used in a CAVE and pdVR system.

Each student within these groups performs the following tasks:

- Garb into the regulation clothing used in standard pharmacy cleanrooms
- Identify contaminants and objects violating safety regulations
- Become familiar with medication and equipment labeling standards
- Validate a medication order and role-play the proper procedure in IV compounding
- Transport the virtual components required to perform the medication preparation into the virtual fume hood
  - Move appropriate medication vial at concentration, syringe, syringe needle, Intravenous (IV)-Bag into fume hood
  - Apply alcohol swab to vials and iv-bag seals
  - Attach syringe needle to syringe and extract appropriate medication quantity
  - Aseptically inject medication into IV-Bag
  - Dispose of syringe needle tip and re-draw air to used volume of medication
  - Transport empty syringe, medication and IV-Bag to pass-through-window

Conventional clean rooms are closed and strictly controlled spaces especially while considering pressure, particulate matter, airborne particles, temperature, humidity, noise, lighting, etc. Federal regulations dictate that the concentration of airborne particles is within specified limits for a room to be considered a clean room. Creating and especially, maintaining such strict
standards for conducting clean room experiments is an arduous task indeed. Having a pdVR system as described in this study makes training students in the clean room procedures a much less cumbersome task.

Limitations and Suggestions for Future Study

There were some important limitations and/or constraints that the authors experienced with this prototype study. The vast majority of the efforts in the study were dedicated towards designing the framework, development, and implementation with due consideration of EE/EET curriculum. Studies were conducted to develop and test applications in diverse disciplines such as MET, Interior Design, Pharmacy etc. However, as part of future studies, the authors endeavor to conduct tests and include data related to student performance. These studies would specifically target measuring the accomplishment of course learning outcomes within the ET disciplines.

Conclusion

In this study, we implemented a pdVR system that is capable of providing Tracking and semi-immersive capabilities at reasonable costs. This is a versatile VR system that is a good trade-off between high-end systems like CAVE that may be extremely expensive and low-end systems like dVR which lack immersion and intuitive interaction. Faculty members do not need intensive training to use the systems as the system is based on intuitive skills such as navigation and immersion. Some of the prominent applications of the pdVR system are listed below.

This system can be used to

- Demonstrate visualization, animations, and simulation applications to schools. Schools may not be equipped with or have access to such high-end facilities. Also, procuring such facilities involves significant cost as well as space requirements. So, with a portable system like ours, mass-distribution can be a lot easier.
- Develop and demonstrate applications for small-scale consulting. For instance, interior designers can implement this low-cost system within their studios and demonstrate potential layouts/designs to clients. Interior design scenarios having a portable system that is also low-cost can be more appealing to the prospective clients than using the conventional displays or resorting to the high-end systems like CAVE.
- Demonstrate Architectural applications. Closely related to the above listed item is the use of this system for visualizing, exploring, and evaluating architectural designs. The affordability and portability of this system makes it an ideal choice for Architectural firms and consultants. (Figure 2 and Figure 4)
- Facilitate PBL and active learning in Engineering and Technology curriculum. Students in various ET disciplines such as Mechanical, Electrical, etc. can gain hands-on (simulated) experience by using these systems.
- Supplement department laboratories. For instance, within the domain of Aerospace Engineering, a pdVR can be used for visualizing orbital dynamics. Once implemented and in place/running, these can be used any number of times without much associated costs. This can be extremely cost-efficient and time-saving.
References:


