COLLABORATIVE VIRTUAL ENVIRONMENT FOR ENGINEERING LABORATORY

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KEYWORDS

3D Virtual Environment, Collaborative Virtual Environment, Open Wonderland, Virtual Laboratory, Virtual Learning Environment

ABSTRACT

In recent years, virtual environments have played a key role in engineering education. The use of virtual environments as learning tools continues to grow on account of the capabilities of providing learners with more interactive and immersive learning experiences than most of the conventional learning methods. This paper aims to introduce the related background and recent research work on the topic of the collaborative virtual environment (CVE) and then presents a solution of implementing a web-based 3D virtual engineering laboratory in a collaborative setting. This will allow users to create their own avatars in the virtual world and work collaboratively over the network. Such a method may also be beneficial for distance learning.

INTRODUCTION

With the recent growth and maturation in computer-based technology, virtual learning environments (VLE) have been widely used in educational settings over the last decade (Baker and Gossman, 2013). Especially in engineering education, such as engineering laboratory experiments, VLE has become a popular learning tool for engineering students because of its ability to support active learning (Pislaru and Mishra, 2009). A VLE not only improves the depth of learning, but also enhances the entire learning experience by providing interactions between students and the virtual environment (Effective Use of VLEs, n.d.). When a VLE is able to support activities with multiple participants, such environment can be considered as a collaborative virtual environment (CVE). CVE helps users work as a team either face to face or online to achieve learning objectives in the same virtual workspace. Essentially, this may permit users to share their ideas and learn from each other. More importantly, CVE increases the level of interactions among the participants themselves, which in essence may lead to better productivity during the collaboration (Schmeil et al. 2007).

Virtual Learning Environment (VLE)

The VLE refers to a set of computer-based learning tools that are designed to support and enhance the teaching and learning experiences in educational settings (d'Entremont, 2004). A VLE not only offers learners to learn and absorb information through multimedia tools, but also allows them to build interactions with the virtual learning scenes by engaging multiple sensories including visual, audio, and touch (Barajas and Owen, 2000). For instance, a head mounted display (HMD) device projects digital images on the data glasses attached to the device, bringing users immersive visual experiences. A virtual training system, such as a virtual operating room, allows the participant to hear the virtual doctors' instruction through an audio system and to speak with virtual doctors using a microphone. Thus, information can be received from the audio sensory. Haptic devices, such as data gloves, allow participants to interact with the virtual objects in the virtual world with touch feedbacks. In addition to having multiple sensory channels throughout the learning process, the VLE also contributes to the following benefits (Hamada, 2008):

- A VLE provides students with more interactions and helps them to learn actively
- A VLE supports collaborative learning through which students can communicate and share learning experiences with each other
- A VLE offers more controls and manipulation to learners during their learning process
- A VLE allows teachers to act as facilitators instead of knowledge transmitters, which means, knowledge is actively constructed and absorbed by students instead of passively transmitted to them

Collaborative Virtual Environment (CVE)

A typical CVE is a virtual space that allows multiple users to work collaboratively online through multi-media communications such as voice chat, drawing panel and video conferencing. The CVE is especially a beneficial tool in learning and education, as it plays a variety of important roles including (Liebregt, 2005):

- Supporting the social awareness of students
- Supporting active learning
- Increasing communication, discussions and interaction possibilities on a wide scale
- Supporting constructivist learning

- Making virtual experiences available for learning difficult concepts
- Incorporating aspects of direct learning into indirect learning and the other way around

Other than the online CVE, an example of large scale immersive CVE would be the Computer Automated Virtual Environment (CAVE), which is a room-sized cube composed of three or four projection walls. The main hardware components of a CAVE typically consist of a displaying system, an audio system and a tracking system. The CAVE provides users with great amount of immersion and interaction, which essentially increase the realism of the virtual scene. With this virtual environment, users are able to work collaboratively by cooperating with each other on the spot and interacting the virtual objects in the virtual scene. Although using the CAVE as a CVE provides users with high level of immersion and interaction, accessibility becomes problematic since users have to physically meet in the same CAVE facility in order to collaborate. On the other hand, an online CVE allows users to collaborate in a same virtual space over a network without being physically presented. Thus, online CVE offers a remote access compared to the large scale immersive CVE.

We have previously built a web browser-based 3D virtual engineering laboratory that is fully interactive, but limited to only one student performing an experiment at a time (Chaturvedi et al., 2012). The objective of the paper is to extend this work and illustrate a method of implementing a single user 3D virtual engineering lab in a more collaborative setting that supports multi-user capability. The remainder of the paper is divided into four sections. The Background section covers a brief background of 3D CVE platform that will be used in this project, as well as a brief introduction of the existing 3D virtual engineering laboratory from our previous work. The Related Research section describes recent publications and articles that discuss applications of CVE especially in the field of engineering education. The Implementation section discusses the workflow of transforming the single user 3D virtual laboratory to a collaborative environment. Lastly, the Conclusion and Future Work section summarizes our development, states the limitation of our work and describes the potential solutions for extending our study.

BACKGROUND

This section presents a brief background introduction of the physical lab experiment, the 3D virtual laboratory based on the physical set-up, and lastly the platform that will be used to implement the existing web browser-based 3D virtual laboratory in an online collaborative setting.

The Jet Force on Vanes Experiment

The Jet Force on Vanes experiment, from a junior level lab course ME 305 Thermal-fluids Laboratory at Old Dominion University, demonstrates the reactions of the jet impact force from a water jet hitting on various shapes of target vanes. The relationship is described as the equation "$F = Cm^n$, where the letter "F" represents the impact force, "m" represents the mass flow rate and "C" represents the type of vane (Chaturvedi et al. 2012). Initially, a type of vane, which includes a flat shaped vane, a funnel-like shaped vane with narrow mouth and a funnel shaped vane with a relatively wider mouth (all vanes have narrow stems), is attached to a jockey sliding weight beam mounted on top of the cylindrical lid. Water is discharged through a nozzle inside the transparent cylindrical storage tank to form a jet, which has impacts on the vane. The flow rate of the water can be adjusted through a valve in a low, medium or high mode. As the flow rate changes, the force deflects the beam from the horizontal position. Thus, the jockey weight can be slid along the beam to bring it back to the horizontal position, which is indicated by a blue tally mark. As water keeps impacting the vane, water falls to the bottom tank for re-circulation. Mass flow rate then can be measured through a stopwatch by collecting a given amount of mass over time. The experiment can be repeated with other shapes of vanes for several mass flow rates.

Figure 1. Physical Set-up of the Jet Force on Vanes Experiment

Web browser-based 3D Virtual Engineering Laboratory

A web browser-based 3D virtual laboratory is developed using the 3D modeling software AutoCAD Maya and a gaming engine 3DVIA Virtools from our previous work (Chaturvedi et al., 2012). Maya provides the modeling and texturing features, which are two important steps in creating the 3D virtual model of the laboratory equipment. Virtools offers developers the ability to assign different behaviors to the 3D objects and models they import, thereby making the 3D objects interactive

according to the given behaviors. Thus, users can interact with the virtual model through a specific input device such as a mouse or a keyboard. The finished 3D virtual model can be exported to a web browser format, allowing the user to run the virtual application through a web browser on a computer. The 3D virtual laboratory is specifically designed for the undergraduate mechanical engineering students as a pre-lab practice session so that students can practice the entire lab experiment procedure in a virtual setting prior to the physical experiment. This allows students to gain more hands-on experiences, familiarize with the experiment concepts and procedures, and learn from mistakes without worrying about damaging the equipment. Figure 2 shows the screenshot of the 3D Jet Force on Vanes virtual lab in a Google Chrome web browser.
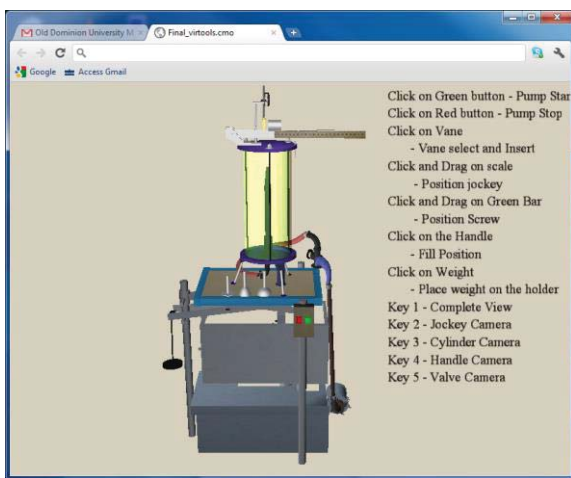

Figure 2. Virtual Set-up of the of the Jet Force on Vanes Experiment in a Web Browser

Open Wonderland – Open Source CVE Platform

The CVE platform that is used to support the online collaboration ability on the existing web browser-based 3D virtual engineering laboratory is called the Open Wonderland. Originally named the Project Wonderland by Sun Microsystems, Open Wonderland now is an independent community-supported 100% Java open source toolkit for developing collaborative 3D virtual worlds. Those virtual worlds offer communications through voice, text and video chat as well as sharing desktop applications and documents. On top of that, Open Wonderland is fully extensible. Developers are able to extend more functionalities such as adding new features, assigning behaviors to the avatars, and adding new plugins in the virtual world. Additionally, Open Wonderland supports the feature of importing 3D arts or models from 3D modeling and animation tools such as Google SketchUp and Blender. Such feature makes the virtual world completely customizable. Developers can import their own 3D models and build their virtual world the way they desire.

Open Wonderland is based on the game server Project Darkstar, which contains two main components, namely, the transaction model and the network protocol (Blair, 2011). The transaction model is in control of managing any access that goes through the Darkstar server while the network protocol assures messages can communicate between the server and the client. Developers are also able to manage the server contents such as client settings, server modules, apps, and users through the Server Admin Console, which is a web-based administration tool that configures various aspect of Open Wonderland including the start and stop of the Wonderland server components as well as monitoring of the server performance.

RELATED RESEARCH

The CVE has become a popular learning tool in classroom settings, especially in engineering education. This section discusses recent publications on the topic of the CVE and related CVE applications in engineering education.

Comparison of 3D CVEs and Text Chats as Collaboration Tools

Schmeil et al. conducted a research study on the comparison of 3D CVEs and simple text chats as collaboration tools (Schmeil et al. 2007). The objective of this study is to investigate whether the high level immersive and interactive 3D CVE as a collaboration tool is more effective than the low level interactive text chat tool.

The experiment was designed to have participants accomplishing three tasks: (1) information sharing, (2) grounding and team discussion, and (3) decision making and subgroup building by using two different collaboration tools. There were 50 participants, who were divided into 10 equal-sized small groups, participated in this experiment. Five experimental groups were assigned in the 3D CVE while other five control groups were assigned to use the simple text chat as the collaboration tool to perform the regarding tasks. The 3D CVE was implemented in the OpenSim environment, which is an open source toolkit for designing 3D collaboration environment. Participants were able to perform all three tasks by using various communication/collaboration tools that were provided in the CVE. On the other hand, control groups were only allowed to use Skype text chat as the collaboration tool. The measurements of participants' performances were based on the post-task questionnaire in terms of subjective and objective measures including satisfaction, productivity, and retention. Satisfaction and productivity were categorized as subjective measures while retention was categorized as an objective measure. Questionnaires that are related to subjective measures use the scale from -3 (strongly disagree) to +3 (strongly agree). In contrast, objective measures such as retention, represents the quantity of recalled items of teammates' profile and of

team decisions made in the collaboration process, has a scale from 0 to number of recalled items.

The results demonstrated that participants in the CVE had a difficult experience with media and technology. However, they outperformed the control groups on other aspects such as common understanding of the task and easy communications and collaborations between teammates. Comparison between the CVE and text chat participants on recalling of teammates' profiles and final role assignment showed that the CVE outperformed all the control groups.

This study provides a good overview on comparing the effectiveness of two collaboration tools: the 3D CVE and the text chat. Results show that despite some technical difficulties that participants experienced in the 3D CVE, as a high interaction level collaboration tool, it is overall more effective in terms of teamwork and collaboration than the text chat tool.

3D CVE for Physics Experiment

Scheucher et al. (2009) integrated a 3D CVE for physics experiment using the Project Wonderland. The goal of this application was to provide an immersive 3D CVE for physics education in which students are able to work together in the same virtual space (Scheucher et al. 2009).

The set-up of the experiment "Force on a Dipole" consists of a small suspended magnet by a spring located in the center of two coils that are mounted horizontally. An electrical current can go through both of the coils. This experiment demonstrates the changes in the magnetic field when the current amplitude and frequency vary. A 3D simulation of this experiment is created by using the TEALsim Toolkit while the parameter controller is developed via the software LabVIEW. The LabVIEW interface enables remote access to manipulate the experiment while the TEALsim software generates a synchronized 3D simulation of the magnetic field lines. Thus, when students change the parameters such as the current amplitude or the frequency on the LabVIEW controller panel, students will be able to observe the changes in magnetic field lines in the 3D simulation in real time.

To extend the collaborative capability of the 3D simulation, Scheucher et al. (2009) took a further step and implemented the 3D virtual experiment in a CVE setting. The first step was to create a virtual space for the experiment in Project Wonderland. This was done by using the existing modules in the Project Wonderland. As mentioned in the previous section, Project Wonderland has the capability of allowing different users to log into the virtual world using their own avatars. Users can interact with the virtual objects and collaborate with other users through build-in voice chat, text chat or drawing panels in Project Wonderland. The most important step is to figure out a way to import the existing 3D simulation into the Project Wonderland and enable it multiple-user interactive. Since the TEALsim rendering engine and the Project

Wonderland's 3D components are also both Java3D–based, such fact made it possible to integrate the two technologies with a few changes to the TEALsim architecture. This made the 3D simulation of the magnetic lines on the dipole easily implementable. The labVIEW parameter controller interface can be integrated in a Virtual Network Computer (VNC) viewer, which is a plugin in Project Wonderland that can connect to a VNC server on the same or another computer. This capability essentially provides a remote control access. In other words, multiple clients are able to connect to the VNC server and interact with the labVIEW parameter controller interface through the VNC viewer window. Thus, users can work together on this experiment collaboratively through multi-media communications that are provided in the Project Wonderland.

This project offers an effective tool to enhance the learning and understanding of abstract physics concepts using active 3D visualizations. Although there was no research study conducted to validate whether the 3D CVE module can significantly improve students' learning, the paper provides helpful techniques in design and implementation phases in which they will be beneficial to the design process in the 3D CVE module for the Jet Force on Vanes Experiment.

IMPLEMENTATION

The previous works from the Related Research section have provided us with helpful insights for our current work. Based on Schmeil et al. (2007)'s study results, we believe that a 3D interactive CVE would be more effective as a collaboration tool comparing to a simple text chat platform. Thus, our implementation tends to incorporate more interactive features into the CVE. Scheucher et al. (2009)'s work offers helpful information from the technical aspects (especially the design and implementation phases). We adopted Scheucher et al. (2009)'s method to develop the 3D virtual lab CVE by using the suggested platform Open Wonderland, which currently supports more collaborative features such as multi-media integration and avatar configuration than other similar platforms.

This section introduces the approach of designing and implementing the existing web browser-based 3D virtual laboratory in the open source CVE platform Open Wonderland.

Starting up the Open Wonderland Server

To create a Wonderland server, it is required to first download and configure the "Wonderland.jar" binary file from the Open Wonderland site. This can be done by entering the command line

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"\Program Files\Java\jdk(version no.)\bin\java
-jar Wonderland.jar"
```

in the CMD on Windows systems. When the server is successfully loaded, developers will have a full access to web server component and several default Wonderland worlds. A link to a web page which has a button to launch a Wonderland client will also be given to the user.

Importing and Editing 3D Models and Artwork

The art path for Open Wonderland is fully opened for developers. This feature gives developers and graphic artists the ability of creating their own artwork and 3D models using third-party modeling software such as Google SketchUp, Maya or Blender, and importing them to the virtual world.

In this project, the authors initially had the plan to model the real laboratory environment as the virtual world and import it to the Open Wonderland. However, due to time constraints, authors downloaded a classroom model as the laboratory environment from the Google SketchUp 3D Warehouse as an alternative. The 3D Warehouse is a website where graphic artists can upload their artwork and 3D models for other users to download and use. The 3D models on the site mostly have the file extension of .skp and .kmz. Open Wonderland allows developers to import artwork by dragging and dropping the .kmz file directly to the virtual world. Developers can also change the coordinates (X, Y, and Z position), adjust the size (scaling) and duplicate the 3D artwork/models that they imported in the Open Wonderland. Besides importing and editing 3D models, users are also able to customize their avatars by changing their appearances such as clothes, hairstyle and facial features. Thus, each user can create his/her own unique avatar that can be distinguished from the look of other avatars.

Adding Functionalities

Once all the necessary 3D models are imported to the Open Wonderland, adding functionalities to the virtual world follows the next step. The method of loading the exsisting 3D web browser-based Jet Force on Vanes Experiment to the virtual world involves using the build-in VNC Viewer plugin in the Open Wonderland. The VNC Viewer permits developers to add a remote desktop screen and display in the virtual world and interact with it. In order to connect a remote desktop computer, it is necessary for that computer to be installed the TightVNC Server with administrative password set up so that only authorized users can connect. With the help of the VNC Viewer plugin, users in Open Wonderland can take control of the VNC Viewer screen and interact with the 3D web browser-based virtual laboratory that is loaded on the remote desktop computer. This essentially permits collaboration among multiple users working on the same task. Figure 4 illustrates the VNC Viewer Plugin loaded in Open Wonderland.
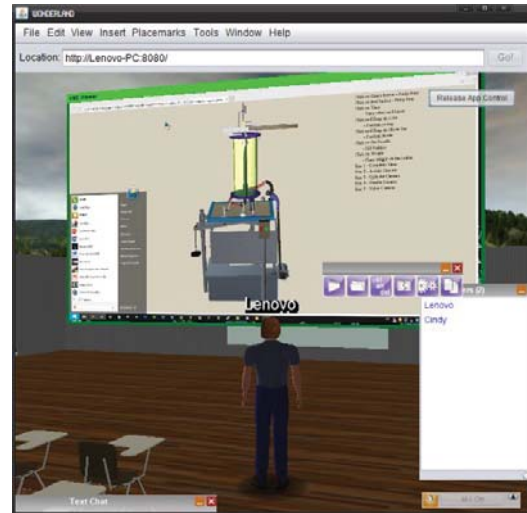

Figure 4. The build-in VNC Viewer Plugin in Open Wonderland

In addition, Open Wonderland has other build-in plugins such as PDF Viewer, Audio Player, and Video Player. PDF Viewer is added to the scene for displaying the 3D virtual lab manual in .PDF format so that users can reference to it while perform the task on the virtual lab. Figure 5 illustrates the PDF Viewer plugin in Open Wonderland.

Figure 5. The build-in PDF Viewer Plugin in Open Wonderland

Testing the CVE

The network structure of the 3D CVE consists of a PC with the 3D virtual lab loaded that provided a remote access to users, a second PC for developers to manage the server and virtual world through web-based admin console, the Open Wonderland server, and lastly the users/clients that will connect to the server. Figure 6 illustrates the 3D CVE network diagram.
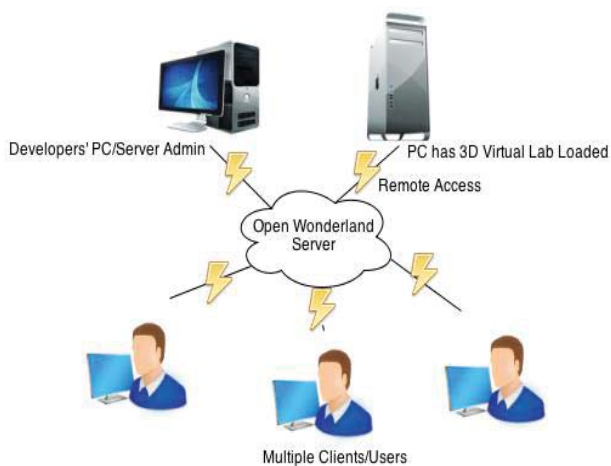
Figure 6. Network Diagram of the 3D CVE on Open Wonderland Server

Once all the components are ready, developer/server admin can provide the web link to users/clients. Through this link, users/clients will be able to log in the server, start customizing the avatar, and eventually explore the virtual world. Figure 7 shows a multiple users scene in the Open Wonderland.
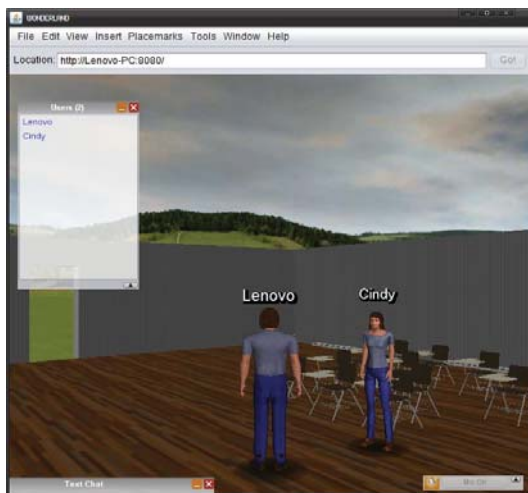

Figure 7. Multiple Users in the Open Wonderland Classroom Scene

Figure 8 illustrates multiple users in the classroom scene working on the 3D virtual laboratory together in the VNC Viewer and communicating with the build-in collaboration tools such as text chat. Users are able to take control of the remote desktop and perform the entire laboratory experiment with ease. Besides the text chat tool, voice chat as the collaboration tool were also tested and worked well in the CVE.
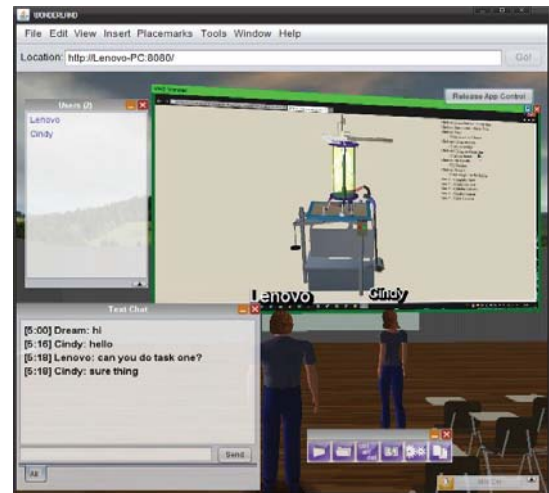

Figure 8. Multiple Users Working on the 3D Virtual Laboratory Collaboratively

CONCLUSION AND FUTURE WORK

This work is primarily to experiment whether the Java-based Open Wonderland is a suitable platform for building a 3D CVE interactive virtual laboratory. Through the development stage and careful observations, we have concluded that the collaboration features such as text and voice communication worked well in Open Wonderland. However, in terms of the interactive and visualization aspects, Open Wonderland might not be an ideal tool for advance interactions and animations, as the platform does not support other input devices (e.g. Wii remote, data gloves) and physics effects such as particle animation in the environment. Performing the web-based virtual experiment that is displayed on the VNC Viewer window sometimes results in slow responses and lags. We also noticed that those problems became slightly worse as more users started to use the experiment displayed on the VNC Viewer simultaneously. The blur on the PDF Viewer Plugin when zooming in caused another concern in the visualization aspect, as we found difficulties to view the texts and images on the .PDF clearly. Thus, relying on displaying the web-based virtual lab on the VNC Viewer is not an optimal solution in the long run. Ideally, importing the actual 3D model of the lab equipment directly to the Wonderland environment and making the model interactive would potentially solve the delay caused by the VNC Viewer and increase the realism of the virtual lab equipment. Unfortunately, Open Wonderland only allows importing of the 3D model, however, adding physics effects such as particle animation and spring effects to the imported 3D models are not supported. Yet, those features are very important to meet the interactive and collaborative requirements for our virtual lab.

Overall, we believed that our paper has provided helpful references on the limitations of Open Wonderland in terms of interaction and animation features for those

researchers who are interested in developing any advanced interactive collaborative virtual laboratories in the future.

The future work of this study includes (1) finding a new platform or gaming engine such as Unity 3D or Unreal Engine that can support physics effects and animations so that the actual 3D model of the lab equipment can be imported directly in to the virtual scene for students to interact with instead of displaying a browser-based virtual lab in Open Wonderland by using the VNC Viewer through a remote desktop computer, and (2) conducting a research study to compare the difference of student performance under two virtual environments: a 3D virtual lab in a CVE and a 3D virtual lab without the collaborative aspects.

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