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Online 3D Collaboration System for Engineering Education

Abstract

The Internet has provided new communication methods for most people is all walks of like, particularly for education and industry. It is common that people email friends, pay bills online and play games together when they are in two countries. Industry has employed video conference to discuss engineering problems and to share files. Education has utilized websites to present education and training materials and discussions. Generally, these applications employ two dimensional collaboration tools. As new Internet technologies develop and the computer processing speeds increase, constructing a real-time online engineering education and training collaboration tool for a team of remotely distributed learners has become an important research topic. However, it is a challenging task to develop and implement a true synchronized interactive three-dimensional system for online connected users. Major obstacles in developing and implementing such a system include large three-dimensional object data size, real-time three-dimensional world rendering, and bandwidth limitation.

This paper introduces the background of doing research on online synchronous three-dimensional engineering learning environment over the Internet for a group of people from various physically separated sites. It also reviews research that has been done in online distance engineering education and training. Finally, this paper presents a real online example, called "3D Bracket", which is designed to help engineering students understand concepts of torque, bending and superposition theory of Mechanics. In this learning environment the users are capable of designing and manipulating three-dimensional models, such as changing the view point and applying forces at various locations of the bracket. All participates are connected online, and are able to view the bracket deflection through a web-browser in real-time from any local. In addition, the students are allowed to exchange ideas via audio and text chat.

This research employs Adobe Director to generate online real-time three-dimensional model in this team-based engineering education environment. Adobe Flash Communication Server (recently renamed Flash Media Server) is used as the synchronous technology to invoke the synchronize changes among the multiple remote learners. The main purpose of this research is the design and implementation of a framework to integrate the instant audio communication and interactive three-dimensional models over the Internet. This framework makes the online real-time team engineering work possible.

Introduction

The Internet is changing Americans' communication methods in many new ways. According to the survey of Pew Internet & American Life project, more than half (55%) of all online American youths ages 12-17 use online social networking sites [1]. Nearly two in five adult Internet users in the US (39%) have gone online to look for information about a place to live, up from 34% in 2004 to 27% in 2000 [2]. Fully 87% of online users have at one time used the Internet to carry out research on a scientific topic or concept [3]. The growth of the Internet is due to many reasons, but several obvious ones are its low cost, convenience, and time saving. Also fueling this growth is, the rapid improvement of Internet technologies, and increasing computer and network processing speeds. With new Internet technologies and faster computer speeds, performing independent online training, viewing video and playing games over the Internet are no longer a bandwidth issue. However, collaboratively training a group of physically separated students with three-dimensional (3D) visualized objects in real-time is still a challenging task due to the large amount of data, Internet bandwidth limitation and real-time rendering [4]. This paper describes the design and implementation of a real-time bracket learning environment which employs low lag audio and interactive 3D models.

Partly because of the convenience of online education and training, a number of researchers have investigated synchronized online systems. Pullen, at George Mason University, has developed and integrated open source software, Network EducationWare (NEW), for a professor to teach a course synchronously to both local students and distance learners over the Internet [5-7]. The NEW system can synchronously deliver the instructor's voice, graphics, dynamic annotations, and optional videos to the students over the Internet. Although the whiteboard of this software can be visually shared by multiple students and basic graphics such as colorful lines, rectangles, and ellipses can be added to it, the instructors or students cannot change anything on the whiteboard because what the students really share is a series of prepared graphics. Unlike HTML files or data files, graphic files have larger file sizes and always require more download time. Although the instructor can draw two dimensional (2D) graphics on the whiteboard, 3D objects are neither generated nor shared among the students to illustrate the concepts.

The researchers, AlRamahi and Gramoll, at the University of Oklahoma developed a drawing board, LectureBoard, to provide an online, collaborative, and spontaneous lecture creation using Adobe Flash Communication Server [8, 9]. In this system, the users can communicate with each other with text chat, speech, and vector-based drawings. The lecture, including the drawing and the audio, can be saved on the server as an Abode Flash file so that it can be reused by students at a later time. All the users are capable of drawing various shapes including lines, arrows, circles, and rectangles, or drawing free hand. The eraser, object selector, grid, shape color, line color, and thickness are also implemented to facilitate clearer and easier drawings. Although a vector-based drawing creates small file size and the scene is resizable without a dramatic decrease in the graphic quality, only 2D graphics can be generated in this system. However, many concepts in engineering classes need 3D models to help student better understand. When the user draws quickly on the screen with the free hand drawing tool, the lines, which display in the LectureBoard, consists of many straight line segments that only simulate curves. In addition, this system cannot continuously share the scene. For example, the person who controls the drawing tool is capable of seeing the pen's moving path immediately on the screen, but all the other users only see the path after the drawing object is completed.

Sun and Gramoll at the University of Oklahoma have developed a 3D Virtual City that allows interactivity and collaboration. The ultimate goal of that project was to provide guidance to students to better understand and integrate the theoretical concepts with the process of design and analysis through an interactive and distributed collaborative process [10-15]. This system allows the students to build real 3D models, such as highway systems, bridges, dams, buildings, and structures, into a 3D virtual world upon the completion of civil engineering courses. This 3D world, which is implemented using Virtual Reality Modeling Language (VRML), is viewable and navigable via the Internet. The system is also used to develop an engineering design and analysis module using Adobe Director Shockwave and Java 3D technologies that allow the generation of 3D objects and finite element analysis.

The Virtual City system implements 3D visualization that is created with diverse computer systems in various locations through the Internet. Virtual City allows real-time multiple users, collaborative learning and doing projects over the Internet. When one student in the team makes changes to a design, other students can see the changes immediately. It is similar to the traditional face-to-face teamwork, yet the designers can be at physically different locations. This system provides a web-based, multi-user engineering analysis tool which allows the designers to import models, specify the material properties, the boundary conditions, the force type, and the number of elements, and then perform finite element analysis. It also supports other designers to modify all the above items. However, the 3D geometric model in this system cannot be dynamically modified once it is generated. In other words, it is a static model, although it can be rotated and downloaded. This system can generate only one 3D object. However, engineering education needs multiple objects and boundary conditions to be displayed as 3D objects.

Another virtual collaboration room (VCR), University21, is a comprehensive group learning and design center which supports real-time dynamic 3D objects sharing functions [16]. This room enables teachers and students to flexibly and naturally conduct their collaborative teaching, learning, and working over the Internet without constraints on collaboration type, working style, group scale, and system platform [17, 18]. VCR consists of a workspace, group chat, and room management. The workspace is further composed with six subspaces such as control audio, video and note board. In order to draw user's attention, a normal user can only view the visible subspace, which has been selected by the chair/presenter. The management function consists of the User Panel, Object Cabinet, Object Panel and Workspace Panel. The User Panel is for user management. The Object Cabinet is for storing and creating available objects. The Object Panel is for controlling the objects in a workspace. The Workspace Panel is for controlling a visible working subspace. A learner or a designer is allowed to modify the dimension of the 3D object, and change the light, color, and view point. However, when a new 3D object generates, all 3D objects in the scene have to be redrawn. This takes both computer and Internet resources. Regular 3D objects, such as balls, boxes and cylinders, can be drawn in the system but the shape of the 3D objects cannot be changed.

The VCR system uses multiple working and manipulation spaces to generate new objects, set up light sources, view points, and manipulating objects. The user needs to input parameters, such as color R, color G, color B, translation X, translation Y, and translation Z. For a computer graphics programmer, these parameters are easily understood. However, for general users, these abstract parameters can be confusing. Although individual 3D objects can be rotated, the whole 3D world cannot be rotated. Thus, if a user builds a house, it can only be viewed from the front. This is not natural because in the real world the designer can go to any side of a product, and in any CAD program, an assembly product can be freely rotated.

System Design and Implementation

As outlined in the previous section, online, dynamic, 3D, collaborative education and training environment still have various limitations. In this section, an online dynamic 3D collaborative education and training environment design system, and its implementation, is presented. The tools employed to build the prototype are discussed.

There are numerous Internet technologies available in the market that can be used to develop online applications. The two key technologies employed in this work are Adobe Flash Communication Server (Flashcom) and Adobe Director. The reasons why these technologies have been chosen and how they are used are discussed in the following paragraphs.

I. 3D Rendering Tool

There are various technologies to render 3D models on the web, but the most commonly used are Virtual Reality Modeling Language (VRML), Java 3D, and Adobe Director (or Shockwave). Director has the ability to create multimedia presentations both on and off the Internet. Director supports the creation of both complex 2D animations and 3D models for interactive course modules and games. It is used in this work to dynamically create and render 3D objects on the web because Director has small file sizes due in part of being vector-based.

Another advantage of Director for any dynamic 3D collaborative system is its ability to provide multi-resolution mesh rendering. Director renders a less resolution 3D world for a slower computer and a higher resolution 3D world for a faster computer based on the developers' design to facilitate short download time. This technology is implemented in this research work by specifying the resolution of the 3D model.

One more advantage of Director is its support of subdivision surfaces. Subdivision surface is a technology that increases the resolution of low-resolution models. It allows the users to first download a small file with a low resolution 3D model, and then use the processing ability of the local computer to generate a higher resolution 3D world. This technology minimizes the Shockwave file size and generates smoother curved surface that was originally created with flat surfaces.

II. Synchronized Tool

In order to design a synchronous collaboration environment, it is essential that the connected users communicate with each other in real-time. This can be done with synchronized tools, such as Adobe Flash Communication Server (Flashcom), Java Remote Method Invocation (RMI) and Adobe Director Multi-user Server (MUS).

Unlike many other streaming media servers which use User Datagram Protocol (UDP) to broadcast the data to multiple IP addresses at the same time, Adobe Flashcom uses Transport Control Protocol (TCP). UDP has a number of advantages including high speed information transferring, excellent broadcast position information, good performance under noisy network conditions, and an efficient method to send animation sub-frames. However, using UDP to send out information cannot guarantee that the message will arrive at the destination computers. In other words, the information may be missing if it is sent using UDP.

Although TCP is slower than UDP, it is highly reliable and can resend the information when deliver fails. Also, TCP is the industry standard, database accessible, and firewalls passable. This protocol has been demonstrated to be reliable and bidirectional.

Flashcom software sends information and manages the server through TCP. Flashcom has its own administrator tools that can manage the user account and configure the ports which allow the Internet user access. This technology guarantees the information, which is sent out or received by Flashcom, to pass through the firewall without missing data.

Another advantage of Flashcom is its ability to pass only the changed data to the clients. For example, when an end user changes a variable, from 2 to 3, Flashcom will send 3 to all the clients whose variable is not 3. This technology helps to reduce data transmission over the Internet. In addition, both Director and Flashcom are the products of the same company, Adobe Inc. and they work well together.

The core usage of Flashcom is handling interactions and coordinating the actions of multiple, connected users, or clients, and transmitting server-side data. It provides two communication technologies that simplify the process of handling user interactions: streams and shared objects. Both of the two communication technologies are used in the design and implementation of this learning system.

The communication technology, “stream”, is employed to facilitate the natural audio communication in this research. Stream is a way to organize and manage the data flow over a network connection [19]. Audio data can be carried within a stream in only one direction and multiple streams can be created within a single network connection. In order to transfer audio over a network connection, it is attached to a stream. In this research, a stream is used to broadcast the speakers’ sound data for each user. Multiple streams are used to receive other user’s sound data for each user. In order to increase the quality of the audio and reduce the data transmission over the Internet, the echo, rate, gain and silence levels are controlled.

The shared object is another communication technology that is employed to handle the data for manipulating 3D objects and sending text chat in this research. Flash shared objects, which store information for later use, can be shared by multiple instances of the application. There are two kinds of shared objects including local shared objects (LSOs) and remote shared objects (RSOs). LSOs can be stored and retrieved locally by multiple Director simulations. RSOs can be shared by multiple Director simulations which are connected to the Flashcom Server in real-time. In this research, remote shared objects are both employed. When one user changes any property of his copy of RSO, updates are automatically sent to all other users’ simulation which shares the same object.

III. System design

To allow a group of learners to work on the same problem, each member needs to see the same object from the same angle in their own browser in real-time. Any edition and manipulation of a 3D object in any of the learners’ own browser will pass to the server and then to all the connected learners. In other words, “What You See Is What I See” (WYSIWIS) environment as shown in Figure 1.

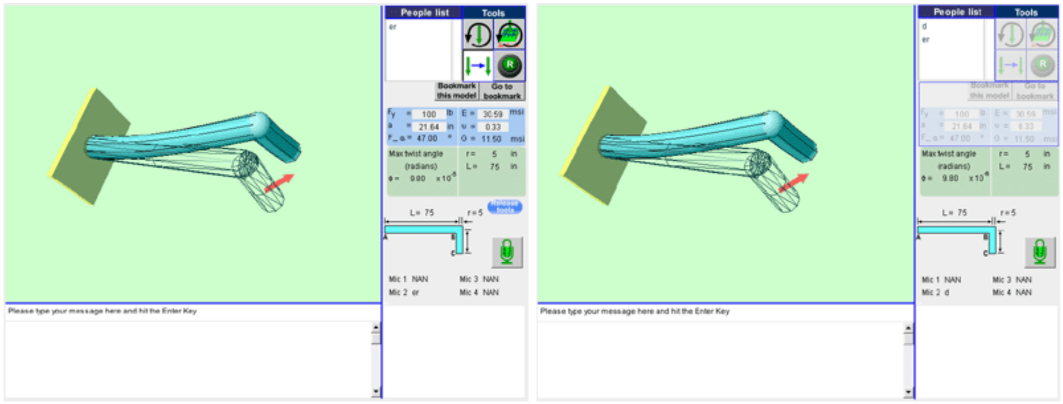

Figure 1. "what you see is what i see" environment

Generating large amounts of geometric data on the server and passing the data back to the users' local computer can quickly reach the upper limitation of the network capacity regardless of the bandwidth. To help reduce this limitation, the system parametrically defines the geometry of the 3D objects. It generates 3D objects based on a few parameters in the client computer and only these parameters are passed from the server to the local computer through the Internet. In order to reduce data transmission, Flashcom is used because only the changed data are passed to all connected client computers through the server. Therefore, the time to display the 3D environment relies only on the client computer's calculation speed. With the constantly increasing computer processing speeds, rendering time drops proportionally.

VI. Implement collaborative Real-time 3D Bracket Learning System

In order to demonstrate that 3D Bracket learning system is a feasible solution for both distance education and engineering analysis, a prototype, 3D bracket, has been developed. The basic goal of this prototype is to help teach engineering principles and concepts through the use of 3D virtual worlds and narrations, which are essential features in engineering education. Students gain knowledge by actually applying loads to virtual 3D objects.

The application is a virtual prototype in which users are able to create, edit and manipulate 3D objects from remote sites. In this virtual prototype, engineering students use simulation to mimic the situation of applying a force on a bracket with a boundary condition. The analysis result, the maximum twist angle, is displayed to all the students' browsers in real-time after a force is applied or moved. To encourage group learning, this virtual world allows the students to learn on the same 3D object synchronously. Furthermore, anyone in the same group can hear others' comments.

To facilitate instructors' teaching classes and the students' learning, there are a number of functions, which are organized groups including a people list, manipulation tools, input values, results and communication tools. These features are shown in Figure 2. The people list displays the names of all the logged students. This helps all users know who is currently participating.

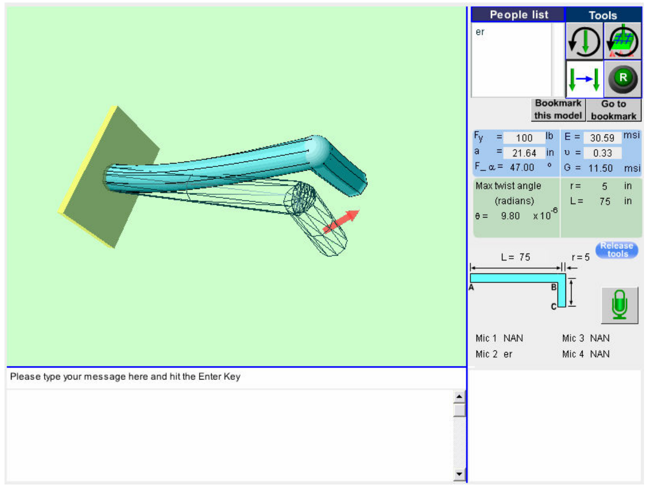

Figure 2. Snapshot of 3D bracket

The tools section provides four functions that can be manipulated including rotating the forces, rotating the 3D world, moving forces, and resetting the 3D world. In order to change the viewpoint of a 3D object, a rotation button is provided. After clicking the rotation button, the cursor changes to the symbol of rotation. A user can click anywhere on the 3D object and rotate the 3D objects by holding the left button and moving the mouse. The change viewpoint function allows the users to observe the 3D virtual world from any desired angle which is similar to actual viewing.

With the purpose of helping the students understand how the direction of a load affects the shear force and the deflection, a function, rotating force, is provided. After clicking this button, a user can rotate any force by clicking and dragging the force with left mouse. In order to apply force to a desired position, the moving force button is provided. After a user clicks the moving force button, he/she can click anywhere on the top surface of the 3D object to apply the force in that particular location. The maximum twist angle of the 3D object is visualized. This function spurs the students' interest by allowing them to change the shape of the bracket based on the load distribution function and the boundary condition.

Since this system is shared by all users that are currently logged onto the system, two users may try to do different thing to the same object. For example, one user may be trying to move the load while another user is trying to rotate the bracket. In such case, the other users may get confused or cause conflicting manipulations. To avoid this situation, a control priority system was developed. When the user is first logged in, nobody has control. However, when a user owns the control ability, all the other users cannot manipulate the 3D objects or analyze the force on the 3D object. The controller needs to release the tool after he/she finishes manipulating. The buttons for the users who do not have control are dimmed as shown in Figure 3.

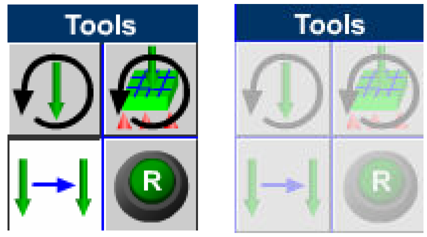

Figure 3. The tools with and without control priority

To help students understand how the force, Young's Modulus, and distance affect the shear force and deflection, a user can specify the value of force in y direction, the Young's Modulus, and the distance. The value of maximum twist angle is displayed in the text box. The deflection force of the bracket are shown in 3D graphics through bracket deform.

The designed communication tools include the text chat and the audio conversation. The previous chat message is displayed in the conversation history window, which is on the bottom of the current input message window. The history window is a text records all chatting after a student logs in.

The audio conversation is an important tool for both instructors and students to broadcast their thoughts to multiple clients at the same time in geographically separated locations. A user can join the audio communication by clicking on the Allow or Deny button in the Macromedia (now Adobe) Flash Player Settings window as shown in Figure 4. This settings panel opens automatically when the Flash application attempts to obtain data from a students' Microphone object.

Figure 4. Macromedia Flash Player Settings Window

When the audio is passed from one learner to all other learners, it hits the bandwidth limitation quickly. In such cases, some audio message may be dropped. To avoid missing audio information, this system employs a microphone pool and allows only four learners to talk at the same time. All others who are logged into the system will be able to hear their talking. A learner needs to click and hold the microphone button to talk. However, an instructor only needs to click the microphone to talk and then click again to release the microphone. The instructor does not need to hold it while talking, but the students do. This design allows the professor to manipulate the 3D objects while he/she is talking.

Conclusion

The primary objective of this research is to investigate and demonstrate the possibility of designing and implementing a collaborative online three-dimensional environment for engineering education. Another objective is to provide a feasible data structure that facilitates less data transition and low lag display over the Internet. The real-time shared view of the 3D world is based on strict What You See Is What I See environment. A synchronized and collaborative learning example, Bracket, is established through the web application under the current bandwidth limitation and computer speed.

In the future, more examples will be built to explore the possibility of making complex color and shape changes on the 3D objects in real-time using the Director 3D and the Flash communication server technologies.

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