

Group-based Real-time Online Three-Dimensional Learning System for Solid Mechanics

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Abstract - With the recent development of new Internet technologies and the rapid increase of computer processing speed, group-based online engineering education and training in real-time for geometrically distributed learners is possible. Previous research on real-time synchronous collaborative learning over the Internet is reviewed. An online group-based cantilever beam learning environment is developed and presented as an example. This system employs low lag audio and interactive three-dimensional models to illustrate abstract concepts in real-time. The learners are capable of manipulating three-dimensional models, changing the view point and applying forces in various locations. All physically separated users are able to view the same analytical results of the objects through the browser in real-time from remote sites. This research provides a framework, built with Macromedia Flash Communication Server and Director, for constructing an online three-dimensional synchronous group study environment.

Index Terms - Group-based, Online, Real-time, Three-dimensional, Collaboration.

INTRODUCTION

According to the survey of Pew Internet & American Life project, in May-June 2005, about 68% of American adults, or about 137 million people, use the Internet, up from 63% one year ago [1]. The Internet is becoming more and more popular due to many factors. The most important two are the rapid improvement of Internet technology and computer processing speed. 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 using 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 [2]. This paper describes the design and implementation of a group-based, real-time cantilever beam learning environment which employs low lag audio and interactive 3D models.

LITERATURE SURVEY

Due in part to 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 [3-5]. The NEW system can synchronously deliver the instructor's voice, graphics, dynamic annotations, and optional video 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, no 3D objects can be generated and shared among the students to illustrate the concepts.

AlRamahi and Gramoll at the University of Oklahoma developed a drawing board, LectureBoard, to provide an online, collaborative, and spontaneous lecture creation using Macromedia Flash Communication Server [6, 7]. 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 a Macromedia 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, grids, shape color, line color, and thickness are also implemented to facilitate clearer and easier drawings. The drawing in this system is 2D. 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 lecture. However, many concepts in engineering classes need 3D models to help student better understand. Also, 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 which makes a curve. In addition, this system cannot instantly share the scene. Although the person who controls the drawing tool is capable of seeing the pen's moving path immediately on the screen, all the other users can see the path only after the drawer finishes sketching.

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

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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 [8-13]. 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 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 teamwork 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 condition, 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 [14]. 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 [15, 16]. 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 and the shape of 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 manipulate 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

From the previous literature review, one can see that an 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 and implement is presented. The tools employed to build the prototype are discussed. The implemented functions are also introduced.

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 Macromedia Flash Communication Server (Flashcom) and Macromedia 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 Macromedia Director (or Shockwave). Macromedia 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 Macromedia Flash Communication Server (Flashcom), Java Remote Method Invocation (RMI) and Macromedia 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, Macromedia 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 subframes. 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 Flash Communication Server (Flashcom) is that it has the technology of passing only the changed data to the clients. For example, when an end user changes a variable, w , from 2 to 3, the 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 Flash Communication Server are the products of the same company, Macromedia Inc. (recently merged with Adobe, Inc.), and they work well together.

The core usage of Flashcom is handling interactions - 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 [17]. 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 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.

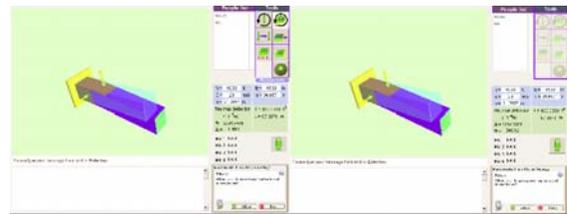


FIGURE 1
WHAT YOU SEE IS WHAT I SEE ENVIRONMENT

Generating large amounts of geometric data on the server and passing the data blocks to the users' local quickly reaches the upper limitation of the network capacity regardless of the bandwidth. To help reduce this limitation this 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 group-based Real-time 3D Cantilever Beam Learning System

In order to demonstrate that group-based real-time 3D cantilever beam learning system is a feasible solution for both distance education and engineering analysis, a prototype, Beam, 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, called Beam, 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 cantilever beam with a boundary condition. The analysis result, shear force and deflection, are displayed as the color mapping on the top and front surface 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.

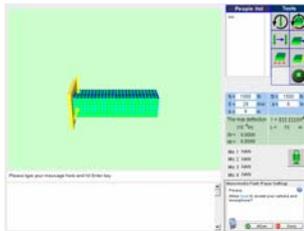


FIGURE 2
SNAPSHOT OF BEAM

The people list displays the names of all the logged students. This helps all users know who is currently participating.

The tools section provide seven functions that can be manipulated including rotating the forces, rotating the 3D world, moving forces, stretching the beam, changing to simple support boundary condition, changing to fixed support boundary condition and resetting the 3D world. In order to change the viewpoint of a 3D object, the 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 shear

force of the 3D object is visualized by the color mapping and beam deflection. This function spurs the students' interest by allowing them to change the color and shape of the beam based on the load distribution function and the boundary condition.

In order to elongate the beam, the stretching beam button is provided for all users. After clicking this button, a stretching bar will appear. By clicking anywhere on this bar, the length of the beam is changed. The purpose for developing this function is to give the student a visual image of showing the students how the length of a beam affects its shear force and deflection.

This prototype application provides two boundary conditions including simple support and fixed support. A user can switch boundary conditions by clicking these two buttons. Boundary condition is one of the determining factors in analyzing shear force, moment, and displacement. Displaying the shear force and the displacement in the visual not only explains theories and concepts clearly, but also invokes the students' interest in learning.

Since this system is shared by all the logged in users, two users may try to do different thing to the same object. For example, one user may be trying to elongate the beam while another user is trying to minimize the beam. In such case, the other user 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.

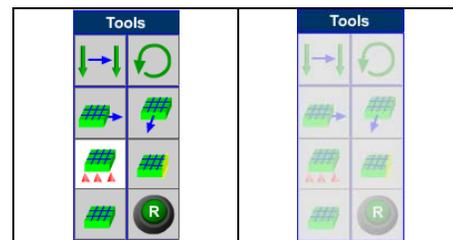


FIGURE 3
THE TOOLS WITH AND WITHOUT CONTROL PRIORITY

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 and z direction, the Young's Modulus, and the distance.

The value of maximum deflection in y and z direction is displayed in the text box. The deflection and share force of the beam are shown in the 3D graphics through beam deform and color mapping.

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

REFERENCES

bottom of the current input message window. The history window is a text record for 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 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. The 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 group-based online dynamic three-dimensional collaborative environment for engineering education and technical training over the Internet. 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, Beam, 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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