World Transactions on Engineering and Technology Education
Vol.5, No.3, 2006
© 2006 UICEE

A scalable platform for remote and virtual laboratories

El-Sayed S. Aziz, Sven K. Esche & Constantin Chassapis

Stevens Institute of Technology
Hoboken, United States of America

ABSTRACT: Web-based multimedia technologies are being applied to create content-rich and flexible student laboratory environments for usage in undergraduate mechanical engineering lecture and laboratory courses at the Stevens Institute of Technology (SIT), Hoboken, USA. In this article, the authors describe the development and implementation of a scalable platform for remote and virtual laboratories. The overall system architecture, hardware and software configuration, as well as the system implementation, are presented. The system supports both remotely operated hardware-based experimental stations plus software-based virtual laboratory exercises. It offers tremendous flexibility by enabling the access to laboratory resources at any time and from anywhere without students having to be physically present in a laboratory facility. The authors summarise the specific outcomes and provide sample screenshots at key stages of a representative experiment – the classical strength-of-materials problem of determining the deflections and stress concentrations of a cantilever beam of linear elastic material with stress raisers.

INTRODUCTION

Modern information technology based on the Internet is rapidly being adopted in engineering education as a tool to enhance the educational experience of students residing on campus and off the local campus. the Stevens Institute of Technology (SIT), Hoboken, USA has implemented a new undergraduate engineering curriculum that reflects the latest trend towards the enhancement of traditional lecture-based courses with both a design spine and a laboratory experience propagating through the entire educational programme. In this context, a student laboratory approach that is founded on Web-based, remotely accessible experimental set-ups was proposed [1-3]. The educational benefits of the proposed laboratory implementation are that more students can be exposed to comprehensive experimental experiences, asynchronous student learning is supported and self-learning of the students is promoted.

Remotely shared laboratory facilities are emerging at many academic institutions as is witnessed by a variety of recent publications and research implementations [4-6]. This type of environment integrates all the components necessary to carry out hands-on practice in a flexible learning context. It has the capability to reach more students and enables those students to access experimental devices from remote locations at any time via the Internet. In addition, equipping the actual physical experimental apparatus with a video camera and microphone allows the capturing of what is really going on in the laboratory in addition to providing students with the resulting experimental data. This helps to provide students who are located remotely with a feeling of real-time presence in a laboratory facility. Web-based experimentation can include virtual (ie software-based) and/or remote (ie hardware-based) laboratory resources [7].

Simulation-based virtual laboratories represent a valuable option in educational laboratories due to the following advantages: inexpensive operation plus lack of time and physical space restrictions. Furthermore, they can also provide a safe learning environment for experimentation with dangerous equipment [8]. Students can perform experiments on simulated systems by means of software that is made accessible to them by a server through a Web browser without actually downloading the source code. Such simulations typically focus on experiments for demonstrating theoretical concepts and run without the involvement of actual experimental instruments. They provide interactive, Web-based experiences aimed at increasing students' understanding of the underlying general principles.

SYSTEM OVERVIEW

The general system architecture required for the creation of Web-based remote and virtual laboratories is discussed below, with a particular emphasis on the integration of hardware and software components. An overview of the development of a scalable platform for delivering remote and virtual experiments is shown in Figure 1.

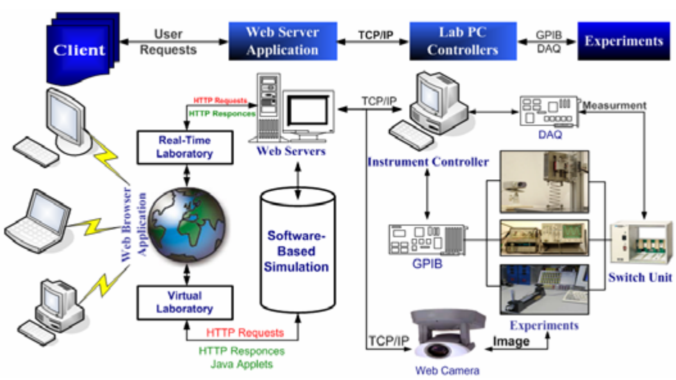

Figure 1: Overview of scalable system architecture for remote and virtual experiments.

REMOTE LABORATORY

In the remote laboratory, students can use the experimental system as a real-time laboratory (see Figure 1). They interact with the experiment through a Web browser. The Internet provides the communication infrastructure between students' client PCs and the Web server in the laboratory. The browser is responsible for sending and receiving HTTP requests, and responses to and from the Web server. A WWW server, which hosts the Web pages for the experiment, is established using a Linux-enabled Web server that is networked to individual data acquisition PC terminals running Windows NT. These terminals execute *LabView* VI scripts that control the experiments and report the experimental results back to the Web server. The interfacing between the server and experimental set-up is realised with a General Purpose Interface Bus (GPIB) and data acquisition (DAQ) cards, which can be installed directly in the expansion slots of the server. The GPIB-based experiments are enabled to accept and execute standard commands and these commands are transferred through the GPIB card to the corresponding experimental device, which interprets the commands and takes appropriate actions. The experiment result is then sent back to the instrument controller PC through the GPIB card. The DAQ card installed on the controller PC provides analog input/output capabilities and allows the software to communicate with the outside world using low-level analog and digital signals. The switch unit is used to route signals from the different experiments. The video camera is employed to record the experiment and thus real-time streaming of video feedback of the experiment is provided through the Web browser.

For each experiment, there is a unique control function on the server to manage standard operations like data input/output, analog-to-digital and digital-to-analog signal conversion, function generation, power amplification and up/down counting. The control software was written using an event driven program structure. A top-level program construct idles in an endless loop, waiting for a user request message to be intercepted. Upon occurrence of this event, a low-level subroutine is invoked that parses the message for its meaning. Based on the interpretation of the message, further subroutines are called that cause some sequence of functions to be performed. After all actions prompted by the original message have been completed, the control program returns to the top-level loop and waits for the next event. Figure 2 summarises the software structure of the system.

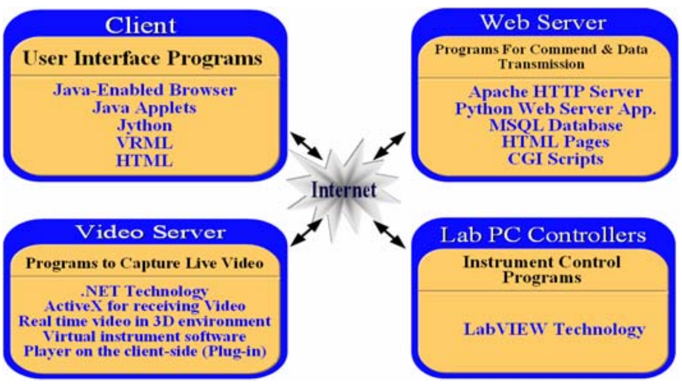

Figure 2: Software structure of the system.

VIRTUAL LABORATORY

Virtual laboratories typically focus on experiments to demonstrate theoretical concepts. The simulation environment described here was designed to convey a strong feeling of immersion to students, as if they were performing a real-world experiment. Students connect from a remote client to the virtual laboratory, choose the desired experiment, provide the input parameters and run the simulation. Figure 3 depicts the interaction between the client-side and server-side for a virtual experiment, as well as the information flow during the execution of the simulation.

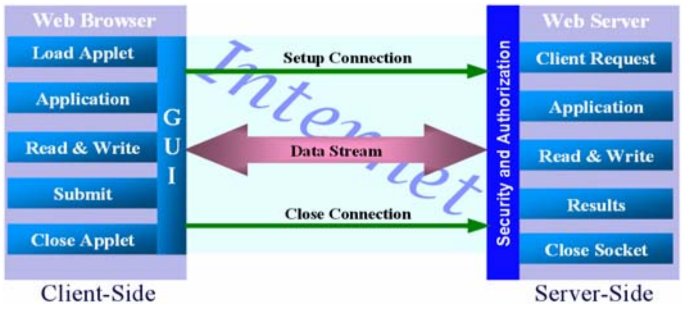

Figure 3: Data flow for virtual experiments.

The client-side is based on Java applets embedded in HTML files, thus guaranteeing access to the virtual experiments from various computer platforms. The Java applets are written using Jython [9]. Jython is an implementation of the Python programming language, which is written in pure Java, combines the advantages of Python and the Java virtual machine and libraries (such as Swing, Java Cryptography, Java API, etc) and serves as a handy complement to the Java platform [10]. Specifically, development times with Jython can be shorter than with Java, owing to the generally shorter code and lack of a compile phase. The Java applet running on the client side sends a request for connection to the program of the selected experiment running on the Web server. The program accepts only an authorised request from the client and sends a request to the controller to establish a link with the client for transferring commands and data and to allow the experimental configuration and parameters to be controlled interactively by the student.

SAMPLE REMOTE EXPERIMENTS

Two cantilever beam experiments are described below, which represent examples for the remote and virtual experiments that were implemented using the scalable platform described here and are currently being used in undergraduate laboratory courses at the SIT. The cantilever beam is a widely used structural element, eg in airplane wings, supports for overhanging roofs, front spindles of automobiles, etc [11]. A cantilever is defined as a beam that is built-in and supported at only one end, and loaded by one or more point loads or distributed loads. These cantilever-beam experiments serve to verify the relationship between the bending moment and stress/strain distributions along the length of a cantilever beam, as well as to familiarise students with the use of strain gauges for measuring strain in a mechanical member (here the axial elongation of the beam). The following two beam experiments were implemented.

Beam without hole: This experiment studies the uniform cantilever beam rigidly clamped at its fixed end and deflected by a single point load on the beam centreline near the free end. Three strain gauges are installed at equal intervals along the axis of the beam as shown in Figure 4. As students learn in class, the stretching of an electrical conductor increases its resistance and the strain gauges are designed to take advantage of this effect. The purpose of this experiment is to determine the shear force and the load from the strain measurements, to verify the linearity of the strain along the beam axis, and to confirm the shear force and bending moment relationships by comparing two different methods for determining the stresses.

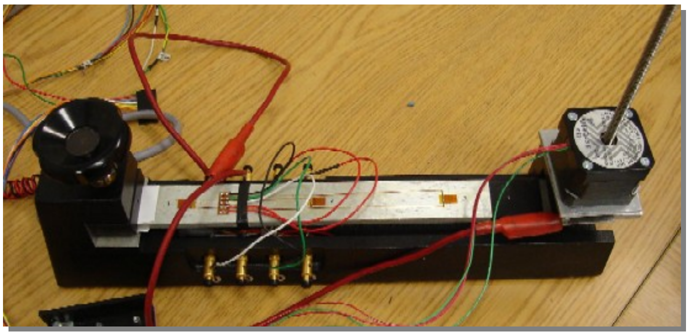

Figure 4: Experimental setup of beam without hole.

Beam with hole: The purpose of this experiment is to demonstrate the existence of stress and strain concentrations in the vicinity of a geometric discontinuity (here a circular hole on the beam centreline) in a cantilever beam and to obtain an approximate measure of the elastic stress concentration factor K. In order to determine the stress concentrations, three strain gauges are installed for measuring the strain field near the hole, together with a fourth gauge, which is located close to the fixed end and in the centre of the beam.

SYSTEM IMPLEMENTATION

Students connect to the homepage of the Web-based remote laboratory by setting the URL in the Web browser to http://dynamics.soe.stevens-tech.edu/. The Web browser then displays a welcome page, which contains a login window for authentication purposes. The student must then enter a valid login name and password to access the server. When the login process is completed, the browser displays the main page for selecting a particular experiment from the list of available experiments, as shown in Figure 5.

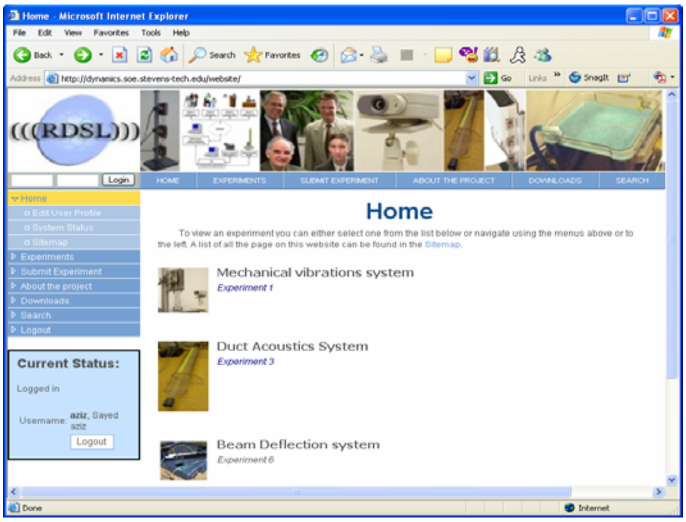

Figure 5: Homepage of the remote/virtual laboratory.

Before conducting the actual remote experiment, the student can view some relevant Web pages relating to the experiment to study the experimental set-up and read the available operating instructions by clicking on the links provided in the menu bar or left menu. The system was implemented using a client-server network approach, which allows the concurrent execution of multiple experiments using separate experimental set-ups. Experiments that require the same set-up are queued and executed in the order of the incoming requests. As an example, a brief description of the implementation and experimental results for the beam deflection system is included here.

In the beam-without-hole experiment, students can input three different revolution sets for the flexor micrometer to apply a specified displacement on the free end of the beam, as shown in Figure 6. After filling out the input form and running the experiment, students are able to view the result either through the *view your results* link found in the window that pops up after the submission request or through the e-mail sent to the address that they have provided.

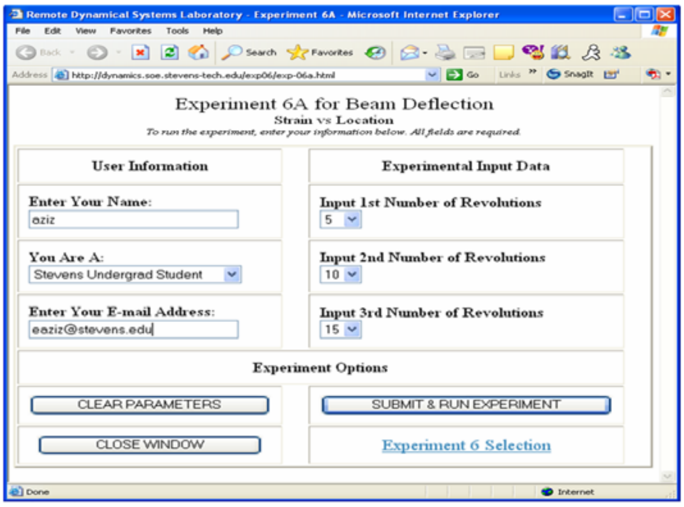

Figure 6: Input panel for the remote beam experiment.

The results include the strain gauge factor GF, the distance of each strain gauge from the point of load application, the zero load output VZ and the load output VL. Also, a video file is included in the results that shows the experiment in action.

SAMPLE VIRTUAL EXPERIMENTS

The virtual laboratory experiment may have more features than the remote experiment. For example, leading the experiment to extreme situations would not be feasible with the remote equipment. In the simulation environment described here, the simulation application programs on the server simulate the experimental procedure as Java applets, process the experiment commands sent and provide students with the simulated experimental results. The flexibility of the simulation system significantly expands the scope of experimentation beyond the limits of the hardware of remote or hands-on experiments, eg enabling students to change the beam dimensions, the beam material and the location along the beam axis or laterally besides the hole where the strain is to be determined. These parameters were included into the simulation model and their effects can thus be demonstrated with the virtual laboratory.

Figure 7 shows the layout of the Web page that is served in the student's Web browser. It is composed of two main panels. The left input panel represents a Java applet with different options to describe the desired cantilever beam simulation, such as selecting the beam type, specifying the geometric parameters of the beam, strain gauge and hole positions, end deflection, as well as a pull-down menu for selecting the beam material. The right panel represents the 3D virtual beam experimentation system. During the experimentation phase, changes in parameters and variables are immediately reflected numerically and graphically as a response to students' inputs. Students can simultaneously view the resulting force, stresses and the theoretical deflection curve. Furthermore, they are also enabled to visualise, tabulate and graph data, thus reducing the time required to process and present the results.

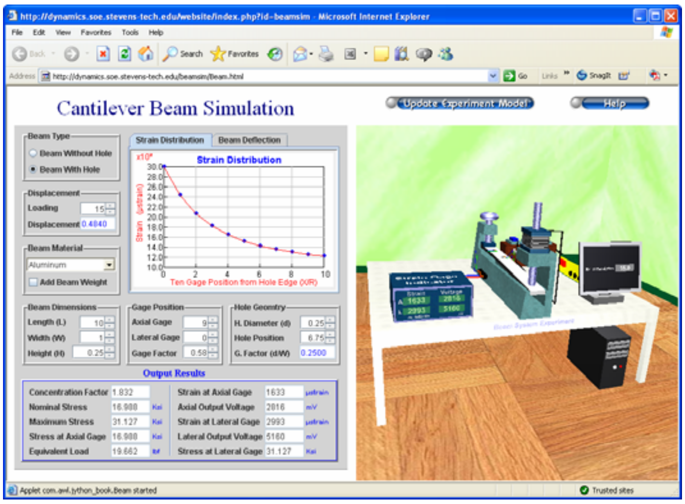

Figure 7: GUI at client side for virtual beam experiment.

The Java applet provides interactivity between users and the VRML worlds and makes VRML fully functional and portable. VRML is a Virtual Reality Modelling Language that can be used to build virtual 3D scenes and script nodes on the World Wide Web. It works even with low-bandwidth Internet connections because of the small amount of transmitted data [12]. All VRML objects of the beam experiment are generated within the Java applet and then the entire virtual model is interactively sent as text to the VRML environment on the student's computer.

The simulation model was developed to convey a strong feeling of immersion. Students can navigate inside the virtual environment using the standard VRML navigation features (see Figure 8). This allows them to move around the beam experiment model and view it from various angles and distances. For instance, students can zoom in at the strain gauge positions in the axial and lateral directions to see where exactly the strain gauges are attached to the upper surface of the beam. Figure 8 shows a strain gauge bonded to the top surface of the cantilever beam and connected to the strain gauge indicator through a wire connection. It is used to measure the axial deformation of the beam when a transverse load is applied to the end of the beam. The load is applied in the form of a number of revolutions of a power screw, which is transferred to a signal generator, to the motor-drive box that operates the stepper motor, which turns the power screw to bend the beam with the appropriate displacement. Based on the mathematical model developed to simulate the real beam experiment, the output strain and voltage values appear on the screen of the strain gauge indicator.

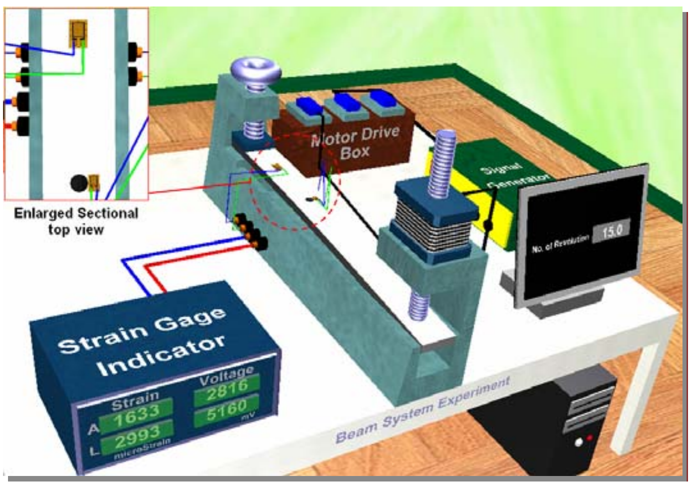

Figure 8: 3D visualisation of the virtual beam experiment.

CONCLUSIONS

In this article, the authors describe a significant step taken towards the objective of improved distance education by the development and implementation of a scalable platform for remote and virtual laboratories. This environment integrates all the components necessary to carry out educational experiments in a flexible manner. It has the capability to reach more students and enables them to access the experimental devices or simulations from remote locations at anytime from anywhere via the Internet. A prototype of a scalable system was implemented for the classical strength-of-materials problem of determining the deflections and stress concentrations of a cantilever beam of linear elastic material. This experiment is used interactively by students to understand the underlying structural engineering concepts.

The flexibility of the simulation system expands the scope of experimentation beyond the limits of the hardware-based remote experiments, allowing students to select the type of the beam, the beam material, the beam parameters (length, width and height) and enabling them to apply a greater range of loads as would be possible for a physical device. During the experimentation phase, changes in parameters and variables are immediately reflected in the graphical user interface. Thus, students can visualise in real time how the model behaves depending on the values of the input variables.

ACKNOWLEDGEMENT

The support for this work by the National Science Foundation under grant No. 0326309 is gratefully acknowledged.

REFERENCES

1. Esche, S.K., Chassapis, C., Nazalewicz, J.W. and Hromin, D.J., An architecture for multi-user remote laboratories. *World Trans. on Engng. and Technology Educ.*, 2, **1**, 7-11 (2003).
2. Esche, S.K., On the integration of remote experimentation into undergraduate laboratories – technical approach. *Inter. J. of Instructional Media*, 33, **3** (2006).
3. Esche, S.K., On the integration of remote experimentation into undergraduate laboratories – pedagogical approach. *Inter. J. of Instructional Media*, 32, **4** (2005).
4. Dabney, J.B., Web-based control of the rice SPENDULAP. *Inter. J. of Engng. Educ.*, 19, **3**, 478-486 (2003).
5. Gustavsson, I., A remote access laboratory for electrical circuit experiments. *Inter. J. of Engng. Educ.*, 19, **3**, 409-419 (2003).
6. Kutlu, A., MicroLab: a Web-based multi-user remote microcontroller laboratory for engineering education. *Inter. J. of Engng. Educ.*, 20, **5**, 879-885 (2004).
7. Gillet, D., Geoffroy, F., Zeramdini, K., Nguyen, A.V., Rekik, Y. and Piguet, Y., The cockpit: an effective metaphor for Web-based experimentation in engineering education. *Inter. J. of Engng. Educ.*, 19, **3**, 389-397 (2003).
8. Eriksson, H., Control the Nuclear Power Plant (Demonstration). Linköping University (1996), http://www.ida.liu.se/~her/npp/demo.html
9. Jython Project (2005), http://www.jython.org/
10. The Source for Java Developers (2006), http://java.sun.com/
11. Measurements Groups, Education Division, Experiments in Mechanics, Strain Gage Series: (1) E-104 Stress and Concentration and (2) E-105 Cantilever Flexure. Raleigh.
12. Masár, I., Röhrig, C., Bischoff, A., Gerke, M. and Hoyer, A., A Virtual Laboratory for an Inverted Pendulum and Crane Control (2004), http://prt.fernuni-hagen.de/~bischoff/research/pdf/Masar04a_TA04.pdf