IT-Enhanced Laboratory Experience within a Modern Undergraduate Engineering Curriculum

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Abstract - **The emergence of Information Technology (IT) is enabling engineering educators to constantly reconsider both the content and means of delivery of modern undergraduate curricula. Online learning environments are rapidly becoming viable options for providing students with a bridge from theoretical concepts to practical engineering applications. They can be made to represent repositories of integrated tools that provide a delivery mechanism for rich learning content, advanced assessment capabilities as well as affordable access to a wide range of other resources. Online educational environments have been used at Stevens Institute of Technology (SIT) to provide undergraduate engineering students with a comprehensive laboratory experience based on content-rich and flexible remote and virtual laboratory experiments. This paper presents an effort to design, implement and evaluate an integrated system for delivering online laboratories (i.e. remote experiments based on actual physical devices and/or virtual experiments representing pure software simulations). The methods and software modules implemented and the pedagogical approach developed for integrating them into a comprehensive student laboratory experience have been used in a sophomore-level core undergraduate course on solid mechanics taken by all undergraduate engineering majors at SIT as well as in a junior-level course on mechanisms and machine dynamics for mechanical engineering majors.**

Index Terms - Information Technology, Remote Laboratory, Simulation, Online Experiment, Liquid-level Control System.

INTRODUCTION

One of the most powerful emerging trends in education is the increasing use of information technology in classrooms. The use of computers, educational software, and the Internet in education has provided students with an array of different learning opportunities. Students expect a lot of services from universities to save them time, for instance online registration, online courses, online assessment, online digital library access, online laboratories, etc. These demands led to the reconsidering of both the content and means of delivery of modern undergraduate curricula by many educators. Information technology is changing the ways in which knowledge is being collected, processed, stored, presented and transmitted [1]. Moreover, it is changing the ways in which course contents are presented and delivered to students. One of the roles of information technologies in the learning environment is to maximize the availability and accessibility of information that will lead learners to acquiring new knowledge [2]. There are several technologies that can be used to create a constructive learning environment such as shared databases, the World Wide Web (WWW), Interactive multimedia and hypermedia programs, simulation software packages, and virtual reality tools. They are very quickly transforming how information is stored and retrieved and how learners collectively communicate, access, contribute, and create information and resources. In this framework, information technology based on the Internet is rapidly being adopted in engineering education as a tool for enhancing the educational experience of students residing on campus as well as to expand the reach of unique programs beyond the local campus through distance learning [3],[4]. Significant efforts have been directed towards the design and implementation of asynchronous learning network environments for distance and flexible Web-based learning. Especially in engineering curricula, a useful and interesting trend to support learning is to expand the available educational resources by providing virtual and real experimentation facilities [5],[6].

The vital importance of educational laboratories is widely recognized by all constituents of academia. Experimental demonstrations and student experiments contribute to the students' motivation for learning and strengthen their understanding of the abstract concepts and theories taught in the traditional lecture setting. Furthermore, coping with the experimental imperfections that usually are not reflected in the textbooks is an essential part of the educational experience [4]. With the advent of the Internet and its rapidly spreading adoption in almost all spheres of society, remotely accessible student laboratory facilities have become feasible and are increasingly gaining popularity. Currently, many educational institutions have implemented remote or virtual laboratories as Internet-based learning environments to support engineering curricula [7],[8],[9].

The idea of online laboratories (i.e. remote experiments based on actual physical devices and/or virtual experiments representing pure software simulations) can be expanded through the use of information technology to create standardized laboratory, experiment, device and simulation descriptions so that students can run experiments that may involve multiple devices in different laboratories at various locations, perform collaborative experiments with multiple participants, and combine experiments and simulations into one integrated laboratory experience [10]. The underlying fundamental promise of such Internet-based laboratory approaches lies in the students' ability to connect to the computer controlled laboratory setup of interest at anytime from anywhere, thus sharing the existing limited resources in a more efficient manner than would be possible with the traditional on-site laboratory approach.

A student laboratory approach based on remotely accessible experimental setups was developed and piloted at SIT [11],[12]. The various virtual and remote experiments that are currently available in this online laboratory can be used through the corresponding homepage [13]. These Web-based tools integrate both remotely operated experiments based on actual experimental devices and virtual experiments representing software simulations. Integration of theoretical knowledge and practical experience into the delivery mechanism is essential for the success in creating unique learning experiences for engineering students. The Web-based integrated system provides an easy flow of data from theory to modeling and measurement, thus bridging the gap between theory and hands-on learning as shown in Figure 1. Also, these tools facilitate the development of learning environments, which – possibly in conjunction with traditional hands-on experiments – allow the expansion of the scope of the students' laboratory experience well beyond the confines of what would be feasible in the context of traditional laboratories. Details of the methods and software modules used to implement remote and virtual experiments in the Web-based integrating system can be found elsewhere.[14]. Currently, SIT's online laboratory comprises the following virtual and remote experiments:

- An industrial-emulator/servo-trainer system
- A cantilever beam deflection system
- A mechanical vibration system
- A liquid-level control system
- A muffler system

All these experiments were designed for small time constants and rapid execution of the remote experiments. This approach keeps the waiting queues very short and thus allows the inclusion of experimental demonstrations into lectures. As an example, a description of the implementation and experimental results for the liquid-level control system is included here. This paper is organized as follows: A detailed description of the remote laboratory system is presented first. The modeling of the liquid-level control system is described based on first principles. Finally, current and future educational uses are described in detail.
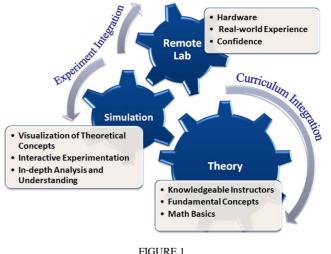

FIGURE 1
FLEXIBLE DELIVERY AND STUDENT SELF-LEARNING MODEL

SYSTEM DESIGN OF ONLINE LABORATORY

The online laboratory system developed at SIT integrates remote and virtual experiments into a comprehensive student laboratory experience. It offers the students several options for conducting experiments. Virtual laboratories are interactive software-based environments for conducting simulated experiments [15]. They are especially suitable for experiments that focus on demonstrating theoretical concepts (rather than emphasizing more hands-on activities such as experimental set-up and calibration, resolution of hardware problems, etc.). In remote laboratories, students can interactively control actual experimental equipment and obtain the corresponding outputs (including raw data, data plots, video/audio streams and recordings) in an integrated browser-based user interface [16].

The overall hardware architecture for the batch-operated remote laboratory system developed at SIT is shown schematically in Figure 2. The system interacts with the student's PC through the Internet and manipulates the laboratory apparatus in the physical laboratory based on the student's commands. It was implemented using a client-server network approach that allows the concurrent execution of multiple experiments using separate experimental setups. Experiments that require the same setup are queued and executed in the order of the incoming requests. The connection from the laboratory to the outside world is established using a Linux-enabled Web server. This server hosts the process queue, the data input and output files generated as well as the graphical user interface, which was developed using conventional HTML pages, Java applets and CGI/Perl scripts. The Web server 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.
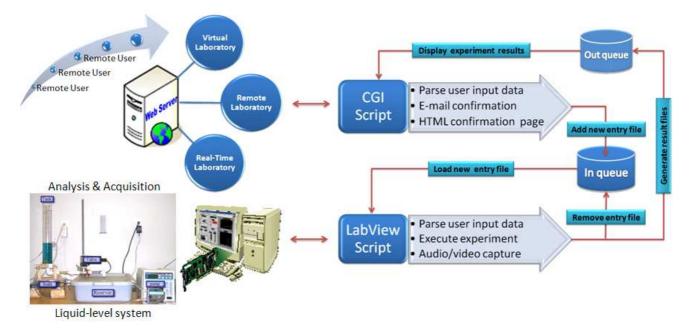
FIGURE 2
REMOTE LABORATORY ARCHITECTURE

For each experiment, there is a unique control function on the Lab PC Controller to manage standard operations such as 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 experiment request message to be intercepted. Upon occurrence of such an event, a low-level subroutine is invoked, which parses the message for its content. Based on the interpretation of this message, further subroutines are called, which cause a 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.

LIQUID-LEVEL CONTROL SYSTEM

The liquid-level control system described below was selected because its simple and clear structure provides a suitable educational example. Three experiments have been designed and set up for the remote laboratory: tank draining, tank filling and PID control of the liquid-level system. These experiments introduce students to the modeling and analysis of a liquid-level control system. This system consists of a reservoir to supply the liquid pumped into the system as well as capture the liquid drained out of the system, a pump to control the inflow rate of the liquid into the tank, a drain valve to regulate the outflow rate from the tank and flexible tubing to connect the various system components. An electronic scale is used to sense (indirectly) the liquid level in the tank as shown in Figure 3.
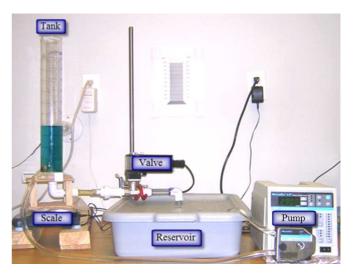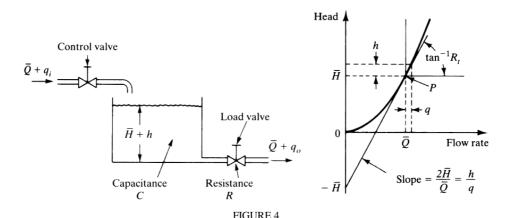

Figure 3
LIQUID-LEVEL CONTROL SYSTEM COMPONENTS

SYSTEM MODELING

For the liquid-level control system with capacitance C and flow resistance R (representing tank outlet, piping, and load valve) as shown schematically in Figure 4, the linearized system behavior around the operating point P characterized by the volumetric inflow rate $Q+q_i$, the volumetric outflow rate $Q+q_o$ and the head $H+h$ is described by either one of the following two inhomogeneous linear differential equations:[17],[18],[19]

$$RC\frac{dh}{dt}+h=Rq_i \qquad RC\frac{dq_o}{dt}+q_o=q_i \qquad (1)$$

FIGURE 4
SCHEMATIC OF LIQUID-LEVEL CONTROL SYSTEM AND HEAD VRSUS VOLUMETRIC FLOW RATE CURVE FOR TURBULENT FLOW

Here, the barred upper-case quantities represent the steady-state values and the lower-case quantities represent small variations around the operating point P. If the flow through the restriction (tank outlet, piping and load valve) is turbulent, the steady-state volumetric flow rate Q is related to the steady-state head H as follows:

$$\bar{Q} = K_t \sqrt{\bar{H}} \qquad (2)$$

where K_t is a proportionality constant. Furthermore, the turbulent flow resistance R_t can be determined by the following relationship:

$$R_t = \frac{2\bar{H}}{\bar{Q}} \qquad (3)$$

The system transfer function G(s) (Laplace domain) takes the form:

$$G(s) = \frac{H(s)}{Q_{in}(s)} = \frac{R_t}{1 + sAR_t} \qquad (4)$$

where H(s) denotes the liquid level, considered as the system output, Q_{in}(s) denotes the liquid filling rate, considered as the system input, (both expressed in the Laplace domain), and A denotes the tank cross-sectional area.

For the liquid-level control system described above, a PID control algorithm as shown in Figure 5 was implemented. The manipulated variable is the flow rate Q that enters the tank and is adjusted through the pump. The level is sensed indirectly using an electronic scale on which the tank rests and that measures the weight of the tank and water contained therein. The digital output of the electronic scale goes to the LabVIEW data acquisition system connected to a PC. The liquid level in the tank is controlled via a PID feedback control loop. The water level is measured, fed back and compared to the setpoint, thus generating an error signal. When an error is detected, the controller changes the input flow rate by applying a voltage to the pump to maintain a specified height of the water in the tank. This PID control was implemented in a LabVIEW script. LabVIEW integrates data acquisition, analysis and presentation into one system [20].
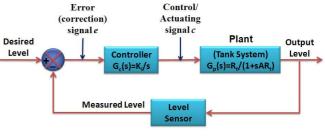

FIGURE 5
BLOCK DIAGRAM FOR LIQUID-LEVEL CONTROL SYSTEM

SYSTEM IMPLEMENTATION

This Web-based laboratory system was developed using various open source programming languages and free software applications (i.e. PHP, Perl, Python, VRML, Java). These open source components form a powerful combination for the cost-efficient development, implementation and sharing of Web-based experimentation systems. This system offers several options for conducting experiments to the students. They can perform collaborative experiments with multiple participants as well as combine experiments and simulations into one integrated laboratory experience. This laboratory system has been used in a sophomore-level core undergraduate course on solid mechanics taken by all undergraduate engineering majors at SIT as well as in a course on mechanisms and machine dynamics for mechanical engineering majors. Based on the overall success of the deployment in the previous years, the development of additional remotely accessible experimental setups for other engineering courses that involve laboratories (i.e. fluid mechanics and engineering control courses) is discussed and achieved here.

For illustrating the use of the remote laboratory system, a short description of an experimental session is presented below. The student's Web browser requests the Web-based experimentation page located at a standard URL. After authentication, the student can select the liquid-level control system from the list of available experiments as shown in Figure 6. For the liquid-level control system, there are three experiments listed; tank draining, tank filling and PID control of liquid-level system. The experiments to be

performed are described in a laboratory instruction manual, which can be downloaded from the Web page in pdf format. As an example, a brief description of the implementation and experimental results for the PID control of the liquid-level system is included here.
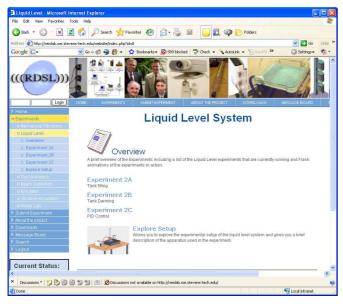

FIGURE 6
WEB PAGE FOR LIQUID-LEVEL CONTROL SYSTEM

The student selects the PID control of liquid-level system and fills out the corresponding input form. This form contains some personal information (name, affiliation, e-mail address) as well as the necessary input data for the experiment as shown in Figure 7. The student is expected to input the values of the desired liquid level (target liquid level) and the values of the proportional-integral-derivative (PID) controller gains for adjusting the liquid level in the tank. The valve can be positioned anywhere in the range from fully open to fully closed depending on the desired outflow rate. Upon clicking on the submit button, the Web server accepts the parameters from the student side and then passes these parameters to a CGI program (coded in Perl). The CGI program first checks whether the input parameters are acceptable or not. If any parameters are outside of the allowable range, the CGI sends an error message back to the student to fix that error and submit the input data again. If the parameters are acceptable, the CGI then parses the student request, generates a unique process identification number, makes an entry in the process queue and sends an e-mail confirmation message to the student, which provides the estimated completion time for the experiment based on the current queue status, the access code necessary for retrieval of the experimental results from the database at a later point in time, and the URL where the output data (numerical results in ASCII format, video file in real media format) can be picked up at any time after the completion of the experiment. Finally, the server returns to waiting mode.

The LabVIEW script, which is executed at the workstation that controls the liquid-level control system, checks for the entry in the experiment queue. When detecting a new entry, it generates the required control signals to operate the liquid-level system based on the student input. The commands for initiating specific actions are sent to the programmable experiments through a GPIB interface which then interprets these commends and takes appropriate action. The LabVIEW script then collects and formats the resulting experimental data in text and HTML files that are saved in the out queue. At the same time, the LabVIEW script deletes the completed experiment in the process queue file and checks for the next entry file.
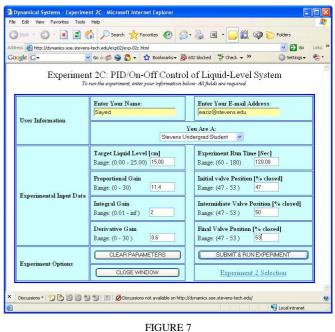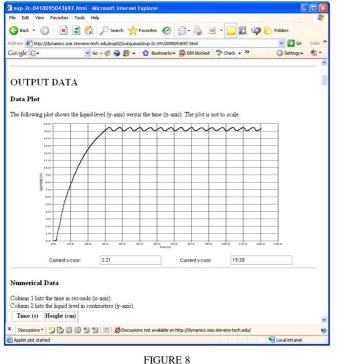

FIGURE 7
INPUT DATA FORM FOR PID CONTROL EXPERIMENT

The student can view the plot of the tank height versus time by clicking on the "View Your Results" link from the HTML confirmation page or from the e-mail confirmation sent to the student. From the sample results shown in Figure 8, it can be seen that the student can observe how the PID controller is used to maintain a constant level at the setpoint by measuring the level as it changes over time and manipulating the pump speed appropriately. The student can easily investigate how changes in the PID parameters (the gains of the proportional, integral and derivative terms) affect the transient and steady-state behavior of the liquid-level control system.

CONCLUSIONS

The use of information technology and the Internet for improving the quality of learning by facilitating access to educational resources and services, as well as remote exchanges and collaboration is providing students with an array of different educational opportunities. In this paper, the design and implementation of a Web-based laboratory system is described, and a liquid-level control system is given as an example to increase the students' motivation towards learning the process control concepts.

FIGURE 8
STEP RESPONSE OF LIQUID-LEVEL CONTROL SYSTEM

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