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Remotely Accessible Laboratory Approach for Undergraduate Education

Sven K. Esche, Marehalli G. Prasad, Constantin Chassapis

Department of Mechanical Engineering, Stevens Institute of Technology

Introduction

Today, the hands-on activities typically associated with educational laboratories are widely recognized by all constituents of academia as imperative and integral elements of modern engineering curricula. This trend is evidenced through the new review criteria applied by educational accreditation boards such as ABET and recent funding initiatives of governmental, charitable and industrial foundations as well as corporate and alumni sponsors.

At Stevens Institute of Technology, an appreciably modified undergraduate engineering curriculum is currently being implemented that acknowledges the trend of enhancing traditional lecture-based courses with a design spine and a laboratory experience that propagates through the entire curriculum. The incorporation of design and laboratory components into all engineering courses places a significant strain on the spatial, temporal and fiscal resources of the institute. To accommodate the anticipated enrollment, new concepts for the implementation of affordable integrated experimental and design laboratories had to be developed that allow for the required student through-put using the limited existing laboratory space without compromising the educational value.

This paper presents the development and implementation of an Internet-based, remotely accessible student laboratory approach as a means to accomplish an affordable integration of laboratory experience into the classroom. This approach is currently being implemented at Stevens into a laboratory to accompany a sophomore-level course on dynamical systems. The presentation of this paper will focus on the general concept of remote experimentation and analyze its advantages and shortcomings. The experimental setup of a muffler system will be used to highlight the cross-fertilization between abstract concepts, experimental validation, and design applications achieved through the integration of course and laboratory material.

The implementation of such a concept has sparked considerable excitement amongst the Stevens faculty, staff and students involved in the development, building and testing of the experimental setups.

Review of approaches for educational laboratories

The traditional approach to educational laboratories is typically characterized by elements of preparatory instruction, preliminary student performance assessment, hands-on experimental work, data analysis, and reporting of the experimental findings. To assure that the students are prepared and qualified to safely and correctly carry out the experimental work, preliminary student performance assessment in oral or written form is conducted. The experimental work itself comprises the setup and calibration of the equipment as well as the data acquisition. The reporting of the experimental findings is typically carried out in the form of an out-of-classroom assignment.

In many laboratories with sophisticated equipment, students first have to spend a disproportionate amount of their allotted laboratory time on the assembly of the particular experimental setup. This phase is then followed by a recipe-type experimental tutorial. On the contrary, the data collection, interpretation and correlation with theoretical formulations presented in the classroom deserve the main focus of the students' attention.

It has been argued by some authors (e.g., Knight and DeWeerth[1]) that this traditional closed educational laboratory setup, where students first spend time in the laboratory and then follow up by a writing assignment, is not the arrangement that is most conducive to learning. A better alternative would be to instead provide open laboratories where students can return later to repeat and refine their experiments.

Accessibility and affordability represent the most severe limitations to the traditional educational laboratory approach. Large student populations require a significant commitment of personnel and other resources. In the usual circumstances where laboratory space is limited, the students are accommodated by dividing them into multiple laboratory sections, both for the preparatory instruction as well as for the experimental work itself. Each section is then further separated into groups. Teams of three to four students have been found to work most effectively in most settings. Due to scheduling constraints, some of these laboratory sections will be forced to tackle the experiment out of tune with the lecture (Chan and So[2]). The number of identical experimental stations governs the size of the laboratory sections. Due to the serious budgetary constraints encountered by most educational institutions, the number of student groups that can perform the experiment concurrently is very small, especially for sophisticated and therefore costly experimental setups. Thus, the time allotted under these circumstances for the students to perform their experiments is reduced to a minimum in order to satisfy the scheduling constraints. As a result, the students do not get as much direct exposure to the laboratory equipment as would be desirable ideally.

Modern undergraduate engineering curricula as devised recently are oriented towards an increased focus on laboratory activities and experimental demonstrations during lectures, and thus, they intensify this problem even more. For example, a whole series of new undergraduate teaching laboratories such as the one discussed in this paper are currently being developed. These laboratories will be used by the entire class of undergraduate engineering majors.

Educational laboratory facilities that effectively address the shortcomings of the traditional laboratory environment are in short supply. Therefore, this widespread shortage has recently become the focus of numerous initiatives involving educational institutions, governmental agencies and professional societies. Through this phase of self examination and assessment, it is becoming clear that a shift of paradigm in laboratory instruction, which would allow for more flexibility in administering preparatory instruction for the laboratory experiments as well as in performing the experimental laboratory work itself, and would take advantage of recent technological advances in information technology and communications must be considered. A review of current laboratory instruction approaches reveals the multitude of computer-based multimedia-type instructional tools that has been developed and implemented into the classroom environment in the last few years. Bugos[3] for instance presented an Interactive Video Laboratory System (IVLS) where the students are guided through actual experimentation using sensors and transducers with computer-controlled data acquisition by interactive multimedia tools. Similarly, a number of educators are integrating the Internet into their instructional approach by using it to distribute documents, offer supplementary and background materials, and provide a means for student communication and multimedia student presentations (e.g., Blanchard et al.,[4,5] Wells et al.[6]).

Compared with traditional instructional methods, studies on the effectiveness of these tools have revealed a measurable improvement in student achievement and performance outcomes (e.g., information retention, learning time). In addition, a positive learning attitude has been observed in today's students who are accustomed to computer use. This improvement is rendered possible because of the ability of the students to proceed at their own pace and obtain online help and background information beyond the classroom material, due to the possibility for active student interaction, and through the inherent stimulation of audio- and video-based learning patterns. Similarly, multimedia tools represent an efficient means for preparatory laboratory instruction that enhances student interest for the experiments and typically results in positive student feedback (Chan and So[2]).

Remotely accessible approach to laboratory education

At Stevens Institute of Technology, an Internet-based remote-access interactive approach to laboratory experimentation is currently being developed and implemented. In this approach, the students will be able to access the laboratory facility remotely through the Internet and connect to the computer-controlled laboratory setup of interest as shown in Figure 1.

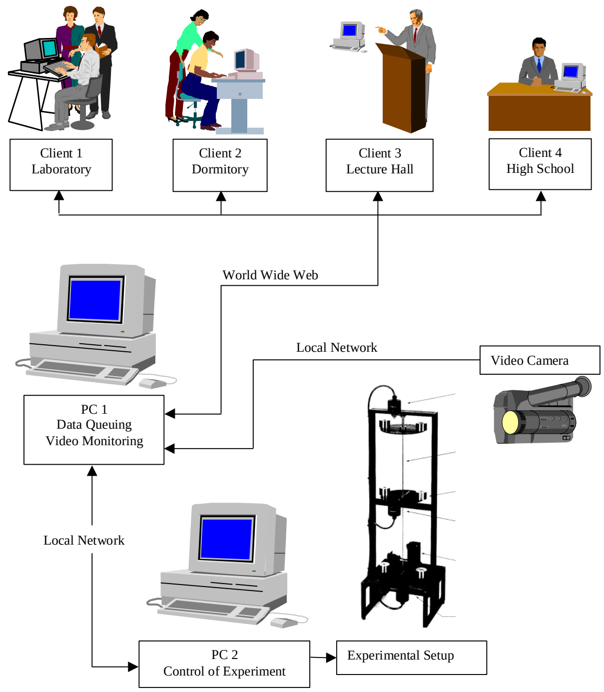

Figure 1: Setup of an Internet-based remote-access interactive laboratory

The students will first undergo online training on the specific equipment. In doing so, they will get re-familiarized with the underlying physical phenomena of the particular experiment to be performed. In addition, the appropriate documentation will be available online to the students to acquaint themselves with the experimental equipment. Before coming to the laboratory session, the students will be asked to successfully complete an online competency test where they have to demonstrate proficiency in the underlying technical background and knowledge of the specific laboratory experiment to be used.

When coming to the laboratory, the students will have the opportunity for a limited amount of direct interaction with the laboratory setups. They will be asked to calibrate the equipment and perform a limited set of experiments. The remote accessibility of the experimental setups will then allow them to continue more detailed experimental studies in a remote fashion thus greatly enhancing the scope and value of the experimental experience. During this remote experimentation, the students will interactively submit sets of input data for the experiment to a first computer that controls a waiting queue and communicates the experimental results to the clients. A second computer will extract the data sets one by one from the waiting queue and initiate their processing by the computer-controlled laboratory equipment. The performing of the experiments will be monitored by video cameras and stored in electronic form as audio and/or video files. Both the results of the experiments and the audio/video files will be made accessible through the Internet for the remote and time-independent inspection and/or post-processing by the students.

The idea of sharing student laboratory facilities as described in this paper is not entirely new. For instance, Aburdene et al.[7] proposed a remotely shared control-systems laboratory based on

Networked Engineering Workstations. Their system allows one to acquire data and transfer them to another computer for further experimentation and processing. Subsequently, Aburdene et al.[8] presented two general approaches for laboratory experiments shared through the Internet. While in the first approach the users access so-called PC-based Integrated Engineering Workstations by a remote login procedure and perform the experiment, in the alternative approach, data acquisition and control units are equipped with Internet addresses and enabled to download programs from remote user sites and perform the experiment. McKee and Barson[9] developed a robotics laboratory that allows the remote control of the robots and sensor modules in the laboratory and the remote viewing of the activity using pan/tilt and zoom/focus controls of a video camera. The data from the sensor modules are accessed remotely for off-line evaluation. McKee and Brooks[10] complimented these developments by devising appropriate strategies for the resource allocation through access controls and resource sharing schemes. Aktan et al.[11] developed a remote-access real-time control-engineering laboratory equipped with audio and video feedback. In their approach, user-developed control codes are uploaded to and run by the experimental equipment. Knight and DeWeerth[1,12,13] presented an instructional laboratory system based on the World Wide Web. This system provides remote access to and control of electronic test equipment. A remote laboratory was presented where the user can characterize scan converter-based transient digitizers (Arpaia et al.[14]) or perform remote measurements and download results for further processing using only a commercial web browser (Arpaia et al.[15]). Later, these authors[16] also addressed the issues of conflict resolution for the user-requests and resource optimization related to a remotely operated measurement laboratory environment. Alegria and Ramos[17] discussed an automated measurement system that is used to characterize semiconductor devices. Using a client server communication, this system can be controlled by any one of the PC's integrated in a Local Area Network. Bertocco et al.[18] described a similar effort in which they developed a client-server architecture for remote control of measurement instrumentation over the Internet, which allows for multi-user, multi-instrument experimental sessions. Zoghi et al.[19] devised a self-sustained video camera system that is remote-controlled through the Internet.

Benefits and shortcomings of the approach

The approach described in this paper takes advantage of a variety of existing and emerging communication technologies. All activities associated with the laboratory courses will be guided through web pages that are implemented using WebCT™, a software package that is currently being adopted in various courses of the undergraduate curriculum at Stevens. This package offers a number of functions that support various activities of the laboratory framework described here. In addition to the functionality of conventional web pages, the capabilities integrated in this package comprise among others a tool to track the student page views, several communications tools (e.g., chat room, e-mail, white board, bulletin board), an online quiz feature and a grade database. All preparatory instructional materials (enhanced by visual tools such as drawings, photographs, computer animations, audio and video files) as well as testing and self-assessment tools for the students can thus be provided in electronic form on the Internet. The Internet-based communication tools will conveniently enable team-based learning activities for students that are exposed to spatial and temporary constraints in their study techniques.

The benefits of this approach are, among others, that:

- during the remote-experimentation phase, identical sets of input data from different users can automatically be combined into one actual experimental run the results of which can then be transmitted to all clients,
- the strain on laboratory class schedules is alleviated significantly,
- budgetary constraints are overcome,
- more students can be exposed to a more comprehensive experimental experience (including students with physical disabilities, non-traditional students, part-time students, students undergoing continued education, participants of on-site industrial training courses),
- instructors are enabled and encouraged to include demonstrations of laboratory experiments into their lectures,
- asynchronous learning is encouraged, which is especially suited to fit the needs of non-traditional, commuting part-time students,
- it is a much closer approximation to hands-on experience compared to purely numerical experimentation and simulation; a process proposed by some as a viable alternative to the traditional laboratory experimentation (Cobby et al.[20]),
- it captures the spirit and imagination of the students who nowadays tend to be increasingly technologically inclined,
- it promotes student self-learning, and
- it renders itself as a tool for integrated student performance assessment and self-assessment.

While offering important benefits, the described remote laboratory setup also exhibits some drawbacks as was rightfully pointed out by the reviewers of the original NSF proposal that led to partial funding of this activity by the NSF-ILI program as well as by other individuals involved in the planning and implementation of the laboratory. One of the main disadvantages compared with traditional laboratory setups is the significant investment in the up-front development effort and time required. This is caused by the tremendous logistical problems that need to be solved in order for the system to be capable of properly handling task scheduling, request conflict resolution, and equipment and network failures. In contrast to the original plans outlining a laboratory to be accessed exclusively in a remote fashion, the development team changed to the hybrid on-site / remote approach described here. This takes into consideration the fact that the majority of people with whom the initially conceived fully remote laboratory approach was discussed found that direct hands-on student interaction with the experimental equipment is of paramount importance for the educational success of the experimental experience. It is believed by the authors that the proposed modified approach to student experimentation will enhance engineering curricula by facilitating improved access to better laboratory equipment to a broader student audience. Another concern voiced by the proposal reviewers related to the perceived difficulties in enforcing the independence of student work when performed remotely. While this might pose a challenging problem at other institutions without an obvious solution, at Stevens there exists a student honor code that removes the need for student proctoring entirely.

Sample implementation

The laboratory approach described in this paper is initially being developed and implemented into the Dynamical Systems course of the new Stevens undergraduate engineering curriculum. A simplified muffler system has been selected as one of the first dynamical systems to be implemented and tested. It consists of a source (realized by a speaker) positioned at the exhaust pipe, an expansion chamber, and a tail pipe. A schematic representation of this system is shown in Figure 2.

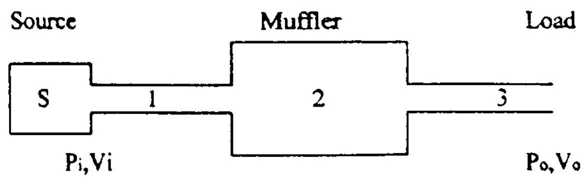

Figure 2: Schematic representation of a simplified muffler system

A simplified muffler as described here is an acoustic system that lends itself nicely both into on-site experimentation as well as remote use. It is currently planned to use this system on several occasions throughout the course on dynamical systems. In the first laboratory session, the insertion loss of the muffler will be determined by measuring and recording the sound-pressure levels at the tail-pipe exit with and without muffler in response to a sinusoidal input sound of varying frequency. This experiment represents a repetitive procedure that would require significant laboratory time to be scheduled for every individual student group. It is this repetitiveness that makes it into a prime candidate for an experiment that can start in the on-site hands-on mode and can then be finished in remote fashion.

In the second laboratory session involving the muffler system, the insertion loss will be determined by applying white noise to the system and then calculating the insertion loss using the Fast Fourier Transform. For all experiments, a Labview™ interface is used to control the experimental devices involved and store the acquired data to a file. Matlab™ is then used to perform data postprocessing and comparisons with theoretical predictions. As an example, Figure 3 displays the comparison of the experimental measurements of the muffler insertion loss with predictions of the transmission loss based on a simplified analytical model.

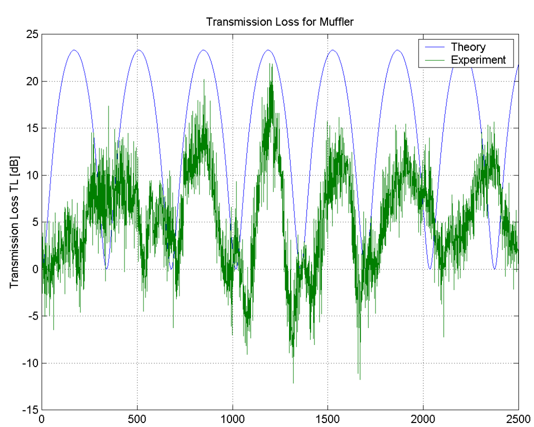

Figure 3: Comparison of experimental insertion loss measurements and theoretical predictions for the muffler transmission loss

In addition to the two experiments described briefly above, the muffler system will also present the foundation for a student design project. After having determined the dynamical behavior of the muffler system through experimentation, the students will then be given the recording of a real sound of a vehicle engine in the form of an audio file. It will then be their task to optimize the muffler behavior by varying its characteristic parameters (effective length of expansion chamber, location of baffle in expansion chamber). This design optimization will be carried out by the students based on their experiences gained from the lecture, the analytical modeling of the muffler behavior and the experimental results.

Future Plans

Currently, significant progress has been made toward the design and construction of a liquid-level control system and a two-degree-of-freedom mechanical vibration system. In the near future, it is planned to extend this laboratory approach to other applications of dynamical systems rooted in mechanical, electrical, civil, and chemical engineering. At a later time, the possibility of integrating remotely accessible experiments into other educational laboratories at Stevens will be explored as well. In addition, some of the laboratory setups developed for the undergraduate laboratory on dynamical systems can potentially provide for classroom demonstrations in graduate courses in controls, fluid mechanics, vibration and noise control and others.

Furthermore, in an effort to assist K-12 teachers in enhancing science instruction, it is being considered to make the technology and a subset of the experimental setups developed in this project available to the Center for Improved Engineering and Science Education (CIESE). CIESE has been established at Stevens Institute of Technology to create a statewide test bed for the utilization of the Internet in mathematics, science and technology instruction in K-12 education.

Besides the proposed application for remote-access interactive laboratory training, it is envisioned that this Internet-based technology will find other fields of application such as the remote access of expensive research equipment and facilities.

Summary

An Internet-based remote-access interactive approach to laboratory instruction is proposed in this paper. In this approach, the students' experimental experience can be greatly expanded by allowing them to remotely access the laboratory facility and connect through the Internet to the computer controlled laboratory setup of interest. This proposed approach enables and encourages instructors to include demonstrations of sophisticated laboratory experiments into their lectures, allows for the automatic combination of multiple identical sets of input data from different users into a single actual experiment, and provides for asynchronous learning. Therefore, the benefits of the proposed laboratory implementation are that more students can be exposed to experimental experiences, the strain on laboratory class schedules is released, and self-learning of the students is promoted.

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