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Integration of Distance Learning Technology into Traditional Engineering Physical Laboratory Exercises

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Abstract – The use of distance learning technology in distributed educational environments has allowed engineering courses to be delivered to locations and populations that have historically not been afforded opportunities for involvement. However, efforts to incorporate distance-learning principles into physical laboratory exercises have not led to a general mechanism or procedure for performing physical labs remotely. Removing these exercises from the course is not a satisfactory solution since physical laboratory exercises are a vital component of any educational curriculum in virtually every major field of engineering. Recently, faculty members from three universities in south Georgia have teamed up to collaboratively develop an innovative approach to integrate distance learning technology into traditional engineering physical laboratory exercises. An overview of this project and findings related to its initial phase are presented in this paper.

Keywords: Distance Learning, Physical Laboratories, Remote Laboratories, Learning Technologies

INTRODUCTION

The use of distance learning technology in distributed educational environments has allowed engineering courses to be delivered to locations and populations that have historically not been afforded opportunities for involvement. However, efforts to incorporate distance-learning principles into physical laboratory exercises have not yet led to a general mechanism or procedure for performing physical labs remotely. In the absence of sufficient laboratory resources at the remote site, the usual practice is to either: remove these exercises from the course, replace the exercises with virtual labs, replace the exercises with experiments that can be done with an inexpensive laboratory kit, or have a mobile lab that can be taken to various sites. Removing the exercises or replacing with virtual exercises is not a satisfactory solution since physical laboratory exercises are a vital component of any educational curriculum in virtually every major field of engineering. The experiment measurements can all be taken via electronic measurement equipment or electronic sensors which can be interfaced to a control computer directly or via data acquisition hardware. The experiments require interaction from the user.

The Georgia Tech Regional Engineering Program (GTREP) is an academic collaboration between Georgia Tech and its three partner institutions Armstrong Atlantic State University, Savannah State University, and Georgia

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Southern University. During freshmen and sophomore years of the undergraduate program, students are enrolled through one of the three partner institutions. These universities offer all of the mathematics and science courses as well as the engineering courses required in the first two years of the Georgia Tech engineering curricula. Prior to their junior year, students apply for transfer admission to Georgia Tech and complete their degree program as Georgia Tech students. During their junior and senior years, students are taught by Georgia Tech Savannah faculty supplemented by distance learning connections. Currently, GTREP offers undergraduate degree programs in Civil, Computer, Electrical, Environmental, and Mechanical Engineering. Students graduating from GTREP receive a Georgia Tech degree with the designation Regional Engineering Program.

While any traditional course can be taught remotely between the GTREP institutions, it is still not feasible to cover physical laboratory exercises. Thus, at present, students attend pre-laboratory classes remotely but have to physically meet at a particular location to carry out the practical parts of the various laboratories. In order to overcome this barrier of contemporary distance learning, GTREP faculty teamed up to collaboratively develop an innovative approach to integrating distance learning technology into traditional engineering physical laboratory exercises. A remote or teleoperated laboratory involves the user conducting physical experiments by controlling the lab equipment remotely. In a virtual laboratory, the experiment is simulated via software. Remote labs can support a large number of students with fewer lab stations and offer more time and location flexibility. An overview of this project and findings related to its initial phase are presented in this paper. Starting off with an overview of the current-state-of-the-art as, an investigation into various types of engineering experiments that may be suitable for distance learning settings is presented.

STATE-OF-THE-ART

The earliest remote laboratory initiatives known to the authors started in the mid to late 1990s. A laboratory that supported a variety of remotely operated laboratory exercises in control systems and chemical, environmental, and mechanical engineering was developed at the University of Tennessee at Chattanooga [Henry, 1, 2]. A remotely controlled physics experiment to determine the speed of light was developed by Enlo et al [Enlo, 3]. Experiments involving semiconductor characterization were developed by Shen et al [Shen, 4]. Hamza et al. [Hamza, 5] developed a prototype remote laboratory system; their initiative led to the development of the Florida Atlantic University CADET (Center for the Advancement of Distance Education Technologies) [CADET, 6]. They developed proof of concept prototypes and at present claim to have laboratories that are under development, including Electrical Element Characterization (for Electrical Engineering), Logic Design (for Computer Engineering), Motion and Friction (for Mechanical Engineering) and Metallic Elasticity (for Physics and materials in engineering).

One of the first comprehensive surveys on online higher education was published by Sloan-C and the Sloan Center for Online Education in 2004 [Sloan-C, 7]. At that time, their main finding was that the Associates degree granting institutions have the largest number of students taking at least one online course, representing about half of all the students studying online, while they were followed, in order, by Masters, Doctoral/Research, Specialized and Baccalaureate institutions with the smallest number.

Based on the Sloan-C survey, Ibrahim and Morsi [Ibrahim, 8] conducted a discipline specific review of undergraduate and/or graduate Electrical and Computer Engineering degrees offered completely or partially online. They reviewed instructional technologies and different systems for offering electrical, electronics, and digital laboratories via distance learning to facilitate online education for engineering disciplines. They concluded that, although simulation may be used to reinforce concepts, practical experiments are needed for undergraduate electrical engineering education to develop the student's skills in dealing with the real instrumentation. They discussed if virtual labs are an alternative to the practical experience: they postulate that they should include the required hands-on control. They proposed a technology available with National Instruments (NI) LabVIEW Remote Panels, which enabled a user to publish the front panel of a LabVIEW program for use in a standard Web browser. Other work accessing the effectiveness of remote laboratories has generally indicated that the achieved learning outcomes are comparable to those obtained from labs performed in person [Hurley, 9] [Lindsay, 10] [Ogot, 11] [Tzafastas, 12]. However, learning outcomes in some areas were degraded. Students who performed the remote laboratories versus simulations were able to identify the nonidealities in the experiment results.

Early attempts at developing remote labs were hindered by internet connectivity, hardware reliability, and the difficulty of controlling the instruments remotely with a web interface and control software. As web tools and instrument control software have become more advanced and easier to use, there has been increasing development of remote laboratories.

Jodl et al. of Technical University of Kaiserslautern, Germany [Jodl, 13], have started an initiative for distributed remotely controlled labs (RCL) in Physics teaching. They have setup classic physics experiments (Electron Diffraction, Photoelectrical Effect, Voltage-Current Characteristics, Diffraction and Interference) in different European locations that can be executed through the internet. A user at a location "A" is allowed to conduct an experiment at a distant location "B" via his or her computer (client). Controlling the experiment is enabled by accessing an interface and a web server. Web cams allow the user to observe the on-going experiment. They directed these RCLs to K-12 (and as a prototype model to build-up RCLs in school projects) and to the lay public, but these remote labs could be immediately used for university teaching as well.

In a recent paper, Gröber et al. [Gröber, 14] review the existence and status of physics experiments in remote labs worldwide: by 2006 they found about 60 projects offering about 120 remote experiments. More than half of these projects were located in the USA and Germany, and some of the projects were joint ventures between universities in different countries. Some recent examples of engineering remote labs are: controls [Sánchez, 15] [Ko, 16], electric motors [Kikuchi, 17] image acquisition and processing [Sebastián, 18], robotics [Chang, 19], PLC control of manufacturing cell [Bellmunt, 20], telecommunications [Scheets, 21], photonics [Tzafestas, 12], power electronics [Hurley, 9], and fluid mechanics [Ogot, 11]. There appears to be more development of remote electrical and control engineering labs than other types of labs. Electrical and control lab equipment typically supports external control and monitoring via RS 232 or GPIB (IEEE-488) interfaces and thus requires less alteration to be performed remotely.

DESIRABLE CHARACTERISTICS OF REMOTE LABS

Based on our experience and other's work on remote labs, the following are desirable characteristics of remote laboratories:

- 1) The user interface should be easy to understand and easy to use.
- 2) The user (client side) should not need any special hardware or software.
- 3) Experiments should be available all days and times.
- 4) Experiments should require minimal or no interaction from on-site lab personnel once the experiment is set up.
- 5) The system in the experiment should neither be too fast or too slow. Too fast and network delays or user inaction can affect the experiment. Too slow and the user may get frustrated and stop the lab and fewer users can access the lab in a given time.
- 6) The experiment should be interesting to observe. Real-time audio and video feedback helps the user experience the lab as if they were performing it in person.
- 7) The lab experiment hardware should be controllable via a computer or computer controlled equipment.
- 8) Experiment measurements should be able to be taken via electronic sensors (ammeters, voltmeters, tachometers, electrical pressure sensors, electrical temperature sensors, etc.)
- 9) The experimental apparatus must lend itself to familiarization via videos or web tutorials
- 10) Access to the remote experiments is secure and protected from unauthorized users.

POTENTIAL REMOTE LABORATORIES FOR DISTANCE LEARNING SETTINGS

In the initial phase of this project a number of physical laboratory experiments that are widely used in Civil, Electrical, and Mechanical Engineering were analyzed with regard to their potential to be carried out remotely within distance learning settings. Typical engineering experiments, which were among those that were considered, are presented in Table 1. The intension was to classify these experiments and consider potential approaches or best practices to make experiments of a particular class accessible to distance learning students. Within that class,

representative experiments from Civil, Electrical, and Mechanical Engineering that are considered to be well suited to be offered as Remote Laboratories within a distance learning setting were selected for potential implementation.

A Selection of Typical Physical Laboratory Exercises		
Civil Engineering	Electrical Engineering	Mechanical Engineering
• Tensile testing of metals	• Verification of KCL and KVL	• Impact of a jet of water
• Triaxial shear tests on soils	• Half and Full wave rectification	• Vapor pressure
• Concrete compression testing	• Transistor amplifier circuits	• Minor and major losses in pipes
• Dynamic response of structures	• System frequency response	• Extended surface heat transfer
• Viscoelastic behavior of polymers	• Transistor amplifier circuits	• Tensile testing
• Moisture/Aging impacts on materials	• Motor control	• Vibrations of a 2 DOF system
• Fracture mechanics	• Audio Signal processing	• Controls (P-PD-PID)
• Fatigue response of materials	• Optics	• Acoustics

Table 1: Typical physical laboratory exercises in Civil, Electrical and Mechanical Engineering

Although the laboratory exercises presented above have some significant differences, there are a number of common characteristics that were identified as consistent within this educational approach:

- 1) The requirement that students actively participate in the laboratory exercise, rather than passively assimilate information presented by a second party.
- 2) The inclusion of physical products or materials in place of abstract theoretical constructs.
- 3) The need for students to make intermediate decisions during the exercise that will ultimately influence the final outcome of the experiment.
- 4) Analysis of the validity of results through proof-testing, comparison to accepted standards, etc.

The remote laboratory exercises detailed in the next section have the following additional characteristics in common:

- 1) The experiment measurements can all be taken via electronic measurement equipment or electronic sensors which can be interfaced to a control computer directly or via data acquisition hardware requirement
- 2) The experiments do not require intervention by on site lab personnel during the experiment.

SELECTED EXAMPLES OF REMOTE LABORATORY EXERCISES

In this section we present selected representative examples of laboratory exercises that are being setup for remote operation within the GTREP distance learning environment. Due to the limited space available, only one experiment per engineering discipline is presented.

Tensile testing of a given specimen (Civil Engineering)

Overview

Tensile testing is a simple way to determine the stress-strain characteristics of materials. Elastic modulus, yield strength, tensile strength, ductility, modulus of resilience and toughness are some of the mechanical properties that can be determined from this experiment

Objective

The main objective of this experiment is to be able to obtain stress-strain data for a given specimen/material, analyze the data and determine material properties such as elastic modulus, yield strength, tensile strength, ductility, modulus of resilience and toughness.

Equipment

- a load frame
- a load cell
- an extensometer
- a computer
- LabVIEW software (specifically LabVIEW VI)
- a webcam
- several material specimens

Lab Procedure

A lab technician will load the specimen onto the load frame, position the load cell and extensometer and turn on the PC as well as the webcam. A student will log into a web-based interface with a webcam view of the apparatus and the LabVIEW VI interface. After receiving a sign of approval from the lab technician, the student will gradually increase the magnitude of the applied load using the LabVIEW VI till the specimen fractures. The displacement data is simultaneously collected by the data acquisition PC. The process is repeated several times for precision and accuracy. The student will then download the displacement data. The lab technician will clear the material specimens as well as turn off all apparatus upon completion. Pre-laboratory data such as specimen dimensions, calibration of the load cell and extensometer will be available for downloading as well. Figure 1 illustrates students conducting a tensile testing experiment in a distance learning setting.

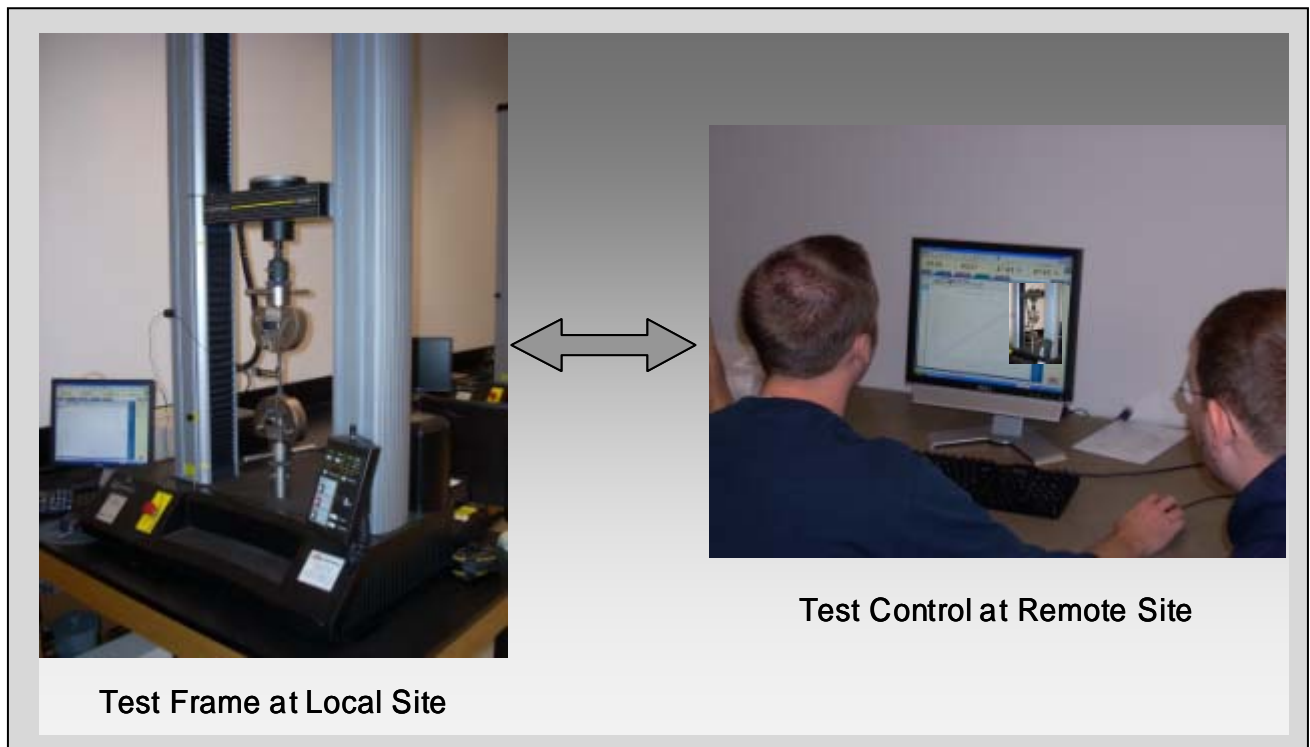


Figure 1: Tensile testing in a distance learning setting

Analysis

Once all the data is obtained, the students can compute stress and strain data using the original dimensions of the specimen. Students can use software such as MATLAB to analyze the data to plot the corresponding stress-strain curve for the material and compute the required material properties. Students learn the theory used in this experiment in courses such as: Introduction to material science and engineering, mechanics of materials, strength of materials, etc. and hence are familiar with it.

Future Work

This work can be easily extended to torsional testing, fatigue testing, etc

Measurement of the Speed of Sound (Mechanical Engineering)

Objective

The speed of sound will be measured using the time of flight method. A sound source and receiver will be set up with the receiver placed at increasing distances from the source. The increased delay time for the sound to reach the source, and the receiver distance can be used to compute an experimental speed of sound. This can be compared with the theoretical value of the speed of sound.

Equipment

1. Loudspeaker
2. Microphone (attach to carriage on a linear track)
3. Ruled linear track (microphone attached to a user movable carriage connected to a stepper motor on the track)
4. LabVIEW based function generator (to produce the output sinusoidal tone burst sound wave)
5. LabVIEW based oscilloscope (to capture triggered output sound wave and input sound wave received by microphone)
6. Webcam
7. PC (to control the experiment and webcam)
8. Digital thermometer (to measure laboratory room temperature)

A LabVIEW Virtual Instrument will be configured to view the experiment, control the webcam (zoom in on the ruled track), hear audio from the experiment, and display measured data.

Lab Procedure

A lab technician would turn on all laboratory equipment for use. No further intervention would be required. In this experiment the user would log in to an interface containing a webcam view of the apparatus and LabVIEW based Virtual Instruments (VI) used to control equipment and collect data. The user would move the microphone carriage to the reference (smallest) distance from the loudspeaker. The user would then initiate the sound wave using the LabVIEW interface. Both output (speaker) and input (microphone) waves will be displayed on a separate LabVIEW oscilloscope window. The user would then manipulate cursors to discern the delay time at that distance. The delay time and distance between source and receiver would be recorded by the user. This process is repeated for several increased distances. For example measurements from 4-40 cm in 2 cm increments could be taken. The room temperature would be collected by zooming the webcam on the display or having it displayed directly in the LabVIEW VI. Once all data is collected, the user can use linear regression to compute experimental speed of sound value for comparison using the theoretical temperature based value.

Signals and Systems or Control Systems (Electrical Engineering)

Objective

Lab involves experimentally determining frequency response of a continuous-time system.

Overview

The continuous-time system, typically an electric circuit, would be designed and simulated using CAD software, such as PSPICE, by the experimenter. The simulated design would be sent to a lab technician who would construct the circuit to be tested.

Lab Procedure

Prior to the experiment, the lab technician would connect a signal generator and measurement devices to the circuit and ensure the circuit was operating properly. The measurements devices would be one or more digital multimeters or oscilloscopes. The equipment would need to be remotely controllable, for example controllable via GPIB interface. Everything would be ready to go by a set time and the experiment would be performed in a time window (say 2 hours).

The experimenter would log into a web site that would be given access to a web interface to control the lab setup. The experimenter via the web interface would set the amplitude and frequency of the signal generator (set to sinusoidal function) and receive output measurements displayed in the web interface from the measurement device(s). A web cam showing the signal generator screen measurement device screen, and circuit would also be desirable. The experimenter could run through a range of frequencies and experimentally determine the frequency response of the system.

Equipment needed:

- Signal generator, multimeter or oscilloscope (controllable via GPIB or similar interface)
- PC for web cam and to provide signals to GPIB controlled equipment or relay signals from them.

Lab support needed

- Lab technician to set up and break down experiment
- Possibly lab technician to construct the circuit.
- Desirable to have lab support during experiment in case things go wrong

Future work

A similar setup with a similar web interface would support remote circuits labs, microelectronic labs.

EVALUATION OF REMOTELY OPERATED LABORATORIES

In 2003, Ogot et al. [Ogot, 11] carried out a study on assessment of in-person and remotely operated laboratories. Their results showed no significant difference with regard to meeting educational outcomes between students who performed an experiment remotely, versus those who carried out the same experiment in-person. In order to validate their findings, the same evaluation procedure will be implemented within our setting.

Key questions to be answered are: (1) “How effective are remotely operated laboratories?” and (2) “Do they provide the same hands-on learning outcomes as laboratory exercises physically carried out in the lab?” In order find answers to these questions, two sets of students will carry out the laboratories in parallel. One of the groups will operate the laboratory remotely, while the other group will carry out the same exercise in a traditional setting. None of the groups will know about the other group and that they are being analyzed.

Both groups will be assessed on the same deliverables: a written laboratory report and a power point presentation summarizing the following characteristics: objective of the experiment, apparatus and experimental setup, data acquisition, data analysis, discussion and error analysis, comparison with theory, calculations and derivations, conclusions drawn, overall technical understanding. These characteristics will be assessed through specific assessment rubrics [Andrade, 22], which allow determining a particular level of accomplishment of a student based on Bloom’s taxonomy [Bloom, 23].

CLOSING COMMENTS AND FUTURE WORK

While there is an increasing development of individual online laboratories, little has been done to develop cohesive sets of remote laboratories to accommodate entire programs. The availability of such a set of remote laboratories is of key importance to any institution offering distance learning programs in either a major engineering discipline or a program based in a cross-disciplinary curriculum. In this regard, the authors are working on a more formal classification scheme for engineering laboratories which best lend themselves to be carried out remotely. As these laboratory exercises are being implemented and tested, an asset of “best” technologies (interface, web server, control software/hardware, etc.) that can be used to support laboratories in any engineering discipline. In addition to this, a pedagogical approach to implementing remote laboratories into an overall curriculum including assessment strategies will be developed. In order to validate the effectiveness of this approach and to determine its impact on the advancement of student learning, an evaluation procedure similar to the one alluded to in the previous section will be carried out and documented.

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