Remotely Controlled Laboratory Experiments: Creation and Examples

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Abstract— **Most users who can only connect to their university through distance learning enabled programs have no other choice than to sit out the experimental side of education. Remote Labs have the greatest potential to overcome the bottleneck in distance education. The goal of Remote Laboratory implementation is to grant these students access to laboratory equipment. Although there is not currently a way to perfectly emulate these encounters completely, there are many practices and tools that will help match a traditional kinesthetic environment in a Remote Lab. An experiment was created during thesis research to obtain experimental data and analyze the ability of Remote Labs to be integrated with current coursework. Surveys were distributed to appraise the perception of the lab. The collected data indicated that the perceptions a student carries about the effectiveness of Remote Laboratories improves after they perform the experiment.**

I. Introduction

PHYSICAL laboratory exercises are the most critical gap in Distance Learning education today [1]. While there has been an increase in development of individual online laboratories, little has been done to develop sets of Remote Laboratories to accommodate entire courses or programs. The ability to provide these is of key importance to institutions offering Distance Learning programs in major engineering disciplines and/or cross-disciplinary short courses in the educational service sector.

The opportunity to be able to fully cover physical laboratory exercises in a Distance Learning setting would not only significantly enhance the student learning experience, it would enable educational institutions to offer programs to a much broader target group of potential students who under no circumstances are able to travel to and attend on-site sessions. Consequently, educational institutions offering this opportunity could benefit from increased revenue through tuition fees. On a larger scale, if proven successful in the higher education sector, the introduction of physical laboratory exercises could also significantly impact the advancement of student learning in the high school sector. Smaller or financially underprivileged schools could offer their students access to first-class education through Distance Learning collaboration with so-called magnet schools that have the physical laboratory facilities and equipment available for use by others.

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A. Motivation

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 laboratories remotely.

In the absence of sufficient laboratory resources at remote sites, the usual practice is as follows: either replace the exercises with virtual laboratories, replace the exercises with experiments that can be done with an inexpensive laboratory kit, have a mobile laboratory that can be taken to various sites, or completely remove these exercises from the course. Removing the exercises or replacing them with virtual exercises is not an ideal solution since physical laboratory exercises are a vital component of any educational curriculum in virtually every major field of engineering [2], and other sciences.

In Distance Learning environments, such as the Georgia Tech Regional Engineering Program, any traditional lecture course can be taught remotely between participating institutions. However, it is still not feasible to cover physical laboratory exercises. Thus, at present, students attend pre-laboratory classes remotely but have to meet at a specific location on a campus to carry out the practical parts of the various laboratories. To overcome this barrier of contemporary Distance Learning, faculty can turn to the development of Remote Laboratories which involve the user conducting physical experiments by controlling laboratory equipment from a remote location.

B. Literature Review

The earliest modern Remote Laboratory initiatives known to the author 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 [3-4]. A remotely controlled physics experiment to determine the speed of light was developed by Enlo et al.[5]. Experiments involving semiconductor characterization were developed by Shen et al. [6]. Hamza et al. [7] 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) [8]. 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 of online higher education was published by Sloan-C and the Sloan Center for Online Education in 2004 [9]. At that time, their main finding was that the Associates degree granting institutions had 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 [10] 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. It was concluded that although simulation may be used to reinforce concepts, practical experiments are needed for undergraduate electrical engineering education to develop students' skills in dealing with the physical instrumentation. They discussed if virtual laboratories are a valid alternative to the practical experience and postulated that laboratories should include the required hands-on control. A proposal was mad to use 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 literature assessing the effectiveness (the ability of a RL to help students achieve the learning objectives of a traditional lab) of Remote Laboratories has generally indicated that the achieved learning outcomes are comparable to those obtained from laboratories performed in person [11-14]. However, learning outcomes in some areas have been degraded. Students who performed the Remote Laboratories versus simulations were able to identify the nonidealities in the experimental results. There is no known method to allow students to obtain the same hands on experiences in areas such as assembly or fine tuning. Early attempts at developing Remote Laboratories 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 the Technical University of Kaiserslautern, Germany [15] have started an initiative for the distribution of remotely controlled laboratories (RCL) in Physics teaching. They have set up classic physics experiments, including Electron Diffraction, Photoelectrical Effect, Voltage-Current Characteristics, Diffraction and Interference, in various 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. Controlling the experiment is enabled by accessing an interface and a web server. Web cams allow the user to observe the ongoing experiment. The researchers directed these RCLs to K-12 students (and as a prototype model to build-up RCLs in school projects) and to the lay public, but these Remote Laboratories could be immediately used for university teaching as well.

In a recent paper, Gröber et al. [16] review the existence and status of physics experiments in Remote Laboratories worldwide. By 2006 they found approximately 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 Laboratories are: controls [17-18], electric motors [19] image acquisition and processing [20], robotics [21], PLC control of manufacturing cells [22], telecommunications [23], photonics [24], power electronics [11], and fluid mechanics [13].

There is also a growing number of remote electrical and control engineering laboratories, more so than other types of laboratories. This may be because electrical and control laboratory equipment typically supports external control and monitoring via RS 232 or GPIB (IEEE-488) interfaces and thus requires less alteration to be performed remotely. In 2003, Ogot et al. [13] 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 [25].

Many universities and colleges lack the funding initiatives to provide extensive setups and are forced to compromise [1], by providing less experimental opportunities to Distance Learning students. If an institution were to develop a Remote Laboratory program for their own uses, they could also become a magnet school for others to use as a synergistic resource. The host facility could collect a fee to cover maintenance and overhead, and the accessing entity would avoid development and storage costs.

II. Steps for Remote Laboratory Implementation

The implementation described in the following Remote Laboratory examples involves four key steps:

1) Configuring the IT infrastructure
2) Initiating a Remote Laboratory experiment
3) Completing Remote Laboratory experiment
4) Assessment and evaluation
5) Configuring the IT infrastructure

These models were used for the creation of the example experiment. It is assumed that the descriptions listed here were used the experiment unless otherwise stated.

A. Configuring the IT Infrastructure

IT infrastructure, as it relates to remote connections, must be taken into consideration before a laboratory is designed. Understanding the concepts from Chapter 3, such as a networks firewall policy or which software is used for the connection and interface, is vital for this initial stage. A Remote Laboratory can only be preformed after these technical aspects are identified since user control can vary between different programming and configurations.

These laboratories utilized a remote desktop connection to gain remote access. Once connected, the students had the ability to control everything that a local student could control through the computer. LabVIEW® was used as the GUI for controlling experimental equipment when there was no commercially available software included with the lab.

B. Initiating a Remote Laboratory Experiment

An experiment is ready to be run after the equipment controls are tested and the GUI is complete. As long as the students have been made aware of the policies and procedures for setting up and working with a remote connection, they should be fully prepared to begin. It may be necessary to have a video tutorial to ease them into the process, but a laboratory manual should have enough description for them to follow.

A student must have been provided with the local computer's remote ID and password to initiate the remote desktop connections. These should be distributed as needed by the teacher or TA so the student could enter the information and be granted control of the local computer. GUIs were only run on the local computer so there would be no need to install laboratory specific software for each experiment.

C. Completing Remote Laboratory Experiment

Students must be given background information on the technical background of the lab, as well as a procedure to follow. These are needed for any experiment whether or not it is preformed remotely. The "Heat Transfer by Convection" experiment was directly adapted from an existing traditional laboratory experimentation class, so the procedure and background was virtually the same. Details on how the experiment was operated and monitored are included in the following sections.

D. Assessment and Evaluation

Surveys were given to the students who operated the Heat Transfer Remote Laboratory before and after the experiment to gain an understanding of their opinions regarding Remote Laboratory experimentation and to gain feedback on the setup and procedures.

These findings should be viewed as insights to the effectiveness of Remote Laboratories, not as hard evidence since there have been a limited number of tests performed. It will take a larger research setup than what was used here to obtain enough samples of reports and surveys to provide proof reliable that Remote Laboratories can be an effective means to teach laboratory experimentation.

III. REMOTE LABS

This section summarizes the Remote Laboratory Experiment created to be operated by undergraduate Mechanical Engineering students.

A. Heat Transfer by Convection Remote Lab

1) Purpose of Experiment

An Armfield® Heat Transfer Laboratory Experiment was used for this Remote Laboratory experiment. Georgia Tech Savannah's Mechanical Engineering 4053 laboratory experimentation class was performing this experiment traditionally. Since they had already been evaluated to conform to the institutional and ABET guidelines, there would be no need to recertify the experiment before it was tested. Additionally, a manufacturer provided software package could be used as the GUI for this experiment, making it was a prime candidate to Remote Laboratory integration.

The laboratory procedure involved temperature collection at different locations on a metal rod with an applied heat source. Students analyzed the data to determine the rod's material composition and understand the temperature response over distance with natural convection and radiation. There was no difference between the manuals for traditional and remote experiments, but slides were distributed to remote students as a reference for controlling the laboratory remotely, available in Appendix C.

2) Equipment

This experiment required three different apparatus, an Armfield® HT10XC Computer Controlled Heat Transfer station, an Armfield® HT15 Extended Surface Heat Exchanger, and a computer. The Armfield® equipment setup is shown in Figure 1.

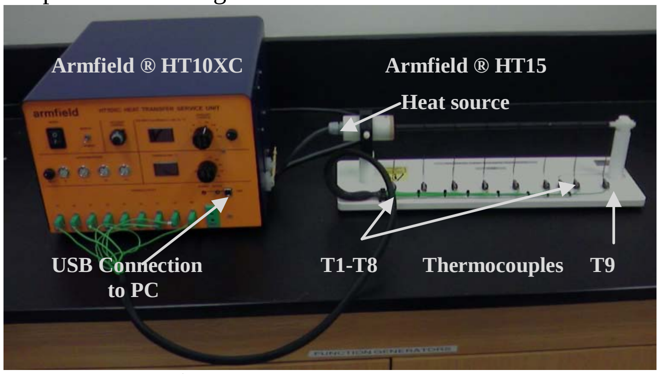

Figure 1: Heat Transfer by Convection Remote Laboratory Setup

These responses were used to help develop future experiments. Since this experiment was an intellectual exercise, there was no graded trial run which would provide data on the participants' level of technical understanding.

There are 9 different thermocouples along the HT15. Thermocouples T1-T8 are located 50 mm apart along a heated rod and T9 measures the ambient air temperature. It connects with the HT10XC to control the heat source and receive temperature data. When connected to a computer through a USB, the Armfield® apparatus communicates with software to send and receive signals.

3) Adaptation for Remote Use

When an existing laboratory experiment is selected for Remote Laboratory use, there is often a need for some adaptations to provide the remote user with a full experience. A webcam and microphone should almost always be installed to provide more feedback for the students. This experiment generated no sound, but an audio signal was sent with a video feed to allow the students to come to that conclusion on their own. There was no need for any extra signal conditioners or mechanical components for this experiment, just the webcam with built-on microphone.

Software to connect the HT15 to a computer had been available since the equipment was purchased, but was never installed since students could obtain all of their readings from a display on the HT10XC15. To enable the laboratory for remote use, the Armfield® software was installed on the computer which would be connected remotely.

4) Communication Protocol

A remote connection was again made via a remote desktop software package where the teacher or TA would provide the ID and password as needed. Having implemented the feedback from a previous experiment, the software was changed to Teamviewer® since it would it allow the user to control the local computer without taking up the entire remote monitor and it has a built-in VOIP function. These features allowed the remote user to manage their own computer and the local computer at simultaneously and view/hear real-time signals without running any extra programs.

5) User Interface

Armfield® provides software to control their equipment through a computer. The module for working with the HT15 shown in Figure 2was used as the primary interface with the equipment. A webcam and microphone was also setup to let the students see and hear any changes in the equipment.

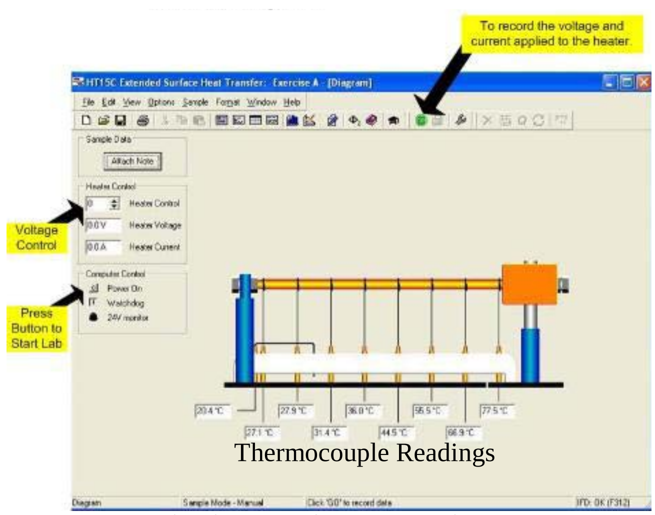

Figure 2: User Interface for the Armfield® HT15 Software

Traditional students were only required to take temperature and voltage measurements displayed on the Armfield HT15. Remote students must use this GUI, so they have the benefit of working with the extra features of the Armfield® software such as watching a graphical representation of temperature changes in real time as opposed to simply watching numbers change. These extra features can be accessed by selecting to "view" different windows that include tables or graphs.

Students were only required to take temperature measurements and change the voltage output after the temperatures have settled. This happened after approximately 15 minutes since heat would only move along the beam through convection. Traditional students manually input sample readings into a spreadsheet or notebooks; remote students have this option too. The software allows the remote student to automatically take sample readings, but this option is not encouraged to maintain similar results between traditional and Remote Laboratories.

This Remote Laboratory is an excellent example of an experiment that is enhanced when adapted for remote use. Many other experiments could benefit from automatic and accurate data collection which is standard with Remote Laboratories. Students have more exposure to numerical trends when they use an apparatus which is interfaced with a computer. Traditional students would also have the option to view the same information, benefiting everyone involved in laboratory experimentation.

6) Findings

Students were asked to take a survey before and after completing this experiment to understand their perceptions of Remote Laboratory experimentation. These surveys are available in Appendix B. A class of 14 students, divided into 3 groups, completed this experiment and surveys in the spring semester of 2010 with 2 groups doing the laboratory remotely.

Presurvey and Postsurvey comparisons are displayed in the following table and figures. Figure 4 includes the Presurvey data taken from the entire class, while Figure 5only includes the students who participated in the laboratory remotely. Figure 6 displays the Postsurvey findings from the 2 Remote Laboratory groups.

Table 1: Traditional and Remote Survey Comparison Questions

Legend Title	**Question**
Traditional Procedures	How useful do you believe a traditional experiment will be with helping you understand *experimental procedures*?
Traditional Concepts	How useful do you believe a traditional experiment will be with helping you understand *technical concepts*?
Remote Procedures	How useful do you believe a remote experiment will be with helping you understand *experimental procedures*?
Remote Concepts	How useful do you believe a remote experiment will be with helping you understand *technical concepts*?

Table 1 is used to summarize the questions asked in the Presurvey and Postsurvey. The x-axis of Figure 4 through Figure 6 relate to how the students believe experimental procedures and technical concepts are affected for either laboratory delivery method.

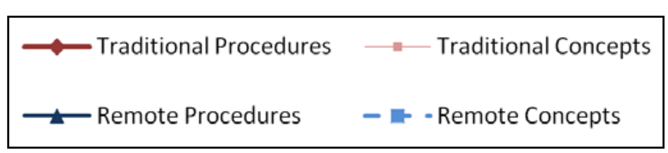

Figure 3: Legend for Presurvey and Postsurvey Findings

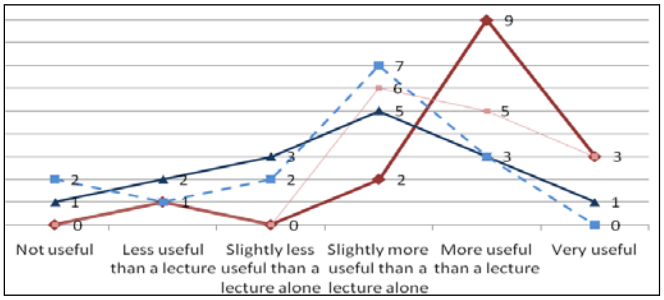

Figure 4: Spring 2010 Full Class Presurvey

Note that the initial student perceptions shown in Figure 4 tend to favor traditional laboratories over Remote Laboratories.

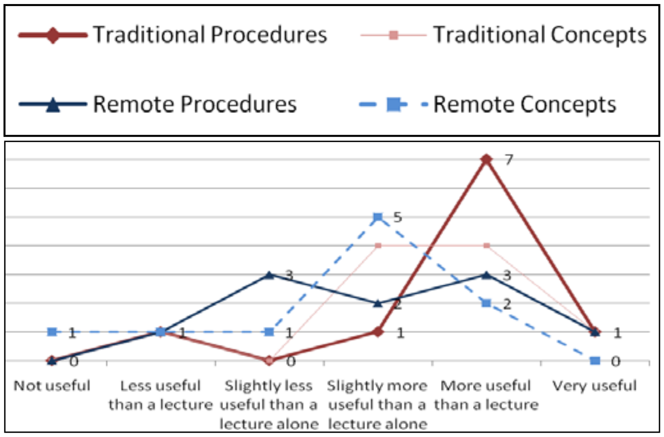

Figure 5: Spring 2010 Experimental Group Presurvey

A similar trend is noticed in Figure 5 after the traditional laboratory groups are removed. Here, students who would perform the laboratory remotely seem to have a more negative opinion as to the usefulness of Remote Laboratories.

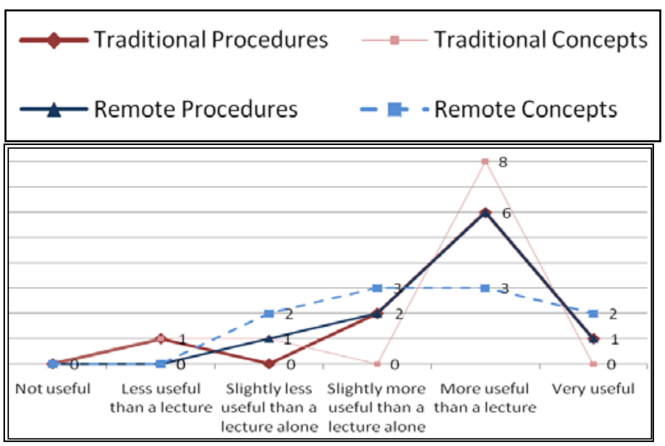

Figure 6: Spring 2010 Experimental Group Postsurvey

After the students complete the experiment remotely, their opinions regarding the usefulness of Remote Laboratories increased, as displayed in Figure 6. Note that the perceptions of traditional laboratories became less negative after completing the experiment remotely.

IV. Review

This work introduces a laboratory experiment and the steps used to make them accessible remotely. These findings indicate that a student with experience performing laboratory experiments in person will have doubt with respect to the usefulness of a Remote Laboratory as to achieving the same educational outcomes as a traditional experiment. Once the students completed a RL, their support for Remote Laboratories increased.

V. Future Work

There is still more work that must be done to prove that laboratory experiments can be preformed remotely to achieve the same educational outcomes as traditional experiments. The following list is used to guide future actions to support this work.

- More remote experiments must be administered to confirm the effectiveness of RLs.
- Templates should become more clearly defined and presented as models for creating RLs.
- An analysis of the faculty bias and costs associated with RL implementation should be preformed.
- The requirements to make a RL program pass an accreditation board should be researched
- The characteristics of an effective human computer interface for RL experimentation and how to create one should be further researched.
- A broader look into the technical issues associated with RL, such as bandwidth limitations and port-forwarding options, should be made.

Acknowledgment

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