ATLANTA
120th ASEE Annual Conference & Exposition
FRANKLY, WE DO GIVE A D*MN
June 23-26, 2013

Paper ID #7055

Survey of Existing Remote Laboratories used to Conduct Laboratory Exercises for Distance Learning Courses

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Abstract

By an ever increasing percentage, college and graduate courses are being offered online via distance learning. Several of these courses have a laboratory component that requires the use of hardware and/or software, which present potential technical, licensing, and other problems when operated remotely. Such problems are generally related to the nature, format, and geographical scope of the course. For instance, courses with a reasonably small geographical scope can be designed with the requirement that online students fulfill a partial residency, such as attendance at weekend labs conducted at the host school.

The purpose of this survey has been to determine and present the means by which various institutions have addressed the remote laboratory component of their distance learning programs. Potential advantages and disadvantages related to technologies and techniques used to implement these remote laboratories are discussed.

Introduction

According to the ninth annual survey of online education, "Going the Distance: Online Education in the United States, 2011," published by Babson Survey Research Group [1] "The 10% growth rate for online enrollments far exceeds the 2% growth in the overall higher education student population." As of fall 2010 6.1 million students had enrolled for at least one online course. The equivalent comparison for the fall 2007 term was 3.94 million students; the equivalent number was only 1.6 million students when the survey began in 2002.

When referring to an online course versus a face-to-face course the Babson survey states that "…there is one dimension that academic leaders believe is equivalent for both types of courses – the level of student satisfaction." In fact the survey data show that academic leaders believe that students satisfaction is roughly equal regarding face-to-face and online courses in the following areas: "Support for students with different leaning styles," "Student-to-faculty communications," and "Presentation of course material." Similar comparisons in the area of "Student-to-student interactions" show a somewhat strong preference for face-to-face instruction, whereas the "Ability of students to work at their own pace" shows a very strong preference for online instruction.

Whereas certain academic disciplines, such as the humanities and mathematics, generally do not incorporate a formal laboratory experience within their curricula, other disciplines, such as the sciences, engineering, and technology, incorporate and wholly depend upon the tangible and conceptual experiences offered in a formal laboratory setting. Often the experiments conducted in these laboratories involve the use of complex equipment and apparatuses, which usually require some manner of pre-configuration by an instructor or lab assistant. In some cases such experiments can be simulated by use of software applications that instantiate virtual instruments running in virtual environments. In other cases, however, real-world instrumentation is required in order to capture and demonstrate the tangible properties and behaviors of the objects and phenomenon being studied. Recreating the laboratory experience from a remote setting can be very challenging and difficult to accomplish.

Online courses that require the use of software only are generally free from the constraints of distance except in cases where centralized applications or license servers are used. Several software applications suitable for educational purposes are available as freeware or at a modest cost (student license). Centralized applications, such as expensive simulation programs or collaborative server systems, require remote access, which might be thwarted by issues such as campus security policies or site license restrictions.

Distance learning-based laboratory exercises that are primarily hardware-based require either physical or virtual access to the associated equipment and support components. Such access can be realized in one of several ways: the purchase of a lab kit, the use of a Virtual Private Network (VPN), or the creation of strategically located remote learning centers. Depending upon the parts and devices required parts kits can be designed, assembled, and distributed via the host school or via a 3rd party provider. Use of a VPN enables students in remote locations to directly access software and/or hardware systems that are physically located on the host campus' local area network via modern communication technologies and protocols; many hardware devices can be remotely accessed and controlled via applications using the TCP/IP protocol. Remote learning centers can be provisioned with the various hardware, software, and pedagogical requirements of distance learning. However, such centers can be expensive to properly build and staff. Strategic partnerships with other host schools can provide yet another viable option.

Different institutions of higher education have addressed the challenge of providing a remote laboratory component to their online courses and programs in various creative ways. And the solution to this challenge is not a “once size fits all” proposition: Some institutions that offer online courses and programs have chosen not to create and maintain a remote laboratory component; Other institutions, such as Southern Polytechnic State University (SPSU), have formed, and are continuing to form, partnerships with other institutions whereby required resources (resources, labs, library) can be “remotely” shared in order to provide “support for blended and low residency degree programs[2];” Certain initiatives, such as the Georgia Tech Regional Engineering Program (GTREP), collaborate with other institutions in order to provide Internet-based access to shared laboratory resources (facilities, equipment, faculty, etc.) necessary to offer remote laboratory exercises[3]; and a number of remote laboratory solutions exist for individual online courses and programs at various institutions. In the following pages we will examine several of these solutions and the cited advantages and disadvantages that they offer.

Survey of Remote Laboratory Solutions

Southern Polytechnic State University

In the “SPSU Distance Learning Strategic Plan 2010-2015” one of the institutional objectives states “Academic computer, lab, and library resource access agreements are in place with partner agencies for students who are geographically distributed and cannot visit SPSU’s campus.” SPSU has already formed several partnerships with member institutions in the Technical College System of Georgia (TCSG). One goal of such partnerships is to enable students to complete laboratory exercises at facilities that are remote to the SPSU campus. In the section of the plan entitled “Academic Year 2014-2015” is stated “Plan for remote controlled labs developed.”

Georgia Institute of Technology, Savannah

As part of his thesis research for a master’s degree in Mechanical Engineering at the Georgia Institute of Technology, Savannah campus, which is member of the GTREP program, A.C. Hyder, designed “The Heat Transfer Remote Laboratory” experiment[4] in order to assess the viability of remote laboratory experiments ‘integrated with current course work.’ Mr. Hyder was careful to consider: the potential IT constraints (e.g. firewalls), the laboratory configuration, and the required student instruction (remote laboratory and pre- and post-survey instructions) necessary to accurately conduct the experiment and assess the student feedback.

The laboratory experiment was conducted by two groups of undergraduate Mechanical Engineering students employing two separate methods of access and operation: traditional (in-class) and remote. The procedure involved sampling the conduction of heat across uniformly spaced positions on a metal rod, whereas the purpose of the experiment was to determine differences in student’s perception of having performed the laboratory experiment in a traditional versus remote manner.

The physical equipment used during the experiment included a PC, which was connected via a USB interface to an Armfield HT10XC Computer Controlled Heat Transfer station, which, in turn, was connected to an Armfield HT15 Extended Surface Heat Exchanger. The metal rod was installed on top of the HT15 Heat Exchanger; 8 thermocouples (heat probes) were vertically connected to the metal rod from the base of the Heat Exchanger; a 9th thermocouple was used to sample the temperature of the ambient air. Armfield software that provided a GUI representation of the physical experiment and transmitted and received signals to and from the Armfield HT10XC Heat Transfer station was installed on the PC. Students at remote locations accessed and controlled the PC, and therefore the experiment, via the Internet using the remote-control application Teamviewer. A microphone and webcam were installed to augment the experience of the remote user.

Three groups of students, one traditional and two remote, participated in the experiment. The three groups of students were asked to take surveys regarding the usefulness of both the traditional and remote procedures and concepts. The pre-survey for all groups showed a clear preference for traditional procedures and a slight preference for remote concepts, whereas the post-survey showed a clear preference for traditional concepts, but an equal preference for traditional and remote procedures. Mr. Hyder concludes that “These findings indicate that a student with experience performing laboratory experiments in person will have doubt with respect to the usefulness of Remote Laboratory as to achieving the same educational outcomes as a traditional experiment.” However, it should be pointed out that a single experiment with a population size of 14 students was used to determine these results.

Georgia State University

In 2003 while still a graduate student the author in collaboration with other graduate students and faculty members of GSU completed work on the first generation of the remote operations facility[5] of the Center for High Angular Resolution Astronomy (CHARA). The telescope array is located atop Mount Wilson, California northeast of Los Angeles, whereas the remote operations facility, referred to as the Arrington Remote Operations Center (AROC), is located on the campus of GSU in Atlanta, Georgia (see Figure 1). The AROC’s primary purpose is to enable faculty and students with the ability to remotely operate the array from Atlanta thereby participating in remote research and greatly reducing travel costs. Since its inception four other remote operations facilities have been established in France, Australia and the US.

Figure 1: Graduate students remotely operating CHARA

The AROC facility is comprised of several Linux-based workstations and an archival server interfaced to the main control computers of the array via a Virtual Private Network (VPN) over the Internet (see figure 2). Although components of the remote operations system have changed the basic configuration and functionality remain the same. The first generation of the AROC used a socket-based (TCP communication endpoints) application program developed in Java (see Figure 3) to communicate with array control computers on Mount Wilson. These computers, in turn, communicated with the various control subsystems via serial communication links.

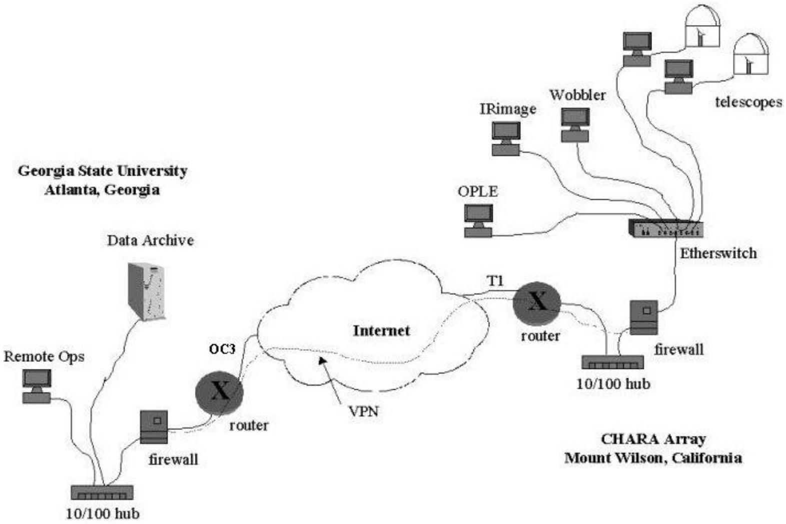
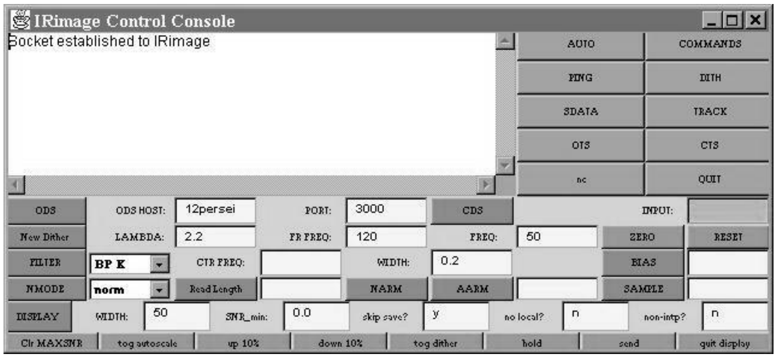


Figure 2: Secure Network Infrastructure of the CHARA Array



Socket established to IRimage

ODS HOST: 12persei
PORT: 3000
INPUT:
LAMBDA: 2.2
FR FREQ: 120
FREQ: 50
FILTER: BP K
CTR FREQ:
WIDTH: 0.2
NMODE: norm
WIDTH: 50
SNR_min: 0.0
skip save? y
no local? n
non-intp? n

Figure 3: Java-based Control for IRimage Subsystem

Due to the complexity of the array a trained operator is present on Mount Wilson during evenings of operation from the AROC in Atlanta to assist with potential problems that may occur during the course of an observation run. The various remote operation facilities are allocated regular observation dates in the CHARA operations schedule allowing graduate students and scientists to conduct research from around the world.

Blekinge Institute of Technology, Sweden

Another remotely operated laboratory accessed from around the world is physically located in a small laboratory in the Department of Telecommunications and Signal Processing at the Blekinge Institute of Technology (BTH) in Sweden[6]. Laboratory exercises for courses in electrical engineering have been developed using a 'remotely controlled switch matrix with five nodes, ten branches, and 40 components, two function generators, a digital multi-meter, and an oscilloscope.' The matrix switch essentially acts like a breadboard allowing students to connect electrical components and jumpers in various circuit configurations. The matrix switch is configured using PSpice netlists, which specify electrical sources, components, positions, values, and various options.

The remote laboratory configuration is comprised of a National Instruments (NI) PXI-1000B 8-slot #U PXI "chassis containing a controller (PXI-8176) and four plug-in boards." The controller is essentially a server system running LabVIEW 6.1 (Laboratory Virtual Instrument Engineering Workbench), which is connected to the Internet on one side and the additional plug-in boards on the other. The other plug-in boards are "two function generators (PXI-5411 and PXI-5401), an oscilloscope (PXI-5112) and a digital I/O board (PXI-6508)." The PXI chassis in interfaced to an Agilent 34970A Data Acquisition/Switch Unit via a General Purpose Instrument Bus (GPIB). The power supply is an HP E3631A.

To remotely access and operate the laboratory students download a library of pre-configured netlists from the laboratory server into their own copy of PSpice, make any necessary modifications to the list, and submit the settings back to the server. Representations of the actual instruments that they will be remotely controlling are graphically presented on their screens as virtual front panels. Once a user's configuration has been dequeued on the server a virtual instructor program verifies the submitted configuration to ensure that it will not harm the electronic instruments and sources. Then the appropriate components and probes are connected, the voltage is applied, and sampled signals are sent back to the virtual front panels on the student's computer.

The remote laboratory developed by BTH allows multiple users to simultaneously prepare and perform electrical circuit analysis. The asynchronous nature of the laboratory allows users to work from any location and at any time during the day. Also, the use of dynamic instrumentation technology enables BTH to maintain relatively low costs while serving many students. However, a lab supervisor or an instructor must change out the components and probes and update the netlist library when new exercises are developed.

Northern Alberta Institute of Technology (NAIT) and Athabasca University, Canada

Northern Alberta Institute of Technology and Athabasca University collaborated on the development of the Canadian Remote Sciences Laboratories[7] (CRSL), which is physically located within the NAIT Chemical Technology Department. The CRSL comprises an impressive collection of remotely controlled chemical analysis instrumentation including: Varian 3800 Gas Chromatograph, Perkin Elmer PE SCIEX API2000 Liquid Chromatograph, Bruker 400MHz Advance III High Performance Digital NMR Spectrometer, and Agilent/Varian 725-ES IEC Optical Emission Spectrometer.

The chemical analysis instruments are controlled via dedicated computer systems that are connected to a high-speed Local Area Network (LAN). The LAN is securely located behind a firewall that is accessed externally by an Internet Security Accelerator Server, which runs NetSupport PC-Duo terminal emulation software in order provide terminal access to the instrumentation computers. Students, in turn, obtain remote access to these computers via a web browser by entering the server's URL and proper access credentials.

The CRSL provides several additional features that aid the remote user in successfully interacting with the laboratory systems including: Webcams used to provide students visual feedback of their experiments; video streaming tutorials that instruct students on the use of the instruments and the experiments for which they have been prepared; qualifier exercises train the student on the minimum set of skills required to use the various instruments; scheduler application that allows students and instructors to secure dedicated blocks of time for conducting experiments; and databases and eLogbooks to store captured data for analysis and enter comments pertinent to the user's experience, respectively.

In order to determine the perceived value of the remote laboratory experience CRSL asked a group of 34 students from an analytical chemistry course to complete pertinent surveys after conducting the three experiments on the following three topics: Chromatography, Fourier Transform Infrared Spectroscopy Methods, and Detector Selectivity and Solid Phase Extraction. Students were asked to rate (1 = unacceptable, 5 = high quality) three categories of metrics related to visual tutorials watched prior to the experiments and two categories of metrics related to ease of use of the remote instrument and the remote access experience. The results of the surveys are as follows:

Metric	Chromatography	FT-IR Spectroscopy	Detector/Solid Phase
Size, Clarity, and Sound of Video	4.3	4.7	4.0
Understanding of Video	4.0	4.1	4.5
Length of Video	3.6	3.7	4.0
Ease of Use of Instrument Remotely versus Onsite	Data Not Supplied	2.8	3.3
Remote Access Experience	Data Not Supplied	2.8	3.2

CRSL summarized their findings of the experiments and data gleaned from the subsequent surveys in the following list of observations:

"Seeing is believing – using a camera to see the experiment is important to the student."

“It is important to match the experiment and student for the appropriate level of experimental and remote environment complexity.

“Students like the additional access and flexibility of the experiments. Faculty like making better use of existing instrumentation by employing them during non-business hours.

“Students reported great desire for in person instructor contact.

“Problems can be a good thing. Unexpected technical and experimental results in small quantities can lead to valuable learning opportunities.”

University of Technology, Sydney (UTS), Australia

The University of Technology, Sydney (UTS) has developed several remote laboratories to be used in engineering education curricula[8]. During the autumn and spring semesters of 2006 three surveys were conducted to determine whether or not the laboratories were “adequate for student learning.” The surveys were based on two particular laboratories: PLC-based pneumatic control and monitoring system, and a water level laboratory. Both remote labs are used by mechatronic and mechanical engineering students in the following courses: Advanced Manufacturing, Dynamics and Control, and Mechatronics 2.

The physical configuration of the PLC laboratory is comprised of “two electro-pneumatic cylinders, two valves, one Allen-Bradley PLC (MicroLogix 1200) and NetENI Ethernet module,” and two reed sensors, which are used to measure the piston position in each cylinder. A camera and microphone, which are connected to a server, are used to record the piston movement and sound. Also, a webcam and microphone are used to monitor the entire PLC rig. Ladder logic diagrams are developed by remote users using the RSLogix programming environment; these diagrams are downloaded into the PLC as instructions for operating the pistons. Streaming video from the camera provides the remote user “with visual feedback on the effectiveness of their programming.”

The physical configuration of the water level laboratory uses a Kent Ridge Instruments coupled tank apparatus, which is comprised of two adjacent tanks connected via a small opening in the adjoining lower portion of the tanks, two pumps and level sensors, and an outflow reservoir. Water is pumped into the first tank, flows into the second tank, and exits into the reservoir. The input connections of a LabJack data acquisition board are connected to the analog outputs of the level sensors and pumps. Also, two cameras and a microphone provide audio-visual feedback to the remote user via the Remote Laboratory webpage, which also provides the user interface for controlling the experiment.

During the post-laboratory surveys students were asked to provide ratings for a list of 14 questions, where “1 = very poor/strongly disagree” and “10 = very good/strongly agree.” The questions were typically targeted at determining the remote user’s experience. A few examples are: “How do you rate the overall performance of the remote PLC lab?” “Is it easy to use the user interface?” and “Did you find it easy to open and view the live video feed?” The overall average for all 14 of the questions was around a 7. One particularly interesting results (around a 6), which was the second lowest score, can from the question “Didn’t you feel a degree of isolation between the physical system and you?” The authors of the survey and associated paper conclude that “Students appreciate more than just the flexibility of access – their appreciation is more than just convenience. They see that the remote access mode transforms the learning experience, offering options (e.g. increased time, ease of recordkeeping) that are not available in a traditional hands-on laboratory.”

East Carolina University

Faculty members at Eastern Carolina University, located in Greenville, North Carolina, have devised an interesting approach to offering a remote laboratory experience to their students: They create a virtual laboratory environment consisting of virtual machines, which communicate with one another over a virtual network. The virtual laboratory environments are then distributed to their students, who, in turn, run them “remotely” on their own computers at home. The particular environment reviewed is a virtual network security laboratory used to teach the operation of an intrusion detection system (IDS) wherein the instructor pre-configured the requisite virtual machines and network trace files[9].

By having the virtual laboratory environment hosted in the non-virtual operation system on the student’s personal computer the student can read the lab manual provided by the instructor and manipulate the applications and files on the virtual machines all from separate windows running on the same monitor screen. In the case of the IDS laboratory one virtual machine is running the IDS application in a Linux operating system, while the other virtual machine is running a separate operating system. The latter virtual machine is then used by the student to “attack” the IDS-enabled machine in order to learn about the behavior and configuration of such security systems.

Surveys regarding the effectiveness of the virtual laboratories were conducted “before the end of fall semesters in 2006 and 2007.” Of the 24 students who completed the survey in both 2006 and 2007 86% responded positively “that the hands-on exercises in the virtual lab were as effective as the ones in a physical computer lab.” Some of the cited advantages of using the virtual laboratory environments were: rapid changes could be made to the environments; the use of virtualization is very cost effective for the academic institution; network access to a centralized network lab is not required, and the virtual environments can run securely on the host computer. A few of the disadvantaged cited were: student’s personal computers may possess insufficient resources (memory, processor speed, hard drive capacity) to efficient run the virtual laboratory; and “remote” users of the virtual laboratory environments would not have access to physical systems.

Conclusion

The ever increasing demand for distance learning-based courses must be accompanied by viable remote laboratory solutions for courses in those disciplines where a “hands-on” aspect of learning is required. In this survey we reviewed several such solutions and addressed many of the advantages and disadvantages peculiar to specific solutions. Although a variety of solutions exist, including the option of not offering a remote laboratory, several are based around the use of the Internet as a means by which remote connectivity and control are used to manipulate physical laboratory exercises. Other solutions involve the formation of partnerships wherein institutions with similar, or exact, program curricula offer the use of remote resources (facilities, faculty, and equipment) in order to fulfill the requirements of laboratory exercises. Yet another solution involves the distribution of virtualized laboratory environments to students, who operate the labs “remotely.”

Generally the use of remote laboratories offers several positive dividends to all stakeholders (students, staff, faculty, and institution) of distance learning. Remote laboratories offer students greater flexibility in terms of schedule and location; they provide institutions with a potential cost effective means of offering complex laboratory exercises to a global enrollment of students; they provide instructors and staff with a potential semi-automated, if not automated, means by which laboratories can be managed; and finally remote laboratories appear to provide a sufficient learning outcome regarding the laboratory component of many distance learning courses.

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