

Enhancement of Freshman Engineering Laboratory through Remote Web-based Experiments

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Introduction - Three remote web-based engineering laboratories were developed and implemented on a large scale - approximately 500 freshman engineering students participated. Before performing the remote labs, students become proficient in the use of a general purpose engineering workstation which includes a precision DMM, function generator, high-speed storage oscilloscope, frequency counter, multiplexer/switching unit, and a precision power supply all interfaced to a controlling computer via GPIB². A fundamental feature is that each engineering workstation be accessible and controllable over the internet using only a generic browser. This strategy has three important benefits. First, since the entire workstation is internet-accessible, an arbitrary number of new remote experiments can be designed just by creating new web pages and connecting the appropriate parts and components to each workstation. Second, students and remote viewers only need a generic browser and an internet connection to fully participate in the remote laboratories. Third, the experiments can be performed on any computer platform. As a result, the Freshman Engineering lab is transformed into an "Engineering Collaboratory" in which multiple remote users can access and perform a myriad of experiments on state-of-the-art engineering workstations.

The three remote labs explore different extremes of the kind of access to the workstation required by the remote user. In all cases, students had a prior 3 hour hands-on laboratory introducing the basic skills and new elements involved.^{1,2} In the first remote lab "Control of a Model Heating System", students explore how Joule heating effects the temperature of a heating element and how effective different control schemes are at achieving a target temperature. Performing the lab changes the properties (temperature) of the experimental apparatus, so each remote user needs exclusive access to the workstation for a finite period of time - one hour.

In the second remote lab, students explore the response characteristics of an operational amplifier circuit and try to identify a mystery element X placed in its feedback loop. Here multiple users can access the workstation at the same time since the data collection requires only a few seconds for each response curve. Multiple remote requests are processed on a first-in first-out basis enabling asynchronous experimentation. Students can do the remote lab whenever and wherever they want.

In the third web-based experiment remote users communicate with and monitor the ECG signals of volunteers in the engineering lab. Here, only one volunteer is at each workstation, but multiple remote users can monitor the same person and ask the volunteer to perform different tasks such as "Please do 10 push-ups." Because of demands placed on the volunteers, the remote users have to be grouped and assigned various time windows when they may perform the lab.

The Enabling Technology - Although the only software needed by a remote user is a web browser, an alternative approach would be to have each student purchase commercial software such as Timbuktu, which allows one computer to control others linked to it. The disadvantages are the high incremental costs and the exclusion of many potential users. We wanted our remote labs to serve as a collaboratory, open to all our students, their friends and family members (younger brother monitors his sister's ECG over the web) and interested external groups at schools and at other engineering colleges throughout the nation. This design specification led to the choice of a purely web-based access to the remote labs.

In addition to a web-server, an internet connection and the general purpose workstations, the enabling technology involves two products both available from National Instruments - LabVIEW and the Internet Developer's Toolkit hereafter referred to as IDT. LabVIEW is designed specifically to generate solutions to instrument control and data acquisition problems in a fraction of the time it would take to write your own instrument drivers using a development package such as Visual Basic.^{3,6} Even better, thousands of instrument drivers provided by the leading manufacturers can be downloaded free from National Instrument's website.⁶ The programs written in LabVIEW are called Virtual Instruments (VI's) and have front panels with dials, knobs and both numerical and graphical indicators just like a real instrument. Programming is performed in a graphical language called G in a process remarkably similar to wiring together electrical components on a breadboard.

The Internet Developer's Toolkit (IDT) is a recent addition to National Instrument's product line and is essentially a collection of tools for generating HTML pages that include information such as real-time data and capturing images of front panels from designated Virtual Instruments running in LabVIEW. Other tools in the toolkit "listen" for remote user requests, parse these for needed parameters and send them to the appropriate VI on the controlling computer. When the remote user commands have been executed and the requested data and images are ready, they are returned to the remote user via a custom webpage as illustrated in Figure 1 below.

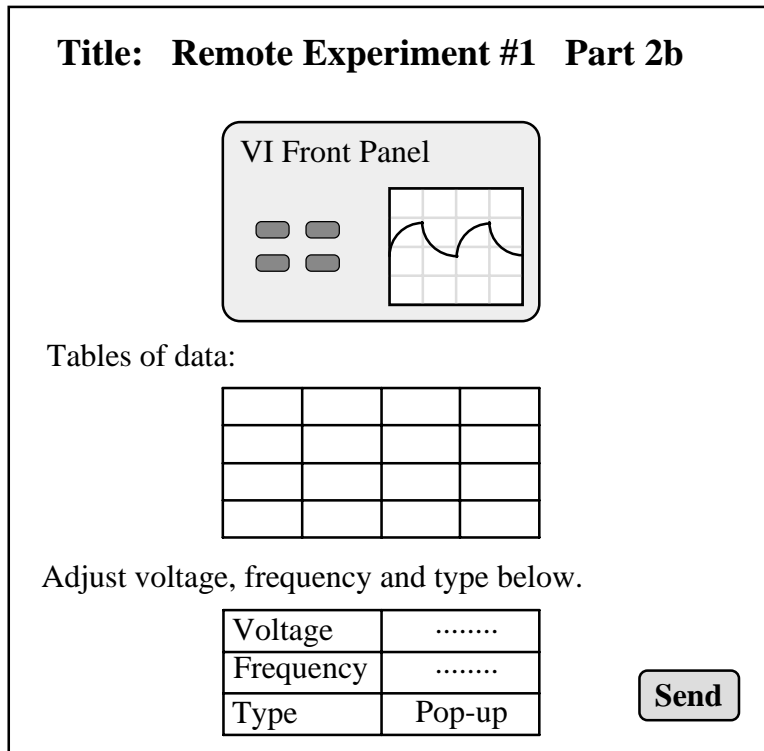


Figure 1 - An idealized web page for a remote lab.

Additional web material such as supporting text, graphics, sound and animations are readily incorporated as usual via HTML. Thus the remote user has almost as much control as a person in the laboratory. However, there is the usual time delay between request and arrival of the data well known to all internet surfers. In addition, the local user would not have to adjust parameters such as voltage and frequency via web-based forms but would more directly adjust the dials and knobs on the front panels of the running VIs.

Remote Lab 1 - Remote Model Heating System

In this remote lab, students design and test various control systems for a model heating system. The different control schemes are explored to see how effective they are in regulating the temperature of the model heating system. The temperature of the heating element (a ceramic resistor) is controlled by applying a voltage V across its leads using the workstation's power supply. This voltage is the control signal $c(t)$. The temperature of the heating element is measured using a thermocouple and the workstation's DMM as shown in figure 2 below.

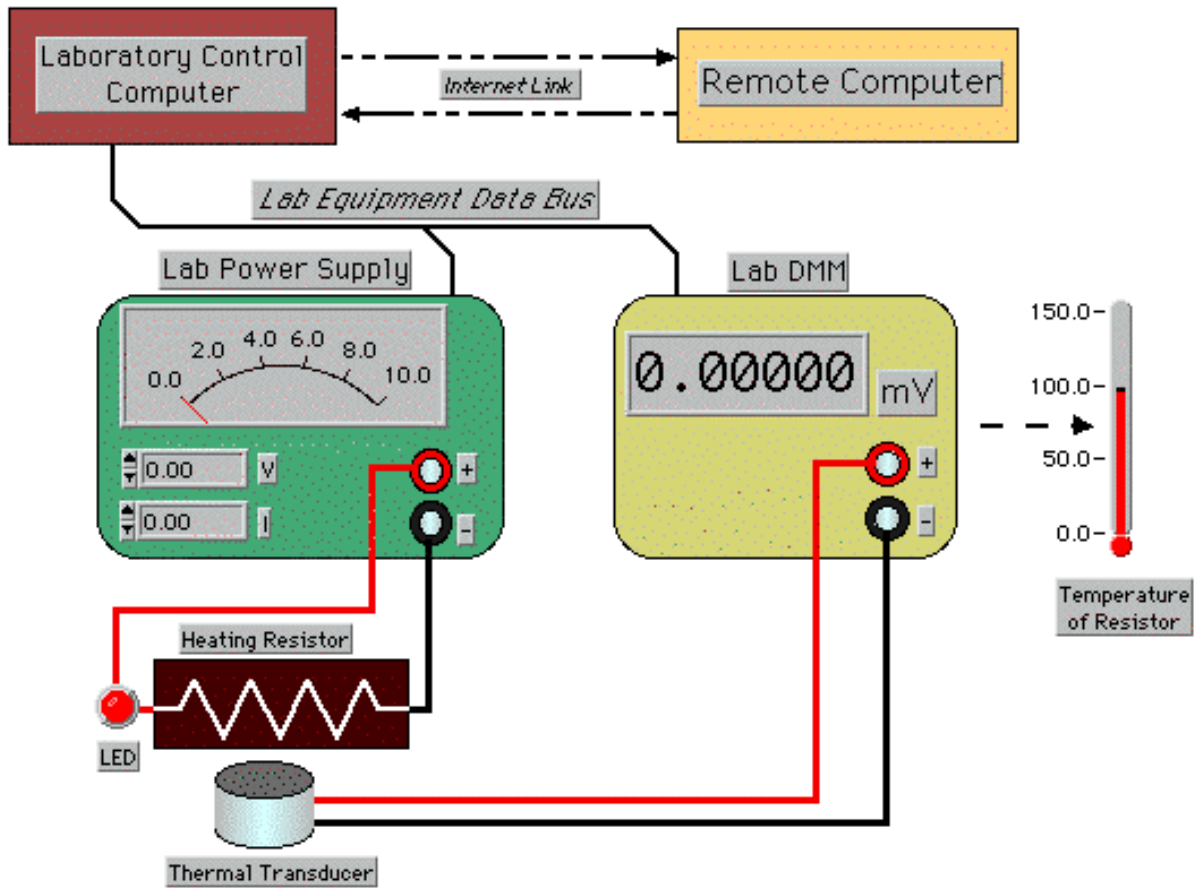


Figure 2 - Portion of web page for remote temperature control lab.

This is the most difficult of the remote labs to implement at full scale, since each of our 500+ freshmen must have exclusive access to the workstation while this experiment is in progress. (In this case the measuring process severely alters the state of the system for the next user.) Each student is assigned a fixed time and a particular workstation on which they must perform the remote lab. Access to a workstation and experimental setup is entirely web-based so that choosing a workstation is as simple as clicking on its link.

Remote Lab 2 - Remote Operational Amplifier Circuits

The operational amplifier is the most common analog integrated chip in electronic circuits today. It's wide range of applications includes inverting and non-inverting amplifiers, buffer amplifiers, integrators, differentiators, signal generators, Schmidt triggers and analog computers. In this web-based remote lab students progress from simple exercises designed to familiarize them with the basic concepts and progress to more advanced questions involving a mystery component X which they place in the feedback loop but cannot see.

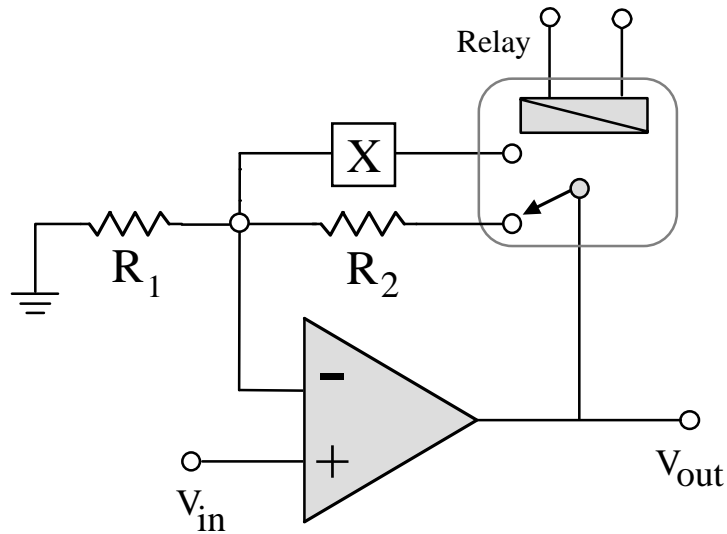


Figure 3 - Remote op-amp circuit.

The response curve below identifies the mystery element X as a resistor with the circuit acting like an inverting amplifier. The data clearly shows the linear region sandwiched between the regions of negative and positive saturation. The slope of the linear region reveals the value of the feedback resistor since R_1 is given.

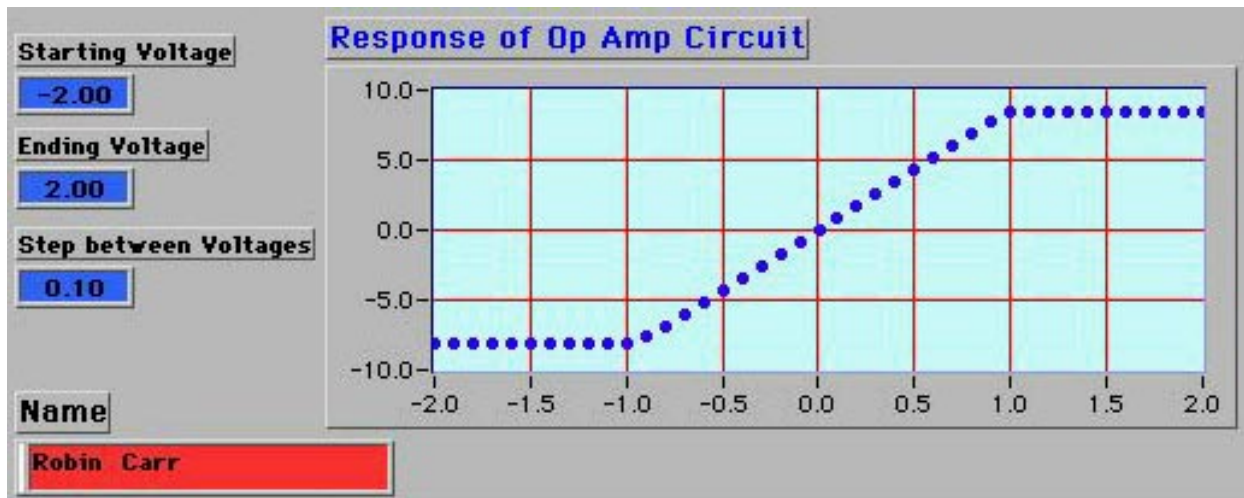


Figure 4 - Response curve typical when $X=R$, an inverting amplifier.

The mystery component X is remotely configured (at the remote user's request) into the op-amp circuit through the use of relays activated by the workstation's DC power supply. Practically anything can serve as the mystery element such as another resistor, a capacitor, an inductor, a diode or even something exotic like an oscilloscope, resulting in a rich environment for discovery-based learning.

The mystery element X is unknown but can be deduced from the nature of various response curves. The mystery component(s) should be different on each of the workstations. In this year's

offering student teams are challenged to identify as many mystery components as possible and to submit their supporting data with carefully reasoned arguments for each identification. In this lab remoteness is an actual advantage for educational purposes. Since the mystery elements cannot be seen – they truly are a mystery.

Multiple users can control and acquire data from multiple workstations at the same time. Each response curve takes only seconds to generate so dozens of students can “simultaneously” use the same workstation on a first-in/first-out basis. By varying the components on each workstation, and allowing the remote users to reconfigure the circuit through relays, a very large number of op-amp circuits can be explored.

While the remote lab was being offered, it was a fascinating and somewhat eerie experience to walk through the laboratory one evening with no one inside, while dozens of relays were clicking and chattering as new response curves were displayed on each of the controlling computers.

Remote Lab 3 - Web-based Electrocardiograms

In this remote experiment, students monitor the heartbeats of class volunteers and various synthetic signals over the internet. The synthetic cardiac signals were generated by an HP 33120A Arbitrary Waveform Generator. Because of the finite number of volunteers, and the very large number of students (+500) it was important to assign the remote users specified time windows. Thus this mode lies somewhere between the two previous extremes – completely asynchronous versus exclusive access for a fixed short interval.

Each of our courageous volunteers was attached to two Ag/AgCl monitoring electrodes. One electrode is near the ankle and the other is on the chest or shoulder – but many variations are possible.

Measuring the tiny potentials generated by the heart with desktop instrumentation requires a fair measure of signal conditioning. The tiny electrical potentials from the two electrodes were input into a quad op-amp chip, conditioned and amplified. The resulting signal was measured directly with a precision DMM, displayed in real-time on the controlling computer and then monitored over the internet by remote students. This year’s version has been upgraded by using an instrumentation amplifier with isolator, using the oscilloscope to acquire the ECG thus freeing up the DMM for use as a respiration monitor, simply constructed from a fast-response thermistor and a straw. Remote monitors can send messages to our volunteers such as “Please do 10 push-ups.” or “Please hold your breath.”

Conclusions - Remote labs intended for a relatively small number of students (<100) can and have been implemented using a variety of technologies for years. However, many of these smaller-scale solutions are not practical if you need to offer remote labs to a freshman class like ours which next year may exceed 700 students. Our remote labs serve several purposes. First they teach the students about remote monitoring and experimentation, a topic which has enhanced status with the explosive growth of the internet. Secondly, they offer the educational advantage of genuine discovery experiments as in the example where students must deduce the nature of a mystery component they cannot even see. Finally they can serve to reinforce concepts and activities from a previous (or future) hands-on real laboratory experiment. Interested readers may wish to also look at the remote labs developed by Jim Henry for a systems course.^{4,5}

Acknowledgments - This project of the Gateway Engineering Education Coalition (NSF Award EEC-9109794 and EEC-9727413), is supported by the Engineering Education and Centers Division of the National Science Foundation.

Many thanks go to our student assistants without who this work would not have been possible - Andrew Gregorowicz, Adam O'Donnell, Hala Jacob, Adam Mieziako and Edward Payne. Thanks to Dr. Steve Dubin (Drexel Biomed) and to Dr. Edward Gerber (Drexel ECE) for many useful tips on the remote ECG lab.

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4. Jim Henry, "Internet Laboratory Server in Engineering Systems Laboratory", Virtual Instrumentation in Education 1997 Conference Proceedings, MIT June 12 and University of California at Berkeley June 27
5. Jim Henry, "Web-based Controls Laboratory Hardware and Software", available via web at <http://chem.engr.utc.edu/Henry-Pub>
6. National Instruments offers many free instrument drivers and other educational products via its web site at <http://www.natinst.com>

Biographical Information

ROBIN CARR is currently Director of the Freshman Engineering Laboratories at Drexel University. His background is in mathematical and applied physics.

ANDREW GREGOROWICZ, our star LabVIEW expert, was a freshman engineering student at the time of this work and is an avid ice-hockey player.

ADAM O'DONNELL was a freshman engineering student at the time of this work and is an avid Bug enthusiast. Based on their entry "Engineering Laboratory On the Internet", Adam and Andy shared the first place in the 1997 Anderson Consulting Web Challenge.

ROBERT QUINN served as Director of the NSF sponsored E⁴ project, "An Enhanced Educational Experience for Engineers" which has since been recognized as a national model in engineering education. He was awarded the special "ASEE Centennial Medallion" commissioned and struck in 1993 to honor outstanding contributors to the engineering profession. In 1995 he received the Alumni Achievement Award in Engineering from the Catholic University of America and in 1997, the Boeing Outstanding Educator Award.