Real Time, Remote Circuits and Electronics
Laboratories for Distance Learning

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Abstract

Employing distance education techniques in teaching electrical engineering courses will continue to grow. One of the major obstacles in distance education is providing relevant, hands-on laboratories for students. This project is aimed at giving students real-time access to standard laboratory instrumentation and electronic circuits via the internet. Students manipulate real instruments such as oscilloscopes and function generators with mouse clicks, change circuit measurement points, modify circuit connections, and adjust component values. The oscilloscope waveforms and meter readings are measured by real instruments in a central laboratory and the resulting data are sent back to the student’s computer for display. The student can view a list of which experiments are currently available and select an experiment to run. The student activity is recorded for evaluation by the instructor.

Overview

The growing trend of distance education can severely limit a student’s access to real laboratory equipment. Remote laboratory experiments have been developed that allow students to gain access to real electronic instruments on a schedule that best suits their needs. The remote student can control and observe real electronic instruments, circuits and circuit elements in the same manner that a traditional, in-lab, student can. This is not a simulated laboratory experience.

Accurate, graphical representations of the specific electronic instruments used in the lab and a circuit schematic are shown on the remote PC monitor. The student can manipulate the knobs on each instrument and make measurements at various points on the schematic.

An example of a remote lab is an operational amplifier configured as Butterworth low pass filter. The student has complete control of the plus and minus power supplies and can verify the supply settings by connecting a digital multimeter to the power supply pins on the opamp. The frequency, offset and waveform of the input function generator can be controlled by the remote student. Channels 1 and 2 on the oscilloscope can be connected to any point on the circuit by the student using mouse clicks. The oscilloscope horizontal time base, the vertical volts/division, vertical position, trigger source and level, and the AC/DC/Gnd switches are all remotely controllable.
In each case the mouse clicks generated by the remote student are transmitted, via the internet, to the on-campus lab and change the settings of real laboratory equipment. The voltage levels and wave forms measured by the real instruments are sent back to and displayed on the remote student’s computer. In addition, the values of the circuit elements can be changed by employing GPIB controllable resistors, capacitors and inductors. The circuit configuration can also be modified via remotely actuated switches.

This system gives the remote student hands-on experience with real laboratory equipment on a 24 hours/day basis.

One virtual experiment that is already on the web is at Carnegie Mellon University (1). This experiment allows remote reading of signal levels, but does not allow the selection of measurement points and the system is slow. Hewlett Packard Bench Link Data Logger and National Instruments LabWindows/CVI allow control of instruments in a windows format. These systems require significant setup by the user.

**Student Access**

Students can access the remote laboratories from their dorm rooms, local community colleges or from their homes. A web browser can be used to obtain an account and password on the system, and to download the needed software. The programs were written using Borland C++ Builder with a built-in TCP/IP interface so a web browser is not used when doing the labs. A PC with a pentium and 28.8 Kilo Baud modem is sufficient to get good data throughput.

Information on accessing the remote labs is available at http://www.stcloudstate.edu/~tawele

**Experiments**

This portion of the overall project is aimed at the circuits and analog electronics laboratories. Several remote experiments have been developed or are under development.

1. Operation of Power Supplies and Digital Multimeters.
2. Introduction to Kirchhoff’s Current and Voltage Laws for DC Circuits
3. Thevenin and Norton equivalent circuits
4. Operation of Oscilloscopes and Function Generators
5. Simple Operational Amplifier Circuits
6. Low and High Pass Filters Using Resistors and Capacitors
7. Resonant Circuits
8. Bipolar Transistor Operation
9. Simple Transistor Amplifiers
10. Multistage Transistor Amplifiers
11. Butterworth Bandpass Filters with Adjustable Cutoff
12. FET Amplifiers

A complete schedule of experiments will be listed on the project web site. Two to three of these experiments will be available for access at any one time, and the students will be able to select which experiment they wish to work on during the logon process. Upon selection of a specific experiment pictures of the instruments used in the experiment and a circuit diagram are displayed on the student’s computer monitor. The windows may need to be resized but there is no software setup or file selection required of the student.

The knobs and buttons on all the instruments can be effectively turned and pushed with the mouse. The resulting voltage measurements or oscilloscope waveforms are returned to the student’s computer monitor for display on the appropriate instruments.

The student can select the desired measurements by clicking on channel 1 or 2 on the scope face and then on a circuit node. The DMM can also be connected to the circuit in a similar manner.

Instruments

At St. Cloud State University the Analog Electronics Laboratory has 10 work stations with an array of Tektronix instruments at each station. The Tektronix oscilloscope is stand alone and the other instruments are in a Tektronix TM 500 mainframe. Visual replicas of these specific instruments are displayed on the student’s computer monitor. The HPIB controllable instruments that make the actual measurements are made by Hewlett Packard. These instruments are described in more detail below.

Oscilloscope  The student sees a replica of a Tektronix 2445 150 MHz Oscilloscope. All of the functions normally used in an experiment can be manipulated by the student. Channel 1 volts/division, vertical position, channel on/off, and AC/DC/ground can be changed. The same controls can be set for channel 2. The time base is controllable using seconds/division, and trigger source, mode and trigger level. The channel waveforms can be combined using the add, invert, and chop/alternate controls. The waveform plots are displayed on an oscilloscope screen with a realistic grid and on-screen text. The actual instrument used in the central lab is a Hewlett Packard 54603B oscilloscope with an HPIB optional interface.

Function Generator  A Tektronix FG 503 Function Generator is visually displayed for the student. All of the front panel controls are accessible to the student including amplitude, frequency, frequency multiplier, sine/triangle/square waveform select, and voltage offset. The actual instrument is an HP 33120A 15 MHz Function/Arbitrary Waveform Generator. More powerful function generators could be displayed for the student since not all of the capabilities of the HP instrument are used.
Power Supply  The visual power supply is a Tektronix PS 503A, and the actual instrument is an HP E3631A Triple Output DC Power Supply. Again all of the functions of the Tektronix instrument are controllable.

Digital Multimeter  The visual instrument is a Tektronix 502A Autoranging DMM. The student can make RMS AC and DC voltage measurements over various ranges, but current measurements are disabled. Since the power supply and functions generators can be turned off or switched out of the circuit, resistance measurements can also be made. The actual laboratory instrument is an HP 34970A Data Acquisition/Switch Unit. In addition to the usual voltage, current and resistance measurements, this unit can measure frequency, period and peak voltage. In the future, a visual frequency counter could be implemented for the remote lab. This HP instrument also contains various plug-in switching units that are HPIB controllable. These features are described below.

Circuit  In addition to the electronic instruments, the student sees a schematic diagram with function generator and/or power supply connections. No oscilloscope or multimeter connections are shown since these are determined by the student. Using mouse clicks, channels 1 or 2 on the oscilloscope and the multimeter input port can be connected to various points on the circuit. Switches shown on the schematic can be opened or closed to disconnect parts of the circuit, short out circuit elements, or add amplifier stages. The values of certain resistors and capacitors in the circuit can also be changed. In this way the student can manipulate the circuit in much the same way as an in-lab student.

The actual circuits are constructed on a protoboard or wire wrap board and most of the circuit nodes are connected via short runs of coaxial cable to the Data Acquisition/Switch Unit. The actual schematic diagram that the student sees is created using Pspice and the image is captured to a bitmap for use in the remote lab software. The Pspice files could be used for computer simulation, but the remote labs do not use simulation.

The HP Data Acquisition/Switch Unit has internal slots for 3 switch modules. The switch modules that are used in the remote analog experiments are a 20 Channel Armature Multiplexer, a 4x8 Two Wire Matrix Switch, and a 20 Channel Actuator/General Purpose Switch. (Other modules are available for RF measurements and high density switching arrangements.)

The 4x8 Matrix Switch is hardwired, with coax, to both oscilloscope channels and to 8 different points on the circuit. The matrix relays open or close depending upon the measurement points selected by the student.

The DMM is internal to the Data Acquisition/Switch Unit and is connected to the circuit through 20 Channel Armature Multiplexer. Since 20 channels are available, the number of circuit nodes that can be monitored seem to be limited only by the mass of coaxial cable and the patience of the lab assistant that sets up the circuit.
The 20 Channel Actuator/General Purpose Switch can be used to short or open circuit elements or connect additional stages to the circuit.

**Data Exchange Format**

The data exchanged between the Client software (student) and the Server software (central lab setup) is done with packets of integers. This improves the instrument update rates as seen by the student. The bitmap images are downloaded only once thus eliminating the overhead needed to repeatedly transmit images.

**Enumeration Types and Switch Statements** Both the server and client software are written in C and C++. The general program logic employs several large enumeration types incorporated into switch statements in both the client and the server. For example, the enumeration type for the oscilloscope is

```c
enum scScopeInst {scNONE=0, scINIT, scERROR, scVOLTSPERDIV1, scVOLTSPERDIV2, scTIMEPERDIV, scAC1, scDC1, scGND1, scAC2, scDC2, scGND2, scADD, scINVERT, scCHOP, scALT, scON1, scOFF1, scON2, scOFF2, scTRIGGERMODE, scTRIGGERSOURCE, scTRIGGERLEVEL, scDISPLAYDATA};
```

All of these enumerated constants shown above are contained in one switch statement in the oscilloscope class. In the client software, each entry in the switch statement is associated with a specific knob or button on the virtual oscilloscope that the student sees. On the server side each entry in the switch statement calls a function that sends GPIB commands controlling the corresponding knob or button on the laboratory oscilloscope. Using this data format the program logic is relatively easy to follow on both the client and the server.

In C, the enumerated constants are alternately represented as integers. The integer values associated with commands can be rapidly transmitted, in packets, over the internet between client and server. Some commands, such as scAC2, which puts channel 2 in the AC mode, are stand alone. Others, such as scVOLTSPERDIV1, are followed by an additional integer that gives the desired numerical level.

**Future Enhancements**

Several enhancements are planned for this software package. While this system is on-line 24 hours/day, only one student can use it at a time. It would be desirable to have more than one set of laboratory instruments connected to each server via separate GPIB cards. It may also be possible to have two students accessing the same instruments on a time-multiplexed basis. Another possibility would be to have two students working together on the same experiment from different locations or have one student do the experiment and allow others to observe the virtual instruments without being able to control them.
A class with a large enrollment would probably need some sort of reservation/scheduling software that would restrict student to access during peak hours. The software could schedule students to specific time slots or allow students to choose times when the system is not busy.

**Acknowledgments**

I would like to thank Prof. Yi Zheng for his advise and assistance on this project. He is developing remote laboratories in digital electronics, communications systems and digital signal processing. He and I are the principal investigators on this project. I would also like to thank Ryan Carlson, Jeff Pollard and Jiong Tang, electrical engineering research assistants, for their invaluable assistance in programming, hardware development, and hardware and software testing over the life of the project. Finally, I would like to thank Minnesota State Colleges and Universities (MnSCU), the granting agency for this project.

**Bibliographic Information**


**Biographical Information**

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Prof. Heneghan received a BSEE and a Ph.D. from the University of Washington in 1966 and 1972 respectively and an MSEE from Seattle University in 1968. He was an assistant and associate professor at Portland State University from 1975 to 1986. He has been a professor at St. Cloud State University since 1986. He has served 3 terms as departmental chairperson while at St. Cloud State.