REMOTE LABORATORY EXPERIMENTS IN ELECTRICAL ENGINEERING EDUCATION

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Abstract — A remote or online laboratory is a laboratory where you can access experiments and instruments or other equipment from outside over the Internet. Laboratories for undergraduate education or vocational training in basic electrical engineering are easy to control remotely. You cannot see the electrical current with your eyes or hear it so there is no need for sound or video transmission. Computer-based instruments do not have any control buttons or displays on the front panel. They have virtual front panels on the host computer only and those panels can be moved to a remote computer screen. However, the manual forming of circuits and connecting of test probes cannot be transferred. These actions have to be performed in another way in a remote laboratory. Remotely controllable switch matrices must be used.

In the remote laboratory at BTH (Blekinge Institute of Technology) a client/server architecture is used. The student makes all the settings wanted on her client computer and then sends them to a lab server. The server makes measurements requested and returns the data obtained. The whole procedure takes only a second or two. A number of clients can access the experiments simultaneously. The laboratory is used in ordinary courses for on-campus students. They access the laboratory from a computer hall or from elsewhere outside the university. Due to the low number of bytes transferred a 56 kbit modem will do.

I. INTRODUCTION

There is no doubt that nothing will replace synchronous learning through face to face interaction but it is not always feasible for students to attend conventional classes. Models for using information technology to enhance learning experience for conventional on-campus students, as well as for students asynchronous in time or space have been presented [1]. The appearance of 'virtual universities' reflects new developments using the Internet and the World Wide Web [2]. The word 'virtual' stems from Latin. 'Virtual' in French can take on the meaning of 'theoretical' or 'potential', something that is not real but possible. In most virtual universities students still have to spend several days a year on campus for special events like oral examinations, seminars and laboratories [3]. During the last decades there has been a trend towards increased use of simulation in engineering

education. One reason is the fact that physical experiments are expensive both to implement and to maintain. Another obvious reason is a belief that simulators can replace physical experiments [4]. Nevertheless, real experiments laboratories are indispensable for the students to develop skills to deal with instrumentation and physical processes.

Remote laboratories deal with performing real experiments remotely over the Internet. This paper focuses on basic electrical experiments for undergraduate education as well as for vocational training. Not only the experiment itself is important but also the measurement procedure and the instrument handling.

In the remote laboratory at BTH (Blekinge Institute of Technology) computer-based instruments are used. Their virtual front panels are easy to move outside the laboratory and the instrument handling is the same if you are in the laboratory or outside. However, the manual handling of the components and the circuits cannot be moved outside the laboratory. The students need very much hands-on practice. At BTH the students get this experience in practical projects. They provide the framework for the acquisition of the right methodology to cope with real-world problems.

II. COMPUTER-BASED INSTRUMENTS

In the local laboratories for undergraduate education in electrical engineering at BTH the students use breadboards to form test circuits and to connect power sources and instruments. The instruments are ordinary box instruments with GPIB (General Purpose Instrument Bus). This bus is an old design. The GPIB bus was invented by Hewlett Packard at the end of the 1960's. The intention was to create a reliable bus system especially designed for connecting computers and instruments. This bus is still popular but its speed is sometimes not sufficient. Many box instruments have another disadvantage when you want to control them remotely from a PC running LabVIEW (Laboratory Virtual Instrument Engineering Workbench). In the LabVIEW drivers for those instruments only a subset of the functionality of the instrument is implemented. Thus for some settings you may have to use manual control buttons on the front panel of the instrument. However, new standards for instrument drivers are now being defined within the IVI Foundation (Inter-

changeable Virtual Instruments). The major instrument manufacturers formed this organization in August 1998.

Computer-based instruments are a category of instruments well suited to remote labs. They consist of a hardware board to be plugged into a host computer and a software driver. An oscilloscope board is shown in figure 1.

FIGURE 1
OSCILLOSCOPE BOARD

There are no control buttons or displays on their small front panels only connectors. They have virtual front panels on the host computer screen. A virtual oscilloscope panel is shown in figure 2.

FIGURE 2
VIRTUAL FRONT PANEL

You have to use the mouse or the keyboard to do the settings. As there are no physical control knobs, software drivers for computer-based instruments must support all functions in the specification.

To plug an instrument into a host computer, which usually is a PC, means that the instrument will be exposed to noise. A better way is to put it into a special low noise expansion box designed for instrument devices. There are different standards for computer-based instruments. One of them is PXI (PCI Extensions for Instrumentation). It was announced by National Instruments in August 1997 as an open specification. PXI instruments are plugged into a low noise box with a PCI bus in the back plane. This PCI bus can be connected to the PCI bus of the host PC via a special bridge device. Then the instruments in the box will become devices on the computer PCI bus. An example of such a box is shown in figure 3.

FIGURE 3
PXI BOX WITH SOME BASE INSTRUMENTS

The number of different instruments designed to support the PXI standard and the number of suppliers on the market is still limited. Today only base instruments for low frequency operation such as oscilloscopes up to a 100 MHz bandwidth are available.

III. ELECTRICAL CIRCUITS LAB EXERCISES

The traditional way of doing experimental exercises is to go to a university's laboratory. Within that lab the students normally work in teams with tutorial help from teachers. The feeling they obtain by being in the laboratory together with others will not be provided by simulations or remote access.

The term 'Virtual lab' can represent different things. Some virtual labs are software simulations of experimental setups and instruments. Others are remote labs equipped with experimental hardware. It is very expensive to implement simulations, which come close to reality and there will always be a gap between simulations and real experiments. New and better simulation software will be produced and so will new experimental procedures. Physical laws must be verified by real experiments. Simulations will not do. However, for the experienced student simulation is an excellent

tool to illustrate complex relationships, which can be formalized by mathematical rules.

There are different types of remote labs. Some are SCADA (Supervisory Control and Data Acquisition) applications and they have been around for many years and used by utility and manufacturing companies to control large processes. The goal of this type of remote operation is to put the user 'in the control room' with full and immediate access to all important system parameters. The test points are fixed and so are the settings of most of the sensors and instruments.

Remote laboratories for engineering education are a relatively new phenomenon. They do offer remote access to instruments and circuits and other equipment to use for experiments over the Internet. Controllable switch matrices are used to form the test circuits and to connect the power sources and the instruments. The equipment is connected to a computer and this computer is controlled from a remote computer via the Internet. The software system is usually based on the client/server paradigm. The computer in the remote laboratory could be called a lab server.

In most electrical experiments in undergraduate education there are no sensations you can perceive with your five senses. If, for example, a resistor in a circuit becomes hot the student has usually made a mistake. In these types of experiments instruments must be used to notice what is happening. You cannot see the electrons with your eyes. Electrical instruments are easy to control remotely and measurement data can be transferred over large distances. You need neither sound nor video transmission. Only a limited bandwidth is needed to transfer the settings and the results. An oscilloscope trace is only some kilobytes. A 56 kbit modem will do. The front panels can be downloaded to the client computer once and for all.

In electrical experiments in undergraduate education the time constants are often short. This means that when you form a circuit using switch matrices the switching transients will disappear almost immediately and the circuit will enter steady state. You get accurate readings when you connect the test probes. Thus it should be possible for the student to select test circuit and do all the settings wanted using the virtual front panel and then send this data to the lab server and also almost immediately get the outcome back. In this way it would be possible for a number of clients to use a lab server simultaneously on a first in first out basis without significant increase of the response time. For a dual channel oscilloscope this means that you get two single shot traces as is shown in figure 4. To get another pair of single shot traces you have to make another request to the server.

IV. REMOTE LAB AT BTH

In the remote laboratory setup by the Department of Telecommunications and Signal Processing at BTH computer-based PXI instruments are used. Their virtual front panels appear on the remote client PC and for the student there is no

difference if she makes the settings on the remote PC screen or on a PC close to experimental setup. Thus, considering the instruments only, there is no difference whether the student is in the laboratory or at home using her own PC to show the virtual front panels of the instruments. However, one significant difference compared to conventional experiments is the lack of manual handling of the circuits and test probes. In a way this could be an advantage. The student may spend four hours in a conventional laboratory and sometimes use a significant part of that time to troubleshoot connecting failures due to a breadboard earlier misused. However, students need hands-on experience. At BTH we have found that practical project courses offer better possibilities for the students to get practical experience of electrical circuits. In such courses better tools for circuit assembly are available.

Today we use switch matrices designed for low frequency applications only. To be able to switch over RF signals high frequency relays are needed. To incorporate the switch matrices in the experimental setup some additional cabling is necessary and care is required not to get EMC problems. The signal integrity is acceptable as shown in figure 4. The time scale in the figure is 10 μ s/div.

FIGURE 4

FUNCTION GENERATOR PULSES DISPLAYED ON THE OSCILLOSCOPE

How does the student know that the experiments are not a fake? The answer is she does not. It could be an advanced simulation. If the student are standing close to the experimental setup in the laboratory but do not touch it she will still not know if the experiment as it appear on a client PC screen nearby is a simulation or not. However the student may hear the clatter from the relays in the switch matrix units when a remote client for example move test probes. May be it would be appropriate to implement sound transmission to let the student hear the relays. Experienced people

realize that such advanced simulation programs do not yet exist.

FIGURE 5
ELECTRICAL EXPERIMENTS – LAB OPTIONS

FIGURE 6
OSCILLOSCOPE

The student makes the settings wanted and then she has two choices. If she presses the 'Single' button in the upper right corner of figure 6 the number of the experiment wanted and the settings selected are sent to the lab server. A second or two later the measurement data obtained is returned from the server. On the other hand, if the student presses the 'Start' button her request is automatically repeated and then the oscilloscope display is updated a number of times per second as on an ordinary oscilloscope. If this mode of operation is selected the response time for other clients will increase. Currently there is a time limit set for this continuous mode. You can only use it for one minute at a time.

Several advanced software solutions for performing laboratory experiments over the Internet are described earlier [5]. At BTH the software system is based on a client/server architecture, where the clients communicate with the lab server using Microsoft Internet Explorer 5.5 or higher. A HTML page containing ActiveX controls is downloaded. Then only control information is sent to the Lab server and the server returns measurement data. The server programs are written in LabVIEW 6i and for the clients Visual Basic 6 with Component Works has been used.

One example from our remote lab is a collection of electrical experiments used in a circuit theory course. In figure 5 the lab options are shown.

The student can do five different experiments. Two sources a DC power supply and a function generator and two indicating instruments a digital multimeter and an oscilloscope are provided. In the AC test of Kirchhoff's voltage law in figure 5 three test points can be selected. The oscilloscope is shown in figure 6.

The virtual front panel in figure 6 looks a bit different from that in figure 2. The oscilloscope panel in figure 2 is from an older client [6]. Then we tried to make the panel look like the front panel of the box oscilloscope 54600B from Agilent. This is the oscilloscope the students will use later in the project courses. The idea was to make it easier for the students to swap from the virtual instrument to the box instrument. May be it is better to use a more general layout. In fact, some new box oscilloscopes have not only control knobs on the front but also a standard keyboard and a mouse and a Microsoft Windows interface with pull down menus on the display.

V. CONCLUSIONS

In this paper the author has discussed remote laboratories for electrical experiments in undergraduate education in general and the ideas implemented in the remote laboratory at BTH. For basic experiments there is no need to use video or sound transmission. You cannot perceive the electrical current with you five senses. Only a limited bandwidth is needed to transfer experiment selection and instrument settings to the server and measurement data back to the client. A 56 kbit modem connection will do.

For basic electric experiments with short time constants several clients can use the same experimental setup. The response time will be low if computer-based instruments are used. In continuous mode the oscilloscope display on the remote client will perform as the display of an ordinary box oscilloscope.

There are no distance courses in circuit theory at BTH to use to test the experiments. Tests have been made by on-campus students at BTH as well as at the Technical University in Luleå using the lab server at BTH in Ronneby. The distance between the two universities is more than 1000 km. The students in Luleå were sitting in a computer hall with tutorial help from a teacher. Today many students are doing

the experiments at home. They appreciate the possibility to do the experiments when they want and to be able to repeat them as many times as they want.

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