

# A Web-based Remote Laboratory for Performing Experiments in Basic Electrical Engineering Courses

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**Abstract** — This paper describes the development and testing of a web-based remote laboratory for performing experiments in basic electrical engineering courses. The prototype experiments are from a variety of courses including circuit analysis, logic design, analog electronics, digital electronics, and industrial control. In addition to observing the waveforms and reading the measured voltage and current values, the remote user can also change certain parameters of the experiment such as signal frequency, amplitude, gain, and digital inputs. A digital camera in the laboratory provides the remote user updated video images of the experimental setup. Audio instructions about the selected experiment are also provided. Some test results are described and limitations of the presented laboratory setup are discussed.

**Index Terms** — Distance education, e-learning, remote laboratory, on-line laboratory, web-based laboratory.

## I. INTRODUCTION

One of the most important factors in widening the scope of web-based e-Learning for engineering disciplines is the development of remote laboratories that can provide practical experience and enhance experimental skills of engineering students nearly similar to that gained by performing the experiments in real laboratories. In some engineering disciplines, such as control systems and electronics, reasonable progress has been made towards achieving this goal. A number of remote as well as software-based virtual laboratories have been reported for performing selected experiments in control [1-6] and electronics [7-10]. Such laboratories have also been developed in other engineering disciplines [11-17].

As compared to software-based virtual laboratories, remote laboratories provide a more realistic learning experience. This is particularly true in the case of tele-operated laboratories; remote laboratories that allow the remote user to conduct the experiments in a real laboratory by controlling certain parameters of the experiment using a web browser. Also, development and upgrading of software-based virtual laboratories with realistic 3-D graphics is expensive and time consuming. In contrast, availability of graphical programming packages such as LabVIEW coupled with advances in network technology has made the development of tele-operated laboratories a relatively easier task. Such laboratories have also been developed

using a Java-based environment [1,18]. A combination of LabVIEW for data acquisition and control in the physical laboratory and Java Applets in the client machine has also been utilized for remote laboratory [13].

This paper describes the development and testing of a remote laboratory for performing experiments in basic electrical engineering courses. The reason for selecting basic courses for prototype experiments was that there are usually large numbers of students attending these courses and sometimes they might have to perform the experiments in real laboratories in larger group sizes. In such situations it is quite helpful to enhance their practical knowledge by complimenting their group learning experience in real laboratories with individual learning through remote laboratories.

The laboratory setup described in this paper comprises of a PC equipped with a multifunction data acquisition (DAQ) card interfaced to the experiment breadboard or PCB. It utilizes LabVIEW package in the server PC, present in the physical laboratory, for developing the experiments and related software. On the client side, the LabVIEW Runtime Engine is installed. Besides providing audio instructions concerning the experiment, updated video images of the experimental setup are transmitted to the remote user by utilizing a digital camera in the laboratory.

A number of prototype experiments from basic electrical engineering courses were developed to test the operation of the tele-operated laboratory. The remote user can monitor these experiments on his/her PC screen, take readings of measured voltage and current values and observe experimental waveforms. In addition, he/she can remotely control certain parameters of the experiments. The audio and video features included in the experiments provide a feeling of observing the experimental setup from a distant location. Some test results for selected experiments are reported in the paper.

## II. SYSTEM CONFIGURATION

A block diagram representation of the developed system is shown in Fig. 1. It comprises of a PC equipped with a generic multifunction data acquisition (DAQ) card and associated electronic and digital circuits

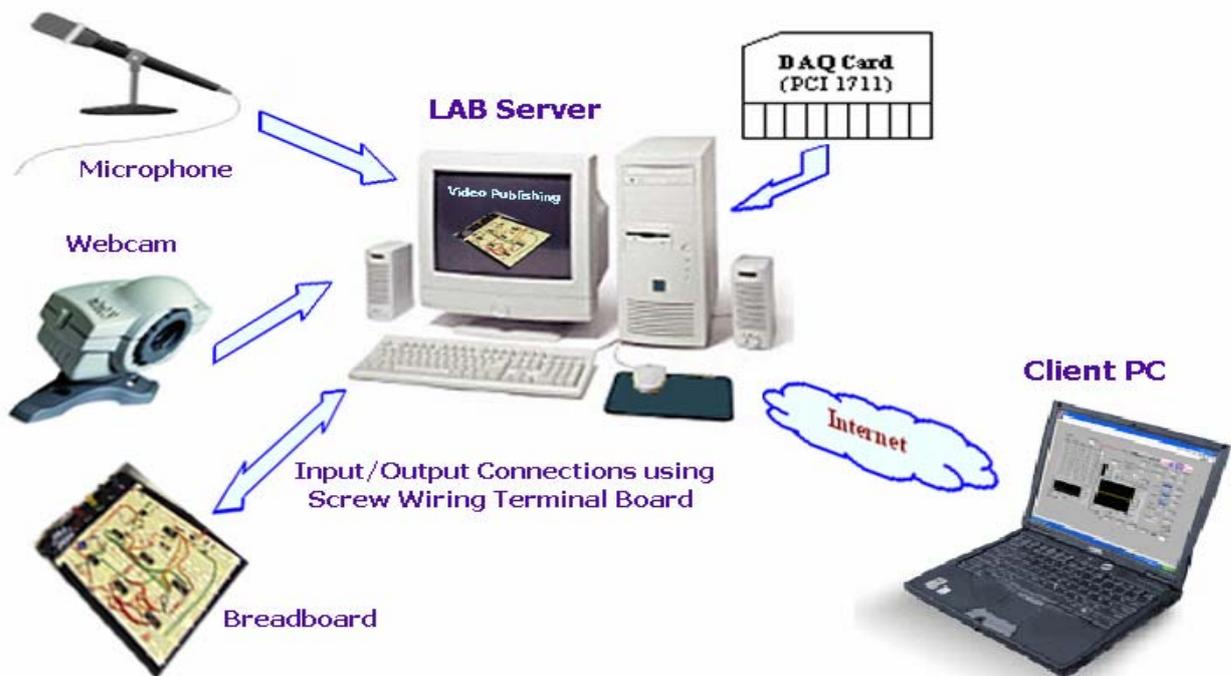


Fig. 1. Block diagram representation of remote laboratory.

constructed on breadboards and PCBs. The PC is configured as a Server. The DAQ card has 16 single-ended analog inputs, two 12-bit analog output channels, 16 digital inputs and 16 digital outputs, a 12-bit A/D converter, with up to 100 kHz sampling rate, and a programmable counter. The digital camera takes video image of the experiment being performed and recorded audio instructions about the experiment and its procedure are provided to guide the student.

To facilitate the interfacing of experiment breadboard or PCB, a 68-pin screw wiring terminal board along with a cable with high resistance to noise was utilized, as shown in Fig. 2 that depicts the actual setup in the laboratory.

The software for data-acquisition, remote monitoring, and controlling certain parameters of the experiments was developed using LabVIEW 7 Express together with the drivers provided for the generic DAQ card. For the remote user the only required software for performing the experiments is LabVIEW Runtime Engine that can be downloaded from National Instruments website [19].

Real-time video transmission and recorded audio play back are two other features of this setup. These features provide the user with a feeling of real-time observation of the experiment. Video transmission was implemented using Webcam Publisher 2.0 Beta. The software acquires an image of the setup every one second and transmits the new image through Internet link. Both video and sound were added to the remote display using HTML codes. The recorded sounds are stored on server

PC and are linked to the experiment by HTML code. Remote user has an audio control bar on remote display that allows him to replay, forward, pause and stop the audio file.

Real-time remote monitoring and control is accomplished by using the web-publishing tool provided by LabVIEW, which allows creating, converting and storing hyper-linked documents on Internet or Intranet web servers so they can be easily shared via web browsers. To gain access to a published VI, the IP address of the server and the name of the published VI should be known by the remote user. It should be noted that the VI to be observed and controlled from a remote location must be running at the server, throughout. Once the server closes the VI, the remote control is immediately terminated. The remote user can control the operation only after requesting and receiving acceptance from the server to transfer control. However, even after transferring control to the client, the server can limit the operations performed by the remote user and re-gain full control at any time.

The laboratory setup also allows saving of selected data values in an Excel file and transmit the file to specified multiple users as an email attachment. This is done using an Email VI. Using this option, the laboratory instructor can save the data values measured from an experiment in an Excel file and transmit it to students at remote locations. These readings could be used by the students to verify the correctness of their own readings for the same experiment.



Fig. 2. Laboratory Setup.

### III. TELE-OPERATED EXPERIMENTS

Experiments were developed for a variety of basic courses in electrical engineering including circuit analysis, analog electronics, digital electronics, logic design, and industrial control. All experiments were performed by remote users from different locations. However, only one user could perform the experiment at a time. A description of some of these experiments along with the test results is presented in the following.

#### A. Experiment No. 1

This experiment from the circuit analysis course is about verification of Kirchoff's Voltage Law (KVL). The circuit constructed on a breadboard in the laboratory has three resistors connected in series with a voltage supply. In order to allow the remote user to vary the supply voltage, one of the analog output channels of the DAQ card is used to provide the supply voltage. The voltages across the three resistors are measured and all the measured voltages are transmitted and displayed on the remote user PC screen as shown in Fig. 3. The remote user can change the value of voltage source and verify that the sum of new voltage values across the three resistors equals the new value of supply voltage.

Prior to starting the experiment, the remote user can listen to the instructions for performing this experiment. A video image of the experimental setup appears on the top of the screen and a "knob" as shown in Fig. 3 allows the user to adjust the value of the supply voltage. A circuit diagram of the experiment with the values of three resistors also appears on the screen so that the student can theoretically calculate the voltage drops across three resistors for the selected value of supply voltage and compare the theoretical results with the experimentally measured values. In this way the student can perform most of the functions as in a real laboratory.

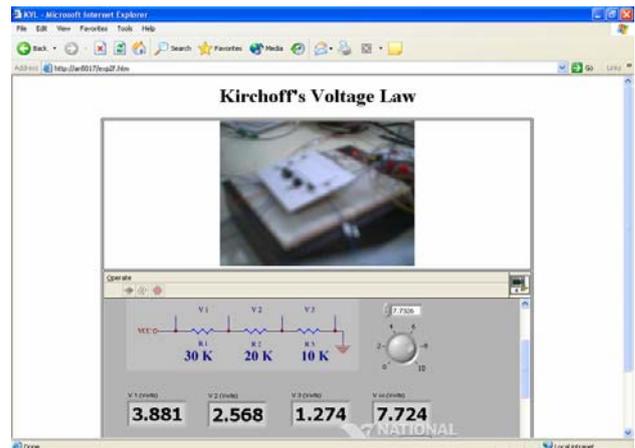


Fig. 3. KVL experiment on remote PC screen.

#### B. Experiment No. 2

Another experiment from the circuit analysis course is presented here. It is about charging and discharging of capacitor in an RC circuit. The circuit diagram of the circuit constructed in the laboratory appears on the remote user screen as shown in Fig. 4. The applied input square waveform and the voltage waveform across the capacitor also appear on the remote screen. The remote user can change the frequency of the applied voltage waveform and observe its effect on the output waveform.

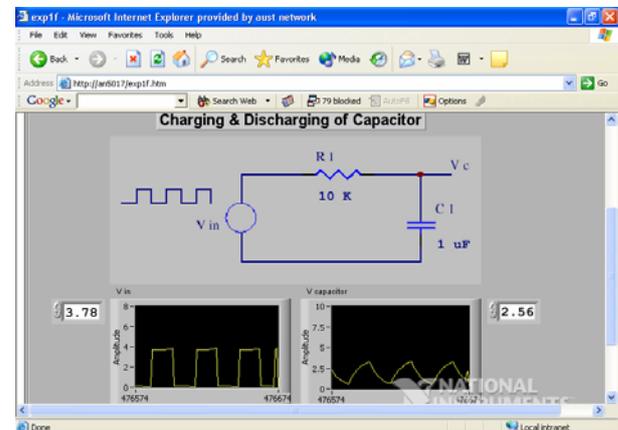


Fig. 4. Charging and discharging of capacitor.

#### C. Experiment No. 3

For this experiment, selected from analog electronics course, a non-inverting amplifier was constructed in the laboratory using an op-amp. The feedback resistor, shown as a variable resistor in Fig. 5, is in fact a digital potentiometer IC (DS1267) so as to allow the remote user to vary the gain of the amplifier. Depending upon the gain selected by the user, a digital code is sent through the DAQ card to the digital potentiometer to vary its resistance to the desired value. For the remote

screen shown in Fig. 5, the remote user was given the option to select either a gain of 2 or 4 by clicking on the "selector switch". The output waveform shown is for a gain of 4 selected by the remote user.

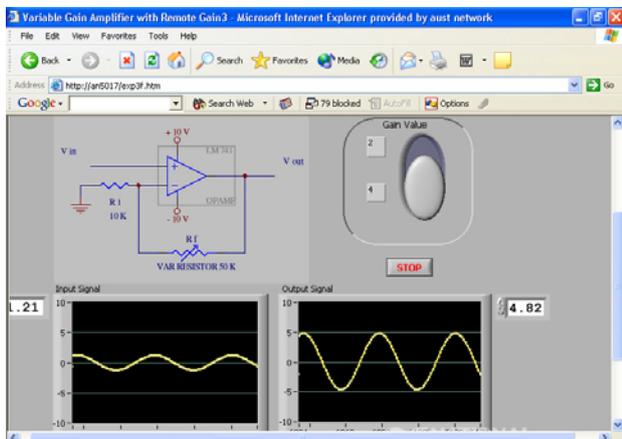


Fig. 5. Adjustable gain amplifier using an op-amp

#### D. Experiment No. 4

A set of experiments from the logic design course was developed and all the experiments were operated from remote stations. Most of these experiments were simple combinational circuits while two experiments were developed using flip flops. The inputs to these logic circuits were provided through the digital output channels of the DAQ card in accordance with their digital values specified by the remote user. The outputs of these logic circuits were connected to the digital input channels of the DAQ card. Their values were transmitted and displayed on the remote user screen.

#### E. Experiment No. 5

This experiment is about remotely controlling a stepper motor that drives a small conveyor belt. The remote user can specify the number of steps as well as the direction of the movement. The physical setup for this experiment is given in Fig. 6 that also shows the digital camera used for capturing the video images of the experimental setup. The video image is transmitted to the remote user and displayed on the PC screen.



Fig. 6. A picture of the stepper motor control system.

## IV. DISCUSSION OF RESULTS

All the prototype experiments developed for testing the remote laboratory setup were performed successfully by the remote users. However, some limitations were observed with respect to system hardware, certain parameters of the experiments, execution time of the programs developed using LabVIEW, and the speed of the Internet connection.

The DAQ card used in the laboratory setup is a low-cost generic card with maximum sampling rate of 100 KHz. This would define an upper limit on the resolution of the waveforms observed on the PC screen. However, this limit on sampling rate was never reached for any of the reported experiments as the program execution time needed between two successive samples was much higher than that allowed by the highest possible sampling rate of 100 KHz. In other words, the limiting factor was the execution time of the program and not the hardware of the DAQ card. The resulting slow sampling rate demanded the frequency of signals used in the experiments be limited to a few hundred Hertz. For all the prototype experiments tested and reported in this paper the signal frequency was less than 400 Hz.

The limitation on signal bandwidth for the presented remote laboratory means that this setup, in its present form, is appropriate for experiments in basic electrical engineering courses that do not require high frequency signals. For experiments dealing with high frequency signals, both high-speed computers and efficient programming are essential.

The delay due to transmission of data to the remote location resulted in some phase shift of waveforms displayed on the remote user screen. However, this phase shift was quite small for low frequencies used in the experiments. Also, the resolution of video image seen on the remote screen was not very high, mainly due to the resolution of the digital camera used in the laboratory.

It is important to emphasize here that the presented remote laboratory was developed specifically for performing basic experiments in electrical engineering curriculum. For a remote laboratory dealing with high-frequency or high-speed experiments, high-speed networks of the gigabit class are needed as has been reported in [2].

## V. CONCLUSION

A remote tele-operated laboratory was setup for performing basic electrical engineering experiments over the Internet. A number of prototype experiments from a variety of basic courses were developed and successfully performed by the remote users. The audio and video features included in the experiments were quite helpful in providing a feeling of performing the

experiments in real-time. It was concluded that the presented low-cost laboratory setup is suitable for remotely performing experiments that either utilize only DC voltages or may include AC voltage signals of frequencies less than few hundred Hertz, as is the case for a number of basic experiments in electrical engineering.

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