

# Web-Based Remote Experimentation

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From the angle of computer based education, the Internet extends the power of personal computers (PC) from being a standalone machine to one that is connected to the world with uncountable resources. Applications such as library access, information search, educational material download, on-line tutorials and even examinations can now be routinely carried out by a low cost PC with Internet connection at any time from practically everywhere.

Most applications are however software oriented and do not involve experimentation through remote access to physical hardware or equipment. While it is natural and easier for more flexible software to establish links and communicate with each other, these setups do provide a good learning experience in many situations. However, as pointed out by Antsaklis et al (1999), it is commonly recognized that effective and complete learning, especially in engineering and science, requires a mixture of theoretical and practical sessions. In particular, to appreciate and use theoretical knowledge to solve real world problems, practical exercises are indispensable.

From the angle of evolution, once problems involving software and communications protocols and standards have been established, the next stage of Internet development may see more applications where hardware can be controlled or accessed, enabling us to have a better working, living and learning environment.

This article gives an overview of the design and use of Internet remote experimentation for the purpose of education. Following a brief survey of some related systems and their design philosophies, the architecture for a typical Web-based laboratory will be presented. The important software and hardware components and subsystems that are needed to develop a user-friendly system will be discussed, followed by some example

implementations where the impacts of using such setups on remote technical education will be highlighted.

## OVERVIEW

### Internet Education

Developed within the midst of universities and government agencies, the Internet has been used for a variety of purposes in education. It serves as a convenience multimedia communication channel between teachers and students, scholars and research centers, and has hosted many new, immersing and innovative ways to enhance learning and expand educational opportunities. Distant education and non-traditional classrooms can reach more students with specialized instruction and self-paced learning, while student projects, virtual field trips and online journals may complement available local resources.

In general, the Internet can be used for education in the following manners:

- Delivering content from a course web site where various teaching materials and course management functions are hosted.
- Delivering programs where multimedia animation or simulation is provided to replace physical experiments.
- Providing access to a Web-based laboratory that enables students to set up parameters and undertake experiments from a remote location.

### Web-Based Course

This is the simplest and most common way in which the Web is used for education. In fact, most universi-

ties in the world have systems that utilize the Internet as a general communication tool and aid for material download and general learning.

In particular, Simone (1997) presented a user-centered web page construction and maintenance model to develop web-based course materials, while Pascoe (1997) developed several methods, including interactive exercises, course note annotation and automatic tailored feedback, to enable students to interact with the course site to enhance learning. Rosenblum (1996) described some web-based collaborative learning communication tools through a CGI program that provides instructors with private course discussion areas. With an intuitive chat interface, these areas allow the instructors to give students a platform-independent ability to communicate in as many groups as is needed by the class.

Recently, Tartaglia et al (2002) explored a web-based evaluation system for technical education, while Ko et al (2004) designed and developed a secured web-based test system where a camera at the client computer is used to capture and deliver images of the student's face and postures at random intervals during the assessment. This scheme overcomes the hurdle of verifying the identity of the student by using just a simple user id and password.

### Internet Simulation Laboratory

This is the second most common way to utilize the Internet for education, and is especially beneficial in helping students to obtain a deeper understanding of hard-to-grasp topics. As an example, the concept of frequency components in a time-domain signal can be much better appreciated by using an interactive multimedia approach where students download and run a program from the Web, play around with the amplitudes of the various spectral components of an audio signal, view the resulting waveform and listen to it at the same time.

Software based demonstrations can be passive or interactive. The former is simpler in structure but only allows student to playback prerecorded audio or video. The latter is more interesting from a learning viewpoint, but is also more complicated to be developed. It can in general be divided into those that need to be downloaded for execution on a local machine running software such as MATLAB, or those that run directly on the web using Java applets.

Numerous demonstration-based laboratories, such as those by Crutchfield et al (1997) and Tilbury et al (1998), can be found on the Web on a variety of topics all over the world. A good example is the simulation laboratory developed in Carnegie Mellon University, where an effective paradigm to use the web for tutoring students on the use of MATLAB and SIMULINK is provided. Students are expected to run MATLAB or SIMULINK in one window of their own computers and a web browser in another. While surfing the tutorial, the student can download examples from the web page and run them locally. This helps students learn how the analysis and design of control systems can be carried out.

### Web-Based Remote Laboratory

The above setups provide students with useful theoretical and simulation materials. However, in science and engineering especially, it is universally recognized that effective and efficient learning requires a mixture of both theoretical knowledge and experimental work or exercises. Essentially, effects due to non-ideal operating conditions, practical components, noise and interferences just cannot be taken into full consideration in any simulation. Simulations are based on the use of models that by and large approximate real physical systems. Even the most complicated models, such as those used for pilot training, assume certain operating parameters and conditions which may be violated in actual operation or flights. In fact, the most important stage in the design of a good simulator is to study the actual system for the purpose of extracting the most important essence that need to be taken into account in the simulation. From this angle, a Web-based experiment is much more valuable than a Web-based simulator. It is impossible for the latter to derive the former, but it will be a very valuable experience to design a simulator from getting actual data from a Web-based experiment.

Nevertheless, some basic resource issues have to be resolved in conducting laboratory-based experimentation sessions. Firstly, physical space must be available for developing the experimental setups and for students to carry out the experiments in a conducive environment. Secondly, technical manpower has to be deployed to ensure safety and proper equipment handling. Thirdly, appropriate time scheduling has to be in place to ensure maximum usage of the laboratory.

In the context of teaching where the various topics

to be covered usually follow a certain sequence, it is often desirable and sometimes necessary for certain experiments to be carried out by the entire class within a short span of time, say, a few weeks. This places a lot of constraint on resources which will inevitably be poorly or not even utilized when the experimentation session is over. Also, students taking courses part-time or in the evening or through distant learning may not have the chance to carry out an experiment due to the unavailability of technical personal and the closure of laboratories.

As illustrated by Foss et al (2000), Gillet et al (2000) and Travis et al (2000), the use of Web-based remote laboratory corresponds to an attempt to overcome these constraints, and may well be the next important step in remote distant learning. Such a system will enable students to gain access to laboratory apparatus anytime anywhere via the Internet, allowing them to conduct experiments in as realistic a manner as possible. An advanced system may even have software that monitors logging on and how the instruments are used, enabling the experiment to be graded in a semi-automatic fashion. In addition, a web-based remote laboratory may allow researchers or students in different locations to carry out research and design work co-operatively and remotely at the same time, including the remote monitoring or observation of vital changes at various stages of the experiment over a long period of time.

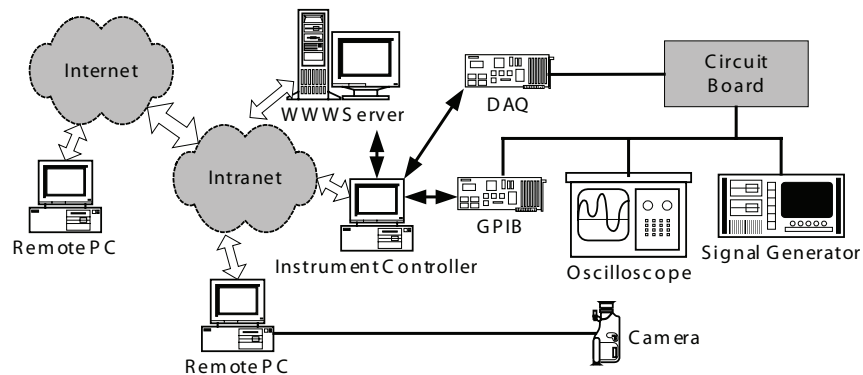
### SYSTEM ARCHITECTURE

Performing experiments from a remote location is a form of remote access that allows interaction with the physical world through the use of appropriate electronic

control and monitoring systems controlled by computers. Typically, after logging on through the Internet, a user will be able to control both the computer and the various equipments in the remote laboratory through an appropriately designed graphical user interface running on the client computer. The interface may include image or video captured in real-time in the laboratory resulting from adjustments made to some apparatus or changes in the dynamics of the objects being studied. Microphone may also be placed at interesting locations to pick up acoustic signals or vibrations in the experimental setup, and data may be captured by some instruments or sensors for sending back to be displayed or downloaded for further analysis by the user on the client computer.

For illustration, Figure 1 shows the hardware architecture of a typical Web-based laboratory in an experiment involving the use of a test circuit board as described by Ko et al (2001). Since multiple computers performing different functions may be needed, the system is hosted on and connected to the Internet through an Intranet. The system may include a number of analog and digital control DAQ cards for acquiring signals and controlling the various non-programmable instruments and the circuit board, while the other programmable instruments may be connected through the use of GPIB or other appropriate cards to the instrument controller PC. The results of the experiment may be sent back in real-time to the remote user, and displayed in an appropriate way in the user interface for analysis or storage. When the need arises, video and audio feedback may be provided by using a video server system that is connected to the Intranet. Since video feedback is bandwidth intensive and more com-

Figure 1. Typical hardware architecture



plicated to set up, this may be left as an optional item in the Web-based laboratory.

Based on the hardware structure outlined, Figure 2 shows the corresponding software structure and tools for the development of the remote laboratory. On the top level, a WWW server with, for example, Red Hat Linux 9.0 and Apache HTTP Server hosts the web pages that contain Java applets for the experiments. At the same time, an SQL database system may be installed to manage user authentication, while a GNU C program transmits command strings from the client side to the instrument controller PC and passes experimental data in the reverse direction. Depending on the user inputs, Java applets embedded in HTML files may be downloaded for running on the client machine. At a lower level, the control of real instruments in the physical laboratory can be conveniently implemented by using LabVIEW, a graphical programming language that can provide real-time support for a rich array of cards, bus and instruments. For every instrument under control, a sub-module will need to be created to process the commands from the user.

### GUI DESIGN

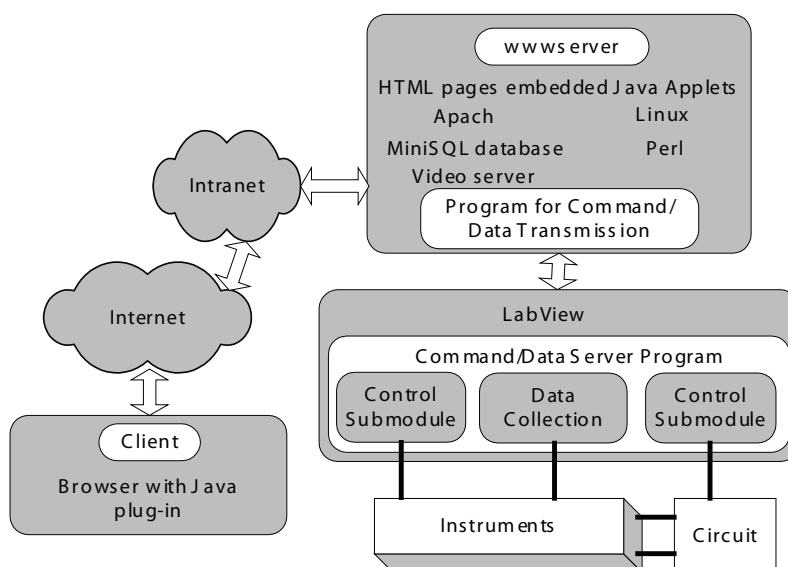
The user interface of a remote laboratory should be as realistic as possible to impress on users that they are actually operating on real physical apparatus. A user-

friendly interface will also enable the user to conduct the experiments conveniently and efficiently. The creation of vivid control and parameter adjustment components such as buttons and knobs are thus essential in any web-based laboratory.

As examples, Figures 3 and 4 show the client graphical user interface or GUI designs in two Web-based laboratories involving the use of an oscilloscope for studying an electronic circuit and the use of an expensive spectrum analyzer in a frequency modulation experiment. As described by Ko et al (2001 and 2005), the former involves the use of real-time video feedback, while the latter is a less bandwidth intensive application that constructs the analyzer display from data sent by the instrument in real-time.

Typically, after a successful log on to the Web-based laboratory, the user will be shown the GUI, which may include several instruments panels, graphs or tables showing experimental results, as well as windows containing various support information such as experimental procedures, instrument usage, time elapsed and communication status. Each instrument panel may consist of several moveable components such as buttons, knobs, terminals and plugs as well as appropriate displays. On the panel, buttons may be pressed or released, knobs may be turned through dragging with the mouse, plugs and may be plugged or unplugged, and cables may be dragged to connect or disconnect relevant input or output terminals. The

Figure 2. Typical software structure



display may be numeric in nature and constructed from real-time data sampled from the instrument or it may correspond to a video streamed from a camera in the physical laboratory.

The GUI may be implemented by using Java, JavaScript and HTML technologies, most of which are

supported by popular web browsers such as Microsoft Internet Explorer and Netscape Navigator. Specifically, Java applets embedded in HTML pages can be easily used to construct the main interface of the experiment. It is a natural choice on the client side because of its flexibility in GUI design, convenient network program-

Figure 3. Client GUI and instrument panel for an oscilloscope experiment

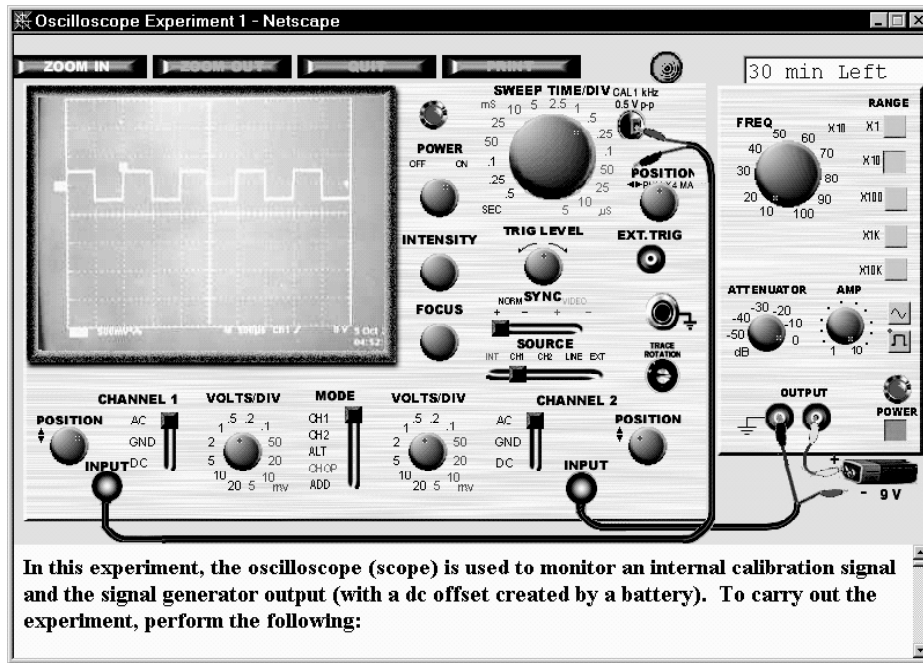
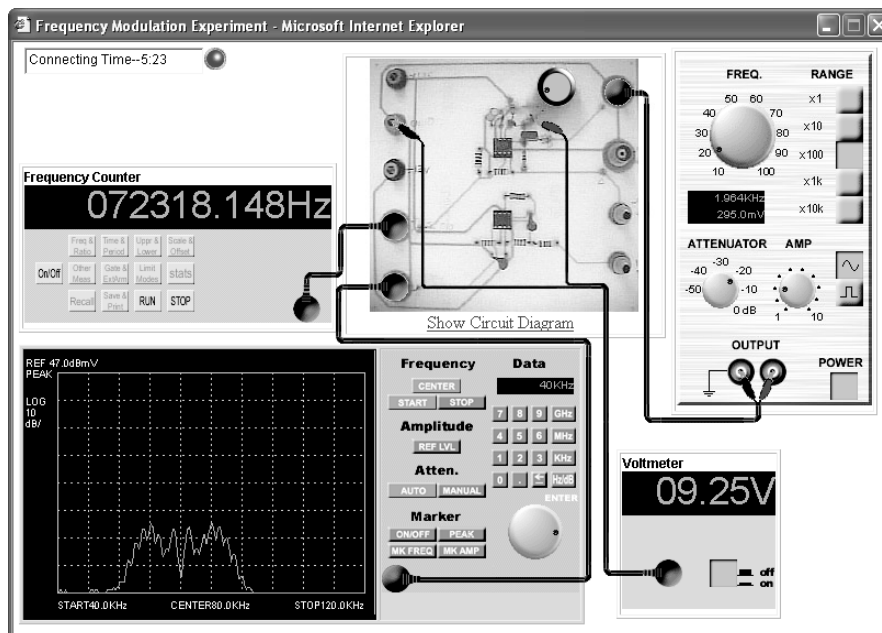


Figure 4. Client GUI and instrument panels for a frequency modulation experiment





ming capability, and platform independence. Platform independence, the last feature, is most significant since it allows the same applet program to run on client machines with different platform.

In addition to being visually similar to those for actual instruments, the user interface must also be designed to work logically. For example, the frequency counter should show an appropriate reading only after the user has connected the frequency counter to a certain point where there is a signal.

### 3D INSTRUMENTS AND SCENE

To be as realistic as possible and to overcome certain limitation posed by 2-D operation panels, using which the actual shapes of 3D instruments and equipment cannot be shown, the use of 3D visualization tools in real time web-based experimentation may be considered. Figures 5 and 6 show two typical example GUI realizations on the client computer developed based on Java 3D.

Java 3D is an efficient tool that provides a very flexible platform for building a wide range of web-based 3-dimensional graphics applications, and is becoming



Figure 5. 3D view on an experiment with a battery

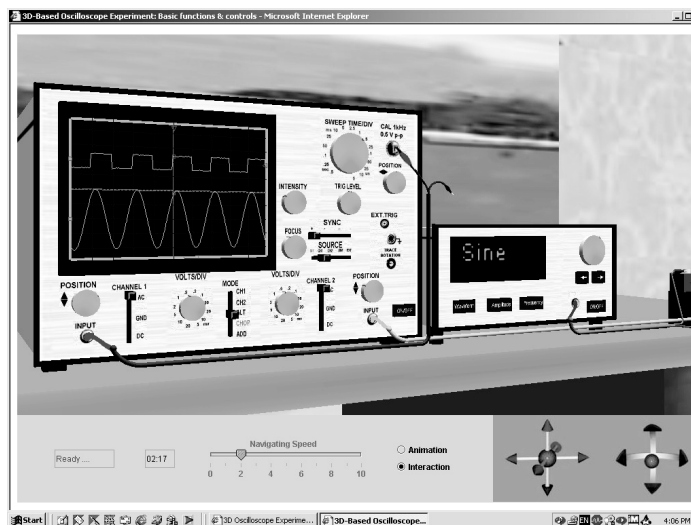
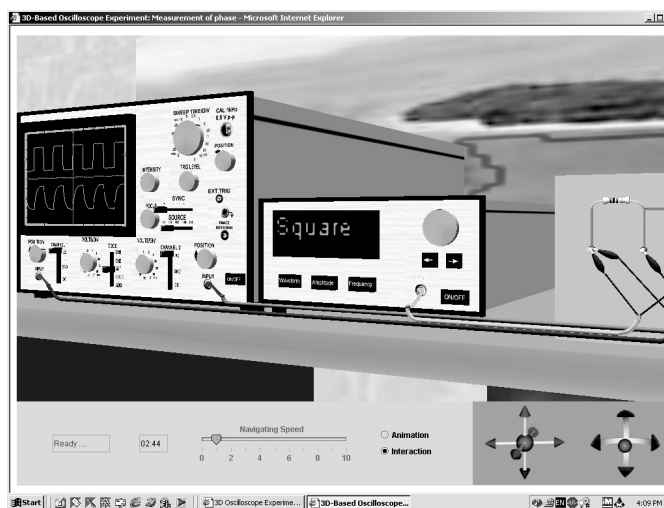


Figure 6. 3D view on an experiment with a circuit board



one of the most attractive tools for creating 3D user interfaces, 3D visualizations and virtual environments.

Ideally, anyone conducting an experiment through the Internet should be able to do it in the same manner as in a real laboratory. This can be accomplished in a 3D environment through three behavior modules on navigating, collision detection and picking in the GUI interface.

The module on navigating behavior controls how the user walks around in the virtual laboratory. Also, as the user attempts to get a better view, it controls indirectly the positions and angles of the view platform. The collision detection module ensures that the user does not traverse any solid objects such as walls, tables and instruments. Through the picking behavior module, the user will be able to adjust the controls of available experimental apparatus precisely.

The main functions and features in such a web-based 3D remote laboratory system are summarized below:

1. A 3D remote laboratory controlling actual instruments and displaying real signals is implemented through a dynamic virtual scene via the Internet. In the examples in Figures 5 and 6, the laboratory has an oscilloscope, a signal generator, a battery, a circuit, a few cables and some other visual objects.
2. A navigation tool for walking around the virtual laboratory is provided. For example, the tool on the bottom right hand corner in Figure 5 allows the user to move around the virtual laboratory and view instruments from different positions and directions through the mouse.
3. A collision detection mechanism is implemented. This guarantees that the viewing platform will not

traverse any solid objects such as walls, doors, windows, tables and virtual instruments.

4. Through the appropriate picking function, the user can adjust individual controls on the instruments in the 3D environment and connect circuits in the same way as he or she operates an actual instrument in the real laboratory. As shown in Figure 7, the operations of turning a knob, adjusting a slider, pressing a button, and making a connection to a terminal can be performed by simply dragging the mouse to move the relevant control when the control is in “focus”. To make it as user friendly as possible, a red point is displayed when the mouse is over a control that has received focus.
5. The adjusted controls are converted into the relevant commands and sent to a control server to control real instruments in the actual physical laboratory. The result of the experiment is sent back by the server to the client to be displayed in the 3D virtual laboratory in real time.

The experiment is performed when the user enters a virtual laboratory as shown in Figure 8. Apart from the virtual instruments and circuit board placed on a table, the virtual laboratory also includes the floor, the ceiling, a few walls, two windows and one door. To enter the virtual laboratory, a user will need to “walk” to the door and press the door open button. Upon opening, the user can walk through the door, move around and carry out the experiment by adjusting the instruments and circuit board on the table.

Similarly, programmable instruments have to be connected to the control server through control cards and cables in a 3D remote experimentation system. For example, two separate TCP/IP interface modules

*Figure 7. Picking controls for instruments*

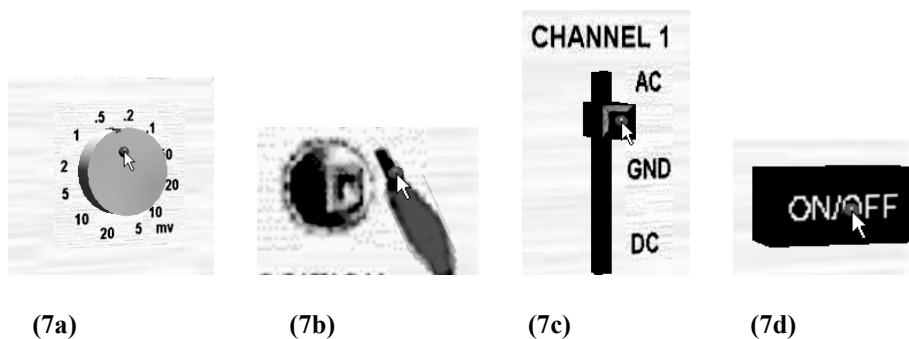
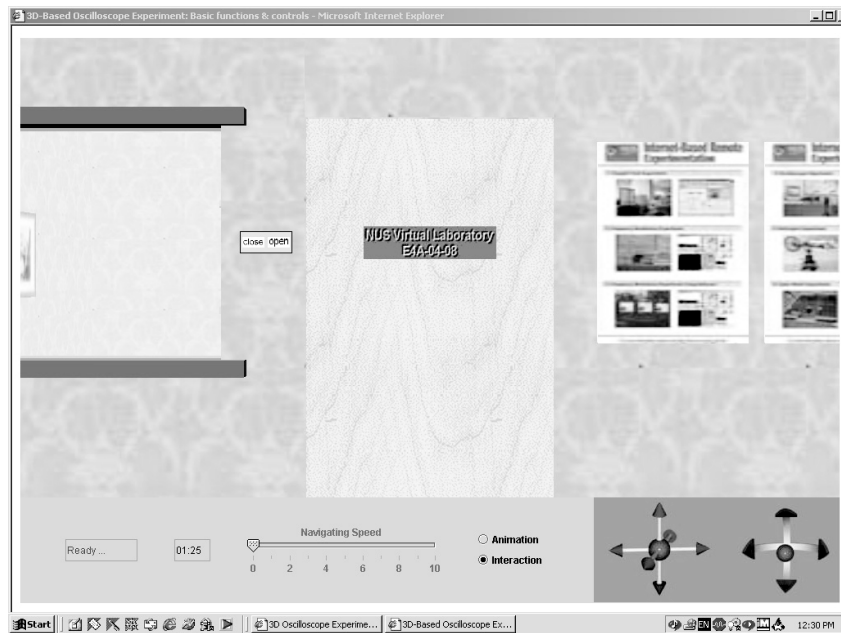


Figure 8. Virtual room of an oscilloscope experiment



are used for real time control and retrieval. The commands coming in through the TCP/IP control interface are converted into the format required before being sent to the programmable instrument to be controlled. Experimental data for the generation of real time curve or text for the user is transmitted to the client through the TCP/IP retrieval module.

## DISPLAY OF EXPERIMENTAL RESULTS

Apart from control buttons and knobs, the display of experimental results is another crucial component of the GUI. While the display and refreshment of numerical results is straightforward, the display of graphical information may be complicated and bandwidth consuming.

The simplest setup involves the use of Microsoft NetMeeting, a typical audiovisual application that uses the H.323 standard [39]. With NetMeeting, audio and video captured by microphone and camera can be streamed to the client side and played through the use of appropriate video and sound cards. Figures 9 and 10 show two Web-based experiments that use NetMeeting to let the user see the status of a coupled tank apparatus and an experimental helicopter in the remote laboratory as these are being controlled. Specifically, a window on

the right shows the water levels in the coupled tank in Figure 9, and a window on the left shows the moving helicopter being controlled in Figure 10.

Instead of NetMeeting, other commercial video server software such as Inetcam can be also used for video feedback and this may sometimes provides more flexibility and the possibility for customization. With Inetcam, the video stream is pushed to the client using JPEG server push technology. The user requires merely a Netscape Communicator browser to carry out the experiment with no additional plug-in that needs to be installed. An example for using this is the oscilloscope display as shown in the remote experiment in Figure 3.

In addition to streaming video, results captured from the instruments can be sent to the client GUI and an appropriate display constructed. This may sometimes save network bandwidth and give faster response. For example, the power spectrum shown on the spectrum analyzer display is constructed from real-time data collected from the actual instrument in Figure 4, and the time waveforms on the oscilloscope scope is constructed from real-time data collected from the corresponding physical instrument in Figures 5 and 6, respectively. For the former, as the spectrum may only change slightly due to noise and other effects, refresh-



Figure 9. Web-based coupled tank experiment illustrating the use of NetMeeting

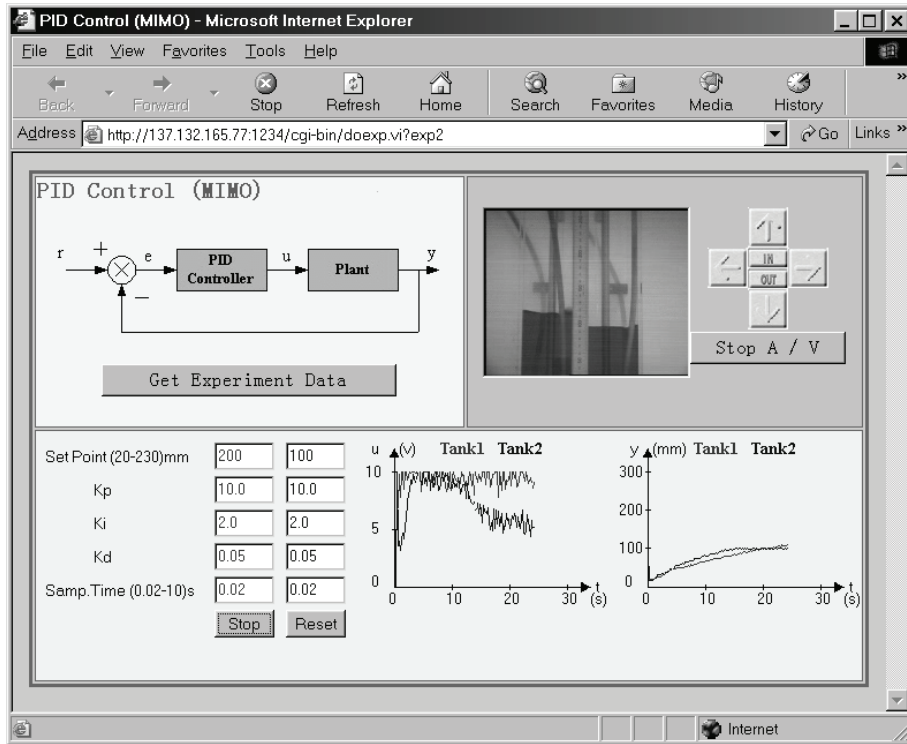
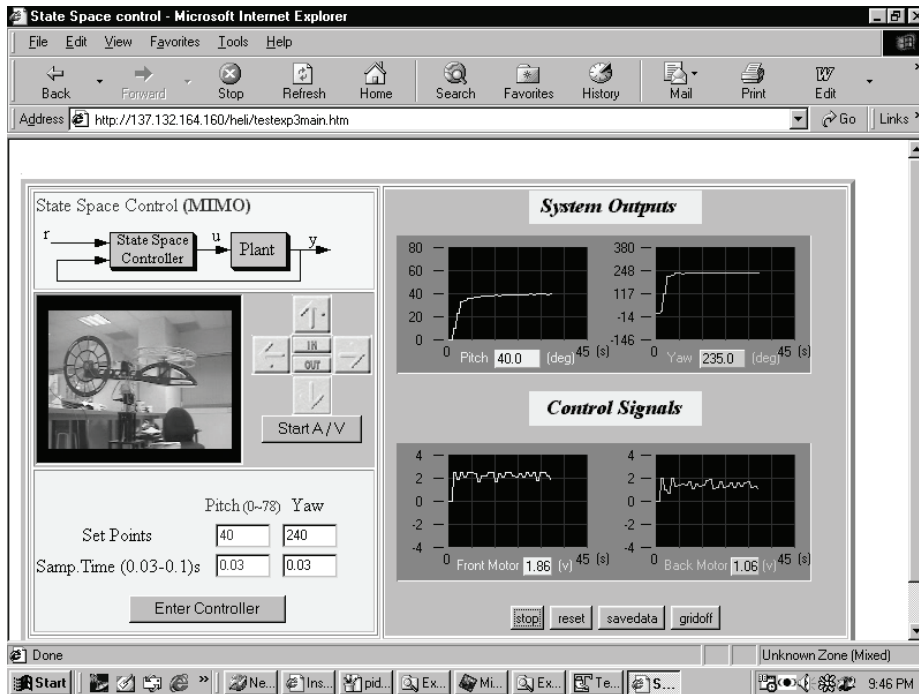


Figure 10. Web-based helicopter experiment illustrating the use of NetMeeting



## Web-Based Remote Experimentation

ing of the display may not require the transmission of the entire spectrum.

In some applications, implementation of the two display modes may provide a more flexible option for a variety of users in different locations. For example, in a web-based soccer robot experiment, two types of image feedback, one using direct image feedback from the video server and another using reconstructed image from a reconstructing algorithm, are implemented. When the user is within the Intranet domain of the host system, real time video can be selected as shown in Figure 11. Otherwise, a reconstructed image can be used in situations where Internet access is slow.

## INSTRUMENT CONTROL

The main difference between a real remote laboratory and a simulation type of so-called laboratory that is based on simulation is that the former is ultimately involved in the control of actual physical instruments and apparatus. Web-control of instruments can be achieved through a variety of PC-based cards, interfaces

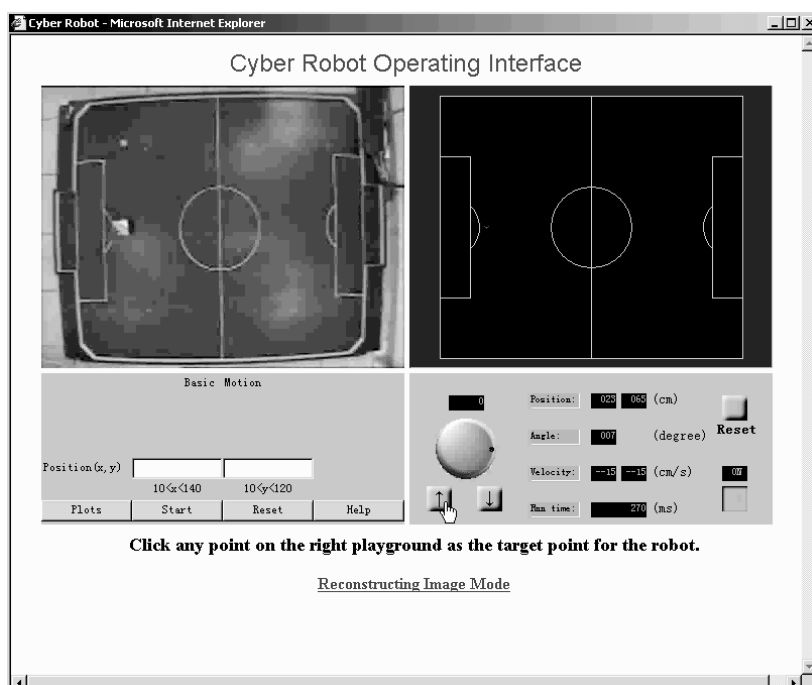
and buses. PC-based instruments that are compatible with standalone instruments can also be used and are becoming popular.

Figure 12 shows some typical cards used in a few Web-based remote laboratories. Specifically, a Data Acquisition (DAQ) card is used to give analog voltages to control the pump motors in a coupled tank apparatus, while reading back the water levels in the two water tanks by sampling the signals from some capacitance probes. For the control of the helicopter, however, a faster programmable Digital Signal Processing (DSP) card with a high speed processor has to be used due to the much faster response of the helicopter as it moves. A General Purpose Interface Bus (GPIB) card is used to provide support for an IEEE488 bus through which commands for the oscilloscope can be issued and status can be retrieved.

## IMPACT ON EDUCATION

While it may not be easy to set up, a properly designed Web-based laboratory can be used for education in a

Figure 11. Real time video mode



variety of ways for enhancing the experience of learning, for students to learn in a self-paced manner on their own, as well as for even an entire course to be designed around the experiment. This is possible because students are no longer limited by the resource constraints associated with traditional physical laboratories.

As an example, the Web-based coupled tank laboratory has been utilized in the teaching of both undergraduate and postgraduate courses in the Department of Electrical Engineering, National University of Singapore. The laboratory for the undergraduate course consists of identifying a physical model for the coupled tank and designing a PID and a fuzzy logic controller to control the water levels in the two tanks. Due to the complexity in tuning the controller parameters, the membership functions and the rule-bases of the fuzzy controller, students are often short of time in implementing their controllers within a 3-hour laboratory session.

The Web-based laboratory, however, allows each student to carry out the laboratory according to his/her own pace and time schedule. The manual control function in the Internet laboratory also allows students to collect real-time input-output data, which is useful in model identification. Moreover, students can interplay or fine-tune the controller parameters and membership functions, and the resulted control performance could be visualized and compared since they are based upon the same laboratory platform.

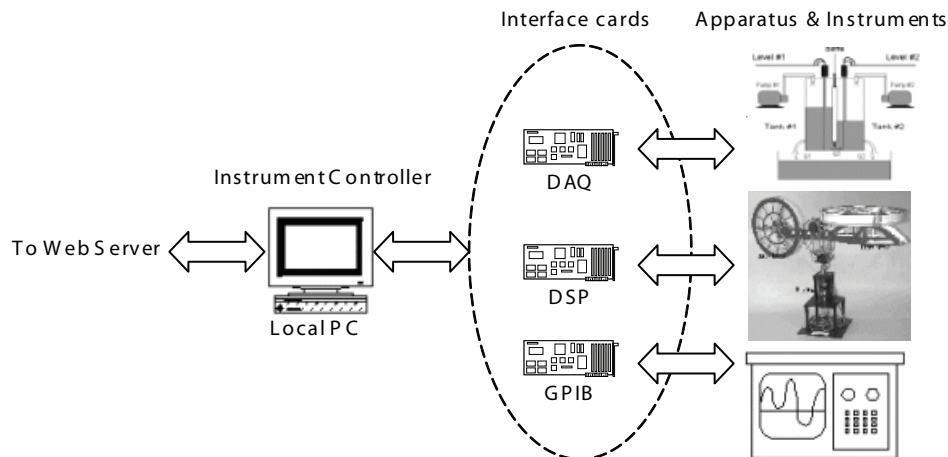
In the postgraduate course, students are introduced to solve both classical optimal control system design problems and advanced robust control problems. Since

half the class consists of part-time students holding full-time employment in industry, classes are conducted in 3-hour sessions in evenings once a week. Due to security, manpower and other constraints, teaching laboratories are generally closed after working hours and it is almost impossible to schedule laboratory experiments or to assign homework assignments on hardware implementations in the past.

With the availability of the Web-based laboratory, a new teaching element on actual experimentation can be introduced. The laboratory is used throughout the course homework assignments, in which students are required to solve an actual problem on the control of the flow levels in the system using techniques learnt in the class, and implement their designs on the actual system through the Internet. To part-time students who can logon when they are free, the laboratory provides a highly flexible access to a real experiment. Feedback and comments from the students are generally very positive. Many students feel that it is superb to see that the controllers they have designed actually work in the real system.

The system offers an excellent and convenient platform for researchers to test and implement their new algorithms as well. As an example, based on a robust and perfect tracking technique developed recently by Chen (2000), a controller for the coupled tank system has been successfully implemented. While the controller is theoretically capable of tracking any reference signal with arbitrary fast settling time from any initial condition, an infinite gain is generally required to guarantee such a performance. With the remote laboratory,

Figure 12. Interface cards for instruments control



certain design parameters can be easily tuned to meet the control constraints of the physical system with some trade-off in overall performance.

## CONCLUSION

In this article, an overview on the design and use of Web-based remote laboratory in education has been presented. Specifically, we have discussed the architecture, design considerations and tools that can be used to create an Internet laboratory that controls real instruments and enables students to have access anytime anywhere. The advantages and impact of such a laboratory for a more immersive laboratory experience, for the teaching of evening classes and distant learning, for collaborative research involving the sharing of expensive facilities, and for the possibility of having courses centered around an experiment are also outlined. As computer hardware and robotics become more powerful and cheaper, the possibility of controlling a robot remotely to carry out experiments from a distant and with safety may become a reality for more and more applications.

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## **TERMS AND DEFINITIONS**

**3D Instruments:** 3-dimensional virtual instruments which are developed using 3D visualization tools.

**Internet Remote Experimentation:** The use of the Internet to carry out physical experimental work at a remote location.

**Online Experiment:** An experiment that is running and controlled by a computer terminal.

**Remote Access:** The ability to control instruments or systems and retrieve relevant information at a distance.

**Virtual Laboratory:** A computer accessible laboratory which may be simulated by running a software package or which may involve real remote experimentation.

**Web-Based Control:** The control of instruments or apparatus through the Internet.

**Web-Based Laboratory:** A laboratory that typically involves physical experiments and that can be accessed remotely through the use of the Internet.