Carnegie Mellon's
Virtual Lab:

Finalist for the
1995 Smithsonian Computerworld Leadership Award

General Information

Application Nominated: Virtual Laboratory Experience
Category: Education and Academia Organization

Short Summary

Remote computer access to laboratory instruments allows undergraduate students to conduct actual experiments at any time and from any location. This technology greatly enhances the flexibility of laboratory education, and introduces students to the new paradigm of remote experimentation.

Long Summary

The demands on the undergraduate laboratory experience are significantly different today than they were just a few years ago. Measurements that once took several hours of careful work by hand can now be made automatically in seconds. Engineers today must deal with massive amounts of data, and with complex systems that may have components in widely separated geographic locations. In the face of these rapid advances, maintaining an up-to-date laboratory experience presents a significant challenge to universities.

A new concept under development at Carnegie Mellon to address these issues is that of a virtual laboratory. The core of the virtual laboratory is a cluster of general-purpose and/or specialized instruments interfaced to a personal computer that is part of the internet. By configuring the instruments and data analysis via software, the instruments can be made to perform the function of other instruments that may not be available. In addition to creating such virtual instruments, measurements can be made, and data can be analyzed for comparison with simulations. This can be done in the laboratory, or remotely over the network (e.g. from a student's dorm room, or even from another country) thereby creating a virtual laboratory. Video connections are available as well as instrument control. In contrast with computer simulations that can be accessed remotely, the virtual laboratory gives access to actual hardware.

Of course, nothing can replace the value of direct hands-on laboratory experience, but remote access can significantly improve the availability of expensive instruments, and thereby broaden their educational impact. We also believe that remote control and reconfiguration of instrumentation will become an increasingly common event in the workplace. The growth of this paradigm will parallel the increasing use of telecommuting and teleconferencing. An example of a workplace application is an automated manufacturing line where an engineer can change parameters or troubleshoot remotely, saving the time and money of traveling to the plant.

1. Benefits

Although many universities have well-equipped undergraduate laboratories, these laboratories are usually only available during scheduled hours. At other times, this equipment is not available for use. Providing students with the means to use this equipment on a 24-hour basis greatly increases the educational impact of this sizable investment without the security concerns associated with an unlocked lab. It can also make the equipment available to users beyond the university.

In many undergraduate courses, more specialized equipment is limited to classroom demonstrations because the cost of providing enough units to equip a laboratory is prohibitive. Configuring a few instruments to allow 24-hour remote access can make it possible for each person in even a moderately large class to have first-hand experience with the equipment.

Finally, the virtual laboratory experience prepares students for working in a mode that we believe will be increasingly common in the workplace. Examples include gaining access to specialized scientific or test equipment at a central government or company laboratory; saving the travel time of an engineer in charge of many systems in different locations; increasing the effectiveness of a support engineer in meeting the needs of his or her clients; and operating systems in locations where travel is not possible, such as space or the depths of the sea.

2. The Importance of Information Technology

The virtual laboratory concept was made possible by an innovative use of commercially available information technology. We believe this will enable the concept to be easily duplicated at other universities.

The instrumentation available in our core laboratory consists of a function generator, a digital multimeter, and a digital oscilloscope. (Remote access to more specialized equipment is available in advanced courses.) The instruments are controlled with HP-VEE software from Hewlett-Packard running under Windows on a personal computer. Remote control of the computer is made possible using Timbuktu software from Farallon Computing, Inc., and PC/TCP software provides the link to the internet. Access is possible from either Macintosh or IBM-compatible computers. High-speed modem access (either dial-up or wireless) is supported using Appletalk Remote Access (Apple Computer, Inc.,) or ShivaPPP (Farallon Computing, Inc.). Live video is possible using a Connectix camera and QuickPICT software. Remote camera manipulation is enabled with a simple motorized mount that was custom designed.

3. Originality

Although remote access of equipment and remote access to simulated laboratories are being done by others, we believe incorporating remote access of real instruments into an undergraduate course is unique. The concept developed over several years at Carnegie Mellon with contributions especially from Professors Pradeep Khosla, Donald Thomas, Virginia Stonick, Bruce Krogh, Rob Rutenbar, and Dan Stancil. The present laboratory was made possible in part by a grant from the National Science Foundation and donations of equipment and software by Hewlett-Packard. Significant assistance with writing and debugging the laboratories was provided by two seniors, Steve Badelt and Jimmy Hsu.

Two key laboratories in the first offering of the course involved remotely engineering solutions for system failures that had occurred in remote locations. In the first of these entitled, "The Black Box," students were instructed to diagnose a telemetry filter failure in a weather station located near the top of a mountain peak in the Rockies. By remotely making frequency response and current-voltage measurements at the input and output terminals of the filter, the students were able to identify the internal components that had failed. In the second laboratory, "Martian Lander," students were told that a failure on a Martian landing craft had made it impossible to control the on-board camera. The operation of this camera was essential so that the landscape could be searched for evidence of life. Their assignment was to remotely configure a new motor driver and use it to pan the camera and download pictures that gave evidence of life. A poster containing images from the early Viking missions provided the backdrop for the camera, and a cartoon character (Hobbes of Calvin & Hobbes) peaking over the edge of the spacecraft added additional interest to the observations.

4. Success

We have assembled a functioning virtual laboratory and demonstrated its capability. The laboratory was successfully used with a group of juniors and seniors during the Fall 1995 semester.

Although the virtual laboratory is fully operational, additional opportunities exist for adding capability. This includes putting additional instruments on the network, adding electronic switches to enable circuit connections to be changed remotely, and additional capability for audio, video, and the remote manipulation of objects. In the future we plan to make the course widely available to students beginning in their sophomore year so that they can use the techniques learned throughout the rest of their educational program. Eventually, the course may be offered remotely over the internet.

The concept is also widely applicable beyond Carnegie Mellon University, and in areas other than electrical and computer engineering. Virtual laboratories can be easily envisioned in fields such as mechanical engineering, chemical engineering, and robotics; and they can be assembled using commercially-available technology at any university.

5. Difficulty

To bring the virtual laboratory into existence, the first hurdle was to locate all of the hardware and software components required, and ensure their basic compatibility. For the core laboratory we have assembled, this involved over a dozen hardware and software components from several different manufacturers.

When such a number of different hardware and software systems are configured together for the first time, technical difficulties were expected, and experienced. These included detecting software bugs, discovering unexpected incompatibilities, and network capacity and reliability.

Assembling these components also required significant resources. These resources were obtained over several years of effort, and involved a National Science Foundation Grant, substantial donations of equipment and software from Hewlett-Packard, educational discounts from other vendors, and matching funds from both the department and college level. Several unsuccessful negotiations for donations and discounts were also experienced along the way to these successes.

Finally, unlike a computer that can simultaneously serve several users, an instrument group can only be accessed by one user at a time. This difficulty can be effectively addressed by making sure multiple instrument groups are available, but etiquette guidelines were still necessary to avoid a remote user taking control of an instrument being used locally by another student, and vice versa!