Web-Based Educational Experiments

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Abstract

Web-based educational experiments allow remote users to conduct laboratory explorations using physical experimental apparatuses in real time over the World Wide Web. Web-based experimentation is evolving rapidly and offers students convenient and repeated access to limited laboratory resources. The immediacy and accessibility of web-based experiments can also assist new student outreach and faculty teaching effectiveness.

Many web-based experiments can be realized with commercial off the shelf hardware and software, linked through a dedicated laboratory PC with a suitable network connection. Users can control the experimental apparatus, initiate data collection, transfer data across the web, and observe the progress of the experiment using a live video link. We report specifically on two web-based experiments operating since spring 1998: a Michelson interferometer that allows mirror movement and fringe counting, and a laser diode characterization experiment that allows current control and power measurements to observe P-I curves and the onset of laser action. Descriptions include benchtop optical and electronic experimental hardware, LabVIEW software tools for hardware interfacing, HTML web interfacing tools, and the video link setup. We also describe a typical user's experience across the web, discuss plans for extended web-based experiments and give suggestions for creating and maintaining a successful web-based experiment at another institution.

Introduction

The World Wide Web (WWW) is a growing vehicle for distance education, but most efforts have treated the web as a communications channel, not as a means for tele-presence. Boston University has been developing several photonics experiments that demonstrate basic principles of science and engineering through active experimental control over the WWW. Visitors to our web-site have real-time control over scientific equipment using their basic web-browsers, and receive observed data across the web. We have found that web-based experiments offer advantages to faculty, students, and general visitors to our web site. Similar efforts are being developed widely[1,2,3,4].

Web-based experiments are an excellent complement to traditional lab resources. They can be superior to simulations, which cannot replicate all of the parameters and factors that accompany a real life educational experiment. They also offer an attraction to users who enjoy their live, real-time aspects. Web-based experiments also give educators increased access to engineering resources, especially during experiments that require expensive or fragile equipment or that

present user safety hazards. This allows educators to offer more interesting experiments and make better use of procedures and equipment.   Even research equipment can be used for education without fear of damage due to inexperienced users. While a start-up investment is needed, the same interfacing can be used in multiple experiments over time.

Faculty requirements for supervision are reduced with web-based experiments. A well-designed web-based experiment can be self-explanatory, offering help pages, frequently asked questions, and additional links to related sites. Users can explore the theory, equipment, and history behind an experiment, and locate equipment specifications directly from the vendors. Users can be encouraged to pursue answers to broader questions, to further explore an interest, and to provide feedback by contacting the instructor electronically.

Web-based experiments also provide a natural supplement to faculty lectures. They can serve as an active introduction to new material or an immediate opportunity to apply a lecture's ideas. The site can also be accessed during lectures to provide classroom demonstrations. These uses of web-based experiments can potentially improve faculty teaching effectiveness.

Students can benefit from the accessibility of a web-based experimental site. They can visit the site at anytime before or after their lecture, and can easily access and capture related information. Experimental learning becomes a more natural part of the student's experience.

Web-based experiments can also stimulate interest in science and engineering within the general public on the WWW. An attractive, intuitive site can engage individuals who have little knowledge of science or engineering. Such experiences help stimulate interest in potential engineering students, and increase awareness of engineering in the general public. While at the time of this publication we have not yet formally introduced these web-based experiments into the curricula of courses here at Boston University, we have immediate plans of doing so in the spring semester of 1999. We will incorporate our site into the curricula of introductory engineering and science courses, where web-based experiments will serve as an introduction to material to be covered in the following lecture, and document the educational benefits of web-based. We also will introduce this site to high school science classes in the spring of 1999.

Creating Web-Based Experiments

In developing web-based laboratories, we sought experiments that had clear learning value, that could easily be computer-controlled, and whose results could be attractively displayed over the WWW. The classic Michelson interferometer has visually interesting fringe patterns, an important history, and widespread applications in photonics. The characterization of power vs. drive current for a visible laser diode is a common engineering measurement that illustrates laser behavior and several basic photonic instruments. These two experiments were put on the WWW at http://orange.bu.edu in spring 1998.

The specific equipment used in a web-based experiment determines computer control options. Signals typically are transferred as analog I/O, digital I/O, serial or parallel port communications, or as GPIB/IEEE 488 bus data. Most new instruments now provide some automation, and many third party boards are available for data I/O, device control, and instrument communications. Our applications use analog voltage I/O through a general commercial DAQ board. We wrote

our automation programs in LabVIEW, a graphical programming language for instrument control and data acquisition.[5] Our network connection is a 10 Mb/s Ethernet connection and our server is a 200MHz PC running Windows NT. We serve WWW interactions from the same computer that automates the experimental setup.

Interfacing from the WWW to our automation programs occurs through common gateway interfaces (CGIs). In general, CGIs accept user parameters through forms embedded in the HTML, and then execute based on these parameters, e.g. a WWW search engine is a CGI. During execution the CGI either creates output web pages or directs the user to an existing site. In our web-based experiments a user inputs experimental controls through a form. The CGI then executes its automation program based on these parameters and creates a web page that displays the experimental results to the user. While you can write a CGI in nearly any programming language, we wrote our CGIs in LabVIEW using National Instruments' extension library, the Internet Developers Toolkit.[6]

The server creates and returns a web-page that displays the results.

User

The user submits parameters through an embedded form.

Server

Server

The server reads the results of the automation setup.

Automation Setup

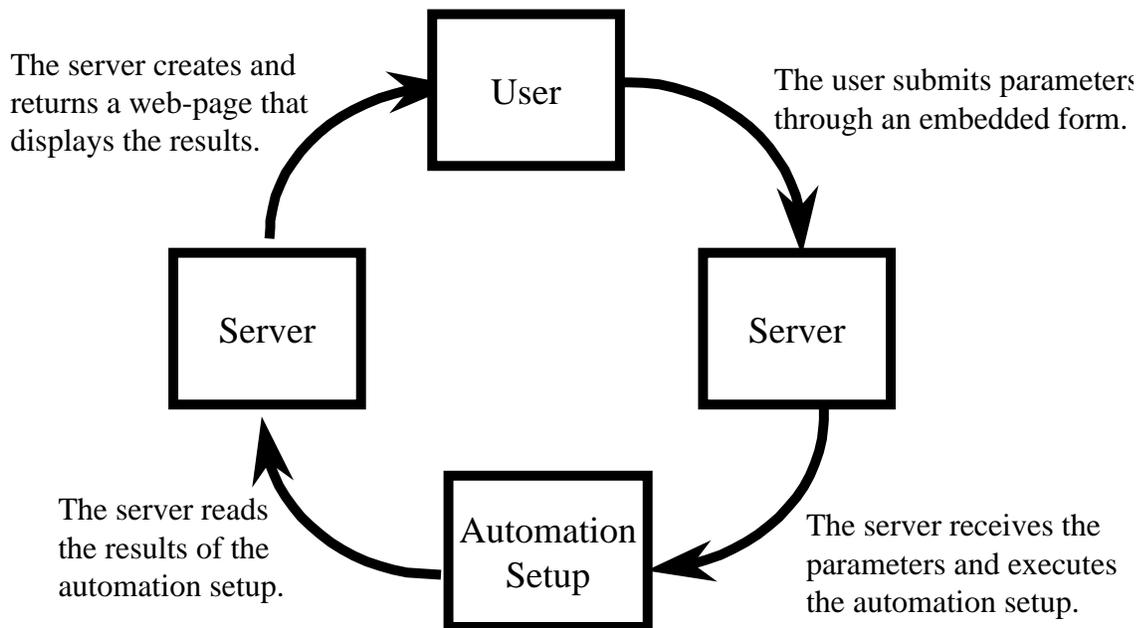The server receives the parameters and executes the automation setup.

Figure 1. CGI Operation

CGIs must establish a new connection for each transfer of a set of parameters, so true continuous real-time control is not implemented. More sophisticated programs (Java, JavaScript, or a plug-in) allow for a constant connection between users and the automation program. However, these programs tend to be more difficult to implement. Since WWW users are accustomed to delays in web responses, we used the simpler LabVIEW CGIs.

One of our initial programming objectives was nearly simultaneous use of the site by multiple users. Of course, with one apparatus, completely simultaneous use is impossible. A queuing scheme was considered, but dropped because of the complexity involved. Our CGIs take less than thirty seconds to execute a user's parameter and return a web page. If one of our CGIs is executing, any other user's form submission is simply postponed until the CGI is finished.

Even with an optimized site, user response depends on the user's hardware and Internet connection. Some users may be unable to use Java, JavaScript, or plugins, or might be unable to view live video streams. We offer options for experimental setup and viewing, so that users can suppress the live video or simplify the return of data.

In order to accommodate different users we have three distinct interfaces. An interface for the general public assumes no prior knowledge and concentrates on the experience of controlling scientific equipment such as lasers. We try to stimulate an interest in the scientific and engineering principles involved. A second, student interface concentrates on the explanation of scientific principles and assumes some prior knowledge. The student interface provides a discovery-based laboratory environment. The third interface is designed for the professional, either educators or other professionals interested in the scientific equipment featured. It provides extensive information about the equipment, automation, and web-based experiments. All three interfaces use the same web-based experiments, but in different ways that best serve their interests. Hierarchical interfacing makes the site attractive to a diverse audience.

Developing web-based experiments can be expensive. Funding came from the University Photonics Center, from a NSF Combined Research and Curriculum Development grant, and from Melles Griot, an optical equipment manufacturer. Melles Griot provided much of the scientific and computer equipment for this project. In return we are developing, along with our web-based experiments, real time demonstrations of their equipment over the WWW. These online demonstrations will be an extension of the professional part of our site and will require minimal additional programming. Web-based experiments offer a unique opportunity for university collaboration with private industry.

Developing a web-based experiment is an excellent introduction to laboratory research for undergraduates. Undergraduates implemented most of our site. They developed strong programming and computer interfacing skills, got to build the experimental apparatus, and gained a better understanding of the concepts behind our web-based experiments. This project provided an excellent introduction to laboratory research.

The Michelson Interferometer Experiment

Our Michelson interferometer takes a coherent laser beam, splits it, sends it down two different paths, and then recombines it. By moving one of the mirrors in the Michelson interferometer you can change the path length of one of the beam, which changes the phase of one beam with respect to another and therefore changes the interference between the two beams. By scanning one of the mirrors you can create an interference pattern where the recombined beams go from constructive to destructive interference. The Michelson Interferometer is an experiment that is often used in introductory physics and engineering courses. It clearly demonstrates interference phenomena and the wave nature of light. A QuickCam video camera shows fringe movement.
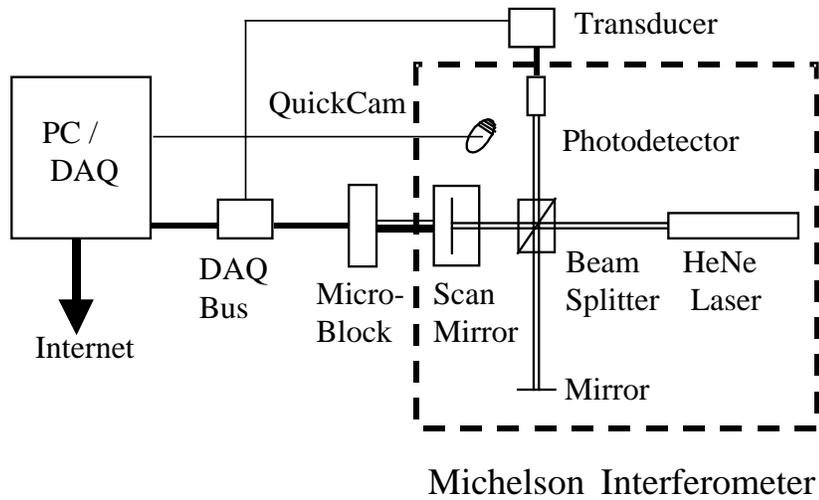
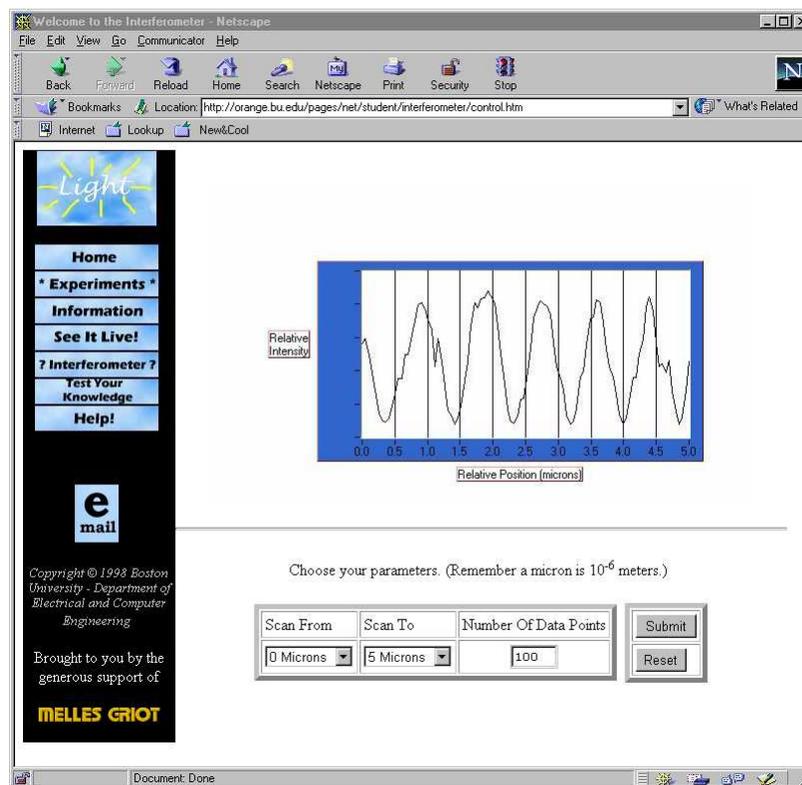Fig. 2 Michelson Interferometer Experimental Setup

Fig. 3. WWW page for the Michelson Interferometer Experiment

Users first select their interface level and optionally complete a user guestbook form. They next choose an experiment to run or explore the site. The professional interface offers information about the Michelson interferometer equipment and about web-based experiments. All users are presented with a blank graph and a form where they enter the scan range of the Michelson interferometer mirrors and the number of samples. They submit the form and then wait as the Michelson interferometer scans over the given range. Users have the option of viewing a live video of the Michelson interferometer fringes becoming brighter and then darker. The live video allows users to actually see what an interference pattern looks like, and also demonstrates that they are conducting an experiment using real instruments in real time and not a simulation. After the scan the intensity is plotted versus mirror position. A help page is available at all times. The student interface includes an interactive quiz on interference.

Laser Diode Characterization Experiment

The laser diode characterization experiment allows users to control the input current to a laser diode and measure the emitted light power. This allows users to chart a P-I curve and to see at what critical current laser action occurs. Users are presented with a data table, a power meter, and an indicator of the input current to the laser diode. They are also provided with form inputs for the input voltage to the laser diode. At each voltage the power of the laser diode and the current are displayed. They then, if they wish, can add this measurement to their data table and repeat the process. Users are also given the option to graph their data table or clear it. Users can also view an image of the laser beam to see the brightness of the laser diode change with current. Again, this live image both engages users and shows them that they are actually controlling real equipment in real time. Execution takes a few seconds.
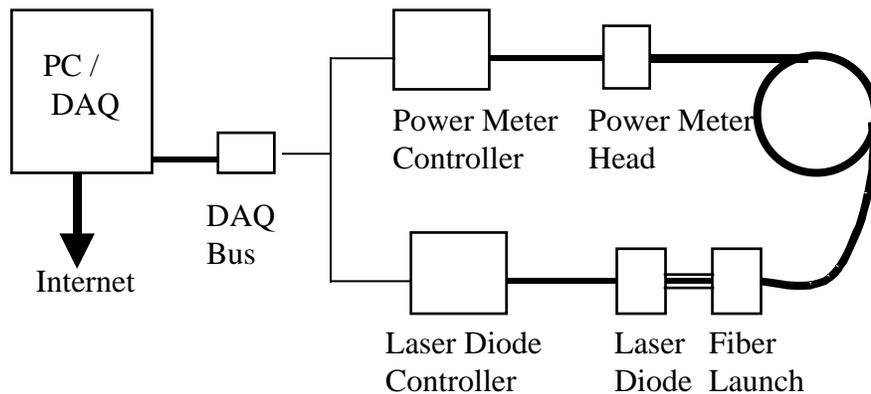

Fig. 4. Laser Diode Characterization Experimental Setup

Laser Diode Control - Netscape

File Edit View Go Communicator Help

Back Forward Reload Home Search Guide Print Security Stop

Bookmarks Location: http://orange.bu.edu/cgi-bin/net/general/0laserdn.vi

Instant Message WebMail People Yellow Pages Download New & Cool Channels RealPlayer

Light

Home
* Experiments *
Information
See It Live!
Help!

e mail

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University - Department of
Electrical and Computer
Engineering

Brought to you by the
generous support of

MELLES GRIOT

Laser Diode

Laser Power

Power [mW]

2.0 4.0 6.0 8.0
0.0   10.0

0.06

Change the laser current
to [   ] mA
Change Current

Would you care to add the
above results to your data table?
Add to Data Table

Clear Data Table

Laser Current

Current [mA]
32.00

Examples: 20, 2.5, 33.3
Please note that the laser current will not
exceed 44.5mA.

Would you like to graph your
data table?
Graph Data Table

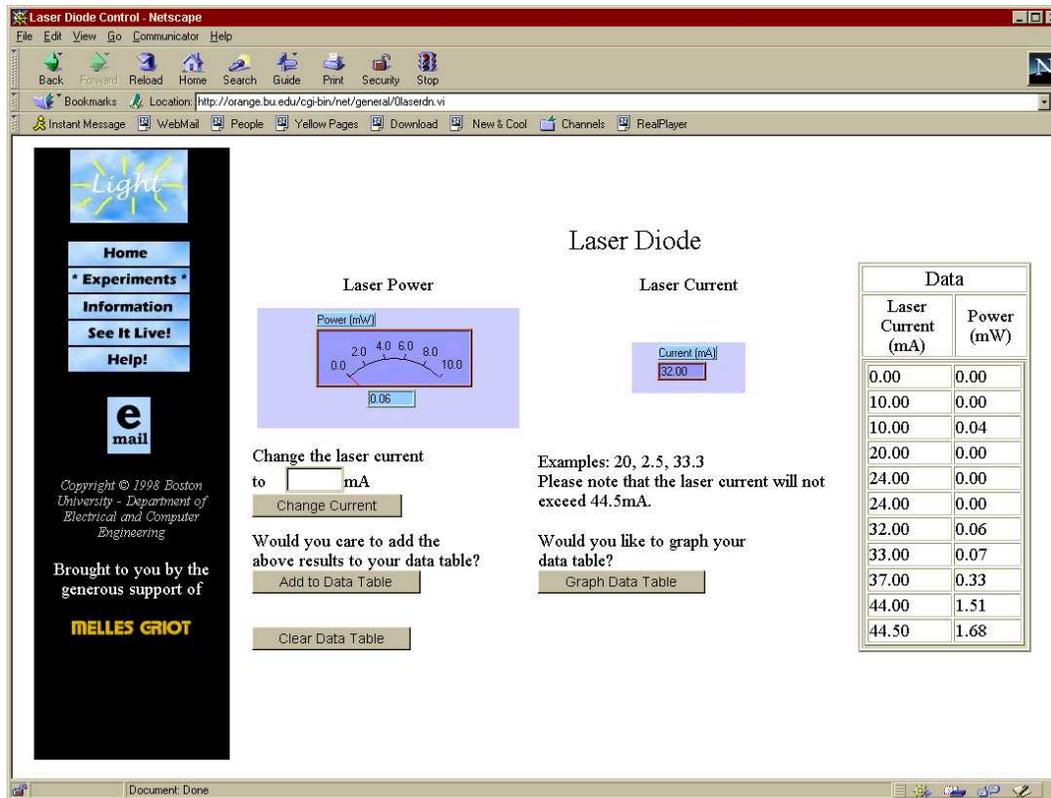| Data	
Laser Current (mA)	Power (mW)
0.00	0.00
10.00	0.00
10.00	0.04
20.00	0.00
24.00	0.00
24.00	0.00
32.00	0.06
33.00	0.07
37.00	0.33
44.00	1.51
44.50	1.68

Document: Done

Fig. 5. Web Page for Laser Diode Experiment

We externally control the experimental setup through the laser diode driver and the power meter. The laser diode driver has analog voltage input and the power meter has an analog voltage output, both of which we connect to the same DAQ board we use in our other experiment. The same computer controls both web-based experiments. As with the Michelson interferometer, users control the automation program with CGIs. The CGI programs used in this laser diode experiment are more complex than those used in our other web-based experiment. In these CGIs we had to incorporate a program that assigns numbers to each user, and uses these numbers to keep track of the data each user collects. The program routinely erases data from past users. There is also a limit on user data that can be saved on our computer at one time to prevent any abuse of our system. We find that this method allows the experiment to be used by simultaneous users without significant delay.

Creating Your Own Web-Based Experiments

We feel it would be easy to duplicate this project at another institution. The prior knowledge necessary to duplicate our project is minimal. One must know or learn how to automate an experimental setup and how to build and program web-pages, CGIs, Java, or their alternatives. While many might not be experts at doing such, there are many references and programs, too numerous to cite here, that can facilitate these activities.

The equipment necessary for duplication is also limited. While we are using some sophisticated scientific equipment in our experimental apparatuses that can be quite expensive, there exist many cheaper alternatives that will serve the same purposes. One can easily substitute any surplus equipment that might be available. Beyond the scientific equipment needed for the experimental setup one only needs a computer with a sufficiently fast internet connection, automation and serving software, and any computer boards that are necessary for communications between the computer and experimental equipment. All necessary hardware and software are commercially available from many sources.

The type of network connection and server you choose depends on your budget and how much traffic you expect the site to generate. For our site we found a personal computer, which is now outdated, to be more than fast enough to serve our needs. You might wish to build off an already existing WWW site. But one thing to keep in mind is that your server must be connected, whether directly or indirectly through another computer, to your experimental setup.

We feel that the scarcest resource needed for this project is time. While it might only take a month to initially create a web-based experiment, additional time is needed in order to ensure that the experiment continues to function and grow.

Conclusion

Web-based experiments offer many advantages to engineering and science education. Adequate control, sensor, automation and server technology is prevalent and reasonably priced. Our two experiments on Michelson interferometry and laser diode characterization have run successfully for several months with minimal operating problems at http://orange.bu.edu.   Based on this experience, we are developing other web-based experiments, improving the site with more live video, Java applets, and better supporting pages, and integrating the web experiments into regular classes in engineering and science. Web-based experiments will play an increasing role in making experimental science available to students and the public.

Acknowledgments

Bibliography

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5.   URL: http://www.natinst.com/labview- information about LabVIEW
6.   URL: http://www.natinst.com/labview/internet - information about Internet Developers Toolkit

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