

INTERNET-BASED LABORATORY EXPERIMENTS AS A PART OF AN ENGINEERING TECHNOLOGY PROGRAM

Abul K. M. Azad and Xueshu Song
Department of Technology
Northern Illinois University
DeKalb, IL 60115, USA.
Email: azad@ceet.niu.edu.

Abstract

This paper presents the design and development of an Internet-based laboratory facility that will be used to deliver an undergraduate digital electronics laboratory course within an engineering technology program over the Internet. The uniqueness of the developed facility is its modularity in design and the use of commercially available hardware and software technologies. This approach is adopted to address some of the major drawbacks of the existing systems for an Internet-based laboratory facility. The facility is also equipped with web-applications for collecting data for evaluating the system's performance. In addition to these, there is a plan for assessing the standard of learning outcomes while using the facility.

Introduction

Providing students with an adequate laboratory experience at a time and place convenient for them is a major challenge for engineering educators. This applies to both the traditional laboratory courses as well as laboratory courses as a part of distance learning programs. Traditional laboratory classes are scheduled only for a specified time period, when students attend a laboratory class located within their academic institution. Considering the mixed ability level of students, the allocated time is often not enough for all students to complete their tasks satisfactorily and also gain sufficient experience through the process.[1, 2] Also, in some cases students want or feel a need to perform additional experiments beyond their assigned tasks. To address these issues, it is difficult to accommodate any extra

experimentation because universities often lack resources to keep their laboratories open.[3] Additionally, laboratory facilities are often inaccessible to the students of other departments within the same institution because of their geographical location. Ironically, too much laboratory equipment lies idle during most of its usable lifetime.[4] An Internet-based laboratory facility would address these problems by providing unlimited access to an experiment and hence maximize the use of available resources.

One of the major limitations of existing Internet-based distance-learning programs is their failure to deliver the laboratory-related courses[5,6,2]. While simulation and multimedia provide a good learning experience for effective and complete learning, especially in applied engineering and technology programs, a mixture of theoretical and practical sessions is needed.[7] Currently, students have to visit a campus to perform the physical laboratory sessions for these kinds of courses or there has to be an arrangement of mobile laboratories stationed at a few predetermined locations for a given period of time.[8,3,9] With such arrangements, students get access to the hands-on facility for only a short period of time, which is usually insufficient to allow them to complete their learning cycle.[1,10] Making the physical laboratory experiments accessible through the Internet would address this need.[11,12,2]

The Internet-based laboratory facility, either as replacement of or supplement to traditional laboratories, has valuable benefits by allowing a more efficient management of the laboratories as well as facilitating distance-learning programs. Moreover, this will allow inter-

laboratory collaboration among universities and research centers by providing research and student groups access to a wide collection of experimental resources at geographically distant locations. An added benefit is the reduced costs incurred when different educational departments and institutions share facilities, since automated, remotely accessible systems are more cost effective than scheduled laboratory sessions conducted by salaried assistants and technicians, not to mention the cost and effort needed to maintain the laboratories.

There are a number of initiatives that have been made to provide experimentation facilities over the Internet.[13,14,15,16,17,18,19] None of these facilities are designed to deliver a complete laboratory course that is a part of a regular educational program. In addition to this, all these suffer from one or more of the three main drawbacks. These are: a) complexity in development; b) higher cost; and c) single server can provide access to only one experiment at a point in time. Although the Internet-based laboratory facilities have a number of potential benefits, these drawbacks hinder the process of their gaining popularity.

The paper will describe the design, development, and evaluation process of an Internet-based laboratory facility that will be used to deliver an undergraduate digital electronics laboratory course within an engineering technology program. This facility will allow the students to perform an experiment over the Internet with unlimited access time. The system is developed through a grant from the National Science Foundation (Course, Curriculum, and Laboratory Improvement program). All the laboratory experiments are located in a teaching laboratory within the Technology Department of Northern Illinois University (NIU). The uniqueness of the developed facility is its modularity in design, use of commercially available hardware and software technologies, and in-built evaluation facility. This approach is adopted to address the drawbacks identified earlier.

The next section describes the target laboratory course. Section three illustrates the structure of the developed system by highlighting its main components. The components involve interfacing hardware and software, GUI and web presentation, web server, software tools, and Internet delivery. Section four illustrates the evaluation process in terms of usefulness of the system and learning outcomes. These are followed by the conclusions, acknowledgements, and references.

Developed System Structure

This section will address the overall structure of the developed facility. As mentioned earlier, the facility is developed in a modular structure so that each module can be changed/modified in an independent manner. Figure 1 shows the different modules and their interaction. The modules are: a) Experiments; b) Interfacing; c) GUI and Web Publication; d) Server; e) Internet delivery; and f) Client PC.

The individual experiments are developed according to the course and connected to the server through a suitable interfacing hardware. An Input/Output (I/O) card from National Instruments is used as the interface hardware. A number of experiments can be connected to the server depending upon the capability of the interfacing hardware. Each of these experiments can be controlled (manipulated) via an individual GUI residing within the server. The GUIs are developed by using National Instrument's LabVIEW software package. The GUIs are subsequently transformed to dynamic web pages and stored within the server. These GUIs (as dynamic web pages) are linked with a web application that hosts the developed facility. The clients with appropriate UserID and Password are able to access the facility and manipulate the GUIs to control an experiment. With this facility, a number of experiments can be delivered simultaneously. A client can access an experiment by accessing the GUI (as a dynamic web page) within the server. A client PC should have Internet explorer (web browser) and LabVIEW player (freeware). In addition to

performing experiments, the Internet delivery part of the facility provides documentations, user profile and password control, client access information, and weekly surveys to assess the system and its effectiveness.

Target Laboratory Course

The laboratory course that has been implemented through this facility is an introductory digital design course. The topics that have been covered through this course are: Boolean laws and rules, De Morgan's Theorem, K-map, combinational system design (adder, decoder, encoder, multiplexer, and demultiplexer), and sequential system design (flip-flops, counter, and register). This laboratory course is to complement a teaching course in this area. There are 12 laboratory sessions, involving a total of 37 tasks (experiments). A list of the laboratory sessions is provided in Appendix-A.

For the implemented Internet-based laboratory facility, the students will be pre-provided with handouts (including a pre-laboratory part) over the facility's web page. Students need to study the handout and complete the pre-laboratory part of the handout before starting a laboratory session. After the laboratory session, students need to submit a post-laboratory report along with the handout.

Interfacing hardware and software

The first step towards the Internet-based physical laboratory facility is to establish an interfacing between the computer and the experiments. The computer will be the gateway to the Internet, while the experiments are the facility that needs to be accessed/operated over the Internet.

All the experiments that need to be accessed are digital in nature. Both the inputs and outputs to-and-from the experiments are logic 0 (0V) and logic 1 (+5V), respectively. A digital I/O card from National Instruments is employed as the interfacing hardware. This is a PCI-6528

with 24 inputs and 24 outputs and is enough to provide sufficient I/O channels to drive a number of experiments at the same time.[20,21, 22]

The software part of the interfacing process was implemented by using LabVIEW, which is also from National Instruments. The LabVIEW software has much more flexibility for data acquisition and control over the Internet. This can also be used along with other third party software, making it more attractive for development applications such as this one. Apart from these, the other reason for choosing LabVIEW is for its inbuilt server facility that can be utilized to publish a GUI for Internet access to the experiments.[23, 24]

GUI and Web presentation

One of the main components of the Internet-based laboratory facility is the GUI. This is serving as the media between the experiments and the students. It is important to provide a user-friendly and effective GUI that is to attract students while performing experiments without any physical supervision and assistance, which are usually provided during a traditional laboratory class. LabVIEW provides a facility to develop a GUI called virtual instrument (VI), which can serve both of the above purposes.[25]

The concept of VI is to create more powerful, flexible, and cost-effective instrumentation systems using a PC. A VI can easily export and share its data and information with other software applications. An image of a GUI developed for a 3-input 1-output experiment is shown in Figure 2. The particular experiment is Laboratory 3 and Task #1.

The left hand side of the GUI is showing all the 3-inputs that are generated within LabVIEW. These inputs could switch between two levels, logic 1 and logic 0. A user can change the time period between the switching. The state of an input can be monitored, either through an LED or on a graph window. The graph windows are labeled as input 1, input 2,

and input 3. The state of output can also be monitored through a graph window as well as through an LED, which is shown on the right hand side of the GUI. The logic diagram between the two sets of graphs is the hardware system that has been used for the specific experiment. The GUI passed the inputs to the experiment and receives corresponding output through appropriate ports of the I/O card.

For the target course, inputs and outputs are digital in nature. This allows grouping the experiments in terms of the number of inputs and outputs and develops a single GUI for each group. A GUI for one group can be used for all the experiments of that group, with only minor modifications. For the specific course, there are a total of 10 reusable GUIs that will handle all 37 tasks for 12 laboratory sessions. The 10 GUIs are: 1input-1-output; 2input-1output; 2input-2output; 2input-3output; 3input-1output; 3input-2output; 4input-1output; and 4input-2output.

Presenting a GUI over the Internet involves publishing the GUI as a dynamic web page. The published GUI is stored within the server at a particular location, and a web application can point the location and filename for access to the GUI. LabVIEW allows multiple numbers of GUIs to be published at the same time, thus allowing the system to handle multiple experiments simultaneously.

An image of the web publishing tool dialog box is shown in Figure 3. Within the web publishing tool there are options to select the level of control that a client can have, once the GUI will be accessed through the web. To provide two levels of access (performer and viewer), each GUI is published in two modes. The former is to allow the user to have full control over an experiment, and the latter is to view an experiment without any control.

Web Server and Software Tools

A web server is hosting the web site for the facility including all the applications and

interfacing hardware and software. In terms of hardware, the web server is having a 3.6GHz processor, 2GB of RAM, 80 GB of HD, and National Instrument's I/O card. For the software part, it has Windows 2003 Server (OS), LabVIEW, Internet information services (IIS) server, .NET, XML (EXtensible Markup Language), XSLT (EXtensible Stylesheet Language Transformations), and SQL server 2000.

LabVIEW is used for data collection and visualization. The IIS provides the services to the http requests coming through the Internet. This is a component provided within Windows 2003 server. The IIS makes it easier to share documents and information over the Internet. Web-publishing, security, administration, and applications can work together to increase performance and reliability, while lowering the cost of ownership and also improving the web application environment. Only an authorized client with a valid password can access the system. This requires password protection and a dynamic web page. This has been implemented using ASP.NET.

The .NET Framework is the infrastructure for the new Microsoft .NET platform and is a common environment for building, deploying, and running Web Services and Web Applications. The .NET Framework contains common class libraries like ADO.NET, ASP.NET, and Windows Forms. This is to provide advanced standard services that can be integrated into a variety of computer systems. This is a language neutral framework and supports C++, C#, Visual Basic, JScript (The Microsoft version of JavaScript), and COBOL. The new Visual Studio.NET is a common development environment for the new .NET Framework and provides a feature-rich application execution environment, simplified developments, and easy integration between a number of different development languages. ASP.NET along with ADO.NET is used to build this web application and has used C# as the programming language for its simplicity and completeness.[26, 27]

Computer systems and databases contain data in incompatible formats. One of the most time-consuming challenges for developers has been to exchange data between such systems over the Internet. XML was created to structure, store and send information. Converting the data to XML can greatly reduce this complexity and create data that can be read by many different types of applications. XML can also be used to store data in files or in databases. Applications can be written to store and retrieve information from the store, and generic applications can be used to display the data.

XSLT describes how the XML document should be displayed; in a way they have the same relationship as CSS (Cascading Style Sheets) shares with HTML. CSS guide a browser about how the HTML should be displayed. XSLT is used to transform an XML document into another XML document, or other type of document that is recognized by a browser, like HTML and XHTML. Normally, XSLT does this by transforming each XML element into an (X)HTML element. With XSLT one can add/remove elements, attributes to or from the output file, rearrange and sort elements, perform tests and make decisions about which elements to hide or display, and a lot more.

Standard Edition of SQL Server 2000 is used as the back-end database for the facility. SQL Server 2000 is a database management system that offers a variety of administrative tools to ease the burdens of database development, maintenance, and administration. These tools are: Enterprise Manager, Query Analyzer, and Data Transformation Services. Enterprise Manager is the main administrative console for SQL Server installations. It provides with a birds-eye view of all of the SQL Server installations. One can perform high-level administrative functions that affect one or more servers, schedule common maintenance tasks or create and modify the structure of individual databases. Query Analyzer offers a quick

method for performing queries against any SQL Server databases. It is a great way to quickly pull information out of a database in response to a user requests test queries before implementing them in other applications, create/modify stored procedures and execute administrative tasks.

Internet Delivery

Internet delivery part of this facility involves a number of issues: system access levels, user profile and password control, providing documentations, performing experiments, weekly surveys, and administrative activities. All these issues are addressed within the facility to make this as effective as possible. Similar to the other modules, the Internet delivery module is independent of other modules and can accept any form of experiments without any change. The only thing that has to change is the experiment related documentations.

The system access level controls the level of access by a facility user. There will be two levels of access to the system. One will be as a client and the other as an administrator. Students will be allowed with client level access. With this status, one can perform or view an experiment, change password and demographic details, and complete the weekly survey questionnaire. An administrator level of access will allow management of experiments and monitor and gather access profile and survey data. Images of the homepages with client and administrative logins are shown in Figures 4 and 5, respectively.

A flowchart showing the browsing map for client and administrative levels of access is presented in Figure 6. Apart from the home page, the client level of access allows the users to have three areas to browse: Documentations, UserProfile, and Experiments. For the administrative level of access, one can be able to activate and deactivate experiments and get access to the user profiles and weekly survey data.

Documentations

There are two documentations that are provided through the web page: guidelines and handouts. The guideline document provides a brief description about the facility, its working principle, and steps to follow to perform an experiment. This is a vital document and provides instruction for successful use of this facility. Apart from periodic minor changes, this document will remain the same during the period of the course. The handout document will provide instructions for each laboratory sessions along with pre-laboratory guidelines. For the target course, the laboratory sessions and handouts are going to change every week in accordance with the delivered experiments. As a pre-laboratory, students need to study the circuit and develop a truth table before performing an experiment.

User profile and password control

The UserProfile button allows the user to access demographic and contact information, the password changing facility, and computer and Internet usage information. During the first login, every user needs to answer few questions regarding the level of computer and Internet usage. This is to establish a background profile for every user. A user can change contact information and password during any login session.

Performing experiments

Students can access the experiments by clicking on the Experiment button within the home page. The experiment page will provide the students with a list of tasks that need to be completed during a laboratory session (for a given week). A flowchart showing the access levels to an experiment is shown in Figure 7. An experiment can be performed by a single user at any point in time; while other users can only view the experiment without any control over it. Depending upon the availability of an experiment, a client may get access either as a performer or as a viewer. Only a performer is

able to change the input status for an experiment.

An image of a performer page for an experiment is shown in Figure 8. Within the page, a performer can start and stop the experiment and change input time periods. While performing an experiment, the student needs to monitor the state of inputs and output(s) and compare them with the truth table that has been developed within the pre-laboratory part of the handout.

An image of the viewer page is shown in Figure 9. Within this page, viewers will view the same GUI as the performer but without any control over the GUI. Any change in the GUI by the performer will be observed by the viewers. There is no limitation on the number of viewers at a time and will be only limited by the server capacity. While viewing a GUI, viewers will be put into a queue to have their turn as a performer. The queue will be allocated on a first come first serve basis. A viewer needs to click on the “Try Again” button to claim the status of the performer.

Administrative activities

The administrative level of access to the facility allows a user to have additional capabilities, such as maintenance of available experiments, gathering user activity data, and results of weekly surveys. These application features allow an administrative user to activate or deactivate a given laboratory session or a specific task within a session at the Internet level. Activation of any experiment should be followed by loading of appropriate GUI and connecting the hardware experiment with the facility. All these need to be synchronized to make a specific experiment available through this facility.

Considering this is 24/7 facility, the system can be accessed any time from anywhere. To understand the user access profile, the system is provided with a provision to gather user activity data in terms of client login time, logout time,

and performance duration for each client for a given experiment task. These data can be accessed by an administrative user through an application. An image of the activity page is shown in Figure 10. With this application, the administrator gathers data using various filters. The filters are: UserID, Access Type, Lab Number, and Task Number. These data can be exported to Excel for further analysis. Similar to the activity data, the weekly survey data can also be gathered by an administrative user and exported to Excel for analysis. Considering the academic use of this facility, these data will allow the course administrator to use this information (in addition to other course data) towards assessment and also to study the students' learning behavior using this facility. These will also enable the administrator to assess the usefulness of the developed facility and adjustments/changes to make the system more efficient and effective.

Evaluation

The evaluation will be performed to assess the effectiveness of the facility in terms of its usefulness and also for achieving learning outcomes. Both of these evaluation issues are considered from the very beginning of the project. Some of the assessment activities are incorporated within the facility as web applications, and data will be collected as the facility will be in use.

Professor Herbert J. Walberg, Ph.D., Research Professor of Education and Psychology at the University of Illinois at Chicago and Visiting Professor at Stanford University, has been appointed as the external evaluator. He is a world renowned scholar and researcher in teaching psychology and evaluation. Dr. Walberg is advising on questionnaire design, evaluation of the pedagogical effects of the system, data analysis, and interpretation. The independent evaluator approved the evaluation criteria and questionnaire with interactions with the authors. The results obtained from the evaluation process will be jointly analyzed by the evaluator and the author. In addition to

these, three members of the program's industrial advisory board will also be involved to assess the cost effectiveness feature of the facility.

Usefulness

The Internet-based laboratory course is a new concept, and evaluation of the facility for its usefulness will provide an understanding in terms of students' point of view. Towards this, a weekly survey is incorporated within the facility that students need to complete at the end each laboratory session. The survey will prompt automatically, and to ensure the data collection, the web application is programmed in such a way that a student can not continue with next week's experiment without completing the survey after the prior experiment. A list of the questions is provided in Appendix-B.

The questions are designed in such a way that these will allow the facilitator to get an understanding about the facility's performance in terms of accessibility, user friendliness, logical arrangement of the information provided, and level of attraction with the web presentation. Students will be queried regarding their interest level in the material, adequacy of background preparation, usefulness of the handouts, effectiveness of the tutorials, knowledge acquired from each topic, relevance of course materials, ease of access to the Internet facility, and suggestions for improvement. The collected data will have both short term and long term use. As a short term use, the responses will be reviewed by the facilitator on a weekly basis and will be modified, upgraded, or altered through improvement/updating of the teaching materials, experimental facility, and delivery approach. The long term use involves the quantitative analysis of the collected data for a complete semester and review to identify the aspects of the facility that can be enhanced for future developments.

In addition to the weekly surveys, the facility is equipped with collecting facility usage data. These data will allow the facilitator to know the

level and timings of use of the facility and hence provide a broader understanding of the students' behavior in terms of use of the facility. The details of the user activities data collection are provided in the section on Administrative activities .

Learning Outcomes

While implementing the project, learning outcome is another important factor that needs to be assessed. Towards this effort, the class will be divided into two groups (control group and test group). The control group will attend the traditional laboratory and will not have access to the developed facility; while the test group will attend the laboratory class using the developed facility. The control group and the test group will be formed with even distribution of gender, ethnic minorities, and achievement levels.

Both groups will be given pre- and post-tests at different stages of the course, and differences between the pre- and post-tests will be compared between the control group and the test group with both descriptive and inferential statistics. In addition, before, during, and after the proposed environment is developed, departmental faculty, and program industrial advisory board members will be completing questionnaires on: a) the usefulness and user-friendliness of the environment and b) their overall assessment of the management of the proposed project.

A formative evaluation will be conducted through pre- and post-tests at the completion of each laboratory session. The summative evaluation will be conceptualized in terms of determining the effectiveness of the project relative to the existing traditional teaching methods. With this intention in mind, tests and surveys will be conducted with two groups of students at the end of the course. The students will be tested to determine their level of mastery of the subject area and their interest level in the topics and applications covered. The final grade from this course will also be used as an input

towards the summative evaluation process. The students' perceptions of the lasting impact of this project and the effectiveness of vertical integration will be addressed through the performance evaluation of the students during their senior years.

Conclusions

The paper presents the development of a modular Internet-based laboratory facility for offering an undergraduate introductory digital electronics laboratory course. This facility will allow the students to perform an experiment over the Internet with unlimited access time. Offering a laboratory course over the Internet as a part of a regular program is a unique initiative. In addition to access to the experiments, the facility has in-built evaluation and maintenance facility and a provision for monitoring client access profiles. In terms of hardware and software, the facility is composed of five independent modules: experiments, interfacing, GUI, sever, and Client access. The modular approach allows the facility to be used for other courses/experiments without much change. Considering the ease of use, flexibility, and Internet adaptability, National Instrument's hardware and software are used to provide the interfacing between the experiment and the server. Internet access and associated applications are developed by using Windows 2003 Server as the operating system, IIS server, .NET, XML, XSLT, and SQL server 2000. All the hardware and software used for this development are currently available commercial technologies. In comparison with custom built existing systems, this approach made the facility adaptable with a range of experiments in a cost effective manner.

There are 12 laboratory sessions implemented through the facility, involving a total of 37 experiments. For each laboratory sessions, a number of experiments will be activated for student access for a week. At any point in time, all the experiments (for a given laboratory session) can be accessed by the students; however, to obtain a meaningful outcome from

an experimental run, a single student can have full control over the experiment and will be known as the performer. While the others (who will try to access the same experiment) will be able to view the experiment without any control over the experiment and will be known as the viewers.

Evaluation is an important factor for the developed facility. There are two approaches of evaluation: one is to evaluate the system itself in terms of its user friendliness and effectiveness and the other is to evaluate students' learning outcomes. The first approach of the evaluation is incorporated within the facility as web applications. While the second approach, involves formative and summative evaluation using a control group and test group.

Acknowledgements

This paper is based on the project titled Design and Development of Internet-based Physical Laboratory Facility for an Undergraduate Course funded by the National Science Foundation under NSF Award Number DUE-0442374. Any opinions, findings and conclusions or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of the National Science Foundation. The authors also like to acknowledge the assistance of Professor Clifford Mirman, Chair of the Technology Department and Professor Promod Vohra, Dean of College of Engineering and Engineering Technology, for their support in various ways.

References

1. A. P. Boyle, D. N. Bryon, and C. R. C. Paul, Computer-based learning and assessment: A palaeontological case study with outcomes and implications, *Computers and Geosciences*, 23(5), 573-580 (1997).
2. T. K. Grose, Can distance education be unlocked, *PRISM*, April, 19-23 (2003).
3. G. Bengu and W. Swart, A computer-aided total quality approach to manufacturing education in engineering, *IEEE Transactions on Education*, 39(3), 415-422 (1996).
4. J. Palais and C. G. Javurek, The Arizona State University electrical engineering undergraduate open laboratory, *IEEE Transactions on Education*, 39(2), 257-264 (1996).
5. K. H. Ng and R. Komiya, Multimedia textbook for virtual education environment, *Engineering Science and Education Journal*, April, 73-79 (2002).
6. J. C. Swearingen, S. Barnes, S. Coe, C. Reinhardt, and K. Subramanian, Globalization and the undergraduate manufacturing engineering curriculum, *Journal of Engineering Education*, April, 255-261 (2002).
7. M. O., Tokhi, A. K. M. Azad, and H. Powrwanto, SCEFMAS: A Simulink environment for dynamic characterization and control of flexible manipulators, *International Journal of Engineering Education*, 15(3), 213-226 (1999).
8. S. Hagg and J. C. Palais, Engineering online: Assessing innovative education, *Journal of Engineering Education*, 91(3), 285-289 (2002).
9. R. L. Mott, G. P. Neff, M. J. Stratton, and D. C. S. Summers, Future directions for mechanical manufacturing, and industrial engineering technology programs, *Journal of Engineering Technology*, 19(1), 8-15 (2002).
10. L. A. Burgess, WebCT as an E-learning tool: A study of technology students' perceptions, *Journal of Technology Education*, 15(1), (2003).

11. K. K. Tan, K. N. Wang, and K. Z. Tang, Mechatronic experiments on remote vibration monitoring and fault diagnosis via the Internet, *International Journal of Engineering Education*, 19(3), 503-511 (2003).
12. Ch. Salzmann, D. Gillet, and P. Huguenin, Introduction to real-time control using LabVIEW with an Application to distance learning, *International Journal of Engineering Education*, 16(3), 255-271 (2000).
13. L. S. Chumbley, C. P. Hargrave, K. Constant, B. Hand, T. Andre, and E. A. Thompson, Project ExCEL: Web-based scanning electron microscopy for K-12 education, *Journal of Engineering Education*, April, 203-210 (2002).
14. J. B. Dabney, J. McCune and F. H. Ghorbel, Web-based Control of the Rice SPENDULAP, *International Journal of Engineering Education*, 19(3), 478-486 (2003).
15. I. Gustavsson, A Remote Access Laboratory for Electrical Circuits Experiments *International Journal of Engineering Education*, 19(3), 409-419 (2003).
16. C. C. Ko, B. M. Chen, S. Hu, V. Ramakrishnan, C. D. Cheng, Y. Zhuang, and J. Chen, A web-based virtual laboratory on a frequency modulation experiment, *IEEE Transaction on Systems, Man, and Cybernetics*, - Part-C, Applications and Reviews, 31(3), 295-303 (2001).
17. M. Manasseh, E. Kausel, and K. Amaratunga, A web-accessible shaking table experiment for the remote monitoring of seismic effects in structures, *Proceedings of the American Society of Engineering Education Annual Conference and Exposition*, Salt Lake City, Utah (2004).
18. N. Chao and B. Mohr, Real hand-on laboratory experiments, anytime, anywhere, *ASEE National Conference*, Albuquerque, New Mexico, June 25, (2001).
19. H.A. Malki and A. Matarrita, Web-based control systems laboratory using LabVIEW, *Journal of Engineering Technology*, Spring, 22-25 (2003).
20. MathWorks, Developers of MATLAB and Simulink for Technical Computing, <http://www.mathworks.com/>, (2004).
21. National Instruments, Measurement and Automation, <http://www.ni.com/>, (2004).
22. Special Issue: LabVIEW applications in engineering education, *The International Journal of Engineering Education*, 16(3), (2000).
23. J. Essick, *Advanced LabVIEW Labs*, Prentice-Hall, (1999).
24. J. Travis, *Internet Applications in LabVIEW*, Prentice-Hall, (2000).
25. S. Kariya, Online education expands and evolves, *IEEE Spectrum*, May, 49-51 (2003).
26. S. Walther, *Active Server Pages Unleashed*, Sams.net Publishing, (1998).
27. ASP Tutorial, Microsoft Corporation, <http://www.w3schools.com/asp/default.asp>, (2000). (viewed on 11th of August 2004).

Biographical Information

Abul K. M. Azad is an Assistant Professor with the Department of Technology of Northern Illinois University, USA since July 2001. He obtained his PhD in 1994 from the University of Sheffield, UK, which was sponsored by the Commonwealth Scholarship, UK. Subsequently he worked with the University of Sheffield and University of Portsmouth (UK) in various capacities. His research and teaching interests

include Internet-based physical experiments, mechatronics, real-time computer control, adaptive/intelligent control, and mobile robotics. Dr. Azad has over 75 referred journal and conference papers and one edited book in these areas. He has active membership and involvement in several learned societies, including the IEE, IEEE, ASEE, and ISA; and is also a IEEE nominated evaluator for the Accreditation Board for Engineering and technology (ABET, USA).

Xueshu Song received his PhD from The Pennsylvania State University in 1989 and is a licensed professional engineer in the State of Illinois. He is a Professor of Engineering Technology at Northern Illinois University, USA. He has been the principal and co-principal investigator for eight application software development projects funded by the National Science Foundation. He is active in professional societies.

Appendix-A

Laboratory sessions those are implemented through the Internet-based laboratory facility are as below:

- Session-1: Basic Logic Gates
- Session -2: Laws and Rules of Boolean algebra
- Session -3: Associative and Distributive Law
- Session -4: DeMorgan's Theorem
- Session -5: Simplification of Logic Function using Karnaugh map
- Session -6: Traffic Light Controller for an Intersection
- Session -7: Alarm System and Copy Machines
- Session -8: Half-Adder and Full-Adder
- Session -9: Multiplier and Comparator
- Session -10: Multiplexer and Demultiplexer
- Session -11: Flip-Flops and Counters
- Session -12: Bi-directional shift register with parallel load

Appendix-B

These are the questions that the students are going to answer every week after completion of a laboratory session.

Please answer the following questions based on your experience in using the Internet-based laboratory facility.

Q1: The Internet-based laboratory facility is a very good idea:

- a) Strongly agree
- b) Agree
- c) Disagree
- d) Strongly disagree

Q2: The Internet-based laboratory facility is not a good idea at all:

- a) Strongly agree
- b) Agree
- c) Disagree
- d) Strongly disagree

Q3: Anywhere/anytime nature of the Internet-based laboratory facility is a useful feature:

- a) Strongly agree
- b) Agree
- c) Disagree
- d) Strongly disagree

Q4: Anywhere/anytime nature of the Internet-based laboratory facility is not that useful feature:

- a) Strongly agree
- b) Agree
- c) Disagree
- d) Strongly disagree

Q5: I would prefer to take another laboratory course over the Internet:

- a) Strongly agree
- b) Agree
- c) Disagree
- d) Strongly disagree

Q6: I would not prefer to take another laboratory course over the Internet:

- a) Strongly agree
- b) Agree
- c) Disagree
- d) Strongly disagree

Q7: From my own perception I think level of learning with Internet-based laboratory is similar to the traditional facility:

- a) Strongly agree
- b) Agree
- c) Disagree
- d) Strongly disagree

Q8: From my own perception I think level of learning with Internet-based laboratory is higher than the traditional facility:

- a) Strongly agree
- b) Agree
- c) Disagree
- d) Strongly disagree

Q9: From my own perception I think level of learning with Internet-based laboratory is less than the traditional facility:

- a) Strongly agree
- b) Agree
- c) Disagree
- d) Strongly disagree

Q10: Support materials provided for the Internet-based laboratory facility was useful:

- a) Strongly agree
- b) Agree
- c) Disagree
- d) Strongly disagree

Q11: Support materials provided for the Internet-based laboratory facility was not useful:

- a) Strongly agree
- b) Agree
- c) Disagree
- d) Strongly disagree

Q12: Performing experiments over the Internet was easier than I expected:

- a) Strongly agree
- b) Agree
- c) Disagree
- d) Strongly disagree

Q13: Performing experiments over the Internet was harder than I expected:

- a) Strongly agree
- b) Agree
- c) Disagree
- d) Strongly disagree

Q14: The amount of work associated with the Internet-based laboratory experiments are more than I expected:

- a) Strongly agree
- b) Agree
- c) Disagree
- d) Strongly disagree

Q15: The amount of work associated with the Internet-based laboratory experiments are less than I expected:

- a) Strongly agree
- b) Agree
- c) Disagree
- d) Strongly disagree

Q16: The navigation through the Internet-based laboratory system was user friendly:

- a) Strongly agree
- b) Agree
- c) Disagree
- d) Strongly disagree

Q17: The navigation through the Internet-based laboratory system was difficult:

- a) Strongly agree
- b) Agree
- c) Disagree
- d) Strongly disagree

Q18: In comparison with other usual sites I rate the speed of this site as quite high:

- a) Strongly agree
- b) Agree
- c) Disagree
- d) Strongly disagree

Q19: The speed of this site is relatively lower in comparison with other usual sites:

- a) Strongly agree
- b) Agree
- c) Disagree
- d) Strongly disagree

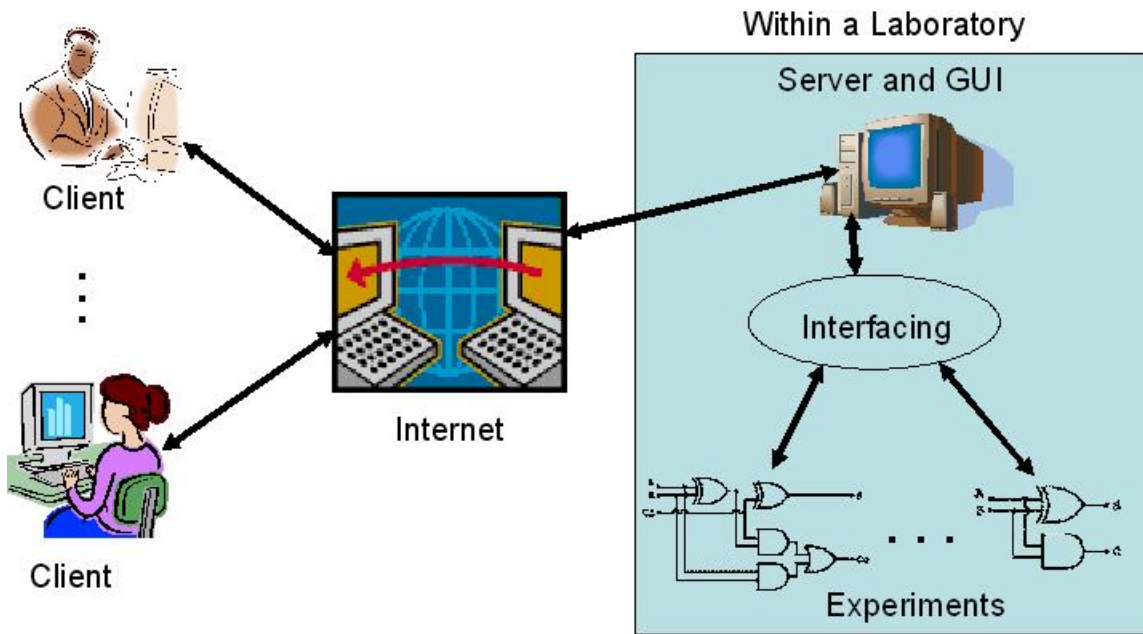


Figure 1: System Structure.

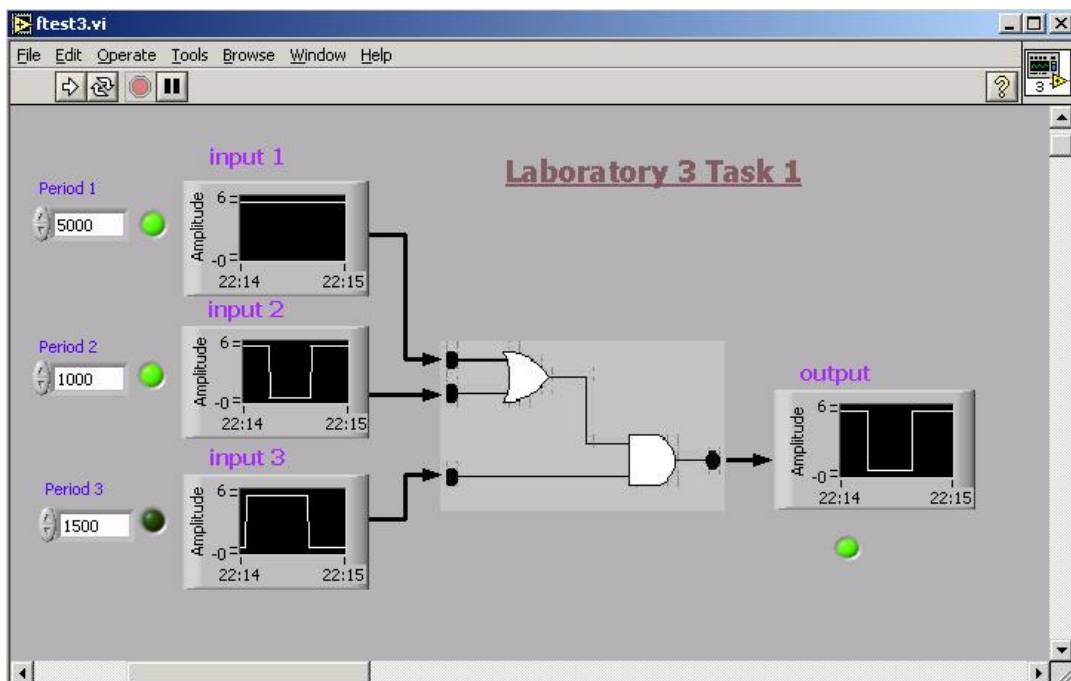


Figure 2: A GUI for 3-input 1-output system.

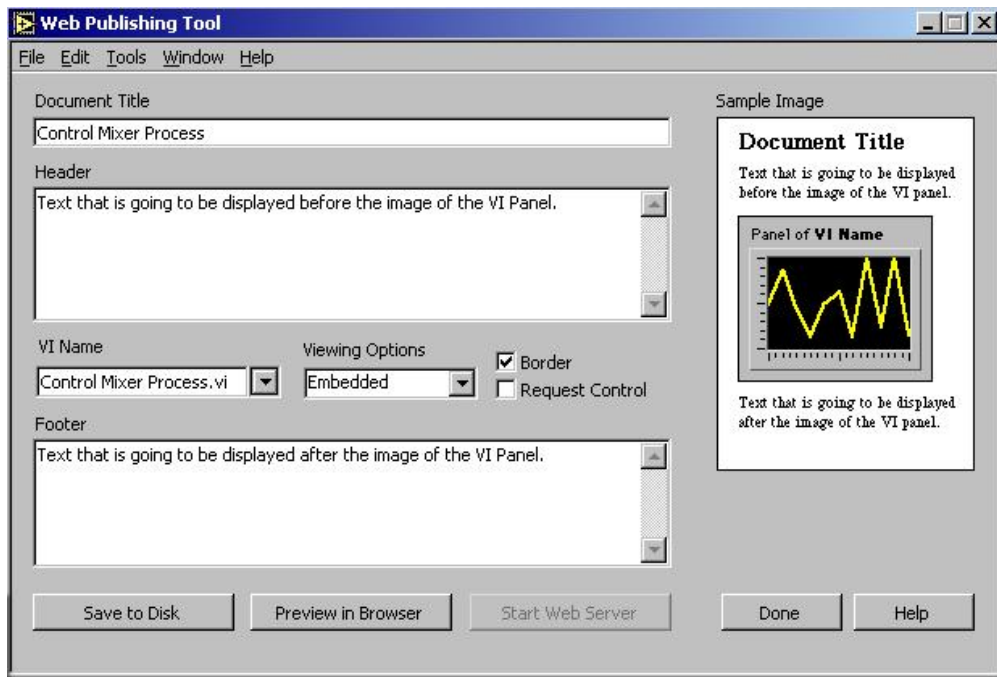


Figure 3: An image of the web publishing tool dialog box.

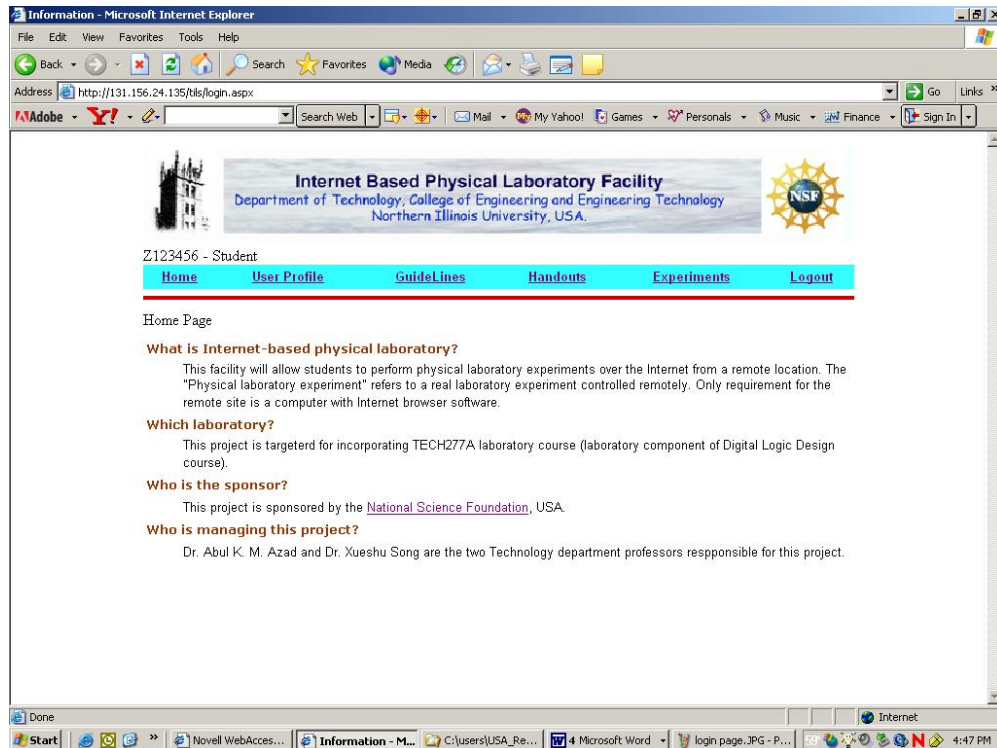


Figure 4: Homepage with client login access.

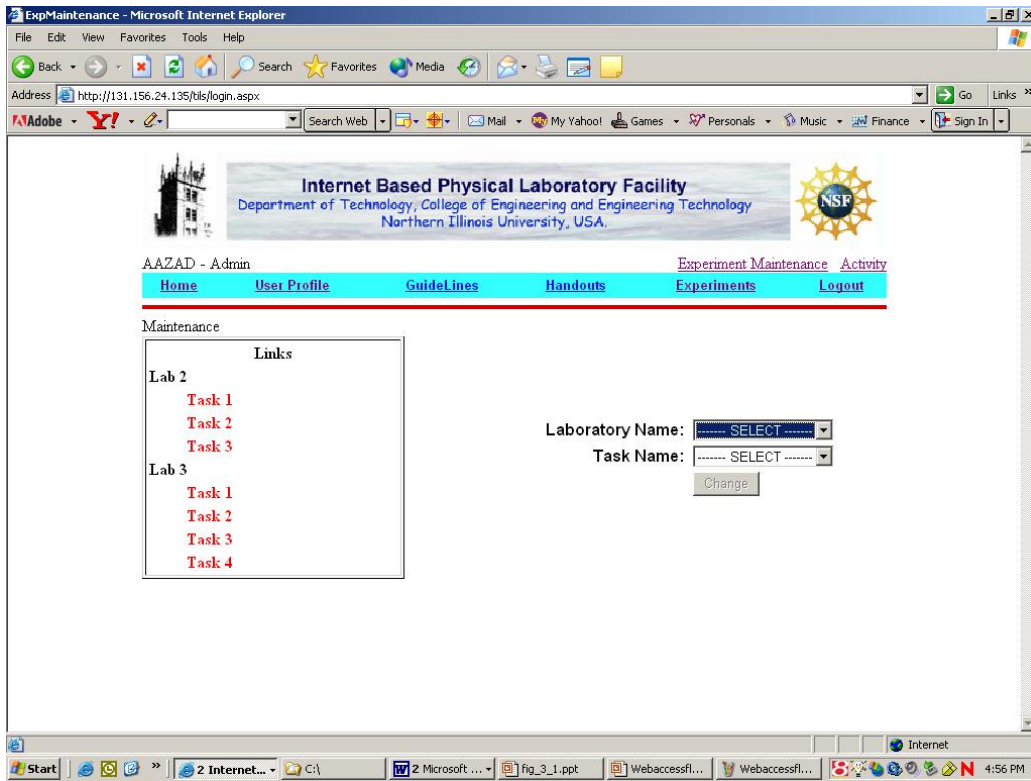


Figure 5: Homepage with administrator login access.

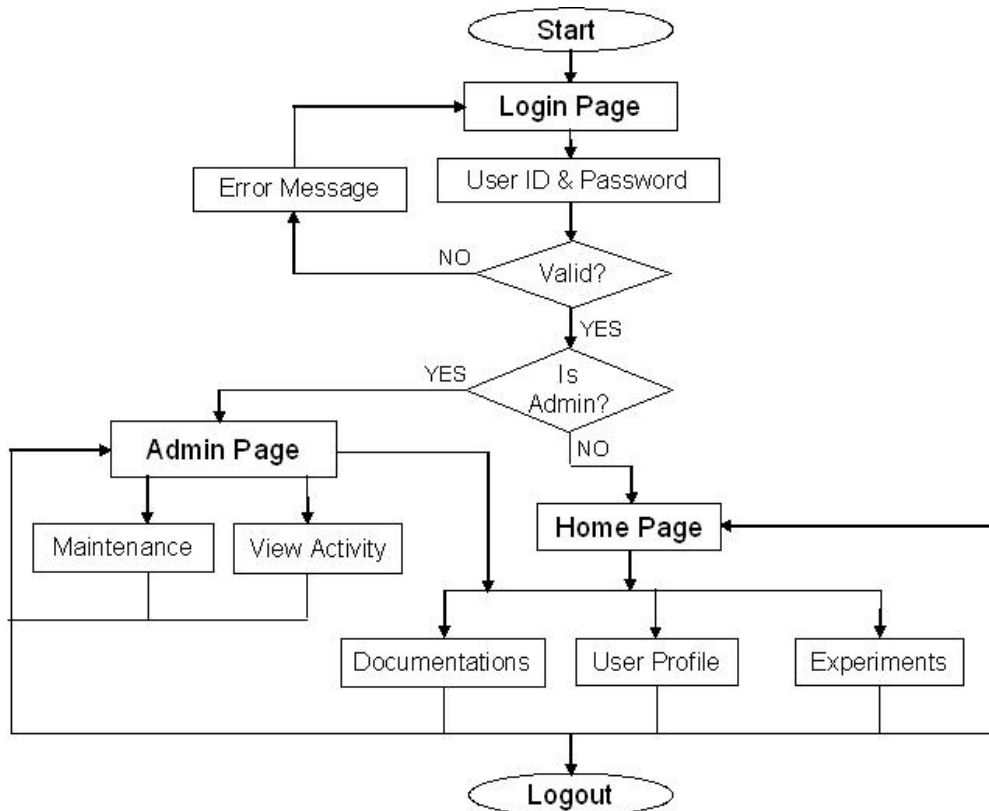


Figure 6: Browsing map for the facility.

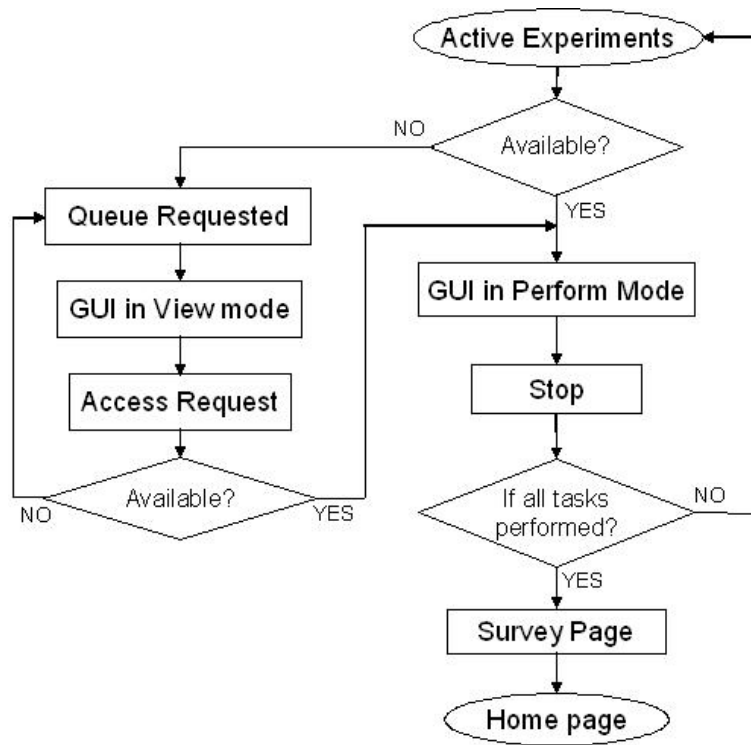


Figure 7: Level of access to the experiments.

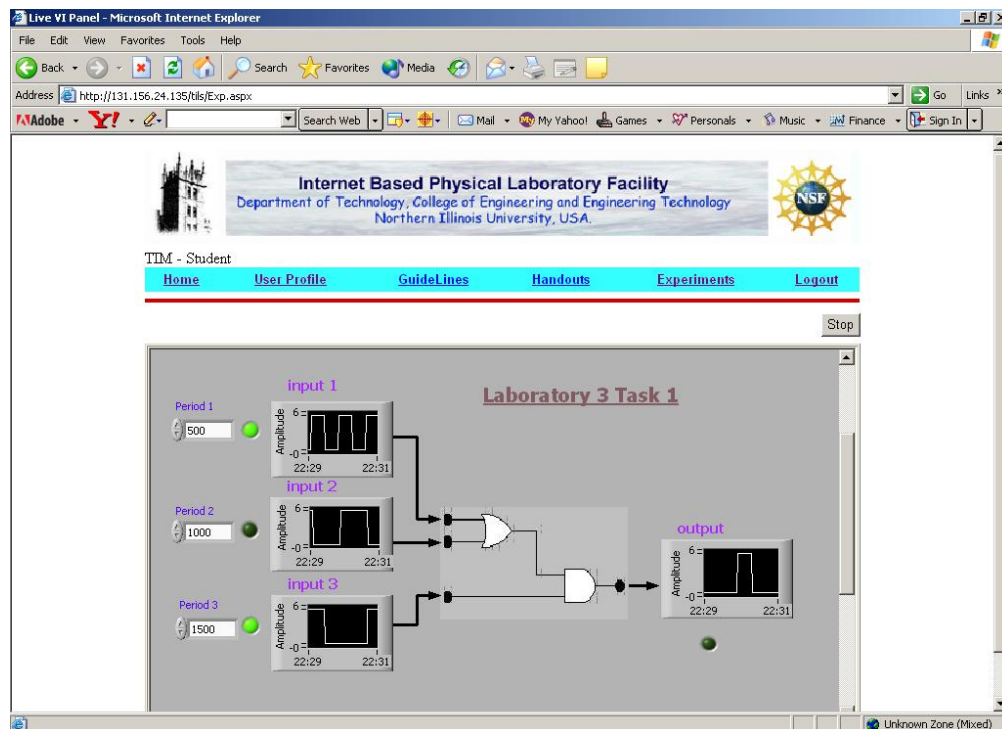


Figure 8: Image of a performer page.

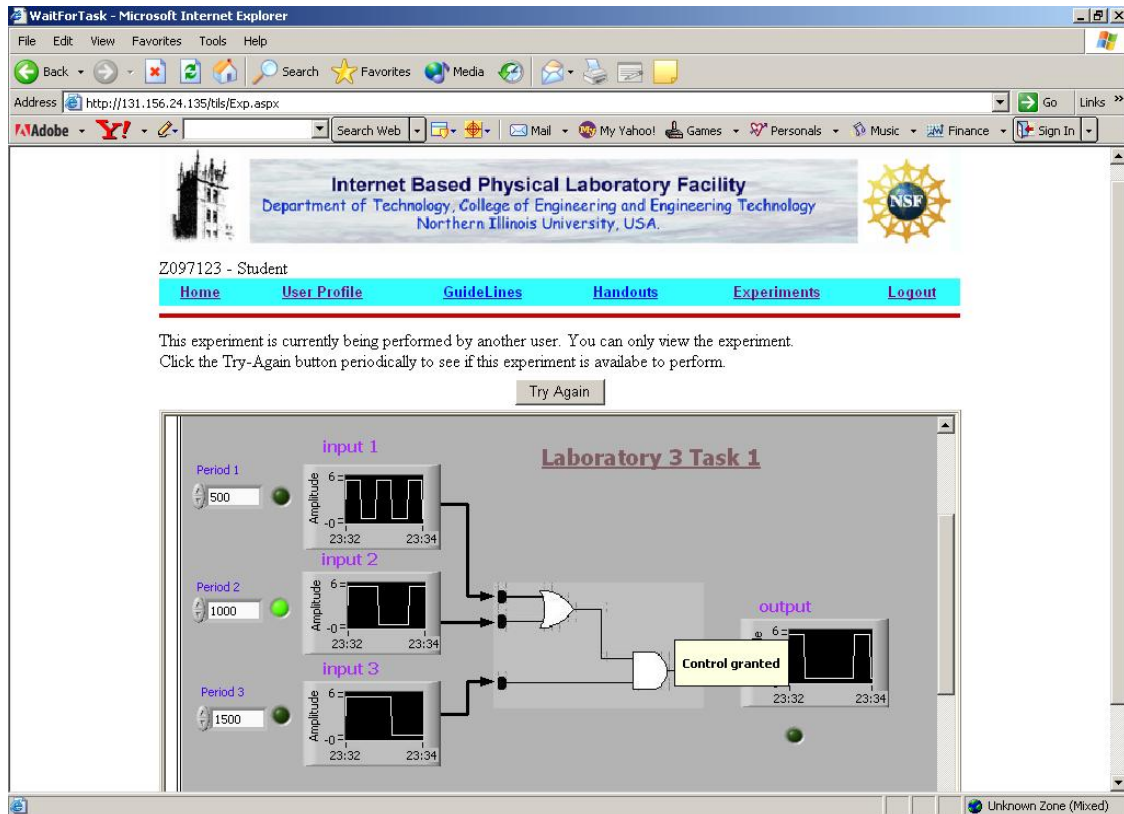


Figure 9: Image of a viewer page.

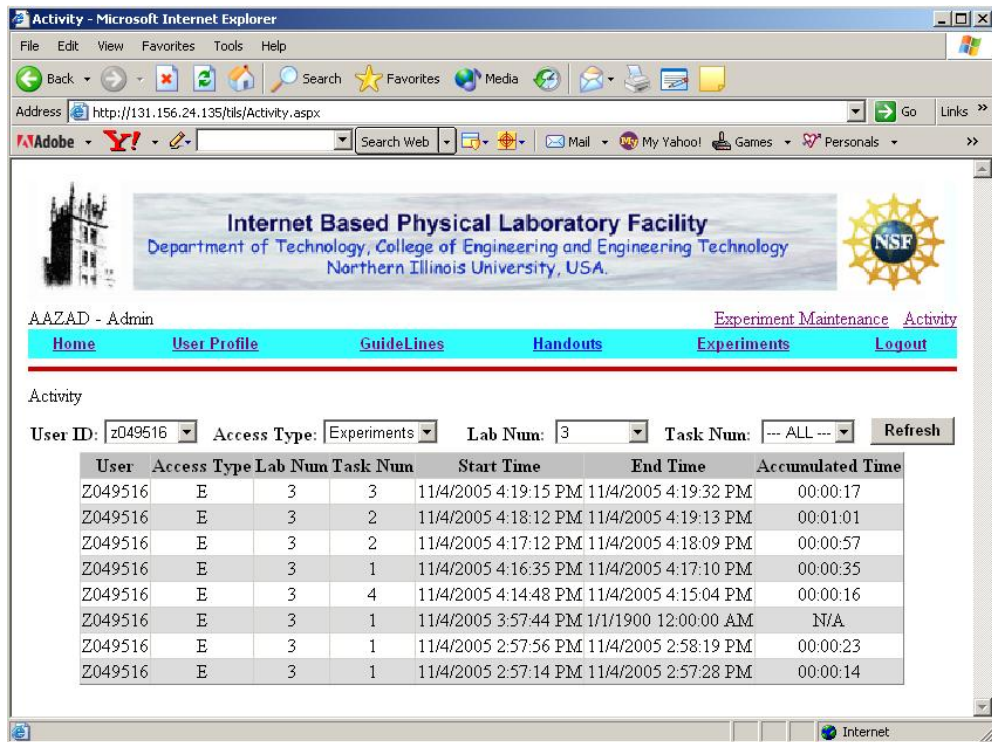


Figure 10: Activity page with administrative login.