Internet-Based Laboratory Experiments: Exploring its Potential

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Abstract

It is a major challenge for engineering and engineering technology educators to provide students with an adequate laboratory experience at a time and place convenient for them. This applies both the traditional laboratory courses as well as laboratory courses as a part of distance learning programs. To address this issue, a number of initiatives have been taken by researches to develop facilities that can be used to deliver Internet-based laboratory experiments. This will allow the students to perform experiments on real-life hardware equipment/experiments from a remote location over the Internet. The Internet-based laboratory facility, either as a replacement of or a supplement to traditional laboratories, has valuable benefits by allowing a more efficient management of the laboratories as well as facilitating distance-learning programs.

The paper illustrates the current status of Internet-based education with an emphasis to remote laboratory facilities. A number of reported research initiatives are reviewed and their features and drawbacks are highlighted. The review process also identified key challenges that need to overcome to make the Internet-based laboratories more efficient, cost effective, and appealing. To address some of these issues the author has developed a modular approach for the design of Internet-based laboratories. The issues that have been addressed through the design include hardware and software selection, computer interfacing, web delivery, network security, and system administration. A number of recommendations have also been presented to explore the potential of Internet-based laboratory and to enhance their popularity.

Introduction

An existing challenge for engineering educators is that of providing students with an adequate laboratory experience at a time and place convenient to the students. A concomitant problem is to adequately use the facilities that exist, but that are often under-used. One potential solution is to create an on-line laboratory that enables students to conduct all necessary experiments at a time and place of their own choosing and to do so at their own pace. It is anticipated that such an on-line facility would enhance students learning process and increase their retention rate. It could be used both as a stand-alone laboratory course within a distance-learning program and also to complement a traditional face-to-face course. It could also be used at the high-school level to provide an affordable laboratory experience that would better prepare students for college level engineering courses.

To address these issues, there are a number of initiatives that have been made to provide experimentation facilities over the Internet [1, 2, 3, 4, 5, 6, 7]. None of these facilities are designed to deliver a laboratory course that is a part of a regular educational program. In addition to these, they 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.

One of the major limitations of existing Internet-based distance-learning programs is their failure to deliver the laboratory related courses [8, 9, 10]. 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. Currently, students have to visit a campus to perform the laboratory sessions for these kinds of courses or there has to be an arrangement of mobile laboratories stationed at few predetermined locations for a given period of time [11, 12, 13]. 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 [14, 15]. Making the laboratory experiments accessible through the Internet would address this need [7, 10].

This paper is divided into three parts. The first part will provide a detailed review of research initiatives in Internet-based education including the Internet-based laboratory facilities. While identifying the potential of Internet-based laboratory, the paper also highlights the drawbacks of the developed systems. The second part of the paper presents the description of Internet-based laboratory facilities that have been developed by the author for last couple of years. The description includes the system design in terms of hardware and software selection, computer interfacing, web delivery, network security, and system administration. The last part of the paper provides some recommendations that can be considered to explore the potential of Internet-based laboratory and to enhance their popularity.

Background Research

Use of Internet Technology in Education

The Internet is now extensively used as a connectivity and reference tool for commercial, personal, and educational purposes [11, 14, 10]. In education, it has opened a variety of new avenues and methodologies for enhancing the experience of learning as well as for expanding educational opportunities for a larger pool of students [16, 17, 18, 19]. Specially, distance education and nontraditional classrooms have the capability to reach more students using specialized instruction and self-paced learning. Furthermore, it appears that on-line education will continue to evolve in all sectors of engineering education around the world and the process is irreversible [20, 21]. Integration of the Internet with the education system has been described by Poindexter and Heck [22, 23]. Furthermore, there are now a number of companies who offer web-based academic resources that can be used for on-line courses [24, 25, 26]. However, in almost all the cases, web courses are only based on theoretical/simulation materials [27, 28, 29, 30]. Yet, though limited, even this offering of engineering and technology courses over the Internet has already proven to increase the student retention rate by providing diversity of choice and convenience [31, 32, 33]. In one instance it is also reported that in terms of learning outcome the on-line method yields a higher level of efficiency than traditional lectures, despite the inherent drawbacks of the approach, such as lack of class interaction and the increased selfdiscipline required by the students [34, 35]. These positive findings indicate the probable benefits of an on-line laboratory facility.

Evidence of Need for Internet-based Laboratories

Traditional laboratory classes are scheduled only for a specified time period. 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 [36]. Sometimes students also like or feel a need to perform additional experiments beyond their assigned tasks. It is difficult to accommodate such extra experimentation because universities often lack of resources to keep their laboratories open for additional hours [31]. On top of it, laboratory facilities are often inaccessible to the students of other departments within a same institution because of their geographical location. Ironically, too, much laboratory equipment lies idle during most of their usable lifetime [9]. An Internet based laboratory facility would address this problem by providing unlimited access to an experiment and hence maximize the use of available resources.

In addition to being a part of a distance-learning program, the Internet based laboratory facility can also be used to complement the classroom based laboratory classes. Meanwhile, at the high school level, the Internet has already proved to be effective in preparing rural and inner-city students where there is no provision of advanced placement courses. It enables them to compete with other students in top colleges and move towards bridging the digital divide [37, 38]. These kinds of facility, either as replacement or supplement of traditional laboratories, have 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.

Research on Internet-based Laboratories

Although, a number of attempts have been made to provide students with practical exercises or experimentation experience through the web, they all suffer from one or more of the three main drawbacks. These are: a) complexity and cost; b) limited availability of experimental data and plots to the client side; c) one server PC can provide access to only one experiment at a point in time. In this light, some of the initiatives towards Internet-based laboratory experiments are discussed below. In two cases researchers have developed experimental demonstrations in which robots can perform a few simple maneuvers from a distant location over the Internet [2, 3]. Implementing these demonstrations required the development of a complex system. Iowa State University, meanwhile, has developed an experimental facility to train K-12 teachers [1]. This facility provides hands-on experimental experience with a scanning electron microscopy (SEM). Considering the cost of an SEM it would be impossible to provide this training without the Internet-based laboratory facility. However, implementation of this experiment was quite costly. Ko and co-researchers, meanwhile implemented Internet based laboratory experiments for a communication course [4]. This was implemented to perform only one experiment while the data are not available to the client PC. Chao & Mohr [6] also developed a mechanism for performing experiments on the Internet. Their system although cost effective, could not address the problem of accessing multiple experiments without human intervention. In addition, the data cannot be made available to the client PC. Although the Internet-based laboratory facilities have a number of potential benefits, these drawbacks hinder the process of gaining their popularity.

Some recent initiatives have attempted to provide a couple of experiments on a dynamic systems laboratory and a basic electronics laboratory over the Internet [39, 40, 41]. All these initiatives suffer restrictions in data accessibility from client PCs and of being capable of operating only one experiment at a time. Apart from this, almost all the above cases entailed custom designed hardware and software to interface with a PC.

While a number of companies have developed components and devices that can be assembled with suitable software to make a laboratory experiment available over the Internet these products are expensive and difficult to customize for more than one experiment without human intervention [42]. There is no single facility where a student can perform all the experiments offered for a laboratory course.

System Structure

This section will present the structure of the systems that has been developed by the author over the last couple of years. All the systems are developed in a modular fashion 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) Clients.

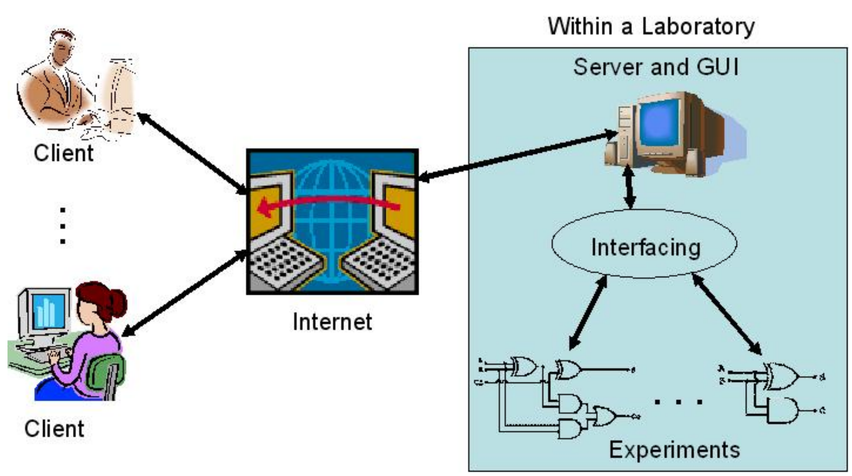

Figure 1: Modular system structure.

The individual laboratory experiments are connected to the server through a suitable interfacing 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 graphical user interface (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.

Interfacing Hardware and Software

The first step towards the Internet-based 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.

Considering both the analog and digital nature of the signals, used Input/ Output (I/O) cards have the capability to deal with both the analog and digital signals. The I/O cards used for these developments are from National Instruments. The selection of a card was based on the number of input and output requirements, number of digital and analog inputs/outputs, and speed of operation required for the experiments.

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 [43, 44].

GUI and Web Presentation

A GUI 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 [21]. 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. Examples of two GUIs developed for two separate experiments are described as follows.

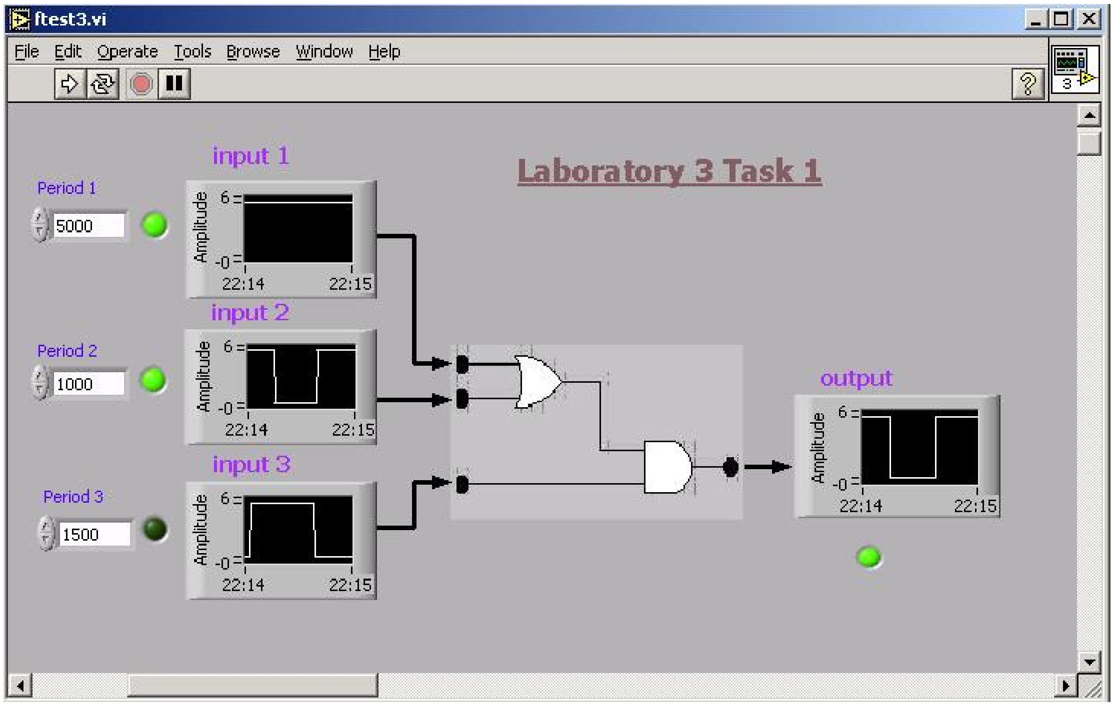

Figure 2: A GUI for 3-input 1-output system.

An image of a GUI developed for a digital laboratory experiment is shown in Figure 2. The left 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 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 passes the inputs to the experiment and receives corresponding output through appropriate ports of the I/O card.

An image of the web page for a motor health condition monitoring experiment is shown in Figure 3. The web page consists of two individual entities. One is the GUI (with graphs and controls) and the other is the Windows Media Player panel. The GUI and the video panel are merged into this web page using the html frames. The graphs within the GUI are presenting time and frequency domain information that can be analyzed remotely.

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.

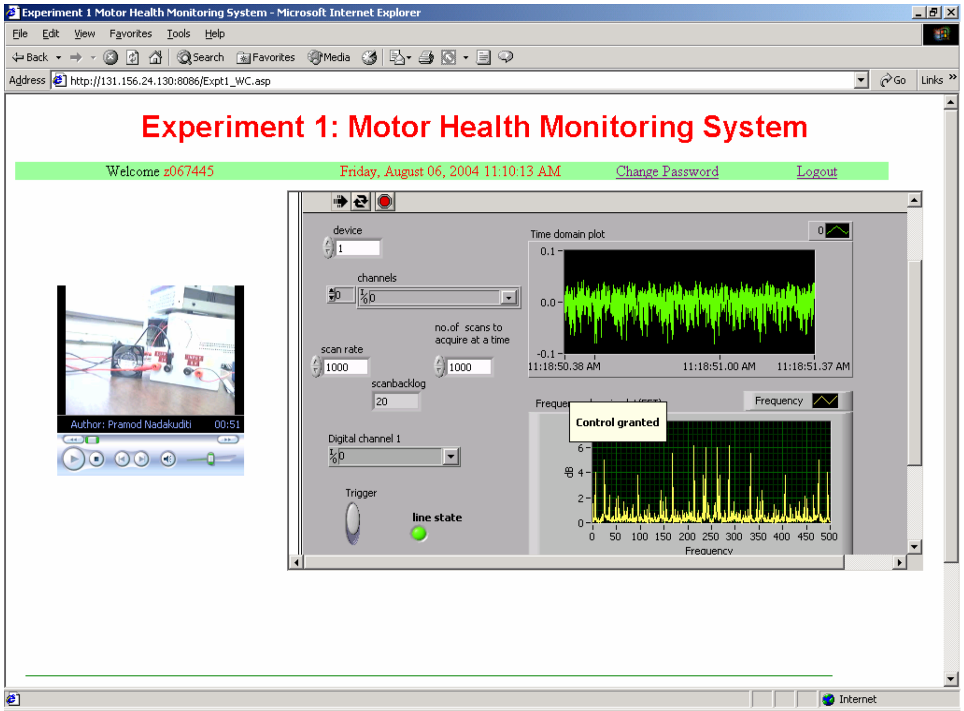

Figure 3: An image of the web page viewed by the clients from a remote location.

A web server is hosting the web site for the facility including all the applications and interfacing hardware and software, with a 3.6GHz processor, 2GB of RAM, 80 GB of HD, and a National Instrument's I/O card. 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.

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 [45, 46].

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.

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. An image of the homepage with client login is shown in Figure 4.

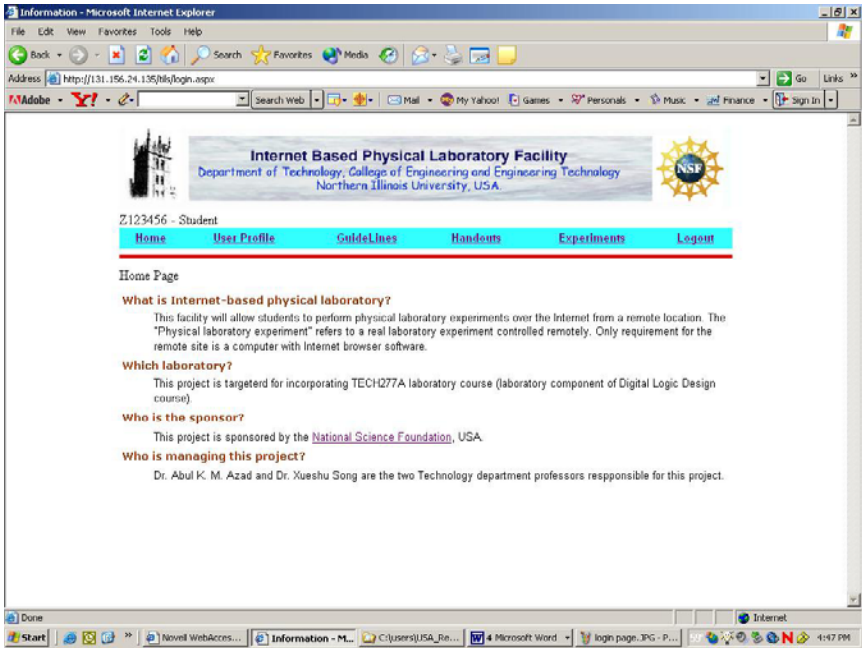

Figure 4: Homepage with client login access.

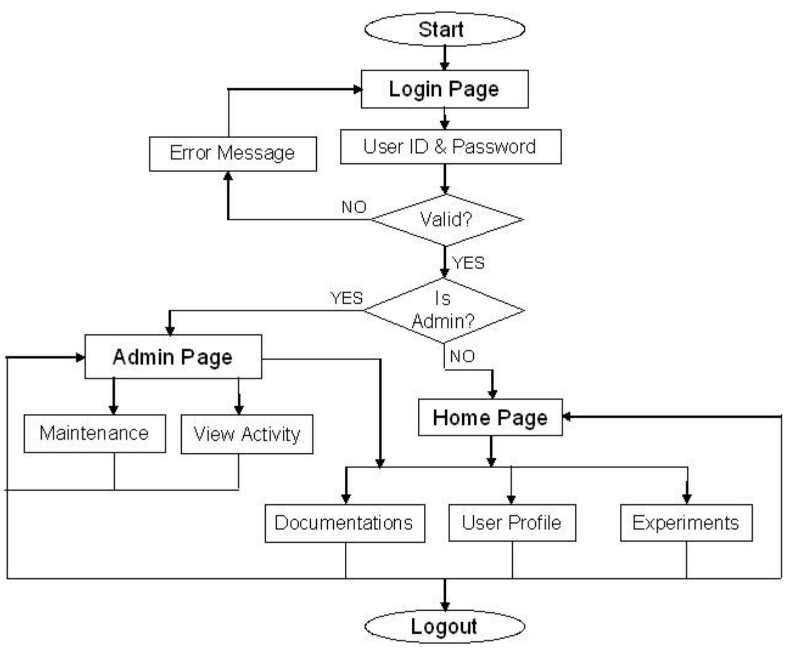

Figure 5: Browsing map for the facility.

A flowchart showing the browsing map for client and administrative levels of access is presented in Figure 5. Apart from the home page, the client level of access allows the users to have three areas to browse: Documentations, UserProfile, and Experiments. While 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.

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.

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.

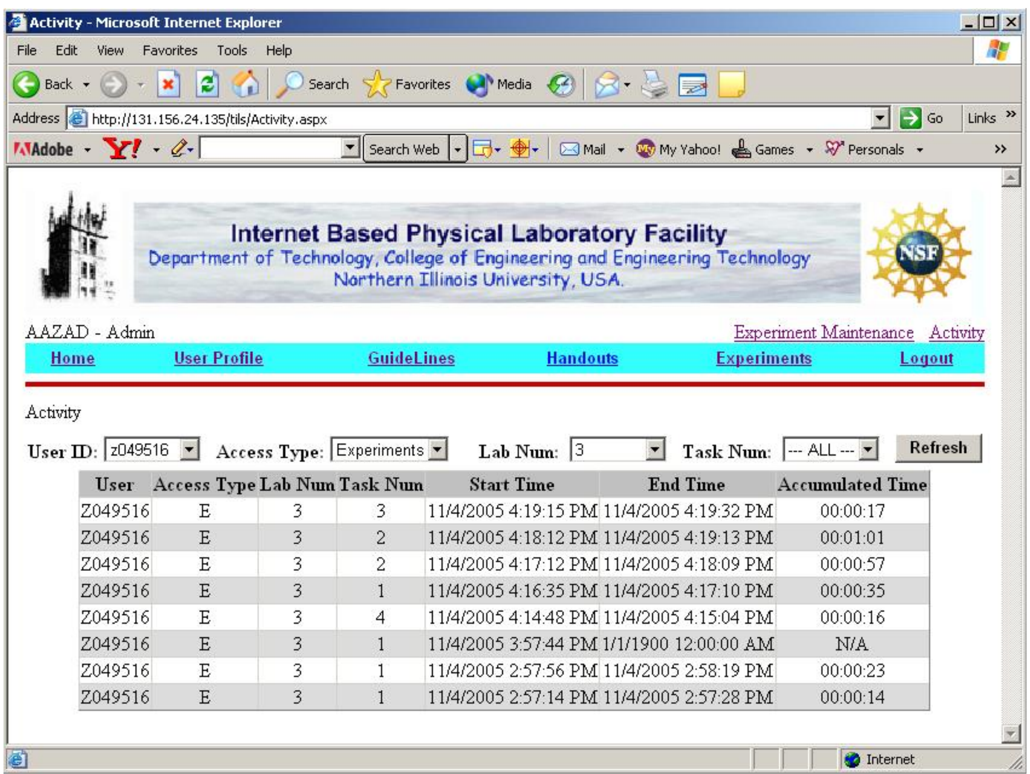

Figure 6: Activity page with administrative login.

Considering this as a 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 web application. An image of the activity page is shown in Figure 6. 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 make adjustments/ changes to enhance the system's efficiency and effectiveness.

Discussions and Recommendations

Performing laboratory experiments over the Internet is a relatively new concept. As discussed in the introduction section, researchers are pursuing this problem in an abrupt manner and are yet to come up with a sustainable solution. Any development in this area requires expertise in computer interfacing, data acquisition and control, computer networking, web security, and real-time control. For the experiments reported in this paper, the author has developed a modular system, which is cost effective, expandable, and sustainable to some degree. The uniqueness of this system is the combination of its ease in implementation, its modularity in design, its web security, and its student evaluation facility. The modularity in system design will enable it to integrate with a large variety of laboratory experiments with very little cost and effort.

Considering different kinds of laboratory experiments in terms of their nature of input(s) and output(s), speed of operation, data collection restrictions, and data presentation, a number of issues need to be addressed to develop an effective, versatile, cost effective, and sustainable system that is acceptable and feasible for general use. The issues are identification of modules, standardization for module input(s) and output(s), and collaboration between academia and industry.

Conclusions

The paper presented a through discussion on the current status of Internet-based education with an emphasis to remote laboratory facilities. The importance and benefits of Internet-based laboratory is also highlighted along with the challenges and possibilities.

A web-based laboratory facility with video and audio feedback along with the provision of monitoring client access profiles has been presented. The system is developed using a modular approach, so that it can be implemented for other experiments without much effort in terms of time and resources. Considering the ease of use, flexibility, and Internet adaptability, NI hardware and software are used to provide the interfacing between the experiment and a PC. Internet access is provided by using an IIS web server, ASP, ActiveX, MS Access, Windows media player, and Windows media encoder. Some are part of the Windows XP operating system, while the others are available as freeware.

A series of web pages have been developed for implementing the client access and for monitoring system use. The authorized clients will be allocated UserID and Passwords to protect the experiments from any mishandling. Only an authorized client can perform an experiment with a full control over the experiment through the Internet; while the others can view the experiment GUI. To obtain a meaningful outcome from an experimental run, only one authorized client can have control over an experiment for any particular period of time.

The provision of the administrator page allows the system administrator to assess the level of use of the system along with the students' learning behavior in terms of the length of their access time. This will allow the administrator to establish the usefulness of the developed system. The developed facility can be used as a stand-alone laboratory course within a distance-learning program as a complement a traditional laboratory course. It can also be used at the high-school level to provide an affordable laboratory experience that would better prepare students for college level courses.

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Biography

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