Delivering a Remote Laboratory Course within an Undergraduate Program

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***Abstract*—This paper describes the offering of an undergraduate laboratory course over the Internet. The paper provides a brief description of a modular Internet-based laboratory facility using commercially available hardware and software, in-built password control and user tracking, and simultaneously accessibility to multiple clients. The modules are adaptable with a variety of laboratory experiments with little effort. The facility was used to deliver a remote laboratory course for an undergraduate digital electronics laboratory. An evaluation scheme was implemented to assess the effectiveness of the system as well students' learning outcomes. In-built capability to collect systems' operational data and weekly survey are used to evaluate the effectiveness of the system, while pre- and post-tests are utilized to measure the student learning outcomes.**

***Index Terms*—Remote laboratory, LabVIEW, embedded evaluation, and modularity in design.**

I. INTRODUCTION

Traditional laboratory classes for engineering and engineering technology programs require physical presence of students and an instructor within a laboratory. This leads to a number of limitations, such as, time limit for a class, geographical location, and management cost [1, 2, 3]. These result in limited laboratory access time and hence limit the utilization of available laboratory equipment during its usable lifetime [4]. A remote 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]. For these programs, currently, students have to visit a campus to perform the laboratory sessions or there has to be an arrangement of mobile laboratories stationed at a few predetermined locations for a given period of time [7]. These provide limited access to the experiments and are usually insufficient to complete their learning process. Making the laboratory experiments accessible through the Internet would address this need.

In addition, the remote laboratory facility can also be used to complement the classroom-based laboratory classes as well as bridge the digital divide by preparing students for their college education [8]. This remote laboratory facility, either as replacement or supplement of 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 while maximizing the use of available resources.

There are a range of technological developments to support the remote labs and a number of attempts have been made to provide students and researchers with practical exercises or experimentation experience over the Internet [9]. An editorial by Pester and Alves provides a general overview of these developments as well as the challenges and future possibilities of remote laboratories [10]. There are a number of reported recent developments providing remote access to mobile robotics, automation and control laboratories, robot control, electron microscopy, and the most challenging one is the offering of a chemistry laboratory [11, 12, 13, 14, 15, 16, 17]. In addition to educational applications, it has been demonstrated that the remote laboratory can also be used for industrial applications [18, 19].

All these initiatives have limitations in terms of restrictions in data accessibility from the clients' end, being capable of operating only one experiment at a time, difficult to expand due to custom built software and hardware, lack of in-built system management provision, and subsequent difficulty in maintenance. On top of this, none of the reported systems are used for delivering a complete regular laboratory course.

To handle some of the problems, the author has designed and developed a modular remote laboratory facility using commercially available hardware and software, in-built password control and user tracking, and accessibility to multiple clients at the same time. Modular design allows the system to adopt a range of experiments with no or little changes, while the use of commercially available products made it cost effective and relatively easy to maintain. In-built password control and user tracking provision allows an administrator/faculty to monitor the use of the facility while offering a laboratory course. Accessibility to the facility for multiple clients makes it efficient and cost effective.

This paper will report a brief description of the developed facility, along with detailed course offerings for a laboratory course. After this introduction, the first section describes the developed facility that has been used for the course offering. The second section provides the details of Internet delivery in terms of web application development and browsing structure. The third section provides the arrangement for course delivery. The fourth section provides the administrative activities within the facility. The fifth section illustrates the evaluation plan and its implementation. The sixth section outlines the future directions for remote laboratory facilities. This is followed by conclusions, acknowledgment, and list of publications.

II. MODULAR REMOTE LABORATORY FACILITY

This section will provide a brief description of the modular remote laboratory facility [20]. The system is developed through a grant from the National Science Foundation (Course, Curriculum, and Laboratory Improvement program). The uniqueness of the developed facility is its modularity in design, use of commercially available hardware and software technologies, and in-built assessment, evaluation, and monitoring facility.

Adopting a modular approach to the problem of designing a remote laboratory facility promises to dramatically improve the adaptability to a range of experiments that entails a wide range of uncertainties [21]. The idea is to decouple design decisions that are likely to change, so the decisions can be changed independently with minimum effects on the system as a whole [22]. Figure 1 shows a block diagram of the designed facility. The modules are a) experimetns; b) LabVIEW I/O and web publish; c) XML and XSLT technologies; d) SQL server; e) Visual Studio .NET; f) Internet cloud; and g) Clients [20].

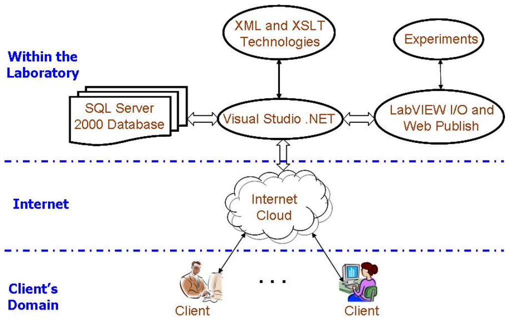

Figure 1: Modular system structure of the Internet-based laboratory facility.

A 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. An interfacing card from National Instruments is used for this purpose [23. 24]. 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, LabVIEW has its in-built server facility that can be utilized to publish a GUI (graphical user interface) to facilitate Internet access to the experiments [25, 26].

B Graphical User Interface and Web Presentation

One of the main components of the Internet-based laboratory facility is the GUI. This serves 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 that 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 [27]. A VI can easily export and share its data and information with other software applications.

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.

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 has 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.

III. INTERNET DELIVERY

The Internet delivery part of this facility involves a number of issues: system access levels, user profile and password control, documentation, experiments, weekly surveys, and administrative activities. All these issues are addressed within the facility to make it 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 documentation.

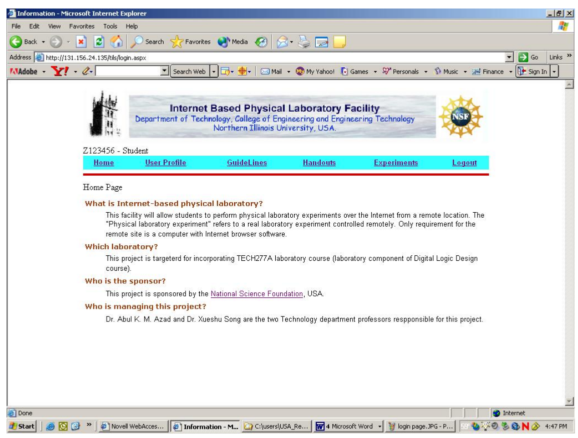

Figure 2: Homepage with client login access.

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 client level access. With this status, they 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 2 and 3, respectively.

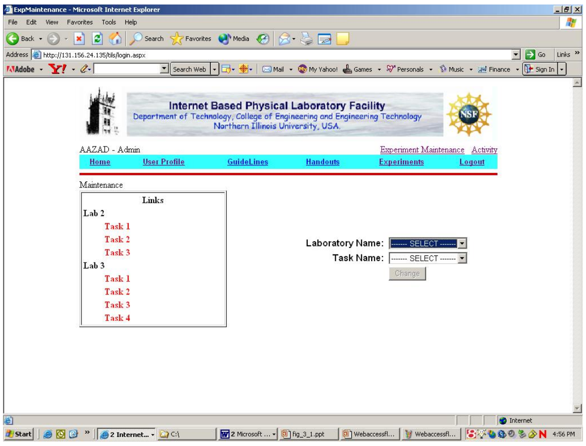

Figure 3: Homepage with administrator login access.

A flowchart showing the browsing map for client and administrative levels of access is presented in Figure 4.

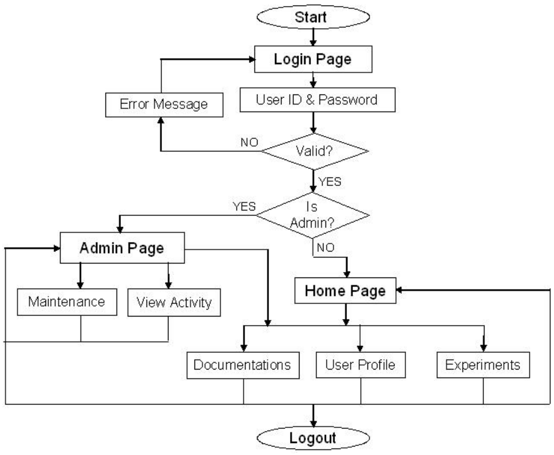

Figure 4: Browsing map for the facility.

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 activate and deactivate experiments and have access to the user profiles and weekly survey data.

IV. COURSE DELIVERY

Northern Illinois University offers the Blackboard system for its course delivery, and it has some features that can be beneficial for the delivery of an Internet-based laboratory course [28]. In addition, the Blackboard provides an additional level of network security. With this understanding, the Blackboard was used as a gateway for the laboratory course offering. The students who are performing experiments through remote laboratory will be enrolled within a Blackboard course. A block diagram presenting the weekly cycle of actions is shown below in Figure 5.

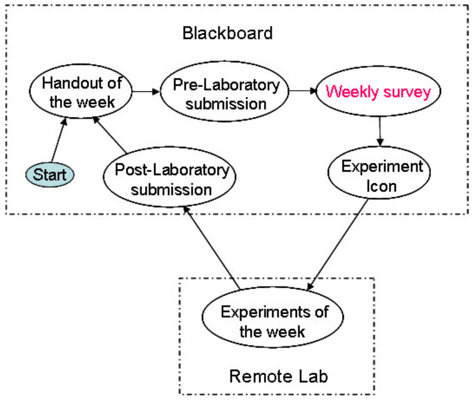

Figure 5: Internet-based laboratory protocol for the delivered course.

The start block shows the starting point for the process. A handout of the week was posted on the Blackboard, and students need to perform some pre-laboratory tasks. After completing the pre-laboratory tasks, the handout should be submitted through the course drop box (within the Blackboard). At the end of each week, students needed to complete a survey considering the previous week's experience with the whole remote laboratory facility. This survey allows the facilitator to update the system for better performance and also gather perceptions of students about the facility. One can't have access to the next week's laboratory without completing the previous week's survey. Once within the remote laboratory facility, one can perform all the tasks that are posted for each week. The timeline for remote laboratory related posting and submissions are shown in Figure 6.

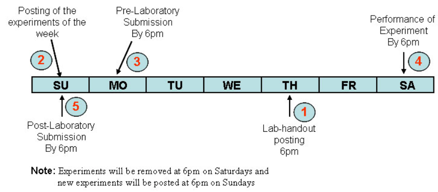

Figure 6: Weekly timeline for the Internet-based laboratory course.

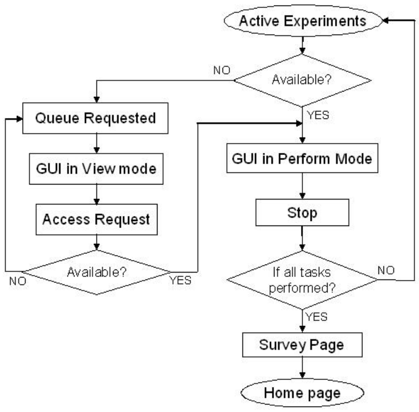

Figure 7: Level of access to the experiments.

A flowchart showing the access levels to an experiment is shown in Figure 7. An experiment can be performed by a single user (performer) at any point in time; while other users (viewers) 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. There is a software queue that provides access to a client to first come first server basis.

V. 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 a 24/7 facility, the experiments can be accessed any time from anywhere. To understand the user access profile, the system has 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. These data can be accessed by an administrative user through an application. An image of the activity page is shown in Figure 8.

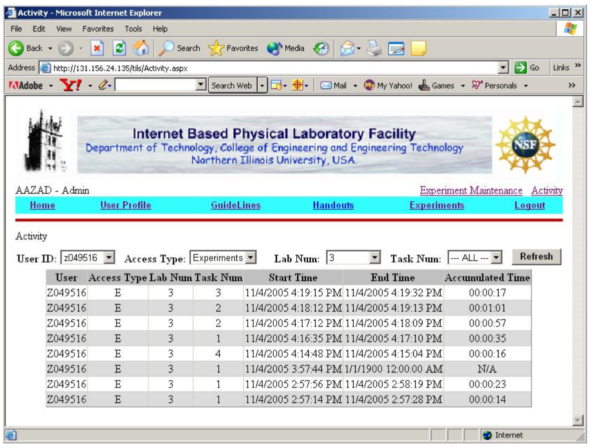

Figure 8: Image of an activity of page.

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) toward 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.

VI. EVALUATION

One of the major aims of the project was to assess the effectiveness of the developed facility as well as evaluate the student learning outcomes. To address these issues the evaluation process is divided into four parts: a) assess students' learning outcomes; b) assess students' learning behavior in terms of the access time and duration of use (in terms of the use of the facility); c) to assess the effectiveness of the facility and students' perception about the facility; and d) ethical issues. First two are achieved through quantitative analysis, while the last one is done through qualitative analysis. Professor Herbert J. Walberg, Research Professor of Education and Psychology at the University of Illinois at Chicago and Visiting Professor at Stanford University, acted as the external evaluator for the project. He is a world renowned scholar and researcher in teaching psychology and evaluation. Dr. Walberg has advised on questionnaire design, evaluation of the pedagogical effects of the system, data analysis, and interpretation.

A Students Learning Outcomes

To assess student learning, the class was divided into control group and test group. The control group took the course using an existing traditional laboratory, while the test group performed the experiments developed through the remote laboratory facility. The test group was composed of male and female students with diverse ethnicity and mixed educational abilities. Both the groups were tested with pre- and post-tests and the results were compared for any difference. It was observed that there were statistically significant differences between pre- and post tests for both the test and the control groups, with the mean of post-test scores significantly higher than the mean pre-test scores with paired, one-tail t-tests. It has also been observed that these differences for the test group and the control group are not statistically different based on two-tail and non-paired t-tests. This can be interpreted that both the test group and the control group learned effectively and the difference between the two groups are not significant.

B Students Learning Behavior

To assess students' learning behavior in terms of the access time and duration of use, the developed facility has in-built capacity to collect students' login and logout times along with the time taken to perform each experiments. These data allow the facilitator to know the level and timing of facility use 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 within Section V (Administrative Activities).

These data allow comparing the leaning efficiency of the control group and the test group and also the students' behavior in terms of the use of the facility. It has been found that there are statistically significant differences between the test and the control groups in their time spent on the laboratory tasks, with the test group spending 67% less time than the control group on the average. It can be interpreted that the test group learned more efficiently than the control group. In terms of access time to the facility, it has been found that the time of the day when students in the test group perform their laboratory tasks range between 9:00 a.m. and 1:00 a.m. of the day, which is a duration of 16 hours, indicating great flexibility and convenience for students who are otherwise impossible because of the cost and administrative limitations under a traditional laboratory configuration. Figure 9 shows the access profile to the remote laboratory experiments.

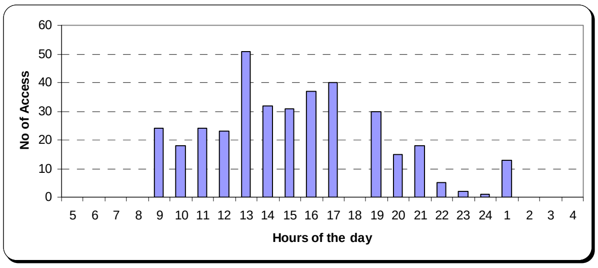

Figure 9: Shows the access profile to the facility in terms of time of the day.

C Effectiveness of the Remote Facility

The third evaluation issue was to assess the effectiveness of the facility and students' perception about the facility. This has been done through a weekly survey along with a descriptive statement from the test group students at the end of the semester. The remote laboratory course is a new concept, and evaluation of the facility for its usefulness will provide an understanding in terms of the students' points of view. Toward this, a weekly survey is incorporated within the facility that students need to complete at the end each laboratory session. The questions are designed in such a way that they 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 were 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 have both short term and long term use. As a short term use, the responses were reviewed by the facilitator on a weekly basis and were 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 a review to identify the aspects of the facility that can be enhanced for future developments.

The survey result shows that in general students liked the system and found the arrangement useful. However, in terms of learning, they found that the remote laboratory is almost same as the traditional lab arrangement. Students also found the system was easy enough to operate. For the descriptive statement, each test group student wrote a descriptive statement on their personal view towards the remote laboratory, benefits of the remote laboratory, and what can be done better for the future. The main benefit pointed out by almost all the students is the anywhere anytime feature of the remote laboratory facility. This allows them to perform experiments at times of their own choice that fit their busy work schedule. Some students raise the point that the remote laboratory does not provide any hands-on experience. This is true, but much research shows that, other things being equal, hands-on laboratory experience does not add knowledge and understanding beyond non-laboratory instruction. Mastering particular apparatus in a laboratory, moreover, may not be applicable to other apparatus and circumstances. A few mentioned the tight schedule for pre- and post-laboratory submission. Considering the junior level undergraduate course (where all of their labs and course works are closely supervised), the remote laboratory is a major responsibility, and some of them are not totally comfortable to deal with this.

D Ethical Issues

The last and most difficult issue for the remote laboratory facility is the ethical issue. With this arrangement, students are performing the experiments on their own, without any direct supervision and they also need to manage other lab-related activities in a timely manner. Along with the laboratory course, students also need to take a teaching course to cover the theoretical part of the topics. So the faculty had an opportunity to meet the students on weekly basis and address any issues related to the remote laboratory. One of the problems was to ensure whether a student really performed all the experiments or not. At the beginning, a few students submitted the final report without performing all the experiments in a timely manner. The developed facility is equipped with a recording of all the laboratory activity timing. With this, the faculty identified the violating students and discussed the matter with the class to avoid any repetition of such practice.

VII. FUTURE DIRECTIONS

Performing laboratory experiments over the Internet is a relatively new concept. As discussed earlier, researchers are pursuing this problem in an abrupt manner and have not yet come up with a sustainable solution. Most of the reported works are within the education and research areas; however, the same philosophy can be used for industrial/manufacturing management and control [19].

Any development in this area requires expertise from computer interfacing, data acquisition and control, computer networking, web security, and real-time control.

In its current form, the developed facility is implemented only in single laboratory course with a small number of students. The outcome of the study is quite encouraging. However, more study needs to be done to explore various aspects of learning outcomes and system effectiveness. The author is now working toward implementing this facility for additional laboratory courses, along with improved evaluation schemes.

Remote laboratory systems are still in their infancy. There are different kinds of experiments in terms of their input(s) and output(s), speed of operation, data collection restrictions, and data presentation. Considering these, a number of issues need to be addressed to develop an effective, versatile, cost effective, and sustainable system to make this concept 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. The technologies that are used for remote laboratory systems (electronics and computer science) are developed extensively; however, these need to be further customized and even to develop new products to maximize the benefit.

VIII. CONCLUSIONS

The use of an Internet-based laboratory facility for offering a digital electronics laboratory course along with an integrated evaluation process has been presented through this paper. The system is developed using a modular approach so the system 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 of these software 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 the system's use. The authorized clients will be allocated UserID and Passwords, and this will protect the experiments from any mishandling.

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 their access time. The developed facility can be used as a stand-alone laboratory course within a distance-learning program and also to complement a traditional laboratory 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 courses.

The evaluation outcome highlights that students like the provision of 24/7 access to the facility and have utilized access the experiments over a extended period of time. Although there is no difference in learning for the test group and control group, it has been found that there are statistically significant differences between the test and the control groups in their time spent on the laboratory tasks, with the test group spending 67% less time than the control group on average. It can be interpreted that the test group learned more efficiently than the control group. The facility is also equipped with an in-built data collection facility that allows an administrator to monitor the proper use of the facility as required by the students.

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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,* vol. 23, no. 5, 1997, pp. 573-580.

[2] T. K. Grose, "Can distance education be unlocked," *PRISM,* April, 2003, pp.19-23.

[3] G. Bengu, W. Swart, "A computer-aided total quality approach to manufacturing education in engineering," *IEEE Transactions on Education*, vol. 39, no. 3, 1996, pp. 415-422.

[4] J. Palais and C. G. Javurek, "The Arizona State University electrical engineering undergraduate open laboratory," *IEEE Transactions on Education,* vol. 30, no. 2, 1996, pp. 257-264.

[5] P. Vohra, "Communication technologies: Are we jumping in too fast," *Proceeding of the ASEE IL-IN Sectional Conference*, Illinois Institute of Technology, Chicago, April 12, 2002.

[6] J. C. Swearengen, S. Barnes, S. Coe, C. Reinhardt, and K. Subramanian, "Globalization and the undergraduate manufacturing engineering curriculum," *Journal of Engineering Education,* April, 2002, pp.255-261.

[7] A. B. Henson, K. J. Fridley, D. B. Pollock, C. J. Brahler, "Efficacy of interactive internet-based education in structural timber design," *Journal of Engineering Education,* vol. 91, no. 4, 2002, pp.371-387.

[8] S. Hagg and J. C. Palais, "Engineering online: Assessing Innovative Education," *Journal of Engineering Education*, vol. 91, no. 3, 2002. pp. 285-289.

[9] C. Mregl, "Comparison of remote labs in different technologies," *International Journal of Online Engineering*, vol. 2, no. 4, 2006.

[10] A. Pester and G. R. Alves, "WebLabs in Education," Guest Editorial," *International Journal of Online Engineering*, vol. 3, no. 2, 2007.

[11] 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, 2002. pp. 203-210.

[12] G. H. Fletcher, "Editorial," *Technical Horizons in Education*, May, 2004, pp.6-8.

[13] O. Neaf, "Real laboratory, virtual laboratory or remote laboratory: What is the most efficient way?," *International Journal of Online Engineering*, vol. 2, no. 3, 2006.

[14] J. Cas, D. Hercog, and R. Safaric, "Web based educational tool for neural network robot control," *International Journal of Online Engineering*, vol. 3, no. 2, 2007.

[15] F. M. Schaf and C. E. Pereira, "Automation and control learning environment with mixed reality remote experiments architecture," *International Journal of Online Engineering*, vol. 3, no. 2, 2007.

[16] E. Sucar, J. Noguez, G. Huesca, and E. Rodriguez, "A semi-open learning environment for mobile robotics," *International Journal of Online Engineering*, vol. 3, no. 2, 2007.

[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 2004 American Society of Engineering Education Annual Conference and Exposition,* Salt Lake City, Utah, 2004), June 20-23.

[18] A. K. M., Azad, A. Otieno, O. Ghrayeb, and N. Anand, (2003). Internet Based Experiments for Physical Laboratory Set-up, *ASEE Annual Conference & Exposition (Information Systems Division), Nashville, Tennessee, USA,* June 22-25.

[19] O. Ghrayeb, A. K. M., Azad, and A. Otieno, "Internet Based Approach to Develop Remote Tool Monitoring System," *2003 Industrial Engineering Research Conference*, May 18 - 20, 2003, Hilton Portland, Portland, Oregon.

[20] A. K. M., Azad, and X. Song, "Internet-Based Laboratory Experiments as a Part of an Engineering Technology Program," *Computers in Education Journal,* vol. 17, no. 1, 2007, pp.18-34.

[21] A. K. M., Azad, and P. Nadakuditi, "Internet-based facility for physical laboratory experiments," *Advanced Technology for Learning*, vol. 3, no. 1, 2006, pp.29-35

[22] K. J. Sullivan, W. G. Griswold, Y. C. B. Hallen, "The structure and value of modularity in software design," *Proceedings of the Joint International Conference on Software Engineering and ACM SIGSOFT Symposium on the Foundation of Software Engineering,* September, 2001, Vienna.

[23] National Instruments, "Measurement and Automation," http://www.ni.com/, 2004.
[24] Special Issue: "LabVIEW applications in engineering education," *The International Journal of Engineering Education*, vol. 16, no. 3, 2000.
[25] J. Essick, *Advanced LabVIEW Labs*, Prentice-Hall, 1999.
[26] J. Travis, *Internet Applications in LabVIEW*, Prentice-Hall, 2000.
[27] S. Kariya, "Online education expands and evolves," *IEEE Spectrum*, 2003, May, pp. 49-51.
[28] Blackboard, http://www.blackboard.com/us/index.Bb, Blackboard, Educate, Innovate, Everywhere, 2007.

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