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Integrating Cyber Infrastructure with Physical Laboratories

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Integrating Cyber Infrastructure with Physical Laboratories

Abstract

Laboratories are indispensible components for engineering and technology curricula. Through systematically designed experiments, students can gain hands-on experience, enhance classroom learning, and cultivate career interests. However, traditional laboratories are often restricted by space, scheduling, staffing, etc. Thus, how to effectively organize laboratories and maximize the utilization of limited resources has gained many researchers' attention. In recent years, integrating cyberspace with educational technology has achieved significant progress. To facilitate the needs of research and education, lots of laboratory equipment has been equipped with interfaces and software add-ons to enable users to operate the devices online.

This paper presents the achievements of some funded projects at Prairie View A&M University. Using an in-house developed online laboratory management system, the investigators redesigned a series of LabVIEW based engineering laboratories in which remote students can rotate to control the equipment, observe the lab results, record data, and submit reports. These setups greatly reduce the cost of experimental facilities, enhance the accessibility of equipment and courseware, and support instructors' instructional needs. The paper introduces the architecture of the online laboratory management system, and several examples to integrate traditional labs with cyber infrastructure are given. Finally, the project implementation strategies and results are also discussed.

Background

The leadership of the United States in Networking and Information Technology (NIT) is essential to its economic prosperity, security, and quality of life[1]. Reports indicate that since 1995, NIT industries have accounted for 25% of the Nation's economic growth, although they represent only 3% of the Gross Domestic Product (GDP) [2,3]. This country's leading position is the product of its entire NIT ecosystem, including dominant high tech companies, efficient commercialization system, and excellent higher education and research system[1]. It is highly recognized that American higher education institutions have contributed well-trained and talented engineers, scientists and technologists to staff the NIT ecosystem. However, due to fast technology evolution and fierce international competition, how to recruit, inspire, and educate students to pipeline in the NIT ecosystem is still a serious challenge for U.S. higher education. Particularly, the number of qualified NIT professionals is inadequate. If vacancies cannot be filled effectively and economically in this county, they may be outsourced abroad[1].

The success of current NIT capabilities can be greatly attributed to early, substantial, and sustained investments in Research & Development by US federal agencies[4]. Such investments will remain a priority because of the prospects for continuing technology advances. President's Council of Advisors on Science and Technology (PCAST), the advisory committee advising the President on matters involving science and technology policy, lists cyber-physical system as one of the four areas which should receive disproportionately larger funding increases because it addresses issues for which progress will have both the greatest effect on important applications and the highest leverage in advancing networking and information technology capabilities. Congruent with this recommendation, federal funding agencies including National Science Foundation (NSF) [5] are encouraging innovative integrations of cyber infrastructure with physical systems to foster scientific and educational efforts in related fields. Along with the technology trend, as well as in response to the job market need to better prepare STEM students[6], the authors successfully obtained several external grants to promote the integration of cyber space with physical laboratories.

Engineering technologists are more practically oriented in implementation than that of scientists and engineers. Accordingly, Engineering Technology (ET) program features hands-on skills training to assist students in solving production and system implementation problems. With industry transition towards technology-intensive production processes and the adoption of advanced manufacturing methods[7,8], it proposes an urgent demand for ET program to update the educational infrastructure along with technology trend. To address this concern, the authors utilize networking and information technologies to improve laboratories, to help student develop appropriate professional skills through college education.

Methodologies

LabVIEW has proven to be effective in facilitating engineering laboratories by creating a dynamic learning environment, from hands-on labs to student design projects. In recent years, LabVIEW has been successfully utilized in online remote education with its remote access toolbox[9,10]. ELVIS (Educational Laboratory Virtual Instrumentation Suite) is a LabVIEW-based design and prototyping environment for university science and engineering laboratories, which include a virtual instrument, a data acquisition device, and a workstation and prototyping board. As a multi-functional platform with many compatible third-party products, it can be utilized in a series of curriculum applications, from circuit, electronics, to instrumentation, control, microcontroller, communication, robotics, etc. In one of the authors' previous NSF projects, a number of undergraduate lab courses had been revamped with LabVIEW and ELVIS. Leveraging on the existing facilities, further efforts were made to create a cyberspace to host online courseware to achieve a sustainable development.

Based on LabVIEW remote engine, the courseware uses an in-house developed web server to bridge physical laboratories with the Internet end users. The web server integrates with account management and scheduling functions through which users can reserve lab equipment and experiment time slots. Whenever a student logs into the system, the web server will first check whether there are laboratories reserved by the user. If a reserved lab is selected and the time slot matches the system clock, the user will be redirected to the experiment server which, in return, verifies the user and reserved lab information with the web server. After that, a new connection will be established between the user's browser and the experiment server. The user can then remotely manipulate experiment instruments to carry out defined lab contents, with guaranteed time and resources. A framework of the system is depicted in Figure 1.

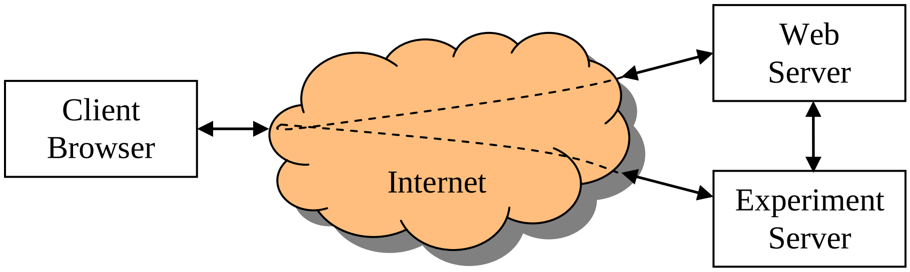

Figure 1. The remote engineering laboratory framework

In the remote labs, the LabVIEW programs are hosted by the experiment server which connects the physical equipment directly. To implement the scheduling function, a header block is added to all LabVIEW programs. When a virtual lab is initiated, its header will retrieve the lab setting (in XML format) and communicate with the web server for user authentication as shown in Figure 2. Once a user is authenticated by the lab header, he will be disconnected from the scheduler and only interact with the experiment server. The lab program will, thereafter, proceed to equipment control and operation. Experiment data will be recorded according to the user ID and lab ID. This ensures that the web server only focuses on user and laboratory scheduling and the experiment server focuses on actual lab conduction.

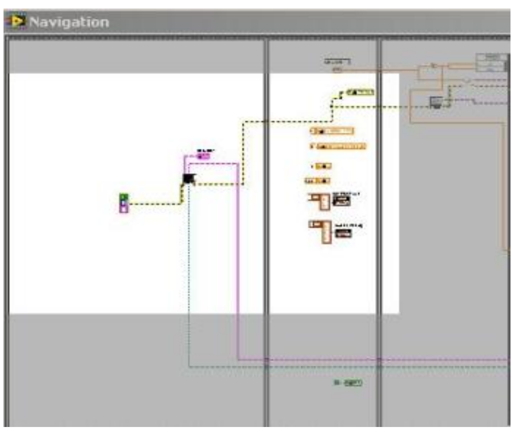


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Figure 2. Virtual lab initial settings for user and experiment verification

To facilitate remote users to observe the equipment, a web camera is plugged into the experiment server and mounted at an appropriate angle with the instruments right within its scope. Through a JavaScript program, the lab scenarios are videotaped by the camera and transmitted to the user browser in real time. Thus, a student can see the devices as if they were directly connected with the user's computer. Meanwhile, the user can control and analyze experimental data through LabVIEW remote engine interface as shown in Figure 3.

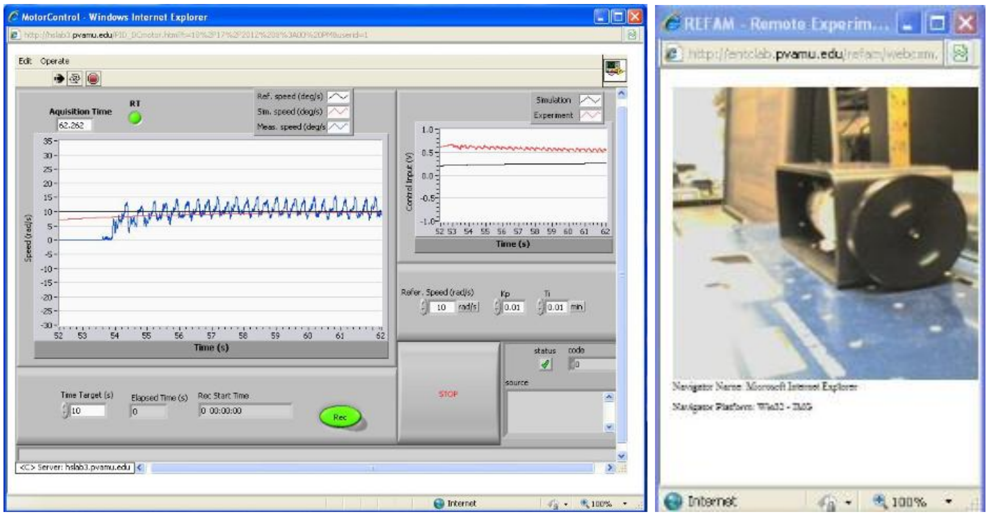

Figure 3. LabVIEW remote engine interface and web camera window

The virtual lab courseware is independent of lab equipment and experimental technology. Although it was initially developed only for LabVIEW based experiments, it has also been expanded to support other virtual experiments. For example, in one of our labs, the web camera and a FPGA device are directly connected with the web server. A student can operate the device and send commands. The experimental data are transmitted to and plotted in the user's browser in real time. In this case, the web server undertakes the responsibilities of both the web server and experiment server in a LabVIEW experiment. Without the support of LabVIEW remote engine, all data display and analyses are done through the in-house developed script programs.

User Interface and Feedback

Figures 4 to 6 are snapshots showing how a student reserves and conducts online laboratories through our virtual remote lab system. The student first logs into the system to reserve the time slot for an experiment.

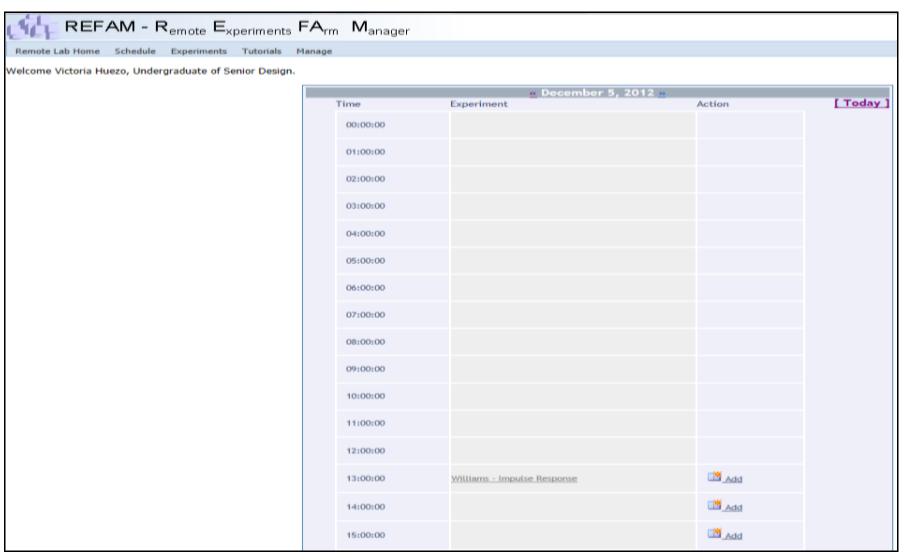

Figure 4. Online scheduler interface

At the scheduled time, the student visits back to activate the experiment, and carry out the experiment activities online.

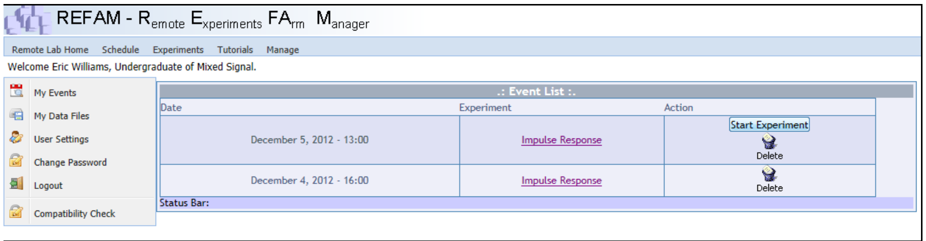

Figure 5. Online experiment interface

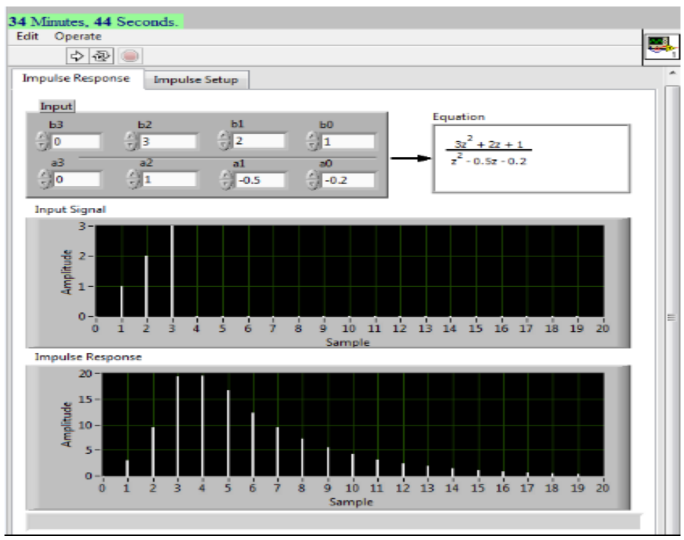

Figure 6. Online experiment for digital system response

The developed remote laboratories have been utilized in the related courses. Surveys were conducted to collect student feedback to further improve the system. Survey stats, as shown in Figure 7, indicate that the online remote laboratories received very positive responses and students expected more innovations to be introduced. Leveraging on multiple ongoing grants, the authors are working to enhance the integration of cyberspace with physical laboratories to benefit more courses and students.

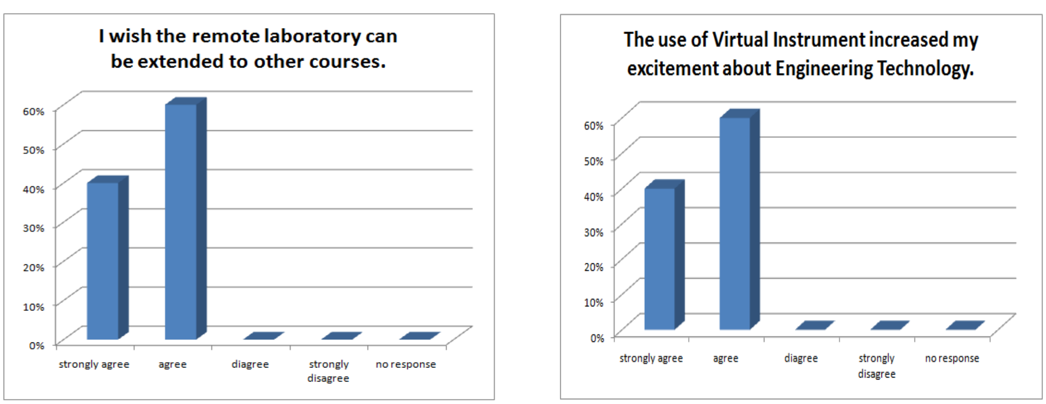

Figure 7. Student survey analysis

Conclusions and Future Work

This paper reviewed the activities for NSF sponsored research projects to develop remote and virtual laboratories at Prairie View A&M University. In the next project year, a distributed network composed of real-time embedded systems will be connected with the developed online management system to incorporate more experiments. The authors and colleagues in other engineering departments will collaborate to share the facilities to achieve a broader impact on multidisciplinary teaching and research.

Acknowledgment

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