

Developing an IP-Based Industrial Process Control Laboratory for Use in a Distance Education Environment

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hiking camping photography steam locomotives

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Abstract

In this paper we present the development of a versatile Industrial Process Control (IPC) remote lab solution for facilitating 24/7 access to students anywhere in the world with an Internet connection. The lab will be built and tested during the spring semester of 2016 and piloted in a fall 2016 electromechanical systems course taught as part the BS in Industrial Engineering Technology (IET) program at East Carolina University. The lab environment will provide distance education students with the foundational hands-on skills needed to configure, maintain, and troubleshoot industrial control systems securely through a remote Internet connection. The centerpiece of the laboratory design is to provide distance education students with the hands-on lab experience of operating industrial process control equipment as though they had physical access to the laboratory equipment.

The laboratory development offers a rare opportunity for inter-program collaboration in the planning, design, and implementation of the laboratory environment. A common discussion topic within academic institutions is the extent that differing, but related, disciplines can be integrated to take advantage of synergies and enhance the knowledge base and skill sets of the related disciplines. In this context, central to the development of the remote lab environment was the collaboration between faculty from Information and Computer Technology (ICT) and Industrial Engineering Technology (IET) programs.

Introduction

Distance education in technology based curriculums has dramatically increased over the last four decades. This has resulted in many opportunities as well as challenges in teaching technology courses. One such challenge is that of hands-on laboratory classes. Traditionally this was done by the students attending laboratory classes on campus, therefore defeating the advantage that distance education offers. There have been many proposed solutions to this obstacle in the IPC curriculum. Those solutions include: simulated laboratory experiments, multimedia lab presentations, and remote access to physical lab equipment. Much research has been done in the first two categories and many products are available for simulated laboratory experiments and multimedia lab presentations. However little has been done in the third category, remote access to physical lab equipment.

One hallmark of an engineering technology program is hands-on laboratory experience. In fact, the criteria for accrediting engineering technology programs specify that theory courses should be accompanied by coordinated laboratory experiences. A laboratory course accompanies almost every electronics engineering technology course in the IET curriculum at East Carolina University. In these laboratories, students design and construct electronic circuits and machines,

then use electrical test equipment to measure the characteristics of the constructed circuits and machines to compare their findings with theory presented in the corresponding lecture courses. A typical hands-on laboratory station provides the student with a suite of expensive test and measurement equipment. While lecture instruction can be delivered at a distance using on-line and other technologies, it is difficult, if not impossible, to reproduce the hands-on experience of an electronics laboratory over the Internet. Nevertheless, an electronic engineering technology program delivered on-line must include concurrent laboratory experiences.

In recent years, a number of computer-aided simulation programs have become available commercially. Researchers have compared the effectiveness of some of these programs to the effectiveness of traditional hands-on laboratory exercises¹⁻³. Most of these research efforts investigated the use of computer-aided software as a method to enhance, enrich, or improve traditional lecture or laboratory courses.

The remote IPC laboratory will provide students the ability to complete hands-on lab activities from anywhere with an Internet connection. Instead of sitting idle, the lab equipment can be utilized on a 24/7 basis. Initially, the use of the remote lab will be limited to face-to-face students who will use the environment for additional homework lab exercises. The longer term goal however is to have a distance education only option for non-traditional students in the IET program.

Related work

Simulated laboratory experiments were conducted by². The study assessed the effect of computer simulated experiments on the attainment of process skills and the acquisition of subject matter content in the high school physics laboratory. Over a 4-month period, 51 students from 2 physics classes were involved in 4 laboratory experiments and simulations. Students were assigned to one of three treatment groups: laboratory, laboratory-computer, and computer. The process skills investigated were the ability to investigate relationships between laboratory variables (Data Manipulation Score), to reach conclusions (Experimental Conclusion Score), and to interpolate, design experiments, and reach conclusions (Process Tests). Among results, it was found that a computer-related group had the highest mean Data Manipulation Score while laboratory-computer and laboratory groups had higher mean Process Test scores.

In a study conducted at Northwestern University, computer simulated laboratory experiments in engineering technology were conducted to examine the effectiveness of using computer simulation software for laboratory instruction verses using actual hands-on components and equipment². The research also analyzed student attitudes toward the two lab approaches. The results showed no significant differences in student achievement between those who used the simulation laboratory exercises and those who performed the same lab exercises on traditional hands-on equipment. The attitudinal aspect of the study revealed some differences in the students' perceived ability to troubleshoot electronics circuits however.

Dr. Brian Woodfield at Brigham Young University (BYU) has pioneered the use of simulation in a chemistry lab with a product called Virtual Chem lab (VCL) ⁴. This software allows students to perform many typical chemistry experiments such as titration, calorimetry, spectrometer, Milikan oil drop, and many others. In a real chemistry lab, experiments are tedious and time consuming to set up. Over the years, BYU has found VCL to be as useful as any other tool in the classroom.

Jimmy B. Linn in his article titled, Using MultiSim/ Electronic Workbench® in Basic Electricity Courses in lieu of or to Complement Live Lab Experiments discusses the use of MultiSim simulated laboratory experiments in a Basic Electricity course ⁵. The effectiveness of using MultiSim as a laboratory tool was measured by collecting exam and lab assignment grade data from a Circuits 1 course where MultiSim was not used as a control and collecting the same data from the same course where MultiSim was used in lieu of live lab experiments. The findings concluded that while performing labs increase student GPA, the lab delivery method did not affect GPA.

Many college and university administrators feel that physical hands-on experience is vital to entering the technology or engineering workforce. This paper addresses the need for IET students to run laboratory experiments from anywhere with an Internet connection and gain experience with the laboratory equipment, from a remote location. This is done by allowing the student to see the physical equipment, run the appropriate software to control the laboratory equipment and manipulate the physical equipment and witness the outcome from the lab equipment.

Review of other programs

A review of accredited Industrial Engineering Technology programs was conducted by searching both the Accreditation Board for Engineering and Technology (ABET) and Association of Technology, Management, and Applied Engineering (ATMAE) program databases. The search yielded a total of fourteen universities with accredited IET programs. Of the fourteen undergraduate IET programs found, only six had similar lab based electromechanical systems courses to that of the pilot course at East Carolina University. Of the six, none were identified as on-line or distance education courses with remote labs.

Course overview

The course which will pilot the remote laboratory environment is a first year electromechanical systems course taught both spring and fall semesters as a sixteen week semester long course and meets four hours per week. The average number of students taking this course is 20 each semester. Currently the course is taught face-2-face, on campus, and only during the traditional daytime hours of between 8am and 4pm. Consequently the normal demographics of this course is the traditional full-time student age 18-21 years. Additionally, the students in this course are in

their second semester and have already completed a basic electronics course as a prerequisite and already have basic theory and would be ready to apply those concepts.

Students study the design and analysis of electromechanical control systems, include the fundamentals of programmable controllers as well as practical applications of interfacing mechanical, electrical, pneumatic and hydraulic systems and components. In the laboratory portion of the class the students work with numerous electronic measuring devices, create various circuits, and are prepared for an electronic shop environment.

This specific electromechanical course was chosen for this pilot because the lab equipment used to support the course already contains networked software and hardware used to operate the equipment and to interface with the college network and the Internet. The existing trainers used in the lab are easily modified with minimal additional cost to allow remote control access. As a second year course the students enrolled in this course will already have prerequisite knowledge.

Course objective and outcomes

The electromechanical systems course is designed to gives students hands-on Programmable Logic Controller (PLC) ladder logic programming skills. Students completing the course will meet the following objectives.

- Explain and demonstrate the basics of several types of power transmission.
- Explain and demonstrate the theory and functional characteristics of both DC and AC electric motors.
- Understand and demonstrate the function and application of variable frequency drives.
- Electrical Transformers, Motors, Generators, Servomotors, and Induction.
- Identify and describe major components of programmable logic controllers.
- Distinguish different type/ categories of PLCs.
- Describe and perform basic Boolean functions.
- Design, develop, and integrate ladder diagrams.
- Describe discrete-state process control systems.
- Write, debug, test, and run programs on the PLC.
- Interface, program, collect and analyze data from PLCs.

Remote lab connection

The primary effort involved in developing the remotely accessible IPC laboratory is enabling access to the on-campus laboratory from the Internet. Past experience and existing equipment used in both the Information and Computer Technology (ICT) and IET programs at East Carolina University to deliver advanced networking courses online served as a basis for this effort.

Remote access to the laboratory PCs is accomplished using VMWare Horizon View, which is a virtual, or hosted, desktop solution. Students will download the VMWare View Client from the university web site to install on their home computers. Once downloaded, the students run through a client setup wizard in which they input the configurations to connect to a VMware Horizon Connection server located on campus. Once the client is correctly configured, students can login to connect to a virtual desktop environment as shown in Figure 1.

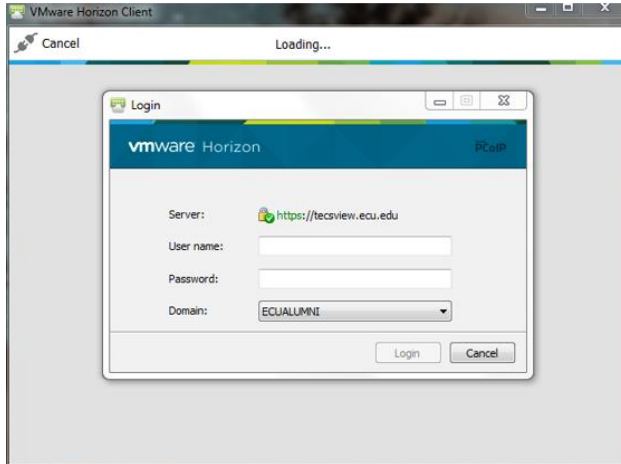


Figure 1. VMWare Horizon Client login window.

The connection server manages the student connections and performs authentication and authorization functions to ensure students can only access the resources they are authorized to access. Students in the electromechanical systems course will have access to the physical PCs located in the IPC laboratory. As shown in Figure 2, a student selects the IPC lab PC resource by selecting an ICON that represents that resource.

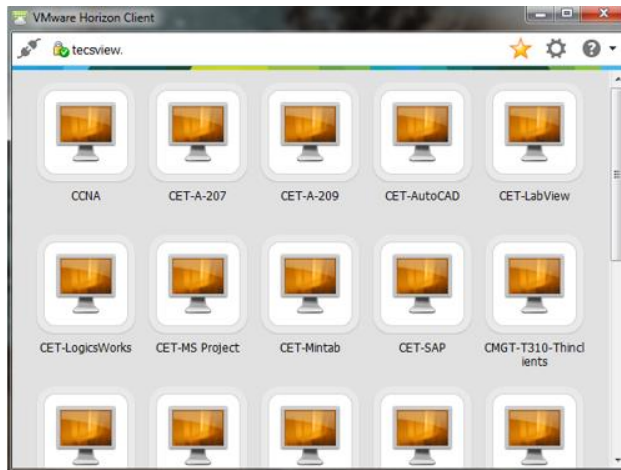


Figure 2. VMWare Horizon Client windows showing resources available to the student.

Once a student clicks on the ICON for the remote industrial process lab, the controller connects the student to one of the four PCs in the lab that are available. The student is able to control the

PC and view the desktop over a PC-over-IP (PCoIP) tunnel that is built between the student's desktop to the laboratory PC. It is through this tunnel that the keystrokes and desktop images are sent for through the remote desktop connection. The view connection manager is licensed for 200 concurrent sessions which far exceeds the number of students enrolled in the course. The bandwidth requirement for each student connection is approximately 100Kbps. Figure 3 illustrates the components of the remote network connection and the laboratory devices.

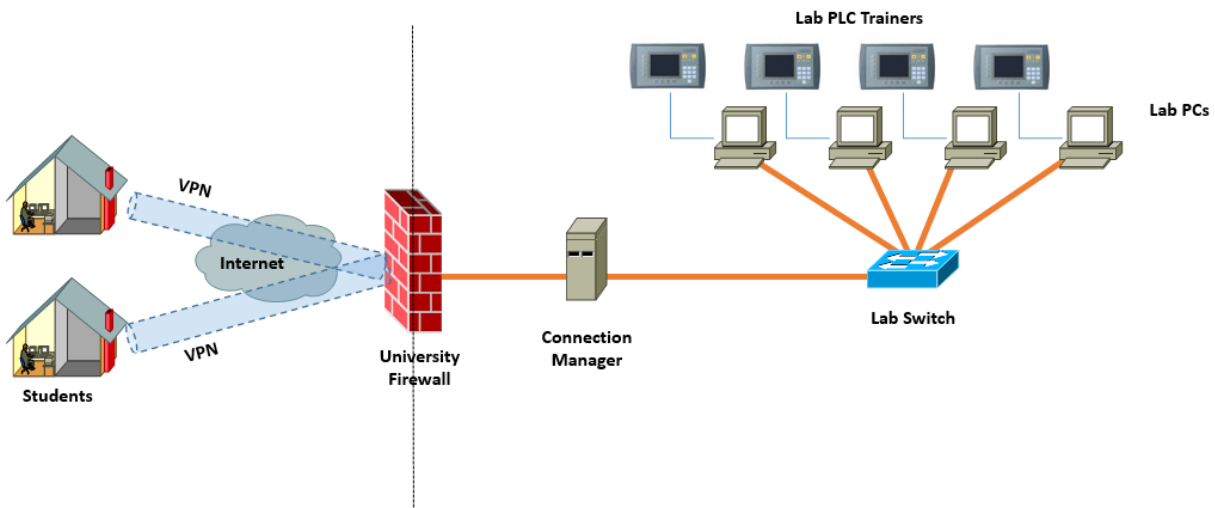


Figure 3. Remote access and lab topology.

There is the risk of failure at various points in the system, however downtime due to failure should not exceed more than a business day. The WAN connection at the firewall is maintained by the university and has redundant failover. The connection manager is maintained by the College is a virtual machine on a redundant storage array. If the connection manager crashes, it is easily and quickly redeployed on another disk in the array. The disk drives in the array are hot-swappable so a drive failure would require a replacement drive to be installed and the VM re-deployed all of which can be accomplished within a few hours. Another potential failure point is the network itself within the college. The network infrastructure is maintained by the university and a failed switch would be replaced within a day.

IPC lab environment

The IPC laboratory consists of four student lab trainer stations as shown in figure 4. Each station consists of an Amatrol Compact Logics PLC trainer with eight inputs and eight outputs and is equipped with a remote access I/O switch to permit student remote access to a PLC Applications trainer, a Variable Frequency Drive trainer, and a webcam to allow students to see the trainers.



Figure 4. Industrial process control laboratory with student lab trainer stations.

Laboratory topics

The electromechanical systems course includes seven labs shown in Table 1. In these labs, students develop the PLC ladder logic programming skills needed in an engineering or plant environment.

Lab Exercise	PLC concepts demonstrated
1. Open PLC program and observe inputs and outputs	Demonstrate student's ability to monitor PLC I/O and observe plant conditions
2. Open PLC processor and configure I/O	Student demonstrates ability to prepare the PLC for programming
3. Lab scenario No. 1, Control of two motors in JOG mode	Demonstrates student's mastery over Boolean AND, OR and NOT logic
4. Lab scenario No. 2 Control the start/stop of two motors	Demonstrates student's continued development of Boolean logic and parallel seal-in circuits
5. Lab scenario No.3 Intersock two motors	Demonstrates student's understanding of interlock protection concepts
6. Lab scenario No. 4 Safety interlock of a motor	Demonstrates students understanding of the use of interlock principles in plant safety
7. Stoplight program	Demonstrates student's understanding of counters and timers

Table 1. PLC lab exercises.

Lab 1. Open PLC program and observe inputs and outputs

Students download an existing PLC program and place the program in Run mode and observe the status of inputs and outputs both at plant floor level on the PLC and at computer level in the control room.

Lab 2. Open PLC processor and configure I/O

Students learn to select the proper PLC processor and configure PLC I/O to prepare the PLC for Ladder Logic programming in Allen Bradley RS Logics 5000.

Lab 3. Lab scenario No. 1, Control of two motors in JOG mode

Students create a ladder logic program in RS Logics 5000 to jog two motors in various configurations to demonstrate their ability to use Boolean logic concepts to develop any desired operating configuration using AND, OR and NOT logic.

Lab 4. Lab scenario No. 2 Control the start/stop of two motors

Students learn independent control of start, stop and seal-in parallel ladder circuitry and how to configure emergency stop control over all equipment in a work area.

Lab 5. Lab scenario No.3 Intersock two motors

Students learn how to interlock two or more motors for protection. Interlocking is used extensively in manufacturing environments to protect equipment and plant engineers must be very familiar with this concept and how to implement it.

Lab 6. . Lab scenario No. 4 Safety interlock of a motor

Students learn to program safety interlocks into a PLC control program. Safety features are used extensively in manufacturing environments and must be distilled into a PLC control program. This exercise develops the student's ability to distill these complex applications into a PLC ladder logic program.

Lab 7. Stoplight program

Students learn how to program timers and counters in a PLC program by writing and implementing a standard street intersection stoplight PLC program.

Assessing success

The construction of the IPC laboratory environment will be completed during the spring 2016 semester and will be ready for piloting in fall of 2016. Assessing the success of the remote laboratory will occur in several stages throughout the process. A timeline of milestones and assessment points are listed below.

- Phase 1 – Building the infrastructure (spring 2016). In this phase IET and ICT faculty working in close collaboration with the college information technology personnel will connect the existing class laboratory components and infrastructure to the campus network. Operational tests of the equipment will take place throughout this phase.
- Phase 2 – Lab trial tests (late spring and summer 2016). In this phase the IET and ICT faculty will work through each lab. Issues identified will be corrected and labs modified as necessary until all labs can be completed 100% from a remote connection.
- Phase 3 – Pilot (fall 2016). In this phase students taking the electromechanical systems course will assess the “user experience” of the labs. The students will work the labs in the traditional manner on campus with physical access to the equipment. Then the students will re-work the labs remotely. Students will be asked to provide feedback on the DE experience and identify and shortcomings in the labs.
- Phase 4 – Production (2017). In this final phase after all corrections and modification are made that were identified in Phase 2 and 3, the electromechanical systems course will be offered to students in a DE format.

Future work

There is a major trend towards technology convergence underway in today’s manufacturing and process control industries. Organizations are converging their Industrial Automation Technology (IAT) with Information Technology (IT). This has led to a rapidly growing demand for industrial control system engineers and traditional network engineers that have the skills sets required to manage and administer today’s connected plant floors. The demand for such technical skill sets is currently not being met in our existing degree programs. Our future goal is to expand the IPC lab into a converged plant-wide Ethernet/IP industrial network lab. This future lab configuration would allow us to develop and offer a DE Industrial Internet of Things (IoT) curriculum concentration that would be available to students in both our IET and ICT programs.

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