e-Lab: Technology-assisted Delivery of a Laboratory Course at a Distance

Hakan Gurocak

Manufacturing Engineering
Washington State University
14204 NE Salmon Creek Ave.
Vancouver, WA 98686

Abstract: This paper presents a new approach for real time delivery of a Manufacturing Automation laboratory course at a distance. The enabling technology is the combination of an interactive TV system and the Internet. The interactive TV system, controlled by operators at each location, establishes real time audio/video connection between two remote classrooms and a local classroom that are *hundreds of miles apart*. Details of five laboratory exercises developed and implemented in the first offering of the course are explained. In addition, a method used to assess course outcomes is presented.

I. Introduction

As courses in everything from art history to engineering are offered on the Internet, we are experiencing a transition from the traditional textbook and lecture teaching method to the virtual classroom. A report[1] released in January 1999 by the International Data Corporation shows that an estimated 85% of the colleges and universities will be offering distance education courses in 2002.

Distance education courses have been offered at Washington State University (WSU) for a long time because the university has four campuses that are hundreds of miles apart throughout the state of Washington. The main campus is located in eastern Washington in Pullman. The Vancouver campus is about 300 miles away from the main campus in southwest Washington. Since the mid 1980s the campuses have been linked by an interactive TV system called WHETS.

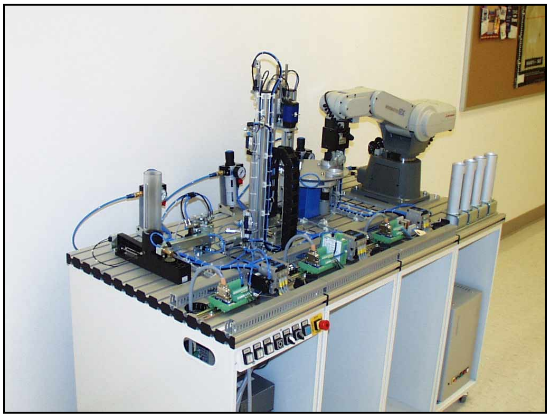
The system facilitates real time, two-way audio/video interaction among classrooms that resemble TV studios. There are a total of 32 such classrooms distributed among all campuses. The system is used extensively to share courses between campuses.

The student profile in the Manufacturing Engineering program at WSU Vancouver consists of four groups: (1) Students who work at local companies, have families and attend the program part time; (2) Full time students; (3) Students from other campuses of WSU who are taking courses originating from Vancouver; and (4) Boeing Company employees in the Seattle area (about 160 miles north of Vancouver). The Boeing Company operates an interactive TV system called BEN. By linking the WHETS to BEN we can offer a course from Vancouver to students at Boeing and Pullman with the local students attending the lecture in the originating WHETS classroom. Depending on the course, another WSU campus in the Tri-Cities area can even join in, creating a virtual classroom that is state-wide.

In Spring 2000, we offered a Manufacturing Automation *laboratory* course turning the virtual classroom into a virtual laboratory. We augmented the WHETS system with the Internet. In this new setting, the WHETS system is used to create the real time audio/video interactive environment among distant sites while the Internet is used as a direct control channel to access the laboratory hardware. The "e-Lab" was set up in the Vancouver classroom by connecting automation hardware and robots to the Internet. During a laboratory session, students at the remote sites joined in the class with the help of the WHETS system. They could control and program the hardware in the e-Lab over the Internet in real time while watching and hearing it in action through the WHETS cameras and TVs. The system also facilitated interaction of students across different sites and with the instructor, creating an environment that was very close to that of an actual laboratory.

II. Equipment in the e-Lab and the remote classrooms

The main emphasis in ME 475 is on automation hardware, software and system integration through Programmable Logic Controller (PLC) programming. In addition, the course covers fundamentals of robot and CNC programming as well as Human Machine Interface (HMI) design.



Two identical Modular Production Systems (MPS) from Festo Didactic, Hauppauge, NY were used for teaching PLC and robot programming as well as for HMI design. The automation hardware on the units is controlled by an ordinary PLC. These units were designed to be used in a normal laboratory setting. However, we specified Allen-Bradley SLC 50/5 PLCs for our units. This is an Internet ready PLC that can be connected to an Ethernet network just like a personal computer. Ladder logic programming and HMI designs are done using RSLogix and RSView software products by Rockwell Automation, respectively. Both of these products can communicate with the PLC over the Internet in real time. Therefore, students can access the PLC over the Internet and program it as if they have the PLC next to them. The result is a capability to fully control the functionality of an MPS unit over the Internet.

Each MPS contains various pneumatic actuators, valves, digital and analog sensors, electric motors and a Mitsubishi RV-M1 industrial robot. The units have casters and are about 5 ft long, 2.5 ft wide and 3 ft high. Each MPS consists of four stations: (1) Distribution, (2) Testing, (3) Processing and (4) Robotic material handling. The distribution station receives pucks (simulating work pieces) from a magazine feeder and delivers them to the testing station where the pucks are measured and their material and color are detected. If a puck is not defective, it is sent to the processing station where a hole is drilled and checked. Finally, the robotic material handling station picks up the pucks from the processing station and stacks them into four silos based on their color and material. Due to the modular design, each station can be used individually or a subset of the stations can be used together.

We developed a custom software to control and program the robots over the Internet. The software, named Web2D2 after the Star Wars character R2D2, uses client/server architecture. It contains more than 23,000 lines of code. The server runs on a networked laptop computer that is directly connected to the robot via the serial port. It manages communication with the robot through the serial port and with the clients over the Internet. The client software contains a virtual teach pendant (VTP) that looks and works just like the actual teach pendant that comes with the robot to control and program it. Once a connection is made, the entire functionality of the robot can be controlled over the Internet by a remote student using the VTP.

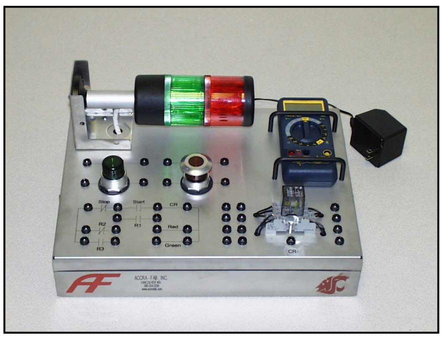
Finally, the e-Lab was also equipped with three student stations to be used by the local students. Each station contains a laptop computer and a touch monitor connected to it. Just like the remote students, the local ones are connected to the equipment over the network. Touch monitors were used to simulate the operator interface of modern machines found in the industry. Besides their role in helping the students understand how to design HMIs for touch monitor applications, they were used to make the robot control over the Internet experience a little bit more realistic. Using a touch monitor, the student can press the keys of the virtual teach pendant with his fingers as if it were an actual teach pendant.

Equipment at each remote classroom consists of student stations with laptop computers and touch monitors. Each computer has RSLogix, RSView and a Web2D2 client installed. In addition, each computer has WWW browsers and FTP software.

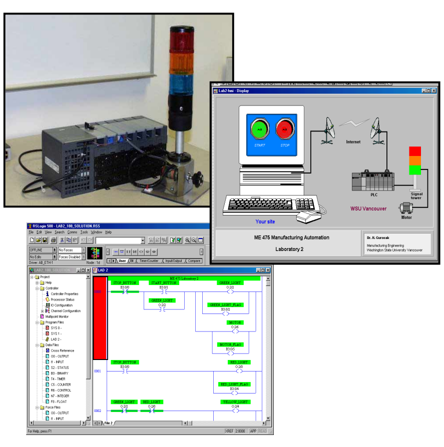
III. Laboratory sessions in the first offering

The development of the course is a two-year project that started in July 1999. When the project is finished, the course will have 10-12 lab sessions. We developed five lab sessions for the first offering of the course in the Spring 2000 semester. There were 5 students at the Boeing classroom, 2 at WSU Pullman and 11 in the WSU Vancouver classroom. Students worked in teams in all laboratory sessions.

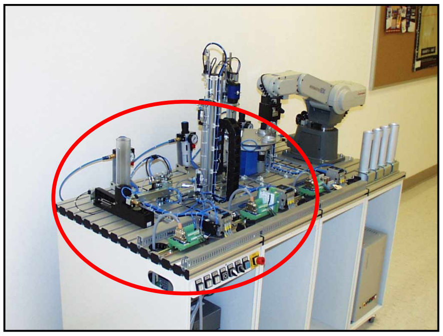
A typical laboratory session starts with the instructor explaining the details of the lab hardware by pointing out parts of the hardware. Meanwhile, the WHETS operator controls cameras to show details of the hardware to the remote students. During this overview, students ask many questions. Details of the software are also shown to the students by connecting the instructor's computer to the WHETS system. Following this overview, the students start working on the lab assignment offline. Often teams want to test an idea with the hardware as they work on the assignment. They ask for permission from the instructor to connect to the hardware. They test their idea and go back to working offline. This simple traffic management method works exceptionally well. During these trial runs students ask questions and discuss their ideas with the instructor as well as other students at other sites. In spite of having only two MPS units for six teams there was no problem in handling the traffic on the equipment due to the teams working in parallel with offline program development and the interwoven online testing periods. In the following sections we will describe the five lab sessions developed for the first offering.



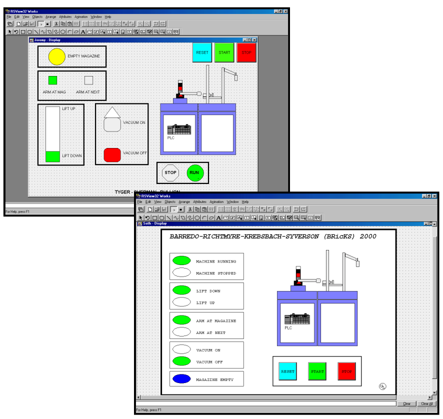
Laboratory 1: This laboratory emphasizes the most fundamental concepts of PLC ladder diagrams using fully hardware implemented control logic. This is the first time students are exposed to normally-open, normally-closed contact types, relays and ladder diagrams. Therefore, we designed and built custom pieces of hardware and mailed them to each remote site. This is the only experiment that does not require remote control and programming of hardware over the Internet. Students explore the contact types with the built-in multimeter and wire the board to implement the control logic.



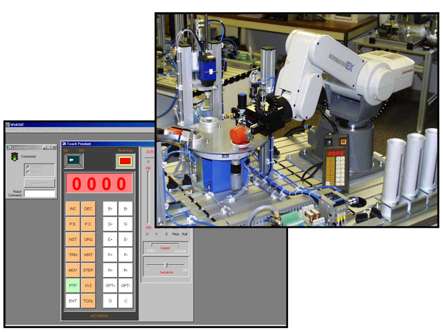
Laboratory 2: This laboratory session was designed mainly to provide a transition from a fully hardware implemented control logic as in laboratory 1 to implementation of the same logic using software. We built two identical sets of hardware, each with a signal tower with three lights and a small motor at the base. Each set was wired to a PLC and both sets were located in the e-Lab in Vancouver. Each team was provided with an HMI to remotely control the hardware. The HMI has an animated green push button and a red latching button just like the hardware designed for laboratory 1. In addition, it has an animated signal tower and a motor. Students had to develop the ladder logic control program, download it to the PLCs over the Internet and try to turn the lights on and off by pressing the buttons on their HMI. The PLC and the signal tower were located in Vancouver, while the user interface with the buttons (HMI) was running on each of the laptop computers at the remote sites.



Laboratory 3: In this laboratory, we used the distribution and testing stations of each MPS system as the hardware. The main purpose of this lab was to learn how a PLC program with subroutines and interlocks was developed for sequential process control. This lab is more difficult than the previous one due to the increased complexity of the hardware and the program structure. An HMI for remote control of the system was provided by the instructor. Student teams wrote control programs and downloaded them to the hardware and tested them by controlling the hardware over the Internet using the HMI and the touch monitors.



Laboratory 4: In this laboratory we used the same hardware as in lab 3. Students learned general principles of designing an HMI for a machine and how to link it to the machine controller. Design of an HMI requires linking it to the tag database of the PLC program that is controlling the machine. Students already knew the details of the PLC program controlling the hardware from the previous lab. This was a good starting point for the design of the HMI. Six student teams worked on the designs independently. At the end of the laboratory session, each team tested their HMI by using it to control the MPS system over the Internet. The figure shows two of the six HMIs designed by the student teams. The lights and parts of the MPS figure are animated in real-time showing the actual states of the machine since the animation is driven by data sent back from the controller over the Internet.



Laboratory 5: This laboratory is on robot programming and integration of the robotic material handling station of the MPS system with the rest of the system through PLC and robot controller communications. The robot in the MPS system is used to pick up processed parts from the processing station index table and to place them in one of the four silos based on their color and material. The laboratory involves two activities: (1) Teaching approach, pick-up and drop-off task positions using the virtual teach pendant by teleoperating the robot over the Internet, and (2) Writing a robot program that describes the motion logic and handles communications between the robot controller and the PLC to synchronize them. All student teams used Web2D2 to teleoperate the robot over the Internet. Once a team made connection to a robot from a Web2D2 client, the VTP was displayed on their touch monitor. By pressing the buttons on the VTP, students could move the robot to a desired position and teach it. We could show split-screen views of the robot with one side of the screen

showing the side view of the silos while the other side shows a zoomed-in view of the gripper. Students at the remote sites could work with the local WHETS operator to get a view of the robot from just about any angle while they were controlling the robot over the Internet using the VTP. The MPS system contains a PLC and the robot controller. The auxiliary I/O port of the robot controller is wired to some of the inputs and outputs on the PLC. Students had to write and test the robot control program that interfaced with the PLC program through the I/O with some basic handshaking to synchronize the two controllers.

IV. Was the e-Lab effective?

The course syllabus lists 12 measurable outcomes such as being able to use I/O mapping of a PLC in hardware interfacing, being able to develop control programs, etc. We studied the course grades to measure these outcomes. In addition, we wanted to quantitatively measure if the e-Lab resulted in an evenly distributed quality of education across all sites.

First, the entire set of homework and exam questions as well as laboratory assignments were examined. Then, questions related to each outcome were combined. Next, scores of each student for each outcome were tabulated. Finally, a normalized average per outcome was computed for (1) All students in class, (2) Boeing students only, (3) Pullman students only, (4) All remote students combined (Pullman and Boeing) and, (5) Vancouver (local) students.

A comparison of the average per outcome for local students to that of all remote students revealed that the scores were very close. This is an indication that the new format resulted in a fairly evenly distributed educational quality irrespective of the physical location of the students.

Finally, a *course success index* was defined by assigning weights to each of the outcomes. The weight assignment is subjective but was done based on the relative importance of each outcome in course objectives. Using the following formula:

$$\text{Course success index} = \sum (\text{Weight per outcome}) * (\text{Average per outcome (All students)})$$

an overall course success index of 0.89 was computed. As mentioned earlier, the course was offered in this new format for the first time. On a scale of zero to one if 0.5 is considered average success, 0.89 can be interpreted as great success indicating that the e-Lab was effective.

V. Conclusions

In this paper a new approach for distance delivery of an upper division Manufacturing Automation laboratory course was presented. The enabling technology is the combination of an interactive two-way audio/video TV system and the Internet. Audio/visual interaction with the hardware, students at other remote sites, and students and the instructor at the local site is provided by the interactive TV system while real time control and interaction with the hardware is enabled over the Internet. To the best of our knowledge this approach has never been tried before anywhere in the nation.

The system provided a very active learning environment. In every lab, teams were in competition with each other to get their machine working first. Although this was not an intended outcome of the new approach it emerged as one of the features of the e-Lab. The student motivation was unprecedented. The labs were so much fun that the students were asking for more lab sessions. This is quite pleasing, yet somewhat unusual, coming from undergraduate students.

The delivery system was very reliable. We did not experience any connection problems with the Internet connections or with WHETS. The time delay in the WHETS video is about one second. The delay in the Internet channel was about the same. When asked, students said they did not even notice or think about the Internet connection between them and the hardware.

The new approach resulted in an evenly distributed educational quality across all sites since both lectures and the laboratory sessions originated from one location. All students, irrespective of their physical location, could use the same set of equipment. The new format has some advantages. It is cost effective since, by augmenting the existing WHETS system with the Internet, we could avoid duplicating expensive and specialized hardware/software at remote locations, developing a custom curriculum for each remote site and hiring additional instructors. However, it also has some disadvantages. The curriculum development was extremely time consuming. While developing the curriculum it was difficult to test a lab session prior to the actual session since the system consisted of many computers and pieces of hardware distributed at multiple sites that came together right before the lab session. Software maintenance on remote PCs was difficult. Finally, interactive TV systems such as the WHETS are only available in 14 states.

Clearly, engineering education on the Internet is in its infancy. While the technology to stream live video over the Internet is improving, combination of an interactive TV system with the Internet is an attractive option to deliver labs at a distance.

Acknowledgements

This project is funded by the Society of Manufacturing Engineers (SME) Education Foundation, the Boeing Company and Washington State University.

Bibliography

1. International Data Corporation, "Online distance learning in higher education, 1998-2002," Report, Jan. 1999. Available: http://www.chea.org/Commentary/distance-learning.html.

2. *Proceedings of 1998 ASEE Annual Conference and Exposition*.

HAKAN GUROCAK

Hakan Gurocak is Assistant Professor in the WSU School of Mechanical and Materials Engineering. He received his Ph.D. from Washington State University at Pullman in 1993. His research interests are robotics, automation, fuzzy logic, technology assisted distance delivery of laboratory courses and haptic interfaces for virtual reality.