Initial Steps Towards Distance Delivery of a Manufacturing Automation Laboratory Course by Combining the Internet and an Interactive TV System

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Abstract: In this paper a new approach for distance delivery of an upper division Manufacturing Automation laboratory course is presented. The enabling technology is the combination of an interactive two-way TV system and the Internet. Using this new platform students at remote sites will be able to interact with each other, with students and the instructor at the local site, and with the hardware at the local site. The paper also presents five laboratory sessions developed as initial steps towards the first offering of the course.

I.   Introduction

Washington State University (WSU) has four campuses. The main campus is located in eastern Washington in Pullman. The newest branch campus of the university is in Vancouver, Washington. The campus serves southwest Washington and the greater Portland, Oregon, metropolitan area.

In Fall 1997, the first engineering curriculum leading to the Bachelor of Science in Manufacturing Engineering was introduced on the new campus. Since Fall 1998, the program is also being delivered to students who are Boeing Company employees in the Seattle area using WSU's two-way interactive TV system called WHETS. The system is linked to Boeing's interactive TV system (BEN). These systems allow two-way real time audio/video interaction among the distant sites.

Using this technology, some of the lecture-only format courses of the Manufacturing Engineering curriculum were sent to the Boeing sites as well as other campuses of the university. Delivery of such traditional lecture-only format classes to distant sites by live video

and audio is a mature technology, at WSU and other educational institutions[1]. The curriculum, however, includes courses with laboratory components.

We offer one of the laboratory courses (ME 311 Manufacturing Processes) at three WSU campuses. This course requires familiar machine tool equipment such as lathes, milling machines, joining and material testing. The course is offered by only one instructor. The lectures are delivered *from one location* using WHETS and the laboratories are *approximated* using the locally available equipment at each remote site. The laboratory experiments that were originally designed for the facilities at WSU Pullman are *approximated* (adapted for locally available equipment) at the other sites. For example, in Vancouver we use the Applied Technology Shops at Clark College -- a local community college.

In a typical semester, we may have students from WSU Pullman, WSU Tri-Cities and WSU Vancouver taking this course. Although these students are taking the same course, their laboratory experiences turn out to be quite different depending on the equipment and temporary laboratory instructor available at each remote site. The main problem we face in approximated laboratories is the inconsistency in the quality of education among the students taking the *same* course. This is unavoidable since it is impossible to find exactly the same set of equipment at every *approximated* laboratory.

When an upper division course requiring specialized equipment is attempted to be delivered at multiple sites using approximated laboratories, the problem of finding similar equipment at each remote site gets even harder. Therefore, maintaining the quality of education across all sites becomes nearly impossible. Ideally, if both the lectures and the laboratories could be delivered from one location, students taking the same course from different sites would use the same set of equipment. As a result, the quality of the course could be maintained across all sites.

One such upper division course in our curriculum is ME 475 "Manufacturing Automation." This course includes laboratory sessions with automation hardware/software, programmable logic controllers (PLC), industrial robots and computer numerical control (CNC) machines.

The lectures of this course can be delivered over the WHETS/BEN systems. However, due to the complexity of the required equipment, it is not possible to approximate the laboratory sessions at the remote sites. Therefore, such courses of the curriculum create a great limitation for the delivery of the Manufacturing Engineering program at a distance. In fact, today the delivery of laboratory courses in engineering distance education is a major progress-limiting step[2].

In Spring 2000 semester, the ME 475 course will be offered in a completely new format. The new format will combine the WHETS/BEN system with the Internet to allow remote interaction with local hardware in Vancouver. The new format will enable distance delivery of laboratories for the first time in our program. It is expected that it will result in an evenly distributed educational quality across all sites since both the lectures and the laboratories will originate from one location -- WSU Vancouver. In the first offering, there will be students in Vancouver, in Pullman and at a Boeing site in Seattle.

Automation hardware will be brought into the WSU Vancouver WHETS classroom where the lectures will originate. Students at the receiving remote WHETS and BEN classrooms will be able to control this hardware over the Internet using computers (Figure 1). The interactive audio and video systems of the WHETS/BEN will allow them to clearly see and hear the equipment in action as they control the hardware. In addition, they will be able to see the instructor in the Vancouver classroom, the students at the other receiving sites, and the details of the hardware on demand since the cameras in these rooms are controlled by operators who also control the live interactive session. Students will be able to ask questions and interact with each other, the instructor and the equipment.
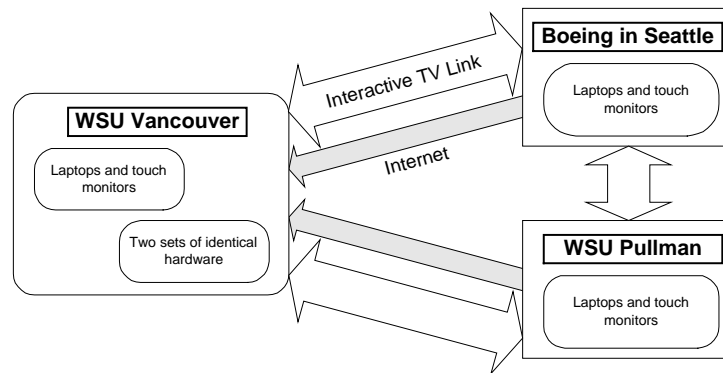

Figure 1. Remote laboratory configuration.

In this paper, five laboratory sessions developed so far as initial steps towards the first offering of the course are presented in detail. But first, the technology used in the implementation will be overviewed.

II. Technological overview of the implementation

The new format requires multiple technological components to be integrated into the course. The interactive environment between all of the remote sites and the local Vancouver site is provided by the audio/visual system. The "laboratory" for the course is established in the Vancouver WHETS classroom by bringing automation hardware and computers into the classroom before each session. The remote classrooms and their connections to the local "laboratory" is accomplished by bringing computers into each of the remote WHETS and BEN classrooms before a laboratory session. In the following sections each one of these components is presented in detail.

II.1. The WHETS system

Today the Internet is successfully being used by many institutions to deliver distance education, including environmental engineering courses[3], a statics course[4], construction education[5], a computer vision course[6], an engineering materials course[7], and a course on wave theory[8].

Laboratory classes such as ME 475, with specialized hardware requirements, can be taught at a distance if the students at the distant sites can access the hardware and the instructor

interactively. The Internet provides a medium that spans thousands of sites through networked computers, and it is readily accessible. Therefore, it is a natural candidate for creating virtual laboratory courses at a distance. Indeed, the Internet is the platform for the rapidly emerging virtual, or distributed, manufacturing enterprise which will help US manufacturing compete internationally.

However, although the Internet can be used in theory, when applied to a practical virtual engineering laboratory class it has a major drawback. One of the most critical components in interactivity -- the visual feedback from the laboratory equipment and the instructor -- cannot be delivered *synchronously* to the remote site due to the slowness of video transmission over the Internet. The delivery of *live* video over the Internet is not a mature, *reliable* technology yet. As a result, the ability to interact with the hardware becomes very limited due to the lack of visual feedback while the ability to interact with the instructor and other students during a session is at best unsatisfactory. This is a major progress-limiting step in distance delivery of laboratory courses and it diminishes the learning experience. Therefore, in this project the audio/video connection will be accomplished over the existing WHETS/BEN system. This system is not unique to WSU. It is available at many K-20 sites and community colleges in the state of Washington. It is also available at many other institutions around the country[9].

Each WHETS site has a specially equipped, sound-proof classroom with multiple cameras, microphones and large TV monitors (Figure 2). The interaction among the remote sites is controlled by site operators. For example, on demand the operators can remotely control the cameras to zoom in on the details of a piece of equipment.

Figure 2.   WHETS Classroom.

II.2.   *Equipment at WSU Vancouver WHETS classroom*

II.2.1. *Automation hardware*
The main emphasis in ME 475 is on automation hardware, software and system integration through PLC programming. In addition, the course covers fundamentals of robot and CNC programming.

The automation hardware, system integration through PLC programming and basic robot programming will be taught using two identical BP700 Modular Production System units by

Festo Didactic. The BP700 contains four stations: (1) distribution station, (2) testing station, (3) processing station, and (4) handling station with a robot. The entire system is mounted on a cart which is about 56" long, 28" deep and 30" high. The system contains various pneumatic actuators, valves, digital and analog sensors, electric motors and a Mitsubishi RV-M1 table top industrial robot. It takes round workpieces with different colors and materials and processes them by drilling a hole in each piece, by inspecting each piece and by sorting them out based on material, defects and color. In Figure 3 the BP700 cart with the robot is shown.

The unit is designed to be controlled by a programmable logic controller. As mentioned earlier, the BP700 is the main hardware that will be used in the course. To meet the goal of allowing the remote students to interact with the hardware a SLC 5/05 PLC by Allen-Bradley was chosen for the unit. This is an Internet ready PLC that can be connected to an Ethernet network just like a personal computer. Therefore, the students can program the PLC over the Internet as if they have the PLC next to them. The result is a capability to fully control the functionality of the BP700 hardware over the Internet.

Figure 3. BP700 cart with the robot (lower half of the photograph).

As mentioned earlier, the BP700 unit contains automation hardware, a PLC and an industrial robot. In some of the laboratory sessions, the robot alone will be used to teach the fundamentals of robot programming. The students will be controlling the robot over the Internet using custom software developed for this project. Details are explained in section III.1, Laboratory 5.

The fundamentals of CNC programming will be taught using two table top Techno Da Vinci CNC milling machines mounted on carts. These are small machines with 10" x 12" tables. Each machine will have a computer connected to it. This computer and a dedicated control software for the CNC will be accessed by the remote students using another software-- pcANYWHERE. This is a software that uses server/client model. The server part of the software will be installed on the local computer that is connected to the CNC. The client part of the software will be used by the remote students. The client is a plug-in that works with any WWW browser such as Netscape or Internet Explorer. Therefore, having a computer with a

Web browser and the plug-in are the only equipment needed by students to access the local computer. Using the WWW a student can take control of the local computer from a remote site. This allows a student to use the local computer as if he or she were sitting in front of it and looking at its screen directly without ever being there. As a result, a student can run the dedicated software to program the CNC. Students will program and test their programs on the CNCs over the Internet. Part loading and unloading will be done by the instructor.

In addition, the WHETS classroom will be equipped with two laptop computers and two touch monitors for the use of the local students taking the course. The details of this equipment and the software are explained in the next section.

II.3. Equipment at remote sites

In ME 475 students will learn about Human-Machine Interface (HMI) design and implementation as part of the PLC programming training. They will use two software packages by Allen-Bradley. RS Logix 500 will be used for PLC programming and RSView32 will be used for HMI design. Using RSView32 an HMI with push buttons, sliding controls, dial indicators, etc. can be designed and linked to the ladder logic program of the PLC.

Each remote site will be equipped with two laptop computers and two touch monitors. The laptops will be used to connect to the hardware in Vancouver over the Internet. A copy of RS Logix 500 and RSView32 will be installed on each laptop. Each laptop will also be connected to a touch monitor. This will allow the students to test their HMI designs and therefore control the remote hardware by pushing buttons etc. of the HMI on the touch monitor with their fingers. The setup simulates the touch monitor operator interface of modern machines found in the industry today. In addition, robot control software and a pcANYWHERE client will be installed on each of the laptops.

III. Initial developments before the first offering of the course

ME 475 is a three semester-credit course. The course normally meets twice a week for lectures and once a week for a three-hour laboratory session. The development of the course in its new format is a two-year project that started in July 1999. Therefore, in the first offering of the course in Spring 2000 only five laboratory sessions will have been developed. The course is projected to have 10-12 laboratory sessions when it is offered for the second time in Spring 2001.

In the first offering, PLC programming and robot programming were chosen to be the initial development areas.

III.1. PLC programming concepts and HMI design

ME 475 was first offered in Fall 1998 in a traditional lecture/laboratory setting with only local students. Experience showed that students have a hard time understanding relay logic and ladder logic programming when these concepts are first introduced. For example, they cannot

grasp how contacts of a relay can be used to latch a push button. Concepts such as normally-open or normally-closed contacts are foreign to many of them. Therefore, the first two laboratory sessions of the course will be devoted to comprehension of the most basic hardware concepts.

Laboratory 1
Since the fundamental idea behind programming a PLC is based on relay operations, the first laboratory session was designed to emphasize understanding of normally-open, normally-closed contacts, and how a relay works.

Figure 4 shows the hardware designed for this experiment. One such piece of hardware will be sent to each of the remote sites and another will be kept in Vancouver for the local students. This is the only laboratory session where a piece of hardware will be sent to the remote sites. All other laboratory sessions will be implemented using Internet access to the hardware in Vancouver.

Figure 4. Hardware for Laboratory 1.

The hardware contains a digital multimeter, a signal tower with red and green lights, a latching stop button, a push button, a relay, a power supply, ladder diagram, connection jacks and wires with banana plugs at both ends. Using the multimeter in continuity mode the students will test the contacts of the buttons and the relay to identify which ones are normally-open and normally-closed. Then, by plugging in wires they will complete the ladder diagram to operate the lights. When none of the buttons is pushed all the lights will be out. When the push button is pushed the green light will come on and the button will be latched by the relay. When the stop button is pushed the red light will come on, the green light will go out and the push button will be unlatched. The hardware was designed by the author, assembled by a student assistant and the case for each unit was manufactured by a local company as a donation to the program.

Laboratory 2
In the first laboratory session, the control logic is implemented using a relay. The device is hard-wired and would require a substantial change if a change in its functionality is required. This is exactly the reason why programmable logic controllers were invented in late 1960s. The

main advantage of using a PLC is that the control logic is implemented in software. Therefore, a change in the functionality of the device can easily be achieved with minimal changes in the hardware and the software.

The second laboratory session was designed to emphasize this point. The laboratory session consists of three parts.

In the first part, the goal is to control the red and green lights of a signal tower, just as in the first laboratory, but this time using a PLC and by implementing the control logic in software. This will enable the students to understand the hardware (relay) logic implementation of the first experiment and its corresponding representation and functionality in software.

The second part of the experiment requires a change in the functionality. The hardware of the first laboratory session was designed such that when the stop button is unlatched and the green button is not pressed, no light will be on. In the second experiment the change in the functionality requires a yellow light to be on in this condition indicating "ready" state. In addition, when the push button is pressed not only does the green light come on but also a motor is started. All these changes require a simple wiring change in the terminals of the PLC and a few additional lines of code in the software. Therefore, the students will see how easy it is to make changes in functionality when a PLC is used to implement the control logic.

Figure 5a shows the hardware designed for this experiment. The signal tower and the motor will be connected to a PLC in Vancouver. Students will be programming the PLC remotely over the Internet. They will test their programs in real time and will watch the results through the WHETS/BEN cameras and TV monitors.

The final part of this session introduces an HMI designed to control the signal tower. The HMI runs on the remote laptop computers with touch monitors. Just like the hardware used in the first laboratory session, it has a push button and a latching stop button (Figure 5b). The students will run the HMI on their laptops and will push its buttons on the touch monitors with their fingers, actuating the lights of the signal tower in Vancouver over the Internet.
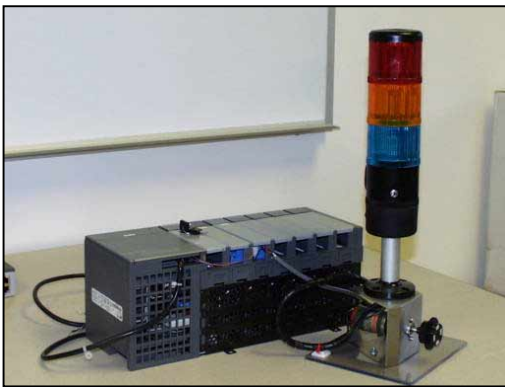

Figure 5a. Hardware for laboratory 2 next to a PLC. A small motor with a reflective wheel was installed under the signal tower.
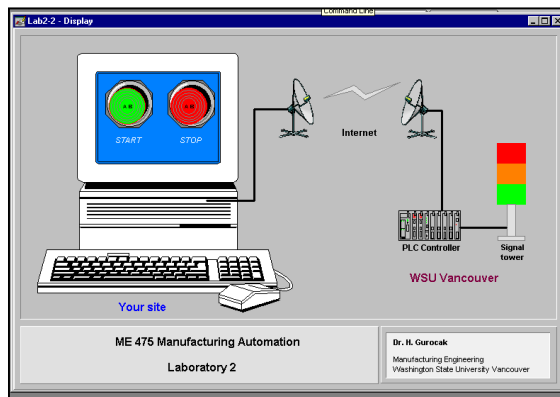

Figure 5b. HMI to be used with touch monitors to control the hardware for laboratory 2 from remote sites over the Internet.

Laboratory 3 and 4

These laboratory sessions are currently being developed. In laboratory 3 students will develop a PLC program for the BP700 to control its testing station. This station takes round work pieces and measures their height and color. It contains analog and digital sensors. They will download the program over the Internet and control the station in real time.

Laboratory 4 is intended to teach HMI design and linking to a PLC tag database. In this session students will design an HMI with push buttons, lights, and indicators for the color and height of workpieces. The HMI will be integrated into the PLC program designed in laboratory 4 to control the testing station. Using the touch monitors and the HMI, they will control and monitor the material flow and the recognition process taking place in the testing station.

Laboratory 5

This laboratory session will introduce basic robot programming concepts. Students will be programming the robotic handling station of the BP700 unit. This station has the task of sorting parts into magazines based on their color and material. Students will be programming and controlling the robot remotely over the Internet.

It is not possible to purchase a commercial software package that would enable control and programming of the robot over the Internet. Therefore, a custom software was developed. The software uses client/server architecture. The server runs on a laptop computer that is directly connected to the robot via the serial port. The clients are installed on the laptop computers at the remote sites. The server was designed to allow only one connection at a time since the robot should be controlled or programmed through one computer at a time. Once a connection is made the entire functionality of the robot can be controlled over the Internet by the remote client.

The robot comes with a teach pendant (Figure 7a) that is used to move it to the desired positions and to program motion commands. The client software contains a teach pendant that looks and works just like the real one (Figure 7b). Using the touch monitors, students at the remote sites can push the buttons of the client teach pendant and have full control of the robot over the Internet.

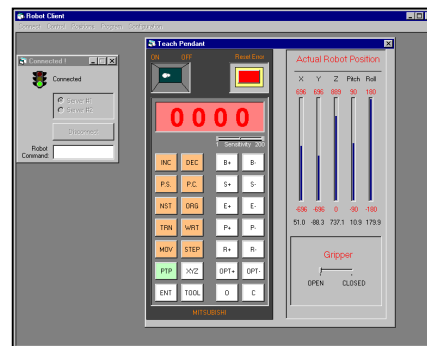**Figure 7a.** Actual robot teach pendant.

Figure 7b. Teach pendant of the client software for remote control of the robot over the Internet.

Recently the software was tested between the WSU Vancouver WHETS classroom and a Boeing BEN site in the Seattle area. The two sites are about 160 miles apart from each other. The robot was brought into the WHETS classroom and a laptop computer with the client software was in the BEN classroom. The WHETS/BEN system proved to be a perfect platform for the audio/visual interaction. The cameras could zoom on robot's hand or could show the robot from different angles. Due to the large TV sets in the BEN classroom, the robot appeared to be full size making its virtual presence in the BEN classroom even more real. The Internet connection was made over a 28.8 Kbps modem. The speed of communication between the robot server and the client was tracked by the client software. In spite of the slow connection, it took about 200 milliseconds on average for the robot to receive and start executing a command from the client. This speed is a factor of the network traffic, yet the 200 ms delay was not noticeable at all.

IV.   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 (WHETS/BEN) and the Internet. The WHETS/BEN system is a mature system and has been used for many years to deliver lecture-only format courses. The system is very reliable but cannot be used to deliver an engineering laboratory course because it does not provide a way of interacting with hardware. By augmenting the system with the Internet, a new platform to deliver an upper division laboratory course was created. Audio/visual interaction with the hardware, students at other remote sites, and students and the instructor at the local site is provided by the WHETS/BEN 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.

It is expected that the new format will result in an evenly distributed educational quality across all sites as opposed to approximated laboratories at each remote site. Because the new format delivers both the lectures and the laboratory sessions from one location, all of the students taking the course at different sites will be using the same set of equipment. The new format is also the most cost effective approach in comparison to the other possible alternatives since it does not require the duplication of the required expensive equipment at remote sites.

The paper also introduced what has been developed so far as the initial steps towards the first offering of the course in its new format. Five laboratory sessions were explained in detail.

As mentioned earlier, using the new approach the course will be offered for the first time in Spring 2000. Results of the first offering will be reported at the conference in June.

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[9]   Some of the major educational network systems similar to WHETS are available in the following states: Maine, Kentucky, South Dakota, California, Texas, Georgia, North Carolina, Ohio, Arizona and Utah. *Source: J. L. Hall, Director of WHETS.*

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