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A Laboratory Course with Remote and Local Students

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Abstract: Hands-on experience gained in a laboratory is an invaluable part of the learning activity in undergraduate education. However, delivery of the laboratory experience in a distance education setting is a challenging problem. Our manufacturing engineering curriculum contains a required control systems course with weekly labs. This paper presents an electronic laboratory book called e-LabBook developed to deliver the "hands-on" lab experience with real equipment over the Internet. Design and implementation details of the e-LabBook are explained. Results from a recent course offering with the e-LabBook indicate that it can be a viable option in providing "hands-on" lab experience.

I. Introduction

Manufacturing engineering is a very broad discipline. Consequently, manufacturing engineers typically engage in a diverse range of activities such as plant engineering, manufacturing processes, machine design and product design. In just about any of these roles a manufacturing engineer is faced with a control system since today's trend is towards a high level of manufacturing automation and design of smart products.

Our Manufacturing Engineering curriculum contains a control systems course, ME375 "Manufacturing Control Systems," with a weekly laboratory component. We have been offering this course in a traditional way where students are required to attend lab sessions to conduct experiments with hardware. However, given the multi-campus university setting, we share courses with other campuses of the university. Since mid 1980s the university has been operating an interactive TV system called WHETS. This system links all campuses and facilitates real time, two-way audio/video interactivity among classrooms across campuses. It is extensively used for distance delivery of *lecture format* courses. Using this system we can offer a course from the Vancouver campus to students at other campuses in real time.

We plan to offer the ME 375 course to the other campuses of the university but the required laboratory component is a challenge to handle in a distance delivery mode. In an attempt to address this problem, we recently finished development of an NSF-funded electronic laboratory book called e-LabBook. The front end of the e-LabBook [1, 2] is on the Internet while the back end of it is connected to various laboratory hardware. A student can read this book and remotely conduct experiments with the actual hardware in real time from anywhere, anytime. They can set up an experiment, collect data and receive streaming video feedback in real time. Eventually, we plan to use the WHETS system to deliver the lectures of the course and the e-LabBook to deliver the lab component of the course at a distance.

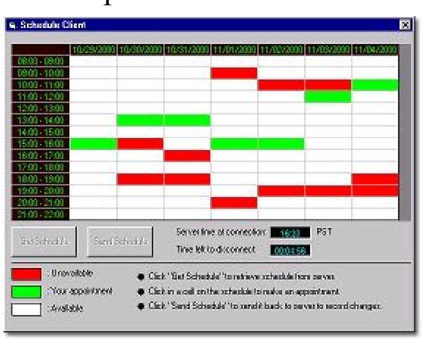
As an initial test of the developed system the e-LabBook has been used in the Fall 2002 offering of the ME 375 course. In this offering, we have not delivered the course at a distance yet. However, we tested the e-LabBook. Due to the ability to access the lab hardware anytime, anywhere, it provided a great flexibility for our students. Most of our students are non-traditional ones who work and attend school part time. With the help of the e-LabBook, one third of the class was able to conduct lab experiments remotely providing some flexibility for the work schedules. In the following sections we present details of the system design, and how the system was integrated into the course.

II. The eLabBook

The eLabBook contains four chapters on: (1) Control systems, (2) Pneumatics, (3) Actuators and sensors, and (4) Robotics. Each chapter is connected to a dedicated piece of hardware in the laboratory through a chapter server computer. The chapters are presented as a series of Web pages on the Internet. A remote student goes to the e-LabBook Web site to read the chapters. When he wants to use the hardware, he runs a client software for that chapter on his computer. The client then communicates with the chapter server computer over the Internet to provide remote access to the hardware. This way the remote student can follow instructions on the e-LabBook Web pages while interacting with the lab hardware using the client software. Each chapter has its dedicated client software that students can download from the e-LabBook Web site.

II.1. Automatic access management

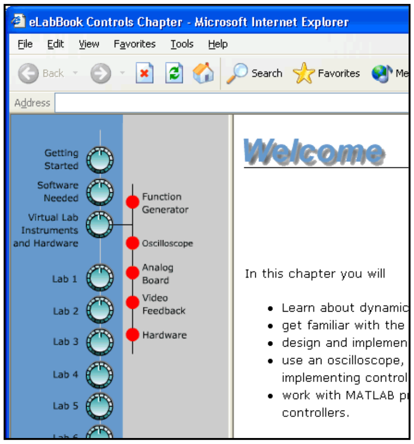
The text part of the eLabBook can be accessed by multiple users at the same time. However, each chapter hardware accessed remotely through the pages of the e-LabBook can be used by only one user at a time. In a typical usage, a student would be reading a chapter and accessing its hardware to try out the exercises or problems of the chapter with the actual hardware. Therefore, a user needs to be able to access the hardware exclusively for a while.



Access to the hardware is managed by a custom designed *scheduler* software (figure on the left). A remote user first runs the scheduler to retrieve the current schedule for a chapter from its schedule server. He or she can then make an appointment with the system to gain exclusive access rights to it during a specific time of a day. The system allows two-hour appointments at a time. When the appointment expires, it automatically terminates the connection to the hardware to allow another user to connect. If there is nobody scheduled to connect to the same hardware during the next time slot, the first user can go back to the scheduler, make another appointment for the next time slot and continue using the hardware. During an appointment, multiple users can read the eLabBook Web pages but only the one with the appointment can access the hardware while reading the related chapter.

II.2. Web page design

To maintain consistency and to make navigation within a chapter easier we chose to use the



popular split frame approach in the design of the web pages for the chapters. We used the left side of the web browser window to create dynamic menus with drop down choices (small red bullets) while the right side of the window was used to display the content the user chose from the menu. One of the advantages of the web is the ability to hyperlink documents so that a user can jump back and forth between different pages. However, usage of hyperlinks too often in a text leads to confusion since the user can get lost among many pages of a site going from one link to another. Therefore, in our design we minimized usage of hyperlinks within the text of the chapter forcing navigation with the menus.

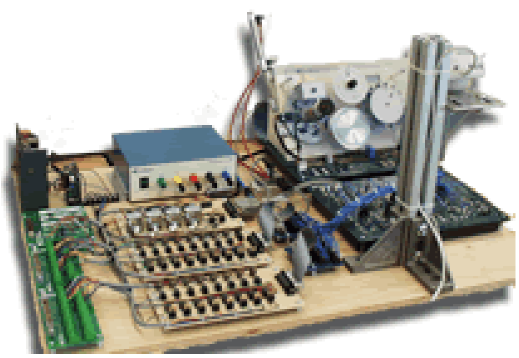
III. Control systems chapter

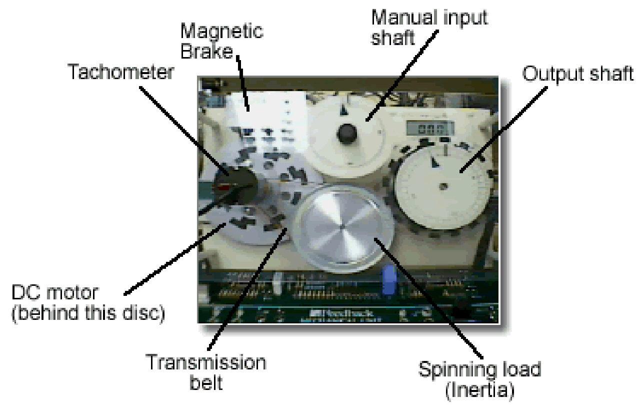
Development of the ME 375 course was initiated with a grant by a prior NSF grant. The grant was used to establish a control systems laboratory and to write a laboratory book with 12 experiments. Part of the recent e-LabBook grant by the NSF was used to convert the previously developed laboratory book into a fully electronic version as the control systems chapter. Therefore, the chapter contains 12 experiments that are identical to those in the paper version of the lab book that the local students use. The experiments cover various aspects of control system design including, system identification, Bode plots, root locus method, and digital controller design.

The content coverage is supported with a lot of figures throughout the chapter. Each experiment contains objectives, necessary theoretical background and instructions to run the experiments. During the development effort we focused on making the experiments as open-ended as possible. This allows the students to discover and experiment with the hardware on their own with "what if" scenarios. From this point of view, reading the e-LabBook is very much like physically being in the laboratory with the hardware and following instructions from the regular lab book. The difference is that with the e-LabBook the user does not have to be in the lab to be able use the hardware.

III.1. Chapter hardware and software

The hardware used in this chapter consists of mechanical unit (model 33-100) and analog control unit (model 33-110) of a servo training system by Feedback, Inc. This is the system available in the rest of the laboratory, as well. The system was designed to be used in a regular laboratory setting. We designed custom electronics (left figure below) and software as additions to the system to facilitate remote access. The mechanical unit (right figure above) comprises the process, namely a DC motor, to be controlled. It contains various sensors, including potentiometers, encoders, tachometer. It also has a rotating disk for inertia and a belt driven transmission. The analog control unit is used to construct an analog control system. It contains OpAmps and analog electronic circuits. The unit is connected to the mechanical unit through a ribbon cable for signal and power interfacing.



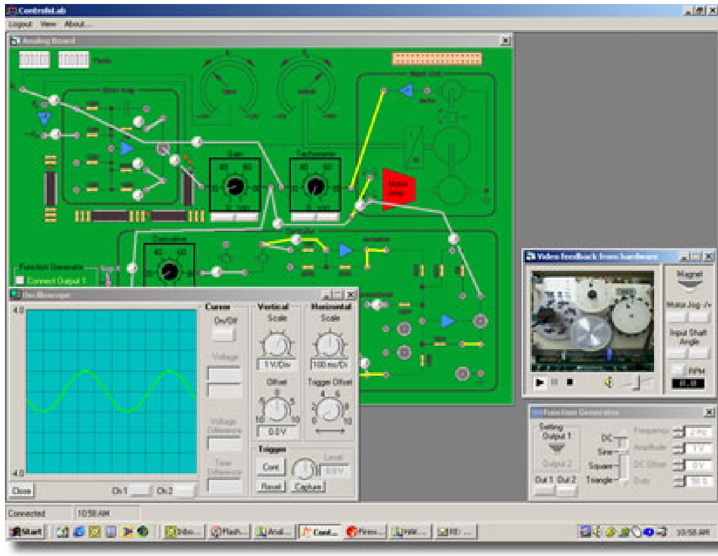


The most challenging part of the chapter implementation was the development of the software. We used Microsoft VisualBasic and Measurement Studio by National Instruments to develop the software. It uses client-server architecture where the server part runs on a computer connected directly to the lab hardware and the client part runs on remote student's computer. The client communicates with the server over the Internet to provide remote access to the hardware.

The client, called ControlsLab, contains (1) Virtual analog controller unit, (2) virtual oscilloscope, (3) virtual function generator, (4) built-in Web browser, and (5) streaming video feedback from the lab hardware. Students can download the client from the e-LabBook Web site and logon to the system with a password.

The virtual oscilloscope and the function generator have the same functionality as the actual ones in the lab. For example, the oscilloscope has two channels with capture and measurement capabilities.

In the regular lab setting, students plug wires into the analog control unit to wire up a specific type of controller. They can then conduct various experiments requiring signal measurements, etc. In the remote version, students "wire up" an experiment by activating and deactivating wires that are drawn on the virtual analog unit. Every time they activate a wire connecting two terminals on the virtual unit, the information is sent to the server computer in the lab. The server then activates a relay to make the same connection on the actual control unit hardware in the lab. This way students can remotely "wire" the system. They can connect the virtual oscilloscope and the function generator to their control board to make measurements and to provide signals to the control system.



Client software showing the virtual oscilloscope, function generator, video feedback and virtual analog control unit (green).

The client also contains a built-in Web browser window. Therefore, students can run the software, open all necessary windows for remote hardware access and the browser to read instructions on the experiment.

IV. Evaluation of the system

As an initial test of the developed system the e-LabBook has been used in the Fall 2002 offering of the ME 375 course. In this offering, we have not delivered the course at a distance yet. However, we tested the e-LabBook using a volunteer group of students taking the course. This semester 10 students took the course 4 of whom volunteered to remotely access the lab. The Manufacturing Engineering program is a growing, relatively new program with about 40 students. Our typical class size is 10 to 15 students. Most of our students are non-traditional ones who work and attend school part time. Therefore, the idea of being able to access the lab remotely and not having to attend the 3-hour long weekly lab sessions was attractive.

The remote students attended the regular lectures of the course twice a week. However, they ran the lab experiments on their own remotely using the e-LabBook. The remaining students attended regular weekly lab sessions. Due to the flexibility provided by the anytime, anywhere access, they could conduct the labs at times and places convenient for them. For example, one student had to go on business trips twice and had to run the experiments from Singapore. Others accessed the hardware from their kitchen table or from a computer in the library.

Throughout the semester there were 12 lab sessions. Some of these required collecting data and analyzing it. There were no noticeable differences in the collected data between the remote and the local groups. In other labs 10-minute lab quizzes were given to measure comprehension of the fundamental concepts in the experiments.

Student course grades were used as a measure of success of the course [3, 4]. The course grade is based on two midterm exams, one final, six homework assignments, four laboratory assignments and four lab quizzes. Table 1 gives the average and standard deviation of course grades of the remote students (R) and the local ones (L). It also shows means of the two samples and their comparison using the t-test statistic. The null hypothesis is that there is no difference in the means of the local and remote students. In other words, the remote students learned the laboratory and course material just as well as the local ones. The alternative hypothesis is that the two means are different. The table also contains a p-value for each mean difference. The p-value indicates the likelihood of obtaining a difference as large as that observed if it occurred simply from randomness in the data. A low p-value implies that we would probably not observe such a large difference from purely random data and the difference must be the result of some systemic effect. By convention, we usually label any difference with a p-value of 0.05 or less as meaningful, that is, statistically significant [3, 5].

Table 1. Remote and local student performance comparison.

	Access	No. of students	Avg. course grade	St. Dev.	t-stat	t-crit. (2-tail)	p-value
Fall 2002	R	4	82.35	10.26	0.287	2.23	0.78
	L	6	80.78	10.93			

It can be seen from Table 1 the t-statistic is less than the t-critical value (or the p-value > 0.05 for a two-tailed test). Based on these results we can conclude that there is no statistically significant difference between the performance of the remote and the local students. Hence, the e-LabBook provided the necessary educational environment irrespective of the physical location of the students.

Table 2 shows results of a survey filled out by the remote students after completing each lab session. These surveys used a Likert scale where 1 = Strongly disagree, 2 = Disagree, 3 = No opinion, 4 = agree, 5 = Strongly agree.

Students found the lab software and the instructions easy to use. In this setting, the live video feedback was nice to have but was not essential for the students to successfully experiment with the lab hardware. After talking with other students in class, the remote students realized that using the hardware remotely was very much like conducting the experiments locally. The course pace required running a new lab every week. Since the remote students could do the lab experiments anytime during the week, scheduling an exclusive session with the hardware was not a problem. The experimental data collected using the remote system had no significant difference from the data collected by the local students attending regular lab sessions. Finally, students felt confident that they learned the material in the remote laboratory sessions.

Table 2. Remote access survey results.

Survey questions	Average	St. Dev.
The lab software was easy to use.	4.65	0.48
The lab instructions were easy to follow.	4.06	0.87
Quality of the graphics/pictures in the instructions was good.	4.18	0.51
The lab instructions Web site was easy to navigate.	3.53	1.29
Live video feedback from the lab hardware helped me feel like I was actually in the lab next to the hardware.	2.35	1.28
Using the lab hardware remotely is very similar to using the actual hardware in the lab.	4.00	0.59
It was easy to schedule appointments (the system was available when I needed it).	4.41	0.77
The data I collected or the system behavior I observed with the remote hardware was in agreement with those collected by others using the lab hardware locally.	4.88	0.32
I felt that I learned the material covered in the remote labs	4.76	0.42

V. Conclusions

In this paper we presented the control systems chapter of an electronic book called e-LabBook. The front end of the e-LabBook is on the Internet while the back end of it is connected to various laboratory hardware. A student can read this book and remotely conduct experiments with actual lab hardware in real time from anywhere, anytime.

As an initial test of the developed system the e-LabBook has been used in the Fall 2002 offering of the course. In this offering, we have not delivered the course at a distance yet. However, we tested the system using a volunteer group of students taking the course. In this semester 10 students took the course 4 of whom volunteered to remotely access the lab.

Although a relatively small sample size has been used due to our current enrollment situation, the results of the initial experiment are very encouraging. Student course grades and a survey were used to assess the effectiveness of the system. Results indicate that there is no statistically significant difference between the performance of the students conducting the experiments remotely or locally. Remote students found the lab software and the instructions easy to use. Using the hardware remotely was very much like conducting the experiments locally. The experimental data collected using the remote system had no significant difference from the data collected by the local students attending regular lab sessions. Students felt confident that they learned the material in the laboratory sessions. The system enabled students to complete their weekly labs by accessing the hardware over the Internet from their kitchen table, the library, and in one case even from Singapore.

The ME375 “Manufacturing Control Systems” is a required course in the Manufacturing Engineering curriculum in Vancouver. We have been working towards the goal of offering the ME 375 course to students at other campuses of the university, as well. We plan to use an Interactive TV system operated by the university to deliver the lectures of the course simultaneously at multiple campuses while the required lab component will be handled by the e-LabBook.

Acknowledgements

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