

eLabBook: An Electronic Laboratory Book on the Internet for Distance Delivery of Laboratory Experience

Hakan Gurocak

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

Abstract: Many educators agree that integrating interactive modes of delivery into distance education will significantly enhance the educational experience for students. This is especially true in undergraduate engineering education since hands-on experience gained in a laboratory is an invaluable part of the learning activity. However, delivery of the laboratory experience at a distance is a challenging problem many institutions are trying to solve. This paper presents an electronic laboratory book called eLabBook to deliver “hands-on” experience with real equipment over the Internet. Details of the design and implementation of its first chapter on robotics are explained. Results of student evaluations of the system are discussed.

I. Introduction

For the past ten years the use of computer-based instruction has been presented as providing learning benefits over traditional classroom methods. With the advent of the browsers for the Internet, ever increasing use of this medium in education has been explored¹. Today the Internet is successfully being used to deliver distance education, including environmental engineering courses², a statics course³, construction education⁴, a computer vision course⁵, an engineering materials course⁶, and a course on wave theory⁷.

In fact, the Internet has been taken a step further from being just a medium to deliver graphics, text, sound and video. Today there are physical devices such as cameras, coffee machines, telescopes and robots connected to web sites all over the world allowing the users to control them remotely⁸. The possibility of controlling actual equipment using the Internet has opened new avenues for laboratory courses at a distance. There are a few examples of such laboratories^{9,10}. The most significant of these is a collection of control systems experiments at

the University of Tennessee at Chattanooga (UTC)^{11, 12}. This on-line laboratory allows remotely located students to conduct experiments with actual devices in the laboratory by accessing them using the Internet.

The eLabBook project also explores the idea of remote access to real equipment over the Internet. Imagine yourself reading a regular engineering textbook. As you read the material you would refer to photographs of machines or schematics of components distributed throughout a chapter. The eLabBook is just like a regular textbook only it is on the Internet. As you read this book you will also see photographs of machines. But this time you will be able to connect to the actual machines in a laboratory at Washington State University Vancouver (WSUV) over the Internet and be able to operate them remotely. In other words, the eLabBook contains actual machines and components in its virtual pages. The chapters of the eLabBook are being designed to be self-contained. Therefore, by combining chapters under different table of contents pages instructors can configure their own eLabBooks to support different courses.

II. Distance education at Washington State University

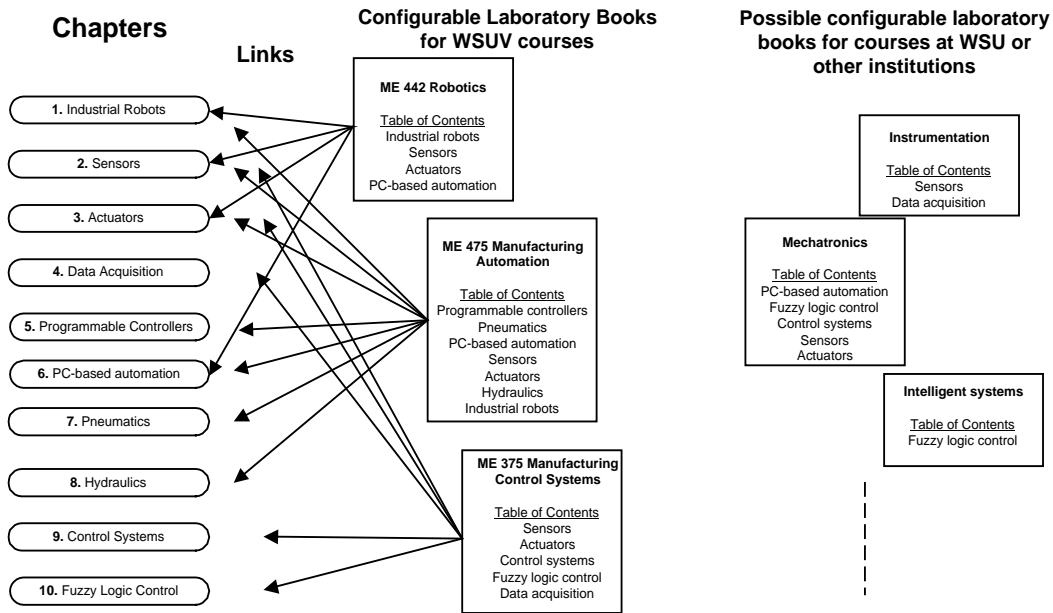
Washington State University is a multi-campus system with the main campus in Pullman and three branch campuses in Spokane, Tri-Cities and Vancouver that are hundreds of miles apart throughout the state of Washington. Since mid 1980s the university has been operating an interactive TV system called WHETS. 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. However, the system was not developed to deliver laboratory courses at a distance. In addition, since it is used by all departments, course scheduling is very difficult.

We use the WHETS system to deliver some of our courses at a distance, too. 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, even another WSU campus in the Tri-Cities area can join in the lectures.

Our curriculum contains courses with laboratory components. The eLabBook project is motivated by the need to deliver some of these courses as part of a distance learning opportunity within and beyond the WSU multi-campus system. Specifically, the eLabBook is being designed to support three courses: ME 375 "Manufacturing Control Systems", ME 475 "Manufacturing Automation" and ME 442 "Robotics".

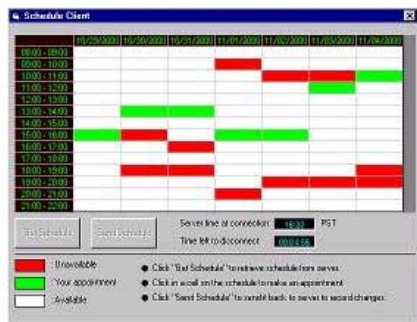
III. The eLabBook

Implementation of the eLabBook involves: (1) Content development for ten chapters to be used to configure different laboratory books. Each chapter will be entirely self-contained. Therefore, the chapters can be combined in any fashion through a table of contents web page, allowing access only to the chapters listed on that page. Each such table of contents defines an eLabBook supporting a different course; (2) Development of custom software to access actual physical devices over the Internet in real time; (3) Development of a consistent web page design for all chapters and; (4) Automatic management of access to hardware to facilitate usage of laboratory resources by multiple users.



III.1. Automatic access management

The eLabBook is a multi-user system. However, the hardware, such as a robot, accessed remotely through the pages of the eLabBook 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 system exclusively for a while.

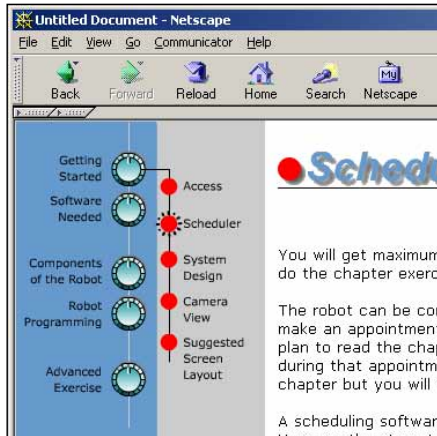


Access to the hardware supporting the eLabBook is managed by a custom designed *scheduler* software. A remote user first runs the scheduler to retrieve the current schedule for a chapter from its schedule server. He or she can then make an appointment with the system to gain exclusive access rights to it during a specific time of a day. The system allows one-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 hour, the first user can go back to the scheduler, make another appointment for the next hour and continue using the hardware. During an

appointment, multiple users can read the eLabBook but only the one with the appointment can access the hardware while reading the related chapter.

III.2. Web page design

As mentioned earlier, it is possible to create eLabBooks for different courses by configuring table of contents pages. 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.

IV. Robotics chapter

The eLabBook is a two year project. The first and only chapter we developed so far is on robotics. The main goals of the chapter are to (1) Supplement the material covered in the lectures of ME442 Robotics course, (2) Provide a self study guide to learn general programming requirements of an industrial robot and, (3) Provide “hands-on” laboratory experience with an actual robot for remote students. The following table summarizes the chapter content.

<p>Components of a robot</p> <ul style="list-style-type: none"> a. Controller b. Robot c. End-effectors d. Actuators e. Sensors 	<p>Robot programming (cont'd)</p> <ul style="list-style-type: none"> c. Robot commands d. Robot View <ul style="list-style-type: none"> i. Absolute and relative angles, X,Y, Z position coordinates e. Exercises
<p>Robot programming</p> <ul style="list-style-type: none"> a. Teach Pendant <ul style="list-style-type: none"> i. Nesting the robot ii. Motion coordinates iii. Joint movement iv. Teaching a position v. Error conditions b. Program Editor <ul style="list-style-type: none"> i. Editor buttons ii. Sending a program to robot iii. Getting a program from robot iv. Example files 	<p>Advanced exercise</p> <p>Robot programming for a pick-and-place operation. This requires using all skills learned and practiced throughout the chapter to be used.</p>

The chapter starts with an introduction of various components of the Mitsubishi RV-M1 light-duty industrial robot used as the hardware. This is followed by an extensive coverage of the two-step process of robot programming. The first step in robot programming involves moving the robot to various task positions (such as a pick-up position) and teaching them using a teach pendant. The second step requires writing a robot program that describes the motion logic to accomplish the task.

The content coverage is supported with a lot of figures and photographs throughout the chapter. When a new subject, such as changing the motion coordinate mode of the robot, is introduced it is followed by a small exercise. These exercises are dispersed throughout the chapter and allow reinforcement of the subjects by testing the ideas with the actual robot. From this point of view, reading the eLabBook is very much like physically being in the laboratory with the robot and following instructions you read from a regular lab book. The difference is that with the eLabBook the user does not have to be in the lab to be able use the robot.

At the end of the robot programming section the chapter contains five exercises. They resemble problems found at the end of a chapter in a regular textbook. There are three levels of difficulty, beginner, intermediate and advanced. The beginner exercises give step by step instructions leading to the solution. As the user goes from the beginner level to the advanced, the tasks get harder and more generic instructions are given. Finally, the chapter is concluded with an advanced exercise. This exercise requires the user to program the robot for an automatic pick-and-place operation. Successful completion of the exercise requires all of the skills learned and practiced throughout the chapter.

IV.1. Remote access software

The most challenging part of the chapter implementation was the development of custom software (over 20,000 lines of code) to access the hardware over the Internet in real time. For the robotics chapter we developed three pieces of software: (1) Virtual Teach Pendant (VTP), (2) Robot View and, (3) Program Editor. These can be downloaded from the chapter web site.



The *Virtual Teach Pendant* (shown left) resembles the real teach pendant that came with the robot. It has all the functionality of the real one and some more. Using the VTP a user can control all joints of the robot, select different motion coordinate modes, teach task positions and test them over the Internet.

The *Robot View* software (shown below) is used along with the VTP. On the left side of the window it provides streaming video feedback from a camera mounted on the hand of the robot. It also has top, front and side views of the robot that are updated in real time based on the current posture of the robot.



The *Program Editor* enables editing, downloading and uploading of robot programs.

The VTP and the Robot View software can be positioned on the user's monitor along with a web browser. This way the user can read the chapter with the web browser, follow the instructions, control the robot with the VTP and receive feedback from the robot with the Robot View. The system has a security feature that prevents collision of the robot with its base table. It intercepts every incoming command from the remote user and computes where the robot would move if it received the command. If the command does not result in a collision it is allowed and sent to the robot. Otherwise, it is cancelled.

IV.2. Robotics chapter hardware



The main hardware used in the chapter is a Mitsubishi RV-M1 light-duty industrial robot with five joints. The robot is equipped with a hand-mounted camera. After some experimentation it was determined that having a hand-mounted camera gave the remote user better views of the manipulated objects. In the video images the user can see the finger tips of the robot and a close-up view of the object manipulated. Therefore, it is easier to position the robot with respect to the object to grasp it.

Many robot applications involve picking and placing objects. In this application we chose to use a puzzle. We mounted a 4" tall soft foam handle to each piece (not shown). This is where the robot can pick up the parts. The soft handles provide some compliance in case of misalignments. The puzzle base simulates an assembly and the pieces simulate parts to be assembled by the robot. Each piece must be properly positioned and oriented by the robot for successful assembly.



The robot controller is connected to a computer which acts as a server for the remote clients, such as the VTP, and also acts as a streaming video encoder for the images captured by the camera.

V. Evaluation of the robotics chapter

The robotics chapter, along with others, is intended to support the ME442 Robotics course. However, the next offering of the course will be in Fall 2001. Therefore, we will not be able to put the chapter in use by a class right away. Yet, to help with the design process of the chapter as well as with the future ones we decided to conduct an experiment with a small group of students.

We formed two focus groups with three students each. None of the students had any experience with a robot and had no background in robotics. Students in Group 1 were given access to the remote control software as well as the chapter while those in Group 2 were given access to only the chapter. The main purpose of the experiment was to determine if having access to the real hardware while reading the chapter made any difference in the comprehension of the material.

The students were given one week to study the chapter individually. At the end of the week we invited each student separately to the lab to work with the robot. We prepared five questions exploring comprehension of the basic material, such as definition of parts of a robot, that they would have seen in the chapter. In addition, we prepared a set of tasks to be done using the robot. The tasks started at a simple level, such as moving the joints of the robot, and gradually got harder requiring complete programming of the robot for automatic pick-and-place operations. Students were given 5 minutes to complete the simple tasks and 20 minutes to complete the complex ones. If they could not complete the tasks in the allocated time they had to stop and move on to the next level of tasks. The following tables summarize the results.

Performance of students with access to both the chapter and the remote control software (GROUP 1).

Task	Student #1		Student #2		Student #3	
	Completion time	# of mistakes	Completion time	# of mistakes	Completion time	# of mistakes
5 questions	Under 5 min.	0	Under 5 min.	0	Under 5 min.	4
Simple tasks (5 min. total)						
Task #1	20 sec.	0	20 sec.	0	20 sec.	0
Task #2	5 sec.	0	3 sec.	0	5 sec.	0
Task #3	25 sec.	0	50 sec.	0	35 sec.	0
Task #4	3 sec.	0	10 sec.	0	3 sec.	0
Task #5	5 sec.	0	10 sec.	0	5 sec.	0
Complex tasks (20 min. total)						
Task #1	2 sec.	0	2 sec.	0	2 sec.	0
Task #2	6 min.	2	7 min.	2	5 min.	4
Task #3	10 min.	3	12 min.	2	12 min.	4

Performance of students with access to only the chapter (GROUP 2).

Task	Student #1		Student #2		Student #3	
	Completion time	# of mistakes	Completion time	# of mistakes	Completion time	# of mistakes
5 questions	Under 5 min.	2	Under 5 min.	3	Under 5 min.	1
Simple tasks (5 min. total)						
Task #1	Gave up	Many	4 min.	0	20 sec.	0
Task #2	Gave up	Many	3 sec.	0	5 sec.	0
Task #3	Gave up	Many	Out of time	Many	4 min.	3
Task #4	Gave up	Many	Out of time	Many	Out of time	Many
Task #5	Gave up	Many	Out of time	Many	Out of time	Many
Complex tasks (20 min. total)						
Task #1	Gave up	Many	12 min.	4	20 sec.	1
Task #2	Gave up	Many	Gave up	Many	20 min.	25
Task #3	Gave up	Many	Gave up	Many	Out of time	Many

The results reveal that having access to the real hardware while reading the chapter made a big difference in the comprehension and retention of the material. The students in Group 1 appeared to be very confident while working with the robot. Whereas those in Group 2 spent most of their time randomly pressing different buttons on the teach pendant trying to figure out what the buttons did. They appeared to be very hesitant as they worked with the robot. They either got frustrated and gave up or ran out of time before completing many of the tasks.

At the end of a session we asked each student in Group 2 if the results would be different if they had access to the robot while reading the chapter. Each one of them said it would have made a great difference because, although they read the chapter, they could not remember how to use the teach pendant or any of the robot commands for programming. None of the students had access to any material related to the robot during the experiments. The results show that access to the hardware *while reading the chapter* clearly made a difference in comprehension and maybe more so in *retention* of the material.

When we asked the students in Group 1 if having access to the robot made a difference, we got an interesting response from them. They said having access to the robot while reading the chapter made the chapter much more fun and kept them interested and made learning the material an enjoyable experience. One of the challenges in distance learning is that it requires self-motivated students who can take a course or follow instructional material on their own without the pressure of an instructor. It appears that interaction with actual hardware as part of the instructional material leads to significantly higher motivation for students to read the material.

VI. Conclusions

In this paper we presented an NSF-sponsored project on development of an electronic laboratory book called eLabBook. The eLabBook is just like a regular text book only it is on the Internet. It allows access over the Internet to actual machines while the user is reading the book. In other words, the eLabBook contains actual machines and components in its virtual pages. The chapters of the eLabBook are being designed to be self-contained. Therefore, by combining chapters under different table of content pages instructors can configure their own eLabBooks to support different courses.

Details of the design and implementation of the first chapter (robotics) were explained. As part of the implementation a scheduler software was developed to automatically manage access rights to all hardware associated with the current and future chapters of the eLabBook.

A preliminary experiment with a small group of students was conducted to determine whether having access to actual hardware while reading the chapter made any difference in the comprehension and retention of the material. The results indicate that it led to a significant improvement in the student performance. In addition, it made the material much more interesting and enjoyable to learn.

Our ultimate goal is to configure the chapters developed for this project into different eLabBooks to support distance delivery of three courses in our curriculum. The lectures will be delivered using the WHETS interactive TV system of the university and the eLabBooks will be used as supplements to deliver “hands-on” experience with actual hardware at remote sites. The first offering of a course with an eLabBook is expected to be in the Fall 2001. Currently, we are developing the next two chapters.

Acknowledgements

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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.