Distance Learning of Engineering Courses with Web-based Real Experimental Experience

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Abstract

Distance learning has been greatly enhanced through the use of the Internet. In Arizona, a joint effort has been made by the three state universities to offer a Master of Engineering Degree primarily through Internet and video distance learning. However, engineering courses often use hands-on laboratory projects with actual physical systems as an integral part of the curriculum and learning process. It is difficult to include these labs in web-based instruction unless one uses simulations or virtual experiments. This paper presents the development of web-based lab projects with actual hardware for courses in linear systems and systems control. Students download control programs to the equipment. Sensor data and a streaming video of the ongoing equipment are transmitted back to the student. The approach allows a higher utilization of lab equipment, saves student travel time, and provides an effective tool for learning as students can debug programs based on visual and sensor information. This development has been jointly conducted in the University of Arizona's Web-based Audio Video Educational Systems (WAVES) Laboratory and the Chinese Academy of Sciences' Complex Systems and Intelligence Science Laboratory. The web site for the materials is: http://pallas.sie.arizona.edu/newwaves/ and the work has been supported by an NSF CRCD grant and an Outstanding Scientist Program grant from the State Planning and Development Commission of China. We focus on system architecture, programming environment, user interface, application and experience in course instruction.

1. Introduction

To address students' concerns in undergraduate education, the College of Engineering and Mines at the University of Arizona conducted a student/faculty survey in which students were asked to rank the importance of 12 issues in undergraduate education. The survey report has indicated that our students consider **1**) *"hands on" experiences with the application of engineering principles,* **2**) *faculty who communicate course material effectively*, and **3)** *the ability to relate studies to career preparation and future employment,* as the three most important issues at the College. The clearly showed that students were not satisfied with the current situation at the College in terms of hand-on experiences and career preparation since

"hands on" experiences with the application of engineering principles received lowest satisfaction score from our students. Nationwide, many engineering departments need to improve laboratory development and facilities. All three issues above depend on the availability of good lab facilities and projects. These often require large resources to develop and this is an expensive undertaking in times where budgets are being sharply reduced. We have developed an open and integrated platform for online laboratory experiments, computer simulation, and course instruction using Internet[1-4]. We believe that all three issues can now be addressed in a cost-effective approach by using this platform.

In fall 1991, students in Systems and Industrial Engineering (SIE) at The University of Arizona first conducted PUMA robot lab experiments via the Internet. The experiment has been repeated successfully by initiating commands from computers in Europe and Asia (sometimes with a delay of two hours) and used by high school students. In fall 1998, the SIE Department spent $50K to develop Internet-based lab experiments for courses in modeling, analysis, and control of dynamical systems and the WAVE (Web-based Audio and Video Education) Lab was created. Three prototype Internet-based experimental systems were constructed (see Figure1). In fall 1999, NSF awarded a CRCD grant of $400K to expand these efforts to their present state.

a) Mass-Damping-Spring b) Train Station Control c) Flexible Arm Control

Figure 1 - SIE Internet-based Labs in WAVES

The uniqueness of the approach is that we conduct experiments using actual hardware via the Internet and we provide students at remote sites with real-time data and slightly delayed (delay depends on bandwidth available) audio/video feedback. Since Internet-based hardware systems can be shared by a large number of remote users, the proposed platform is a cost-effective way to address the issue of "hands on" experiences with expensive lab and/or industrial hardware systems. Only one piece of equipment or system needs to be deployed and this will reduce duplication costs and increase overall system utilization.

The platform allows faculty and students to develop and conduct Internet based lab projects and our development process provides a case study for constructing similar cost-effective systems in other areas for research and teaching based on Internet technology. We believe that this can significantly change the way science and engineering are taught and learned in both secondary and post-secondary educational systems. The new approach is cost-effective, easily accessible by everyone, useful in promoting "learning by doing," and in developing a student's capability and motivation to engage in lifelong learning. Our eventual vision is a **National Internet-Based Laboratory for Research and Education** that provides state-of-art facilities and high quality services for conducting lab experiments and computer simulations via Internet. It would be available to all educational institutions in the United States.

In Arizona, a joint effort has been made by the three state universities to offer a Master of Engineering Degree primarily through the Internet-based distance learning, and our system is an integral part of such effort. Graduate students have developed various online experimental modules for different courses, such as dynamic, control, manufacturing, and real-time embedded systems [5-13]. Recently, an international joint effort has been formed with the Chinese Academy of Sciences to export both the Master of Engineering Program and on-line lab experimental projects to China, with the support from its Knowledge Innovation Program.

2. System Architecture

An open and integrated system architecture (Figure 2) for online laboratory experiment, computer simulation, and course instruction is described in this section. To conduct the hardware experiment, WAVES provides a remote hardware-accessing environment via the Internet and provides students at remote sites with real-time sensor data and audio/video of experiment results. There are several components in the WAVES system, including the RemoteNode, the RemoteNode Client, the Dispatcher and the Coordinator.

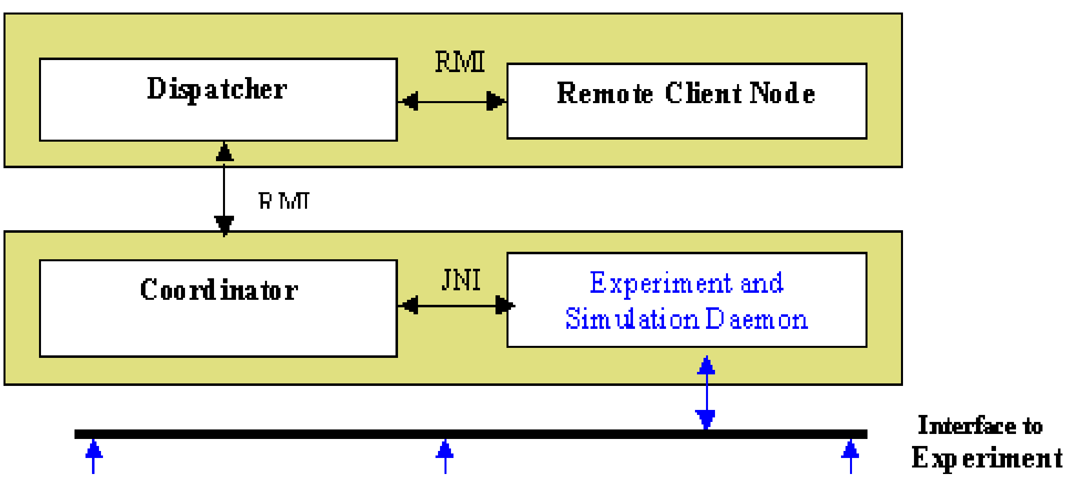

Figure 2. - System Architecture

RemoteNode and RemoteNode Client

A RemoteNode is an entity that is accessed a user (a RemoteNode Client) or another RemoteNode. A RemoteNode may be a software simulation or a hardware device and has a layered architecture of: hardware layer, algorithm layer and data transfer layer.

A WAVES system consists of RemoteNodes that work together to perform a particular task. Elements of a WAVES system group together and share access to a RemoteNode. The dynamic nature of a WAVES system enables a RemoteNode to be added or withdrawn from a group at any time according to demand, need, or the changing requirements of the RemoteNode Client using it.

The WAVES system provides mechanisms for RemoteNode construction, lookup, communication, and use in a distributed system. Examples of RemoteNode include hardware devices such as a printer, a display, or a camera, and software such as an application or utility program.

The RemoteNode Client is a special kind of RemoteNode, which is only used by the clients. The RemoteNode Client initiates the request to receive data from a Coordinator and processes most of the data. It contains the vision module (responsible for acquiring and plotting data) and a process for monitoring and controlling the RemoteNode (picking up data from the vision module to determine the status of and command to the controlled hardware).

Dispatcher

In a small-scale system, hard coding connections and interactions is reasonable, but as a system gets larger, it becomes desirable to have a scheme for dynamically creating connections. To solve this, the WAVES system implements a dispatching mechanism and a lookup service. The ID of the Dispatcher is published in the WAVES system and is dynamically updated if no physical location changes or there are no other changes of the Dispatcher configuration. Every node connects to the Dispatcher without extra lookup steps.

In the WAVES system, the RemoteNode Clients use the lookup system to find RemoteNode objects. The location of each RemoteNode object must be known by a Coordinator. The Dispatcher locates all of the Coordinators by keeping a dynamic list of attributes that include the address, the port and the RemoteNode service description at the corresponding Coordinator.

With a central Dispatcher, it is easy to implement a RemoteNode built-in capability. Every time a new RemoteNode is added to the system, we only needs to add its attributes (address, port and service description) to the Dispatcher. The RemoteNode Client gets this information from the Dispatcher and then connects to the new RemoteNode. In the same way, when a RemoteNode leaves the system, we only need to send a notification to the Dispatcher to delete the corresponding attributes in the list. Since every request must be submitted to the Dispatcher first, the Dispatcher is the busiest node in the WAVES system (and the speed of this node is a dominant element in the speed of the system). Hence, to reduce the workload on the dispatcher, we forward work the Coordinator to process.

Effective system management can result from using this architecture. For example, the centra; Dispatcher can know the workload of each Coordinator. With this information, it then can allocate the resource of the whole system more effectively.

Coordinator

The Coordinator provides a domain for the RemoteNode. The Dispatcher stores the information of the Coordinator while the Coordinator stores information of the RemoteNode. A Coordinator can be a node residing in another Coordinator and this provides a hierarchical architecture. A RemoteNode Client may go through several coordinator nodes until it finally reaches the one for the RemoteNode it needs.

The Coordinator waits for the Dispatcher to forward the clients' requests, then creates a new RemoteNode that captures a resource for the request. After finishing the request, the Coordinator deletes the RemoteNode object and releases the resource. A notification is issued to the Dispatcher after the deletion.

The Coordinator is implemented using a "lease-based" technology. A lease is guaranteed access to a resource for a set time period. Each lease is negotiated between the RemoteNode Client and the Coordinator for the RemoteNode). The lease is only implemented in the Coordinator. If one RemoteNode Client holds the Coordinator too long and "breaks the lease," then the Coordinator disconnects itself and releases the resource. We do not use the Dispatcher to do the timing and disconnect as it already has a high processing load.

3. Programming Environment

The programming environment in WAVES is mainly the Java Compiling Environment. However we use C++ and C to communicate with the hardware. Java acts like the middleware to communicate to the user interface and the hardware devices. We also use Matlab code for device control.

To run a remote experiment, the WAVES system controls the hardware using a two layer hierarchy. The upper layer is responsible for communication, while the lower one is for the hardware interface. In the upper layer, a Java applet is running to enable the remote clients to upload Matlab codes to the remote server that is connected to the experiment device. After the Matlab codes are transferred to the server side, lower layer processes the job. First, there is a daemon running on the server, scanning for any incoming codes. Once it sees any Matlab codes, it translates the codes into C while fixing all control variables, parameters, and algorithms. The newly generated C code performs the communication between the web server and the hardware. Figure 3 shows the hierarchy of remote control experiments.

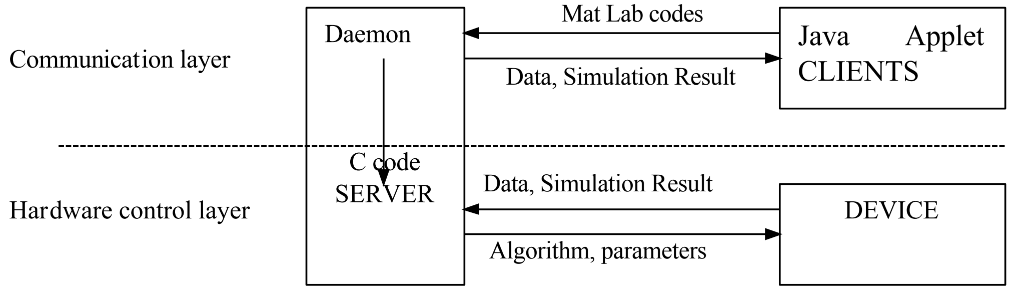

Figure 3 - Hierarchy of the remote control experiment in WAVES

4. User interface: A User Centric Approach

A user-centric system is one that is designed based on the needs of the user. WAVES provides a broad range of functions to the user such as a personalized interface, and the ability to customize the logon default page, and the ability to use a single mouse click view specific class information. However, different types of users must have different user interfaces. Now, we enable four kinds of users: student, TA, Professor, and Administration.

4.1 The Student Scenario

Students log on to the system using a userid and password. They can then see homework assignments due for this week. Upon clicking on the link for the problem set the student goes to the assignment information page, where they get information and can eventually upload a solution attempt. Figure 4 contains the "scheduler page" where students can reserve lab time. Also, information for next week's assignment is also available. The following additional features are available:

- Course and individual class announcements and reminders
- Team discussion areas
- Class discussion area.

4.2 The TA Scenario

The TA's workspace, enables adding a course problem set (with due date) and monitoring student progress on the assignments. The TA can download student work for evaluation, annotate the solutions with comments, and then uploads marked papers to be returned to the students. The TA also fills out a grade sheet for the problem set for each student and submits the form with the grades and comments. These evaluations go into the database, and a class grade list is complied and stored.

4.3 The Professor Scenario

A professor logs on to WAVES from the main page, and has access to all the necessary commands for the corresponding course including:

- Uploading lecture notes and materials for class
- Viewing student grades
- Checking on class enrollment
- Uploading assignments
- Constructing and sending announcements

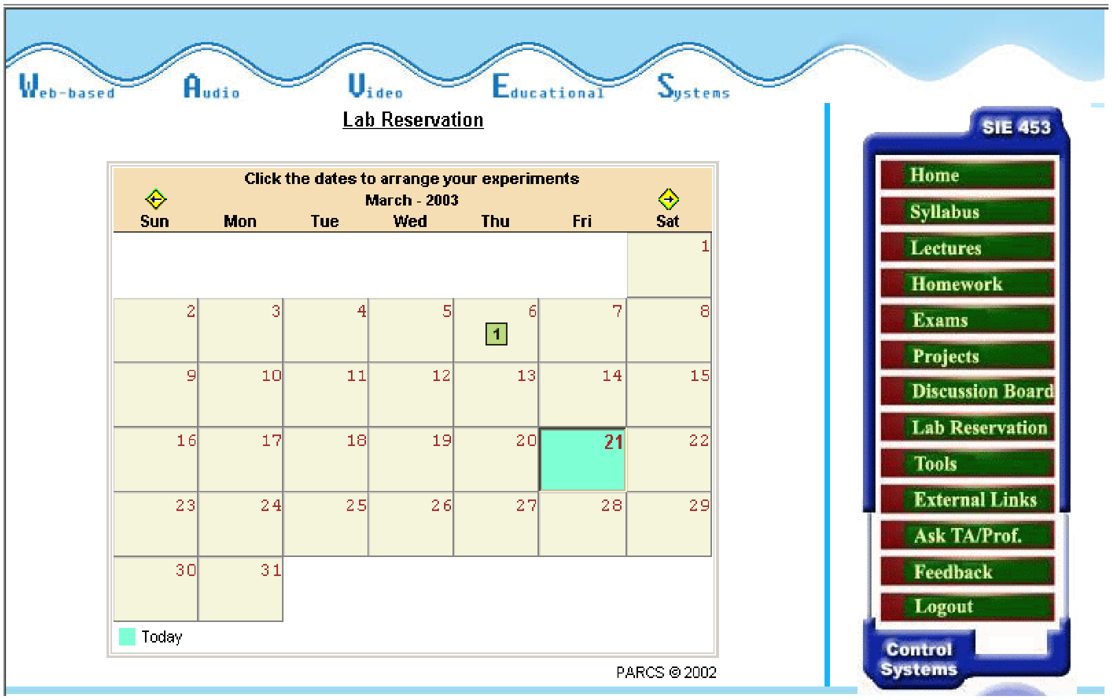

Figure 4 - Lab scheduling page and course menu

4.4 The System Administration Scenario

The System Administrator, can control all courses in the system for the particular semester. This includes the following capacilities:

- Creating new classes and a new semster
- Deleting old classes
- Monitoring usage statistics
- Monitoring the availability and status of the equipment
- Sending announcements to the professor/TA/students when there is a problem.

5. Application

In this section, we discuss our implementation of the WAVES system for the course, SIE 453 Feedback Control Systems. This is a senior level class in control and students have already had significant material in programming, linear systems theory, and mathematics.

Based on the system architecture of WAVES, the SIE 453 website provides the following main applications and functions:

- User administration - Students will see a password protected login screen upon entering the website. This is the only access point to the course website. Students can modify their attributes via the profile function provided by the system.
- Course instruction - This part includes several modules such as the course syllabus, lectures, homework/exams and solutions, grades, lab reservations, group discussion, "ask TA," "ask Professor," and feedback/comments. With these modules, students and the instructor can conduct the course process in a largely online fashion, however there are on-campus classes, and the WAVES system is currently being used as a class supplement.
- Experiment implementation - Currently, the Inverted Pendulum is implemented in this section and Figure 5 contains the real time sensor data and streaming video of the equipment. Students design an algorithm for control using the concepts and methods of the Linear Quadratic Regulator (LQR) state feedback design. The inverted pendulum consists of a cart, which moves on a ground stainless steel shaft. The cart is equipped with a motor and a potentiometer. The cart along with the motor and potentiometer are coupled to a rack and pinion mechanism used to transmit a driving force to the system as well as to measure the position of the cart. The motor shaft is connected to a small gear while the potentiometer shaft is connected to a large gear. Both gears mesh with the toothed rack. When the motor turns, the torque created at the output shaft is translated to a linear force, which results in the cart's motion. When the cart moves, the potentiometer shaft turns and the voltage measured from the potentiometer can be calibrated to obtain the precise position on the track. A rod whose axis of rotation is perpendicular to the direction of motion of the cart is mounted on the front of the cart. A potentiometer mounted on the axis of rotation of the cart allows us to measure the angle of the rod in the vertical direction. After an impulse input is given to the system, the pendulum experiences a displacement. The objective of this experiment is to design a controller that stabilizes the rod at a given position and keeps the cart at a desired point. The project is divided into two parts: software simulation and hardware control.

  Software Simulation - Students must control both the pendulum's angle and the cart's position. In addition, in order to make the design more challenging, disturbances are applied to the pendulum. The requirement for the student is to have the cart achieve its desired position within 20 seconds. Also, the pendulum's overshoot is limited to 20 degrees and must obtain this level of control in less than 20 seconds. The students do this using Matlab and simulate both an open loop and closed loop response.

Hardware Control - Students also design a controller that stabilizes the pendulum at a given position and keeps the cart at a desired point. The pendulum must stay upright while the cart is in motion and remains on the track. Adjustments were then made to the software simulation to make it more appropriate to use as a hardware controller. Note that the rod must remain straight up as the cart moves. An integrator of the rod position was used in the feedback loop to reduce the steady state error in rod position. The drive motor voltage is now controlled instead of the linear force of the cart. The server automatically converts the Matlab file to a C file, and this is used to control the hardware through the RemoteNode Client setup.

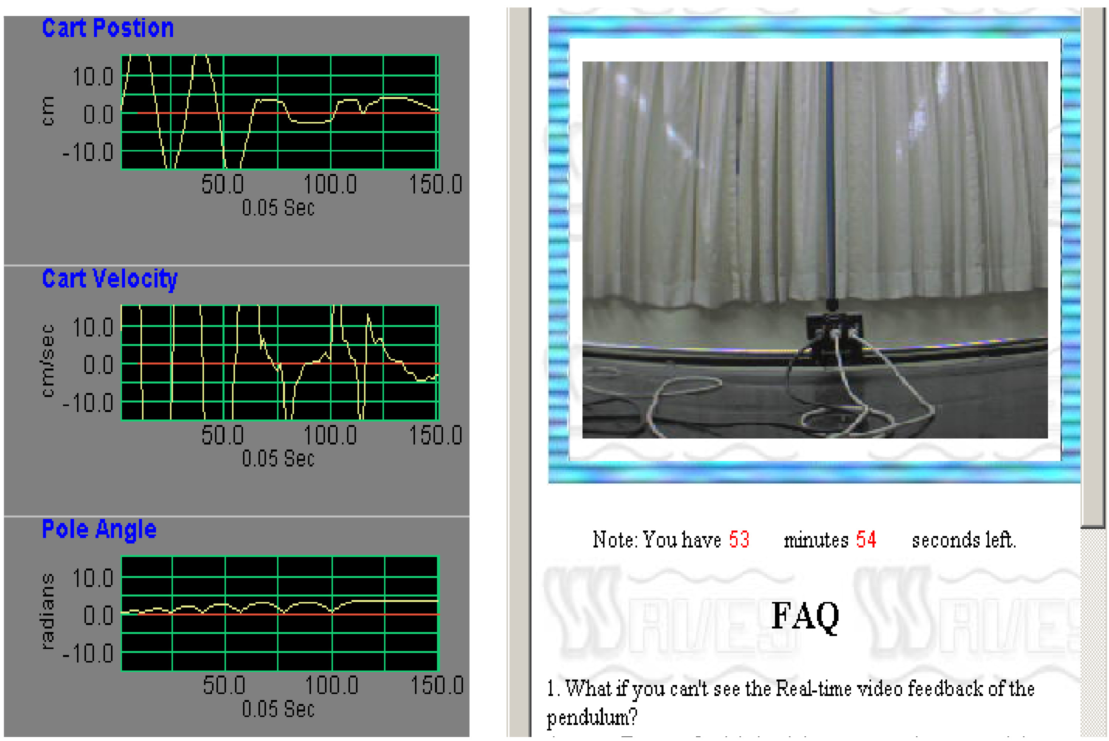

Figure 5 - Real Time Sensor Data and Streaming Video

6. Conclusions

The goal of this project is to develop an open and integrated platform for online laboratory experiments, computer simulation, and course instruction. The uniqueness of the approach is that we use actual hardware lab experiments via Internet and provide remote sites with real-time data and audio/video feedback of experimental results. Since Internet-based hardware systems can be shared and scheduled for a large number of people in various locations, the proposed platform is a cost-effective way to address the issue of "hands on" experiences with laboratory and/or industrial hardware systems. Eventually, our goal is to develop many Internet Integrated Science and Engineering Experiments (**I²SEE)** Labs for areas, such as physics, chemistry, biology, computer, and material science and engineering, so that both colleges and secondary schools can use labs for instruction and for research.

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Biographical Information

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Haijun Gao received his Ph.D. degree in Automation from the Chinese Academy of Sciences, Beijing, China, in 2003 and currently is an Assistant Research Scientist at the Institute of Automation, Chinese Academy of Sciences. His research interests include engineering education, intelligent control, intelligent transportation systems, and intelligent vehicles.