The 5th World Multiconference on Systemics, Cybernetics and Informatics, July, 22-25, 2001, Orlando, Florida, USA

Construction of an On-line Education Course Using an Experiment System

Yasuhiro Ohyama, Jin-Hua She, Jun Yoshizawa, and Masayuki Kimura
Department of Mechatronics, School of Engineering, Tokyo University of Technology
1404-1 Katakura, Hachioji, Tokyo, 192-0982, Japan
E-mail: {ohyama, she}@cc.teu.ac.jp, {yjun, arumik}@ikeoh.mech.teu.ac.jp

ABSTRACT

This paper describes an on-line education course for control engineering. The course employs an Internet experiment control system for an inverted pendulum and ways of using the experiment system were investigated. Several improvements were made to the system to make it easy and safe for beginners to use. This system is suitable for various stages of the learning process. With it, a student can carry out system identification, design a controller, and perform simulations and experiments.

Keywords: On-line Education Course, Internet Experiment System, Inverted Pendulum, Web-based Control, Control Education.

1. INTRODUCTION

Over the last decade, along with the expanding use of the Internet in our daily lives, interest in Internet-based on-line education has been mounting [1]. Generally speaking, the three main aspects of an engineering education course are: learning the theory, exercises, and application of the theory. Nowadays, the verification of the theory and its practicality can be handled fairly well by means of computer simulations. However, since the control results are strongly influenced by disturbances and sensor noise, the accuracy of the measurement instruments and the unmodeled dynamics of the plant, experiments are indispensable to making students aware of them and making them mindful of the gap between theory and practice; and they are also one of the best ways to gain a deeper understanding of the theory. So, how an experiment system can be built and used are key points in the construction of an on-line engineering education course. Several articles have appeared that deal with the study of Internet experiment systems (e.g., [2]-[6]). In those systems, the plant was connected to the Internet and could be run remotely over the Internet from a client machine. However, they were mainly designed as benchmark test systems for researchers. To our knowledge, no such experiment system has actually been used yet in an on-line education course.

We previously built a prototype Internet experiment system for control engineering ([7]). Based on the information acquired in that study, we built a new Internet experiment control system for an inverted pendulum, constructed an on-line control engineering course which makes use of it, and investigated how the experiment system could be used in the course. The experiment system was set up in a laboratory and connected to the Internet. Students enrolled in the on-line education course can run the experiment just by accessing the web page of the course. The experiment system is used at different stages of the course to help students gain a deeper understanding of the theory.

2. THE EXPERIMENT SYSTEM

The structure of the experiment system is shown in Fig. 1.

The client side is a student and the provider side is the server of the on-line course. The provider is comprised of three parts: the plant (a cartand-rail-type inverted pendulum), a control machine, and the server. A client connects to the server over the Internet. The server and the control machine are connected via an RS232C cable, and an A/D and D/A converter board on the control machine provides input to and output from the plant. The server runs Windows 98 and the control machine runs PC-DOS 7.0.

Three programs are executed on these machines to perform an experiment. The client program stored on the server machine is run from a WWW browser to set an experiment up. The server program, which is stored and executed on the server machine, processes commands from clients, supervises the control machine, and sends experimental results back to clients. The control program, which is stored and executed on the control machine according to instructions from the server, runs the plant.

There are two main reasons that an inverted pendulum was chosen as the plant: first, since the plant is unstable at the straight-up equilibrium position, it is easy to use this plant to explain the concept of stability and stabilization; and second,

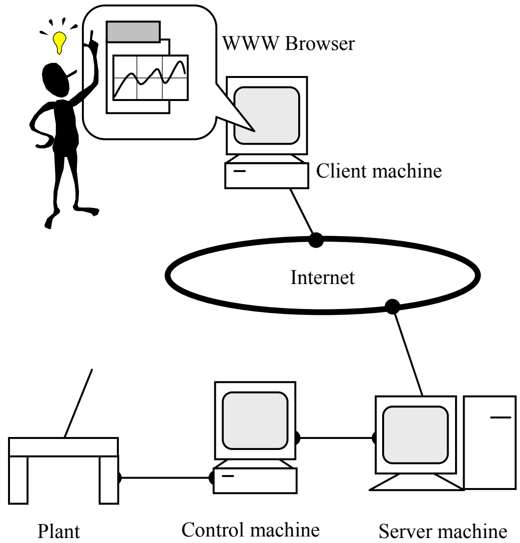

Figure 1. Structure of the experiment system.

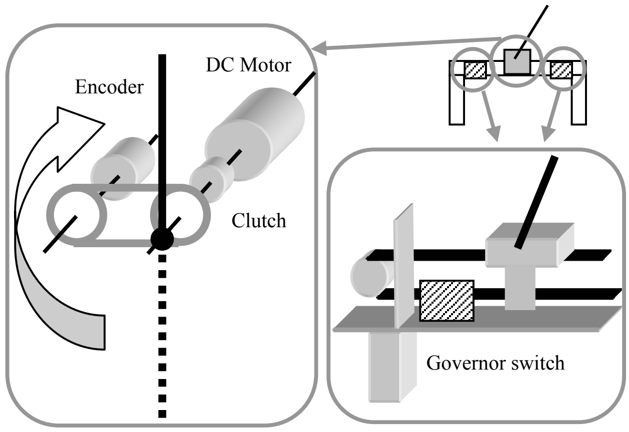

Figure 2. Modified experimental apparatus.

the stabilization results and the efficiency of the control method can easily be checked visually. To prepare the experiment automatically, a special circuit centers the inverted pendulum within its range of motion; a swing-up motor swings the inverted pendulum up to the straight-up position; and a clutch holds the pendulum to keep it at that position before the experiment starts. The clutch guarantees that an experiment begins with the pendulum in the initial state. To ensure that the system runs safely by itself, that is, without the need for a supervisor to be present, two governor switches prevent the pendulum from running away (Fig. 2). An emergency stop function is also incorporated into the control machine. As a result of these improvements, the system always runs automatically and safely.

When the server receives a request to perform an experiment from a client, it asks the client to submit the necessary information, such as the parameters of the controller, the control time, etc., to set the experiment up. When a start command is sent from the client, the server forwards all of the parameters to the control machine.

Once it receives the start command, the control machine starts the experiment under the supervision of the server. When the experiment ends, the experimental results (logged data) are stored in a file in HTML format and returned to the server. Then, the server sends not only the date file, but also a Java Applet back to the client. The Java Applet is a data-displaying program. It draws curves and animation based on the experimental data so

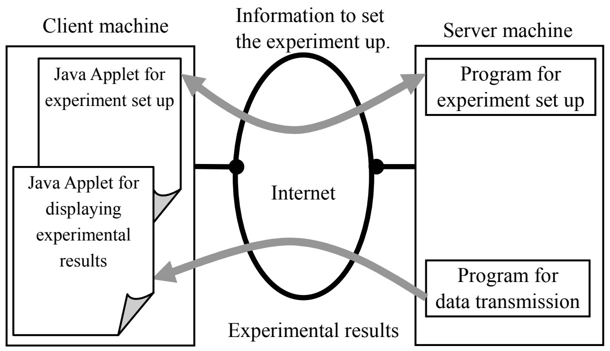

Figure 3. Communication between the server and a client.

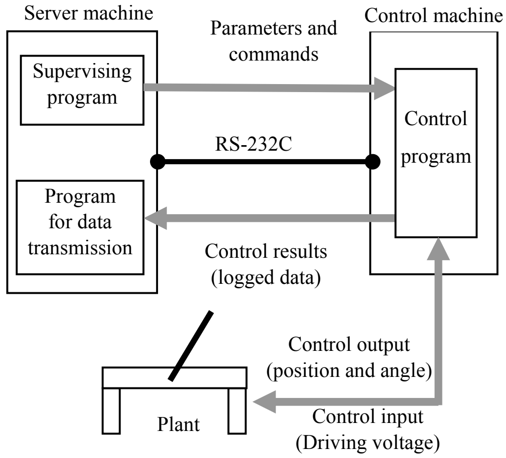

Figure 4. Communication between the server and the control machine.

that the results are easy to understand.

The Communication between the server and a client, and the control machine is illustrated in Figs. 3 and 4.

3. THE ON-LINE CONTROL EDUCATION COURSE

The on-line control engineering course is designed for third-year students in the Department of Mechatronics. Students taking this course are assumed to have a good grasp of the fundamentals of mathematics, electricity, electronics and mechanics. This course gives students a first glance at control engineering. Higher levels of control theory will be taught in later courses.

All of the teaching material for the course has been written in HTML format and stored on the server. The programs required for a client to run a simulation/experiment are Java Applets. So, the only thing a student needs to take the course is a Web browser.

When a student accesses the home page of the course, the screen in Fig. 5 is displayed. It is divided into five parts:

- News
- Documents
- Assignments
- Chat Forum
- Directions for use

Announcements, instructions and answers to common questions are posted in the News area. Exercises, self tests and assignments are placed in the Assignments area in a timely fashion. Students can log in to the Chat Forum to talk with each other and ask for help.

The course is comprised of the following sections.

1. Instructions for the Course
2. Introduction
3. Mathematical Preparation
4. Plant Modeling
5. Controller Design
6. Simulation
7. Experiment
8. Design Project

Figure 5. Home page of the on-line course.

The Instructions for the Course present an overview of the course; the prerequisites for taking the course; and the final goal of the course.

The experiment system is used in all stages but the first. In the Introduction, students are asked to run the system with and without a fixed controller so that they can get an intuitive feel for how effective a control system is. This gives them the motivation to take the course.

Before students start to learn control theory, they can review some basic mathematics, such as Laplace transformations, linear algebra, etc. At this stage, the plant of the experiment system is used as an example in teaching the derivation of mathematical models.

A student at the stage of learning identification can use the system to identify the parameters of the plant. The dynamic model of the plant is given by

$$\begin{cases}(M+m)\ddot{x}+f\dot{x}+ml\ddot{\theta}\cos\theta-ml\dot{\theta}^2\sin\theta=ku,\\(J+ml^2)\ddot{\theta}+c\dot{\theta}+ml\ddot{x}\cos\theta-mgl\sin\theta=0,\end{cases} \quad (1)$$

where M [kg], m [kg] and J [kg m^2] are mass of the carriage and pendulum and the moment of inertia around the center of gravity, respectively; l [m] is the center of mass of the pendulum; f [kg/s] and c [kg m^2/s] are the coefficients of viscous friction of the carriage and the pendulum, respectively; and k [kg m/V s^2] is the transfer coefficient from volts to driving force.

All seven parameters of the plant have to be identified. At present, a student cannot actually run an experiment for the purpose of identification, but can only download real-time data that has been obtained in an identification process and use it to calculate the parameters in Eq. (1). Then, the student can compare those results with typical results displayed on the web page.

Since the original plant is nonlinear, linear control theory cannot be applied directly. So, linearization approaches are taught, and students have to calculate the following linear approximation model in the state space of Eq. (1)

$$\dot{x}=Ax+Bu. \quad (2)$$

The design of controllers is carried out based on the linear model (2).

In the Controller Design section, students who are just beginning their study of design methods for controllers can run the system with and without a fixed controller so that they can understand whether a control system is valid or not, which may stimulate their interest in design. Later, after learning how to design a control system, they can use any of several design methods to design a controller for the plant and carry out simulations on the system to evaluate the design. At this stage, if a student accesses the course, the window shown in Fig. 6 is displayed on the client machine.

Regarding the design of a controller, the control system configuration in Fig. 7 is employed and the pole assignment method is the main method taught. When a student inputs the desired closed-loop poles, the corresponding feedback gain of the controller is calculated and displayed in the window by a Java Applet. After the student inputs the initial angle of the inverted pendulum, sets the control time and pushes the simulation start button, a simulator on the server starts the simulation. The simulation results are then sent back to the student and displayed on the client machine.

Figure 6. Client window of the simulation/experiment system.

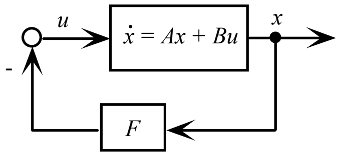

Figure 7. Configuration of the control system.

The experiment system and the simulation share the same window. When a satisfactory controller is obtained in the simulation, the server sends the parameters of the controller to the system and starts running an experiment after the student sets the control time and pushes the experiment start button. Finally, the window in Fig. 8, which plots the experimental results, appears on the client screen.

At present, the operations available to a student include modification of the parameters of the controller, stabilizing control within a certain range from an initial state, and the comparison of simulation and experimental results. The results are displayed on the client machine in the form of raw data, time response curves and animation.

A student's grade for the course is based on the result of the Design Project and the assignments.

Part of this on-line course was tested in a control engineering training program (The course was on-line, but the experiment system was only accessible in a laboratory). Below are some of our impressions of this course.

- Since the teaching material could be obtained from the web page, it was easy for students to prepare.
- The fact that students could communicate with each other on the web anytime anywhere resulted in deep discussion.
- There was a big flood of questions and discussion after an assignment was posted, especially in the evening of that day. So, we spent much more time on the course than on a traditional course.
- Since the questions asked could be seen by other students, students were reluctant to ask simple questions at first. It took a while for them to become familiar with this environment and to feel comfortable asking questions.
- Students are more conscious of the resolution of the sensor and the significant digits of the data, after they carry out experiments under different conditions.
- Students understood what results the theory predicted and what the limitations of the experiment system were after analyzing the simulation and experimental results and having a full discussion of these points for a few days.

4. CONCLUSIONS

An on-line control engineering education course has been described in this paper. The key feature of the course is that an Internet experiment system was built and was used in all stages of the course. Part of this course has been tested in a training program. The results provide some hints on how to improve the environment of the course. The course will be launched in our department.

It is also very important for a student to operate the plant manually at the beginning of the course to strengthen his or her motivation to study. Furthermore, the addition of still pictures and streaming video to the system would significantly enhance

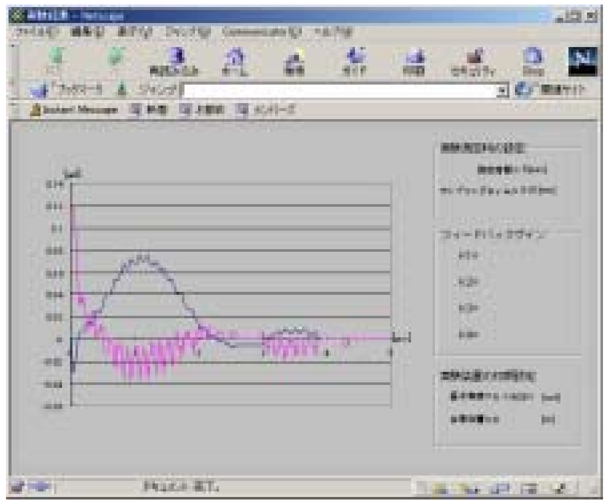

Figure 8. Window displaying experimental results.

+the user experience by providing a sense of reality. These features are now being added to the system.

5. REFERENCES

[1] R. Ubell, "Engineers turn to e-learning", IEEE Spectrum, Vol. 37, No. 10, 2000, pp. 59-63.

[2] V. Ramakrishnan, Y. Zhuang, S. Y. Hu, J. P. Chen, C. C. Ko, Ben M. Chen and K. C. Tan, "Development of a Web-Based Control Experiment for a Coupled Tank Apparatus", Proc. of the American Control Conf., 2000, pp. 4409-4413

[3] J. W. Overstreet and A. Tzes, "An Internet-Based Real-Time Control Engineering Laboratory", IEEE Control System, Vol. 19, No. 5, 1999, pp. 19-33

[4] T. Fitzpatrick, "Live Remote Control of a Robot via the Internet", IEEE Robotics & Automation Magazine, Vol. 6, No. 3, 1999, pp. 7-8

[5] IEEE Robotics & Automation Magazine, Vol. 7, No. 1, 2000

[6] IEEE Robotics & Automation Magazine, Vol. 7, No. 2, 2000

[7] Y. Ohyama, J.-H. She and K. Watanabe, "A Prototype Internet Experiment System for Control Engineering", Proc. of 1999 IEEE Int. Conf. on Systems, Man, and Cybernetics, Vol. 1, 1999, pp. 894-898