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An Online Internet Laboratory for Control Experiments

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Abstract: Control engineering courses conducted in the classroom need to be integrated with design and implementation of controllers. This paper describes the implementation of an online Internet laboratory for control experiments for this purpose. It could be an effective alternative to setting up a fully equipped laboratory. The pilot plant used is the rotary inverted pendulum. The setup allows the user to select an appropriate test signal and collect real data for estimating the plant parameters. Using the model identified as a basis for controller design, the students then verify their design by specifying the controller parameters and perform a swing up and balancing experiment on the actual inverted pendulum over the Internet.

Keywords: Control education, Laboratory techniques, Telecontrol, Internet, Inverted Pendulum.

1. INTRODUCTION

Control engineering courses conducted in the classroom need to be integrated with design and implementation of controllers for laboratory scale plants. However, setting up and preparing instructional materials for laboratory experiments is time consuming and resource intensive. There is also the limitation of space and timetable constraints to consider.

The rapid progress of Internet technology and its increasing popularity has prompted several educational institutions to develop Internet laboratories (Shaheen et al., 1998; Overstreet and Tzes, 1999; Aktan et al., 1996). With the help of an online Internet laboratory for control experiments, the educator can be encouraged to design control engineering courses that combine theories without neglecting the practical experiments. Via the Internet, the online laboratory could provide the instructors more flexibility to prepare assignments for their students that require some experimentation with the real plant. In addition, Internet laboratory allow equipment to be better utilised, by both local and remote users since the laboratories can be accessed from anywhere with an Internet connection. This sharing of resources not only brings down the experiment cost per student, equipment will also be made available to more students as the time and space constraints normally associated with traditional laboratory can be removed. In order to give remote users as close as possible, the laboratory experience as obtained by the local users, experiments are based on real systems rather than computer simulations or virtual reality.

In this paper, we described two experiments adapted for online Internet laboratory. The apparatus used is a rotary inverted pendulum and the two experiments are (1) parameter estimation of the inverted pendulum and (2) design of a swing up and balancing controller. The objective of the laboratory experiments is to supplement the control systems courses covering the topics of parameter estimation and controller design.

2. THEORY

Fig.1 The Rotary Inverted Pendulum

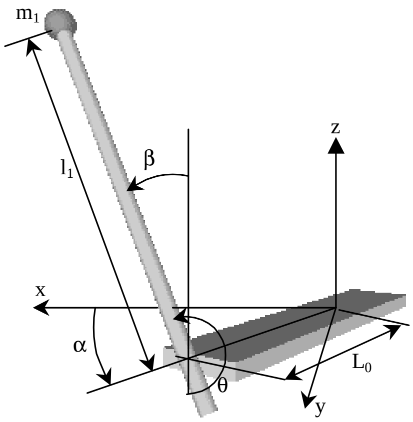

Fig. 2 Schematic of the Rotary Inverted Pendulum

Fig. 1 shows a rotary arm version of the inverted pendulum system used in this project. The schematic is represented in Fig. 2.

The inverted pendulum system consists of two sections, namely the rotating arm and the pendulum. A dynamic model for the pendulum system can be expressed as (KRI, 1999):

$$\begin{bmatrix} J_0 + m_1L_0^2 + m_1l_1^2\sin^2\theta & m_1L_0l_1\cos\theta \\ m_1L_0l_1\cos\theta & J_1 + m_1l_1^2 \end{bmatrix}\begin{bmatrix}\ddot{\alpha} \\ \ddot{\theta}\end{bmatrix} + \begin{bmatrix} C_0 + \frac{K_tK_b}{R_a} + \frac{1}{2}m_1l_1^2\dot{\theta}\sin 2\theta & -m_1L_0l_1\dot{\theta}\sin\theta + \frac{1}{2}m_1l_1^2\dot{\alpha}\sin 2\theta \\ -\frac{1}{2}m_1l_1^2\dot{\alpha}\sin 2\theta & C_1 \end{bmatrix}\begin{bmatrix}\dot{\alpha} \\ \dot{\theta}\end{bmatrix} + \begin{bmatrix} 0 \\ m_1gl_1\sin\theta \end{bmatrix} = \begin{bmatrix}\frac{K_tK_u}{R_a} \\ 0\end{bmatrix}u \qquad (1)$$

where u is the control input to the system. The measurements available are the arm speed of rotation, $\dot{\alpha}$, and the pendulum position, θ.

To design a linear controller to balance the pendulum in the upright position, the following linearised model can be used:

$$\begin{bmatrix} J_0 + m_1L_0^2 & -m_1L_0l_1 \\ -m_1L_0l_1 & J_1 + m_1l_1^2 \end{bmatrix}\begin{bmatrix}\ddot{\alpha} \\ \ddot{\beta}\end{bmatrix} + \begin{bmatrix} C_0 + \frac{K_tK_b}{R_a} & 0 \\ 0 & C_1 \end{bmatrix}\begin{bmatrix}\dot{\alpha} \\ \dot{\beta}\end{bmatrix} + \begin{bmatrix} 0 & 0 \\ 0 & -m_1gl_1 \end{bmatrix}\begin{bmatrix}\alpha \\ \beta\end{bmatrix} = \begin{bmatrix}\frac{K_tK_u}{R_a} \\ 0\end{bmatrix}u \qquad (2)$$

To swing up the pendulum from the pendent to the upright position, we use the energy method (Astrom and Furata, 1996) which gives the control law

$$u = \mathrm{sat}(\mathrm{kE})\,sign(\dot{\beta}\cos\beta) \qquad (3)$$

where $E = \frac{\dot{\beta}^2}{2}J_1 + m_1g\ell_1\cos\beta - m_1g\ell_1$, is the total energy of the system, k is the tuning parameter and sat is the saturation function saturated at the limits of the control signal u.

However, in order to design the required controller, the numerical values of the parameters, such as J_0, J_1, etc, need to be determined. This can be achieved via least squares fitting of the input/output data collected experimentally using the nonlinear model of Eq.(1). Practical issues such as the choice of input test signal, data scaling and filtering and implementation of the parameter estimation algorithm can be emphasised through experimentation with real data collected. Once the required model parameters have been obtained, the student can then proceed to design a linear controller based on the linearised model of Eq.(2), using various design techniques such as the pole-placement method.

In section 4, we will describe the user interface that allow the students to perform the parameter estimation experiment as well as to verify their swing up and balancing controller design. The students will have a sense of achievement when they can identify a model of the plant and successfully design a controller to balance the inverted pendulum.

3. ONLINE INTERNET LABORATORY

It is fairly simple to setup the online laboratory. The hardware comprises of a web server, a video server, the inverted pendulum apparatus, and a low cost USB digital camera. Fig. 3 shows the system architecture of the online laboratory.

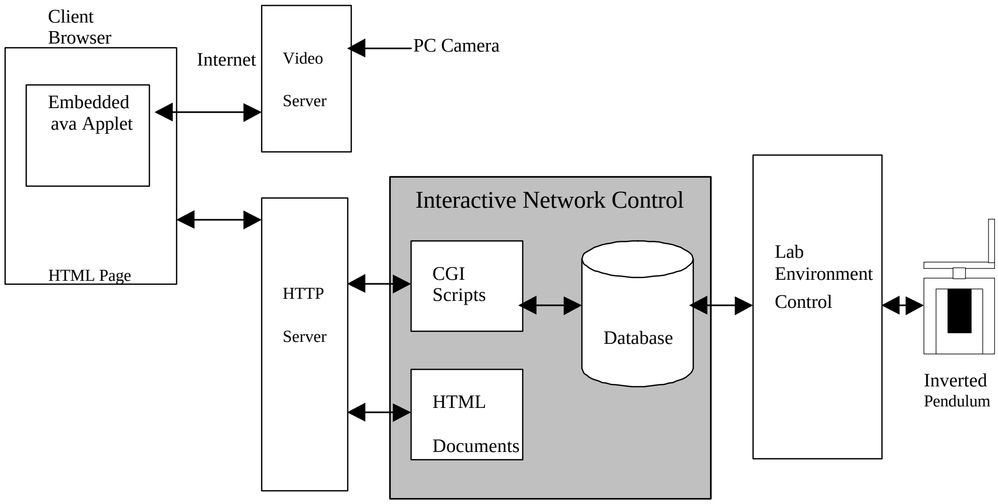

Fig. 3 The Online Laboratory System Architecture.

4. THE EXPERIMENTS

4.1 Parameter Estimation

The student can perform the parameter estimation experiment using the Internet laboratory. The user interface for this experiment is shown in Fig. 4.

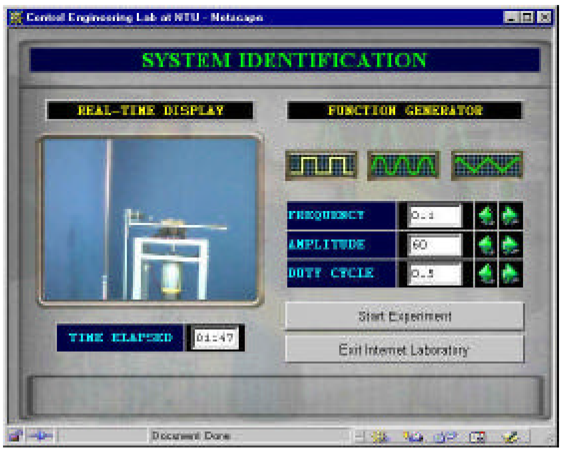

Fig. 4. User Interface for System Identification Experiment

During the parameter estimation of the inverted pendulum, the student will be able to select the type, the frequency, the amplitude and the duty cycle of the test signal. The user can then observe the behaviour of the pendulum apparatus via real-time video over the Internet and subsequently, download the experimental data onto the local hard disk for offline processing. Fig. 5 shows the result of a typical experiment. The top graph shows the test signal, with the rotary arm and velocity pendulum position in the middle and bottom graph respectively. The students can then develop a software algorithm, say with MATLAB, to implement a least square parameter estimation algorithm to determine the unknown parameters of the plant. As these data are collected in a ASCII file, with raw values recorded, the

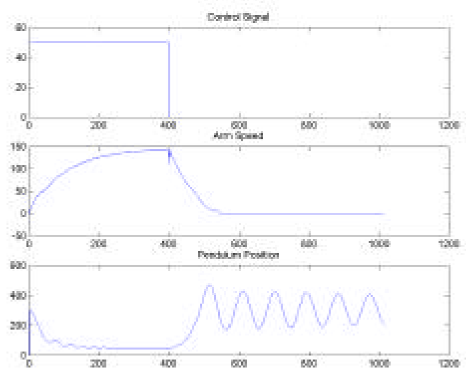

Fig. 5 Data from Parameter Estimation Experiment

students will learn and appreciate the need for scaling and unit conversion, filtering out the noise in the data, in order to achieve a successful parameter estimation. The result of this exercise can then be sent back to the instructor for grading, with the attached MATLAB script file.

4.2 Swing up and Balancing

After the estimation of the system parameters, students can then proceed to designing their own

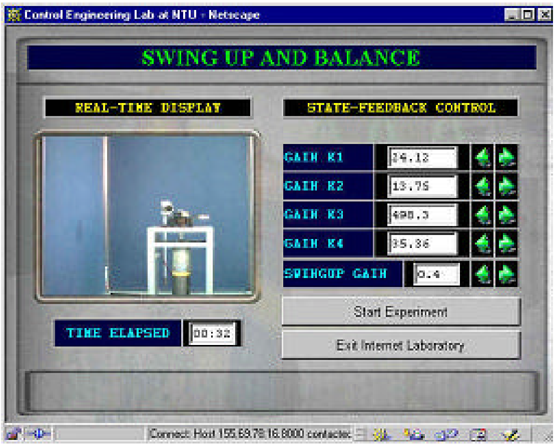

Fig. 6. User Interface for Swing Up and Balancing Experiment

controllers and verify their design via the swing-up and balancing experiment. The user interface is as shown in Fig.6. Through this interface, students can input their controller gains which they have calculated based on the model that they obtained from the parameter estimation experiment. Again the students could see, via real-time video window on the user interface, the behaviour of the inverted pendulum throughout the experiment, thus giving the students a sense of being in the laboratory. A typical result of the experiment is shown in Fig. 7.

5. CONCLUSIONS

The Internet laboratory is a viable alternative compare to setting up a traditional laboratory to support control courses conducted in the classroom. Its main attraction is that it allows students easy access to real plant and carry out experiments to collect real data so as to appreciate the strength and limitations of textbook theory and algorithms. Students can access the laboratory at anytime and from anywhere, without the time tabling and laboratory opening hours constraints. With Internet laboratory, educational institutions throughout the world can also share their unique and interesting experiments via the Internet.

The video feedback, plays an important role to keep the students engage when they are logged on to conduct their experiments. Real-time video can now be easily provided with a low cost USB digital camera. However, the quality of the video is a still very much a function of the network bandwidth and the traffic.

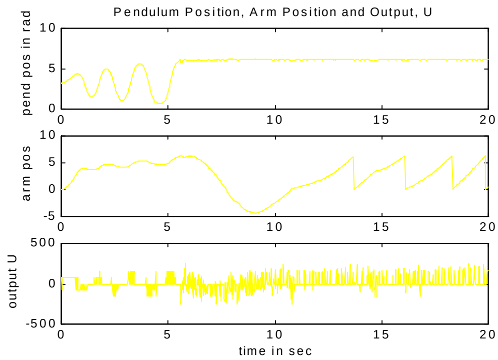

Fig. 7. Experimental Result of Swing up and Balancing the Pendulum

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