Effective Control Education by Means of Motion Control Practice

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1. Introduction

In modern technological society the basic principles of controls becomes more and more important, and control course in undergraduate engineering education is changing gradually from elective one to required one.

Many people have recently identified the decreasing presence of practical experience in the classroom as a basic problem in engineering education, and industry has voiced concern as to the quality and suitability of university graduates[1-3]. In the United States, the Accreditation Board for Engineering and Technology, and National Science Foundation have targeted for action to emphasize the engineering design in engineering education.

The issues on control education has been discussed several times in the last few years. The IEEE Control Systems Magazine (April 1989) published four papers describing efforts within a classroom structure aimed at supplying the student with direct hands-on experience and exposure to design[4], based on the papers presented at the 1988 American Control Conference. Also, the IEEE Control Systems Magazine (June 1992) surveyed control education based on the Second IFAC ACE Symposium held in 1991(Boston)[5]. In the articles of these issues, the problems, challenges, and some answers of control education are discussed, and also Professor Stephen Yurkovich raised several intriguing questions regarding control education that are worth considering as we move on toward the 21st century[2].

The Third IFAC ACE Symposium held in 1994 (Tokyo) showed the growing awareness of the importance and the urgency in solving some acute issues in control education, and the IEEE Control Systems Magazine (April 1996) surveyed control education around the world (12 feature articles highlighting control education in 12 countries or regions) based on the Third IFAC ACE Symposium[6]. In all control curricula surveyed herein, classical control theory was used as the entry point, and was emphasized at the undergraduate level, and each stressed the importance of control laboratories. Use of digital computers and CAD programs such as MATLAB was a common practice.

I believe that the practice of control system design is very important in control education, and some control experiments with physical system should be included in the course in order to get hands-on experience.

In this paper, I introduce a control course which is developed in my department. This control course is mainly offered to the mechanical engineering students, and so we focus on the mechanical control problems in the laboratory experiments. It includes two laboratory experiments which are carefully selected among many other choices for the non-expert's student environment vulnerable to system breakdowns. The hands-on experience of students on the motion control is emphasized in the course.

2. Control Course Descriptions

The control courses offered in my department are composed of three courses, *automatic control* for senior undergraduate students, *advanced control theory* and *microprocessor-based real-time control* for graduate students[7].

The course, *advanced control theory*, mostly deals with modern control theory starting from state feedback control to diverse modern control theories such as H^∞ control, μ-synthesis, fuzzy logic control, neuro-fuzzy control etc. Every year one control theory is selected and taught as a main topic in the course and the other control theories are introduced with the main ideas of the theories. At the point of two thirds of the semester, the students determine the models of their plants and start the simulation projects using the learned control theory. Lectures continue until the end of the semester.

The course, *microprocessor-based real-time control*, is offered to the students who took an undergraduate control course, and is focused on the hands-on experience on microprocessors, computer interfaces, I/O programming, timer interrupt, real-time scheduling, and the application of motion controls. Lectures are given during two thirds of the semester, and laboratory experiments and projects are started at the point of one third of the semester.

The rest of this paper concerns the undergraduate course, *automatic control*, and focuses on the undergraduate control education.

This introductory control course covers the classical control theory, introduction to modern control theory, and basic skills for control application to mechanical systems. The detailed items of the course includes the history of the automatic control, Laplace transformation, mathematical modeling and a linearization, system representations such as transfer functions, state equations and block diagrams, transient responses, steady-state error analysis, root locus method, frequency response method, stability analysis, PID controls and the discretization of them, state feedback controls, simulation algorithm using the Runge-Kutta method, computer interfacing such as D/A converting, A/D converting and parallel I/O, real-time programming using timer interrupts.

This course is lectured during 16 weeks, and at the point of one third of the semester, the students start the first experimental project of the motion control with the provided belt-and-pulley system in groups (basically three students in a group). At the point of two thirds of the semester, the students start the second experimental project of the motion control with the prepared inverted pendulum system in the same groups. At the end of the semester, the students are encouraged to demonstrate and present their results in front of the other students and the professor to have a chance to train presentations.

As the evaluation results by the professor for experimental works of each group, the best group receives an honorary certificate which may be listed on their resume for job interviews. The grading is done in terms of 50 % in midterm and final examination results and 50 % in two experimental project results.

3. Experimental Apparatus

The experimental apparatus should be rugged and reliable to prevent from the breakdown of the apparatus for students who are assumed to be non experts in dealing with mechanical systems, and computer hardwares and softwares. Also, from the experimental works, the students should learn the basic idea of the feedback control, the powerfulness of it, and the techniques to implement it. Among many other choices, two experimental items are carefully selected to achieve the above goals.

The first experimental setup is called as a "belt-and-pulley system" which is made by using a timing belt, two pulleys, a DC servomotor, a controller, an encoder, an indexing panel, and a needle. This system is a kind of an infinity-loop system, so even if the students run erroneous program, the system will not be hurt. Fig. 1 shows the schematics of the experimental setup and Fig. 2 shows the photograph of the system.

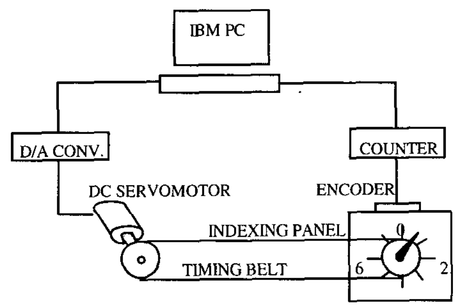

Fig 1. Schematic diagram of the belt-and-pulley system.

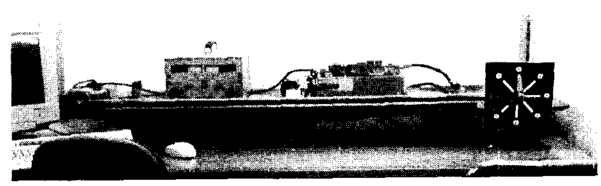

Fig 2. Front view of the belt-and-pulley system.

The goal of this control system is to position the needle to specific points at specific instants. The controller or control computer IBM PC 486 Compatible reads the present needle position in the indexing panel through the encoder and counting board, and inputs control signals to the DC servomotor through D/A converter, and the DC servomotor drives the belt pulley and indexing needle through the timing belt. Each semester, different indexing goals are given to the students.

The second experimental setup chosen is a well-known inverted pendulum system. The inverted pendulum systems are classified into three categories according to the track the base of the inverted pendulum moves along with; one with linear track, one with vertically circular track, and one with horizontally circular track.

It is reported that the inverted pendulum system with vertically circular track is used in control education[8,9]. But in this paper, the inverted pendulum system with horizontally circular track is selected since it is considered to have infinite length of track, and it has sufficiently complex dynamics including 3 degrees-of-freedom motions and Coriolis acceleration etc. This system is made to be rugged and reliable, and so, even if the students run erroneous program, the system will not be hurt. If the length of the track is limited, the system can be broken down easily by erroneous operations. This system is composed of a pendulum, an arm, a AC servomotor with an encoder, a potentiometer, a controller, and a supporting frame. The schematics of the experimental setup is shown in Fig. 3, and the photograph of it is shown in Fig. 4.

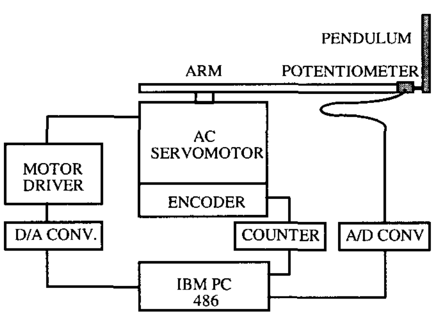

Fig 3. Schematic diagram of the inverted pendulum system using a horizontally circular track..

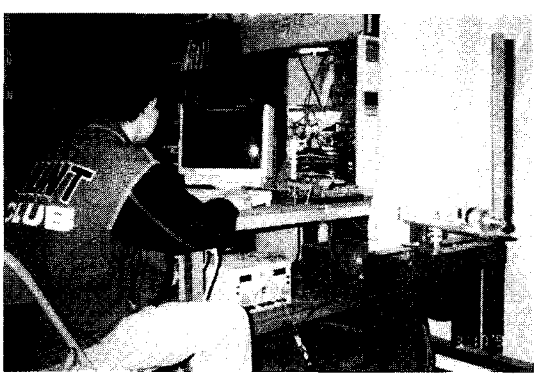

Fig 4. Photograph of the inverted pendulum system.

The pendulum is rotating freely on the perpendicular planes to the arm which is rotating at a horizontal plane by the servomotor. The angle of the pendulum is measured by a potentiometer, and the position of the arm is measured by the encoder attached to the motor. The position and velocity informations of the pendulum and the arm are fed back to the controller, IBM PC 486 Compatible, and the controller makes the control input signals and sends them to motor driver through D/A converter.

The goal of this control system is to erect the inverted pendulum at specific arm position. In order to escape from the problem of signal line twisting, a mechanical contact device on the motor shaft is developed which can transfer the signal of the inverted pendulum to the computer without twisting signal lines.

From the second experimental practices, the student are supposed to experience the effectiveness of the state feedback control compared to the PID control. Furthermore, it is hoped that this experiment stimulate the curiosity of the students, and to motivate to learn advanced control theories.

4. Illustrative Control Practice

In the spring semester of 1999, the following two experimental projects are given to the students for the controller design practice;

4.1 Experimental Project 1

Objective : In the indexing panel of Fig. 1, 0, 2, 4, 6 points are placed in the interval of 90 degrees. Position the needle as fast as possible and as accurate as possible to points 0, 2, 0, 4, 0, 6 (in this order), and repeat this series of motion ten times. The needle should stay at each point for 0.1 sec. The whole running time will be measured and the integral of the squared error during 0.1 sec stays will be calculated.

Procedure :

(1) Derive mathematical models and draw a block diagram of the whole system.

(2) Design a PID controller

(3) Conduct digital computer simulations and tune the control parameters

(4) Conduct experiments

4.2 Experimental Project 2

Objective : In the inverted pendulum system of Fig. 3, erect the inverted pendulum in upright position when it is released with a initial position error of about 5 degrees from the upright position, and position the arm at 0 degree on a horizontal plane. Make the integral of the absolute error for 10 sec be small, and reduce the chattering phenomena.

Procedure :

(1) Derive mathematical models and linearize the nonlinear models about an operating point. Draw a block diagram of the whole system.
(2) Design a PID controller (why not working?)
(3) Design a state feedback controller
(4) Tune control parameters using available control softwares.
(5) Conduct experiments

All the system parameters are given to the students for the modeling, and a sample program for real-time programming is handed out to the students. It seems these two projects burden students lots of learning load, but the students have fun and curiosity from the controls of these two mechanical systems. The samples of student's experimental results for both projects are shown in Fig. 5 and Fig. 6.

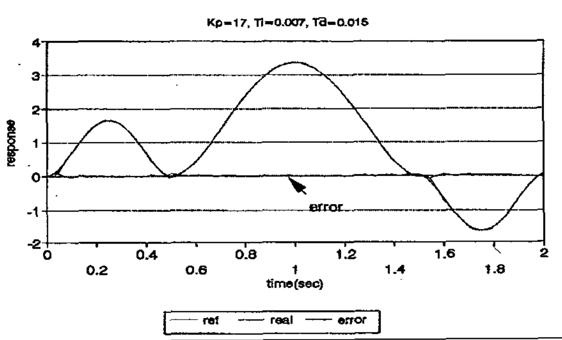

Fig 5. A sample result of students control practice for the belt-and-pulley system.

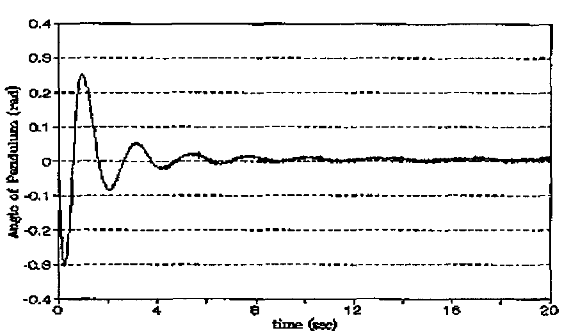

Fig 6. A sample result of students control practice of the inverted pendulum system.

5. Conclusion

This paper presents control curriculums developed for hands-on experience on motion control using a belt-and-pulley system and also an inverted pendulum system. The practice of control system design is very important in control education, and I believe that some control experiments using physical systems should be included in the course. The experimental setups should be rugged and reliable to prevent from the breakdown by the students who are non-experts in dealing with hardwares and softwares.

The control course described in this paper was successful to excite students curiosity, and to motivate studying control theories, and to give hands-on experiences on the control by including these two experimental projects in the course.

References

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