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e-Learning Experiences in Control Education

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Abstract: Educational environment has been drastically changed since the advent of Internet and computers, for example, from classroom teaching to e-Learning education. Control education should try to positively make use of these new technologies in order to fill lack of control professionals well qualified and to redirect an overall decline of interest in control engineering study among young people. This paper presents a control engineering course developed for hands-on experience on motion control using a practical control problem, and also presents e-Learning experiences in undergraduate control education at the Department of Mechanical Engineering, Konkuk University.

1. INTRODUCTION

Educational environment has been drastically changed since the advent of Internet and computers, for example, from classroom teaching to e-Learning (electronic learning) education. Control education should try to positively make use of these new technologies in order to fill lack of control professionals well qualified and to redirect an overall decline of interest in control engineering study among young people. Recently there have been several public voices on lack of well-educated control professionals from industry, and an overall decline of interest among young people in the study of control engineering from academia.

In order to cope wisely with those problems, several approaches have been tried for better control education. For example, control disciplines are taught using simulation tools, control software, or hands-on experimental equipments to increase students' understandability for control theory, or they are taught via virtual laboratory, remote experiments, or internet-based experiments to stimulate students' curiosity and to conduct easily control experiments without being disturbed by physical distance and space. Moreover, web-based learning, e-Learning, b-Learning (blended learning, that is, partial classroom teaching plus partial on-line teaching), and u-Learning (ubiquitous learning, that is, teaching under ubiquitous environment), are tried to give more chances to students with restrictions on time and distance.

The issues on control education have been discussed several times in the last 30 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 (Klein et al., 1989), based on the papers presented at the 1998 American Control Conference. Also, the IEEE Control Systems Magazine (June 1992) surveyed control education based on the Second IFAC ACE (Advances in Control Education) Symposium held in 1991(Boston) (Astroem et al., 1992). 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 (Yurkovich, 1992).

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 (Ezzine, 1996). 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.

Continued the Fourth ACE Symposium (1997, Istanbul), the Fifth ACE Symposium (2000, Gold Coast), the Sixth ACE Symposium (2003, Oulu), and the Seventh ACE Symposium (2006, Madrid) have shown continuously growing concerns about control education, and disseminated knowledge and experience in a variety of methods and approaches in control education. In the 7th ACE Symposium, K.J. Astroem presented the importance of control principle understanding as a required part of any educated scientist's or engineer's background since feedback is fundamental (Astroem, 2007), and M.W. Spong showed that solving real control problems rather than textbook problems is a tremendous motivator and well within the grasp of many students, and project-based control is a holistic method of education that offers advantages that cannot be obtained in the classroom (Spong, 2007).

Currently control education is exploiting the advantages of Internet and web technologies to develop distance learning paradigms. For example, remote laboratory allows control system students to operate real processes without being physically present in the lab. In the remote laboratory, students can design their own controllers using software such as Simulink and test them through Internet. This feature helps develop a student competition mechanism, where groups of students can compare their own user-designed controllers (Casini et al., 2004) Web-based control software packages such as WCDAS (Yu et al., 2004) have been developed to enhance the teaching and learning of control concepts via providing interactive study environment related to course management, online exercises and virtual laboratories. For a survey on web technologies used in control education, refer to the reference (Dormido, 2002).

Recently, control education for high school and middle school students and teachers has been tried to promote an increased awareness of the importance and cross-disciplinary nature of control concept and control technologies (Shor et al., 2004; Mukai et al., 2004; Kapila et al., 2004). Moreover, LEGO-based control education have been introduced (Gawthrop et al., 2004; Heck et al., 2004).

This paper introduces a control course which is developed in our mechanical engineering department of Konkuk University, and then presents e-Learning experiences in undergraduate control education and discusses effective methodology for better control education. This control course is mainly offered to the mechanical engineering students, and so includes mainly mechanical control problems in the laboratory works. Previously, it included two laboratory experiments which were 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. Previously, control experiments were practiced with physical experimental setup, but recently have been conducted via computer simulations using Simulink because of too many students attending the e-Learning class.

2. CONTROL COURSE DESCRIPTIONS

The control courses offered in my department are basically composed of three courses, *control engineering* for senior undergraduate students, *advanced control systems* and *microprocessor-based real-time control* for graduate students (Konkuk University, 2007). Besides these three courses, there are graduate courses such as *intelligent control theory*, *robust control*, *control system engineering*, *linear systems theory* and *motion simulator*, but these courses are offered intermittently by several professors if need be.

The course, *advanced control systems,* 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 third 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 and microcontrollers, 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 thirds of the semester.

The rest of this paper concerns the undergraduate course, *control engineering*, 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 using CEMTool (or MATLAB), and real-time control concepts.

Until two years ago, at the point of one third of the 16 weeks semester, the students were started 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 third of the semester, the students were started 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 were encouraged to demonstrate and present their results in front of the other students and the professor to have a chance to train presentations. But recently two actual experiments were replaced with one simulation project that realizes motion control of the inverted pendulum developed in our laboratory. The project starts at the point of two thirds of the semester after showing actual operation of the physical inverted pendulum device.

As the evaluation results by the professor for project works of each group, the best group receives an honorary certificate which may be listed on their resume for job interviews. The grading has been done in terms of 70 % in midterm and final examination results and 30 % in two experimental project or one simulation project results.

3. PREVIOUS DEVELOPED EXPERIMENTAL SETUPS

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 were 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.

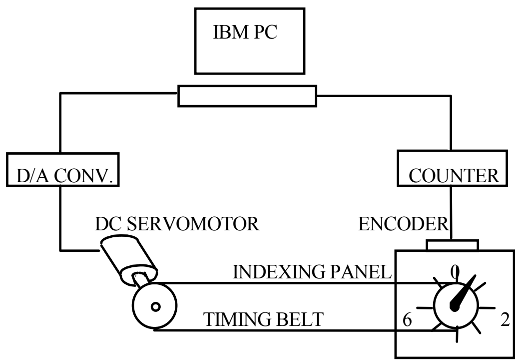

Fig. 1 Schematic diagram of the belt-and-pulley system

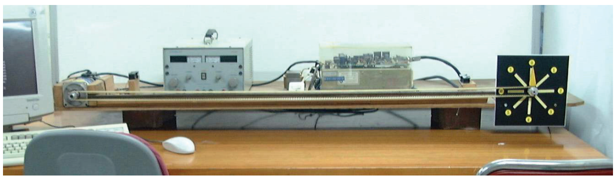

Fig. 2 Front view of the belt-and-pulley system

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 was reported that the inverted pendulum system with vertically circular track is used in control education (Misawa et al., 1995; Chrisman et al., 1995). 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.

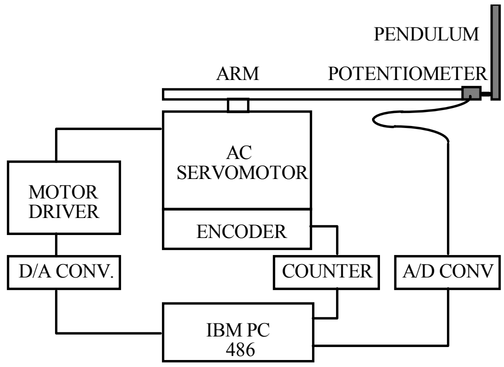

Fig. 3 Schematic diagram of the inverted pendulum system using a horizontally circular track.

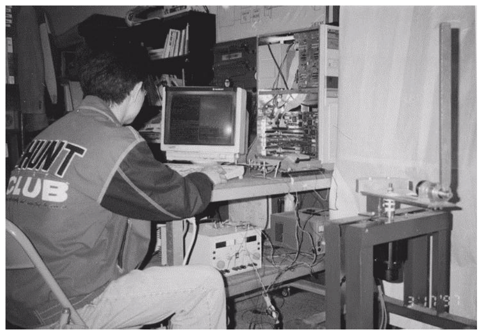

Fig. 4 Photograph of the inverted pendulum system.

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 (PC), 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 students 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. STUDENT'S SAMPLE RESULTS

In the spring semester of 2004, the following two experimental projects were given to the students for the controller design practice;

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

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 nonli near models about an operating point. Draw a block diagram o f 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 students' experimental results for both projects are shown in Fig. 5 and Fig. 6.

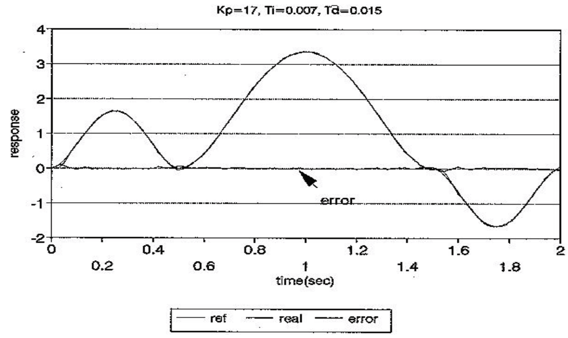

Fig. 5 A sample result of students' control practice for the belt-and-pulley system.

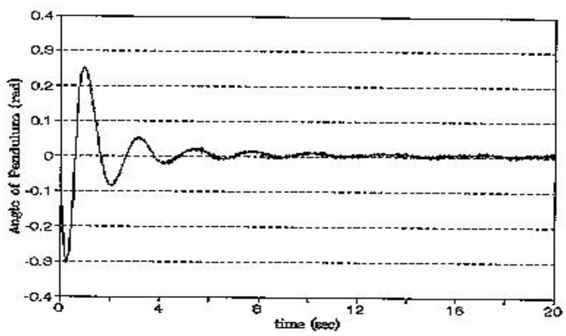

Fig. 6 A sample result of students' control practice of the inverted pendulum system.

From 2005 school year, the control engineering course has been provided as an e-Learning class through Internet, and the above two project were replaced with one simulation project that is based on the above experimental project 2, but the experimental work is changed to simulation work using CEMTool and SIMTool (or MATLAB and Simulink). The main reason for this change is due to the increase of the number of students taking this course, and the handling problem of the course by the teaching assistant.

5. e-LEARNING EXPERIENCES

Previously control engineering course had been taught as a classroom teaching for more than 10 years, and each semester during this period a few students complained the fact that they could not attend the control class because of overlapped class timing problem. In order to resolve this problem, I decided the control engineering class to make e-Learning course via Internet from the 2005 school year. Fortunately, our university supports all the software programs and hardware equipments for online teaching. The Center for Teaching and Learning of Konkuk University (KCTL; http://ctl.konkuk.ac.kr) has a special studio for audio and video recording of the lecture.

As a professor lectures at the studio, then a teaching assistant edits the moving picture, prepares all the contents for online release, and uploads them to the e-Learning site (http://ecampus.konkuk.ac.kr). KCTL trains the teaching assistants for the procedures and software usages for online publishing during one whole week of summer or winter vacation.

Every week, 3 or 4 lectures of about 30 minutes each are given to every student on Monday, and the student should take the online lectures in that week. If not, attendance checking program counts automatically him as absence of the class. Students can watch past online lectures as many times as they want.

Fig. 7 shows the first page of the online lecture site (provided in the 2nd semester of 2007) that shows the lecture schedule for the semester. If a student clicks one 'Taking the lecture' icon in the lecture list, he can take that lecture online. Fig. 8 shows one frame of the online lecture of the first week of September, 2007, in which professor's lecture is displaying as moving picture at the upper right corner, and the corresponding lecture note is shown in the middle of the screen. The student can print out the lecture note in advance before watching online lecture.

The professor and teaching assistant can check each student's progress of classwork as shown in Fig. 9, and then the professor or teaching assistant can email each student a message encouraging to study more, or send a SMS message through student's mobile phone.

Our e-Learning site has much more functions such as online group discussion, online quiz and exams, online questions and answers, score and attendance managements, automatic grading, etc.

Table 1 shows the statistical data of the student's enrolment for the *control engineering* course for last 6 years. During 2003 school year, the other lecturer taught the control engineering course. In the table, the total number of students implies the total number of junior students when they enter into the university. For example, the number of the admitted students in mechanical engineering department was 170 until 1999 school year, and was 150 after 2000 school year. In the table, we see that about 66 to 67% of the students took the control engineering course during classroom teaching period, but about 72 to 74% of the students has taken it during e-Learning class period. It seems that e-Learning attracts the students' enrolment for the class.

The online contents of lecture are basically reusable for the next year. Each year, however, I revised partial online contents of a few weeks' lecture, and sometimes added new materials such as, for example, problem solving. This has relieved significantly my burden for the lecture. Also the class evaluation by the students at the end of the semester becomes better compared to the one of the previous classroom lecture.

Fig. 7 The first page of the online lecture site of control engineering that shows the lecture schedule for the semester.

Fig. 8 One frame of the online lecture of the control engineering course

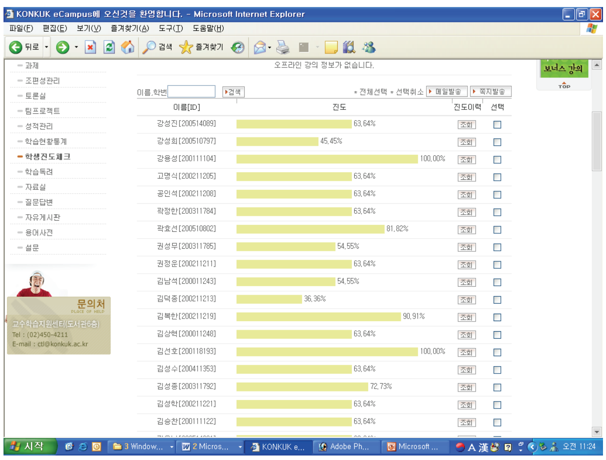

Fig. 9 A scene showing each student's progress of classwork.

Table 1. Statistical data for the enrolment of the control engineering course during last 6 years

School year	No. of class enrolment	Total no. of students	Enrolment percentage
2001	112	170	66%
2002	114	170	67%
2004	101	150	67%
2005	108	150	72%
2006	102	138	74%
2007	106	138	77%

6. CONCLUSIONS

This paper has presented a control course developed for hands-on experience on motion control using a belt-and-pulley system and an inverted pendulum system, and also discussed experiences of e-Learning control education. The practice of control system design is very important in control education through physical experimental setups or simulation packages. 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 practical control problems as a project in the course. Moreover, replacing the existing control course with e-Learning course has attracted more students' enrolment, and alleviated a burden of the professor's lecture significantly, yet students' responses for the lecture are still good.

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