A Method of Undergraduate Control Education, Especially for Mechanical Engineering Students

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1. Introduction

The Introductory course on automatic control is usually offered at senior level, because students should understand how a dynamic system behaves prior to learning how automatic control works. In mechanical engineering, for example, a good control engineer should understand the dynamic behaviors of various physical systems such as pure mechanical, heat and flow, hydraulic or pneumatic, and even electrical system. A mechanical engineering student learns how to analyze and interpret the dynamic behaviors of systems by taking courses such as dynamics, mechanical vibration, fluid mechanics, thermodynamics, heat transfer, and so on. The students take most of these courses before taking the automatic control class. Since a model of the plant to be controlled is the basis of a controller design, a good control engineer should be able to obtain a good model of the system. A system to be controlled may be simple, or can be complex and thus complicated modeling skills may be required. A subject on unified methods for modeling physical dynamic systems can consist of a lecture course throughout a semester. Even though modeling skill for a complex system may not be necessary for senior level students, the importance of modeling for a control engineer should not be neglected. This is why almost all of the textbooks on introductory control subject spare considerable amount of pages for physical system modeling. However, one semester with three-hours-per-week lecture does not allow enough time to equally cover both modeling and control methodologies. Thus, to my knowledge, in most universities, modeling is not intensively dealt with.

The subject of control is taught in various majors in engineering, since automatic control is applicable to any dynamic systems in wide areas of engineering. (In a broad sense, it even can be applied to social or economical systems.) The physical plant to be controlled is, therefore, different for different engineering fields. However, regardless of the types of the plant, the undergraduate-level control theories can generally be explained using one unified language i.e., Laplace transform and the same tools such as Root Locus, Bode diagram, Nyquist plot, and so on. Some emphases, however, may be given for different applications of engineering. For example, electrical engineers may want to use electrical circuits for plant examples, and for chemical engineers chemical processes may be of major concerns as the plants to be controlled. A mechanical engineer as a control engineer basically deals with any moving physical system, and as aims to improve its dynamic behavior by the use of control.

Like any other engineering courses, it would be better for a control class to have a laboratory session in order for students to get hands-on experiences on automatic control. For example, in the Department of Mechanical Engineering at M.I.T., the control course consists of three-hours-per-week lecture plus three-hours-per-week lab. In the lab, using a dc motor, the students learn how to investigate the transient response, how the controller types and control gain affect the motor behavior, how to apply root locus design method, and etc. To the author's knowledge, not every university offers a control course with a lab session.

In our Department of Mechanical Engineering at Yonsei University, an introductory automatic control course is offered to senior students as a cumpulsory subject. It consists of three-hours-per-week lectures and a term project. The topics of in-class lectures cover the so-called classical control theories. In the term project, the students are asked to design and build any moving mechanisms of their own idea, using any type of actuators such as dc-motor, stepping motor or hydraulic

actuator, interfaced with and controlled by a personal computer.

2. Undergraduate control with term project

In our department, the automatic control course is mandatory to senior students, namely, every student should pass the course for a bachelor's degree. The course is composed of three-hours-per-week in-class lectures and a term project. In this section, we will give some details on how the lecture is offered and what the students are required to do for the term project.

1.1 In-Class Lecture

The presently-used text book is "Feedback Control of Dynamic Systems" by G.F. Franklin, et al. (the third edition). Other books, which cover mainly classical control subjects, such as "Modern Control Engineering" by K. Ogata, were formerly used as a text book. There exist a lot of good books suitable for an undergraduate control class, and the authors believe that the decision on which one to use as a text book is a matter of lecturer's preference. As is mentioned in the above section, three-hours-per-week lectures for sixteen weeks (one semester) do not allow enough time to give details on systematic modeling of dynamic systems, and thus modeling is just briefly introduced at the beginning of the course. The students, however, get a chance to practice a modeling procedure while going through their term projects. The lecture mainly covers the materials on classical control theories. Namely, how dynamic system behaviors are analyzed and how controllers are designed in Laplace-domain using transfer functions, are mainly discussed. As is common for most of undergraduate control classes, the topics are on properties of poles and zeroes, transient response characteristics, stability, properties of basic PID control, root locus design method, frequency response analysis, and etc. Practicing a controller design procedure using simulation is helpful to understand the subject. Learning a computer-aided simulation package such as MATLAB and practicing it, is not obligatorily asked to the students, but the text book includes a lot of good examples for MATLAB and the students are encouraged to use it.

1.2 Term Project

Every student in the class is required to do a term project. The term project has been included as a part of the course since 1991. Three or four students form a team. About thirty teams are usually formed each year. Each team should design and build a moving mechanism of its own idea, which uses any types of actuators and sensors. We encourage the students to devise a creative and interesting idea. For example, some of the works produced by the students for the past three years are automatic basketball shooting machine, autonomous mouse-catching car, autonomous car-parking system, ball-juggling fur seal, and etc. The mechanism should be interfaced with and controlled by a personal computer. The semester begins on the second day of March and the project work should be completed by the first week of May, although the semster ends on the third week of June. The completed works are presented at the annual "Automatic Control Exhibition" held on the second week of May (the week of anniversary of the university foundation) as a celebration for the foundation of this department. Due to the tight time schedule, the students actually start working on the project during the winter vacation before the semester begins. A team of graduate students in Robotics Lab in this department (TA group for project) are assigned to supervise the project. During the winter vacation, the teams are organized and what is to be built is discussed and decided. In this department, Basic Electrical and Digital Experiment Lab is offered to the sophomore students as a compulsory subject. The lab includes basic electrical and digital theories, op-amp application, PC-interfacing, A/D, D/A conversion, and etc. From the experiment lab, the students learn how to handle basic electrical and digital devices. However, to help further the students set up hardware environment for interfacing, the TA group gives a series of lectures on this subject during the winter vacation. After the semester begins, the TA group and the professor meet each team every two or three weeks, and discuss problems and guide the process.

The purpose of mandatorily imposing the term project to every student in this department of mechanical engineering, can be stated in several view points.

First, by doing the project, the students learn how to bring their ideas into reality. In the beginning, members in a team discuss their ideas on what to build, i.e., the target function of their product. Then, they practice how to design a product. They have to decide many things at the design stage, because the product they are going to build has not been built before. For example, they

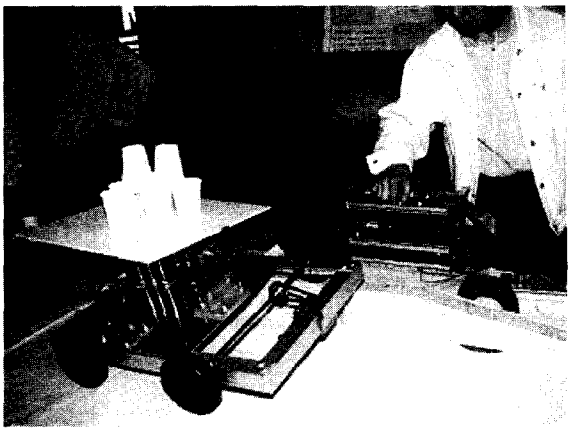
should decide the materials to be used, whether the strength of the structure is appropriate, what kind of transmission mechanism is to be used (e.g. gears, timing belt, links), what kind of actuators is to be used (e.g. dc motor, stepping motor) and how much power is adequate, which sensors are most suitable, and etc.

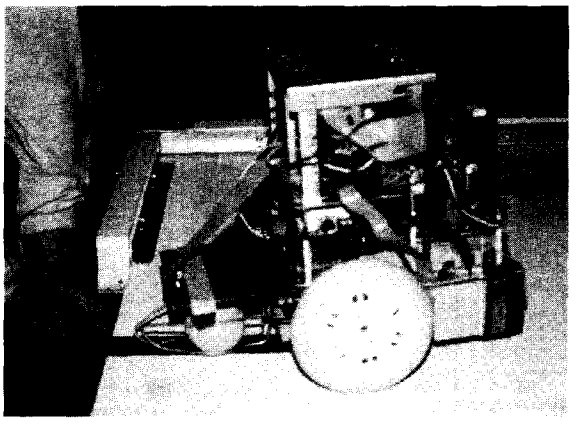
Second, the students can go through the controller design procedures in practice and by hands. Even though modeling skill is not covered in detail in the lecture, they get a chance to go through the derivation process of the dynamic model of their products. Namely, they learn how to derive the dynamic modeling of the components used, and learn how mechanical systems are connected to electrical or hydraulic systems, and thus understand how the whole system can be modeled. The students can practice how feedback control works and see how control can improve the dynamic behavior of a physical system. (Depending on the function of the mechanism, some of the products may need only open-loop control.)

Third, the students learn how to handle electrical and digital devices and interfacing techniques. The use of electrical/electronic and digital devices are more and more expanding in all the engineering majors. In particular, mechanical engineers should not be unfamiliar with such devices and should have basic skills to handle them. The automatic control course is compulsory for all the students in order to graduate from this department, and through this term project, every student gets hand-on experiences on electronics and digital devices. Feedback from former students tells us that the project experience was a great help regardless of where they are working now.

Other objectives of this term project are to let the students learn to cooperate with others and to experience how hard it is to make things work. A group of three or four students works together. The students should finish the project successfully under a tight time-schedule. They cut and drill and assemble the components, and mostly, they undergo trials and errors and thus need more time and efforts than they expected. If any one member of a team is insincere in doing his allotted job, the completion of the work on schedule is hard to be achieved. Thus, the students learn how teamwork is important and how hard making a real thing is.

The students' works are displayed on the annual "Automatic Control Exhibition" held on the second week of May as one of the ceremonies for the





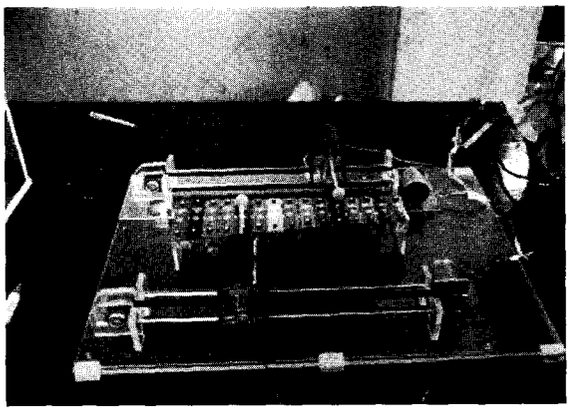


Fig 1. Demonstration in the exhibition.

anniversary the of department foundation. The exhibition is held for two days during the university foundation ceremonial week. It is open to general public and offers an opportunity for students of different majors, people from industrial companies, and outsiders to come and see the works of the mechanical engineering students' fresh ideas. It is estimated that several thousands people come and see the exhibition each year. The event is sponsored by many industrial companies in Korea and the authors are grateful to them. To name some of them, LG Electronics Co., Samsung Electro-Mechanics Co., Daewoo Motor Co., Kia Motor Co., Hyundai Motor Co., SSangyong Motor Co., and etc., have sponsored the exhibition. Fig. 1 show some of the students' works for the past three years.

3. Concluding Remarks

This article addressed how introductory automatic control, a mandatory subject for senior students, is taught in the Department of Mechanical Engineering at Yonsei University in Korea. Besides three-hours-per-week lectures, the course includes a term project. Thus, we try to let the students not only learn control theories but also get hands-on experiences on the subject.

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