Control Education via Experiments and Technical Visits

Yoichi Hori
Department of Electrical Engineering, The University of Tokyo.

1. Lectures

Needless to say, control engineering is one of the most imporiant basic lectures for all students in Electrical, Information and Electronic Engineerings, but it is the small number who select control engineering as their own long term research field[1].

1.1 Lectures of Control Engineering

We have the following lectures on control engineering itself. Three successive lectures are now the backbone of our control education.

■ **Control Engineering (1) (3rd year, summer term)**

1. Introduction
   (something like "What is control engineering?")
2. Representation of System Dynamics
3. Stability of Control System
   (Routh-Hurwitz criterion, Nyquist stability criterion,...)
4. Basics of Linear Feedback System
5. Compensation of Linear Feedback System
   (Nichols chart, root locus, PID control,...)

■ **Control Engineering (2) (3rd year, winter term)**

1. Digital Control
   (discrete time domain, pulse transfer function, z-transform, finite settling time contol,...)
2. Nonlinear System
   (descriptive function, phase plane analysis,...)
3. State Space Method
   (realization, state feedback, optimal control, system identification,...)
4. Advanced Control and Industry Applications

■ **Advaned Control System (postgraduate course, summer term)**

1. History of Control Engineering

Table 1. Control related lectures for 3rd year students in undergraduate course.
* This "experiment(2)" has been changed to "exercise" from this year.

		8:30-10:00	10:15-11:45	13:00-16:00	
Mon	S	control eng.(1)	electric machinery	experiment (1)	
	W	control eng.(2)		experiment (2)	
Tue	S	micro-processor applications		experiment (1)	
	W			experiment (2)*	
Wed	S				
	W	system math enginecring			
Thu	S			experiment (1)	
	W		power system(1)	experiment (2)	
Fri	S				
	W	power electronics			

Table 2. Control related lectures for 4th year students in undergraduate course.

		8:30-10:00	10:15-11:45	13:00-16:00	
Mon	S			graduation research	
	W	graduation research			
Tue	S			graduation research	
	W	graduation research			
Wed	S				
	W	graduation research			
Thu	S	applied control	power system(2)	graduation research	
	W	graduation research			
Fri	S	control of electrical machines			
	W	graduation research			

2. Basics of Dynamical System
   (state equations, controllability and observability, canonical forms, realization, stability)
3. Optimization of Dynamical System
   (Kuhn-Tucker's theorem, maximum principle, bang-band control...)
4. Optimal Control of Dynamical System
   (optimal regulator, state observer, numerical solution of Riccati equation, numerical solution of nonlinear optimal control, optimal robust tracking system)
5. Control of Sampled Data System
   (discrete time domain, pulse transfer function, deadbeat control, digital optimal control, LTR, other various problems in sampled data system)
6. Robust Control
   (disturbance observer, TDOF control, H-infinity control)
7. State Estimation and System Identification
   (observer, Kalman filter, adaptive identification)
8. Other Techniques
   (preview control, adaptive control,...)

Table 3. Control related lectures for postgraduate course.

		8:20-10:00	10:05-11:45	13:00-14:40	14:45-16:25	16:30-18:10
Mon	S			Advanced Control System	electric railway system	traffic system (1)
	W		advanced electric machinery (2)	traffic system (2)		
				neural network		
Tue	S	artificial intel-ligence		advanced electric machinery (1)	pattern recogni-tion	
	W		robotics			
Wed	S	appl. of super-conductivity		doctor course exercise		
	W			doctor course exercise		
Thu	S	master course experiments				
	W	master course experiments				
Fri	S	motion control	presentation exercise			
	W	thyristor circuit	presentation exercise			

1.2 Lectures on Electric Machinery

Electric machinery has been also an important filed from a viewpoint of control engineering. It has been lectured for many years, but recently we have put special emphasis on control techniques of electrical machines.

■ **Basics of Electric Machines (3rd year, summer term)**

1. General View - Introduction of Electric Machines
2. Magnetic Circuit and Transformer
3. Electric-Mechanical Energy Conversion
4. Induction Machine
5. Synchronous Machine
6. DC Machine
7. Basics of Power Electronics

■ **Power Electronics (3rd yeay, winter term)**

1. Introduction
2. Power Devices and their Characteristics
   (diodes, thyristors, power transistors, compound devices)
3. Power Conversion Circuits and Control Functions
   (extemally- and self-commutated circuits)
4. Application of Power Electronics
   (power supply, control applications)

■ **Control of Electric Machines (4th year, summer term)**

1. Dynamics and Control of DC Motor
   (4-quadrant operation and controlled power source, basic design of torque and speed controllers, disturbance observer, motion control)
2. Dynamics and Control of Induction Motor
   (state space model of induction machine, vector control, flux observer, maximum efficiency operation, speed sensorless control)
3. Dynamics and Control of Synchronous Motor
   (*d-q* transformation and Park's equations, transient reactance, position sensorless control)
4. Applications
   (motion control and robotics, electric vehicle)

1.3 Other Control Related Lectures and Unique Trial of Exercise in a Lecture

The following lectures has relation with control engineering.

- Microprocessor Applications(*)
- Robotics
- Advanced Electric Machinery (1) (2)

- Thyristor Circuit
- Electric Railway System
- Traffic System (1) (2)
- Pattern Recognition
- Artificial Intelligence
- Application of Superconductivity
- Motion Control

In Microprocessor Applications(*), several years ago, we introduced exercise using many "TMS320C50 DSP Starter Kits" into the lecture and give students home work in winter vacation.

This is not the formal experiment, but the trial to combine a lecture and experiment. This lecture was established in 1993, and two associate professors were assigned, whose special areas are not in microprocessor. In the first year we did a normal type lecture, and students evaluation was extremely low.

We changed this lecture to Lecture + Exercise. Using 20 TMS320C50 DSP Starter Kits which Texas Instruments Co.(TI) gave us in the University Program and 20 host computers presented from IBM, we started. Program of DSP is developed in PC and downloaded into DSP via RS232C line. After simple numerical calculations, real time signal processing via AD/DA converters is given as the subject.

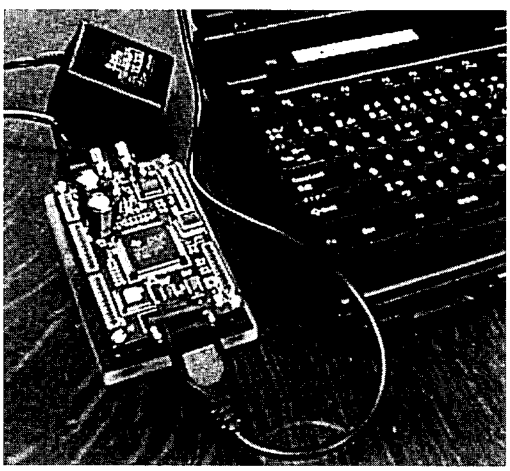


Fig 1. C50 DSP Starter Kit connected to IBM Think Pad by RS232C Cable.

In 1995, we increased the kit number to 40, and IBM gave us 20 Think Pad's (See Fig.1). In 1996 and 1997, more than half students bought the kits by themselves. As TI will not provide the C50 kits anymore, in 1998, the department bought 70 kits more. This is the enough number to serve all students.

The winter vacation homework is "Make a minimum scale microcomputer gathering necessary parts in Akihabara area." Students should make presentation on their works in the new year in front of their classmates.

2. Student Experiments and Exercise

2.1 Experiments for Undergraduate Students

Afternoons of Monday, Tuesday and Thursday are assigned for student experiment for 3rd year students through the year. The aims of this experimental course are different from each other by terms. In summer term, all subjects are mandatory and very basic techniques beginning with voltage and current measurement are included. Some of them are energy and control related subjects: Discharge Phenomena and AC Apparatus (transformer and induction machine).

In the winter term, student experiments are divided into three categories, i.e., Energy & Control, Communication & Information, and Device & Material. At least one subject from each category is mandatory and others can be selected by each student group which consists of 4 members.

The aim of this winter term experiment is to give students research ability to be needed in their 4th year period. The contexts are specific but the manuals are very poor. This unkindness forces the students to consider how to design their actual experiment. For

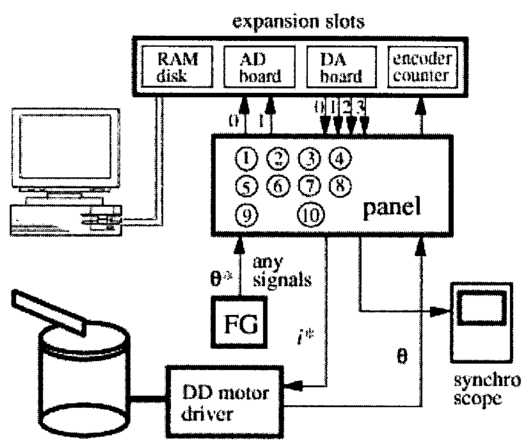


Fig 2. Student experiment of Servo Control for all 3rd year students in undergraduate course.

example, the wiring of equipments are not completed. Students should select and design their own experimental system by themselves.

Actual subjects in Energy & Control course are as follows. The first one is mandatory for all students.

■ **Basics of System & Control**

(1) Power System

Synchronous generator is given. The aims of this subject are to understand the generator's characteristics and to perform the synchronous operation. By using the transmission line simulator, non-symmetrical line-to-ground fault is experimented and analyzed.

(2) Servo Control

The axis position of torque controlled DD motor is controlled by using software program written by C. Data communication with AD/DA converters and the encoder counter board is investigated, and the sampling time are also designed. Simple robust servo controls based on disturbance observer and TDOF controller are included.

■ **Exercise of "CAD of Controller Design"**

This year, we have just started the "Exercise" of "CAD of Controller Design". Using 20 personal computers (Celeron 400HMz, Windows-NT4.0), one computer is given to each student. MATLAB/ SIMULINK (educational version) is installed. Students try to be familiar with this kind of CAD system using 3 hours/day × 6 days. Final subjects are relatively advanced, i.e., robust servo system, vibration control of 2-inertia system, simulation of double pendulum, and vehicle behavior simulation, etc. As we have just started this system, we have not yet evaluated its effectiveness. Total 10 exercise subjects have been newly established in the Departments and they are now running.

■ **Power Flow Control using Semiconductor Power Devices**

Measurement of basic switching characteristics of silicon diode, thyristor, IGBT, etc., and understanding of commutation circuit, phase control circuit, etc.

■ **High Voltage Physics**

Generation of very high voltage of several tens to hundreds thousand volts and observation of interesting nonlinear phenomena, e.g., corona discharge and flushover. It is also important to study how to operate the HV generator, how to measure HV.

■ **Variable Speed Drive of Induction Motor**

Study on the principle of sinusoidal wave PWM VVVF inverter and measurement of various characteristics by driving the induction motor.

■ **AC to DC Power Conversion**

Study on the principle of rectification. The simplest 3 phase mixed bridge circuit is used. Experience of unique characteristics of power electronic circuits, which can not be seen in small power electronic circuits.

■ **Sequence Control**

As an example of sequence control, students try to write microcomputer program of labyrinth evacuation. By operating XY parallel manipulator, they study on the basics of sequence control, which is important in actual systems.

■ **Circuit Breaking Phenomena and Surge Simulation**

Study on function of switchgear to cut DC and AC currents at accident in power transmission network, and on the mechanism of switchgear, analyzing recorder, physics of arc, etc. Based on surge simulation, students understand surge transmission, reflection, over-voltage protection from surge caused by lightning and circuit break.

■ **Application of Static Electricity**

Understanding of physics of static electricity through the measurement of electric field distribution. As application examples, micro particle capturing by corona discharge, and electric filed curtain are experimented.

■ **Numerical Calculation of Electromagnetic Field**

Study on the principle of difference method, finite element method, and simultaneous equations needed in equipment design and device analysis.

■ **Nonlinear Magnetic Phenomena**

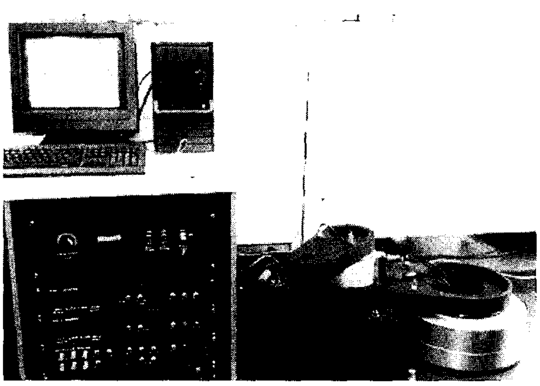
Nonlinear characteristics between the magnetic field (*H*) and flux density (*B*) is important for memory device, hysteresis motor, saturable reactor, etc. Here, students measure the *B-H* characteristics and study on interesting application examples of magnetic amplifier and iron resonance circuit.

■ **Process Control**

Industrial process is a very difficult object to control because it often has a long time constant and deadtime. Here, by using a hardware model of heating process, temperature control by PID controller is experimented. Based on a simple system identification, optimal design of the controller parameters are examined.

(a) 3-Mass Torsional System

(b) M-G Set for Motor Control Experiment



(c) DSP-based DD Manipulator Control System

Fig 3. Some Experimental Setups being used for Robust Motion Control in my laboratory.

2.2 Experiments for Postgraduate Students in Master Course

Presently about 60 faculty members (40 professors, 20 associate professors, and a few lecturers) are in the postgraduate courses. Each student should choose one of the faculty members as his/her research supervisor. The master course experiment and the doctor course exercise are provided for these graduated students opportunity to touch some different fields from their own supervisors' special research fields.

In the post graduate course, professors prepare the advanced experimental subjects related with their own research fields. These themes can be selected by students. More than 100 themes are provided in a year. Here I would like to list-up only the control related subjects.

- Circuit Analysis using Bergeron Method
- Application of Neural Computing to Power System
- Converter Control using Transputer
- Design of Traffic System
- Self Position Estimation if Wheel Type Mobile Robot.
- Control of Magnetic Levitated Momentum Wheel
- Attitude Control of Scientific Satellite System
- Behavior Planning of Planet Rover using Camera Image Information
- Autonomous Rendezvous of Deep Space Explorer
- Large Scale Energy Model
- Ultra Micro Actuator
- Distributed Autonomous System
- Robust Motion Control
- Multi-inertia System and CAD for Controller Design
- Autonomous Robot System using Laser Rangefinder
- Tele-robotics and Virtual Reality
- Basics and Evaluation of Electromagnetic Actuators
- Group Control of Trains

2.3 Doctor Course Exercise

In the doctor course, a student group consisted of several students can select a few professors to discuss deeply on subjects of the professors' research fields. In most cases, technical visit to one of the industries is included, with whom the professor may be performing cooperation research.

3. Technical Visit to Industries

We prepare for 3rd year students in undergraduate course several technical visit plans to private industries, factories and research institutes. This must be a great help for students to understand how the knowledge learned from lectures and student experiment is utilized in actual industries.

This courses are divided into two categories. One is done in every Wednesday afternoon. The total number of visits is about more than 10. Therefore, the destination is limited only in Tokyo area, for example, Fujitsu, NEC, Toshiba, Sumitomo Metal, JR-East, TEPCO, NTT, Meidensha, Hitachi, Fuji Electric, etc.

During summer vacation, students can visit dams and hydraulic power plants in mountain area. Also, during spring vacation, they can visit some industries in Kansai area (West part of Japan) using about one week. For example, DENSO, Toyota, Nihon Gaishi, Sharp, Mitsubishi, Matsushita, Sumitomo Electric, etc., kindly accept out request. In the past, we visited Kyushu area, like Yaskawa Electric, Nippon Steel Company, etc.

Students can not get any degrees from this technical visits, but these chances to see industries are very much effective for them also in finding their jobs after graduation.

4. Conclusion

In our three departments, control education is absolutely based on application to electrical engineering. It is our strong opinion that any control theories are meaningless if they are not used in actual industrial applications.

Professors and technical staffs in our deparments are taking much effort in students experiment and technical visit to industries. The problem is that students are reluctant in not-beautiful experiments. They often believes simulation results more than experimental results.

Reference

[1] General Catalog, The University of Tokyo, 1999.

Yoichi Hori

He received the B.S., M.S. and Ph.D degrees in Electrical Engineering from the University of Tokyo in 1978, 1980 and 1983, respectively. He joined the University of Tokyo, the Department of Electrical Engineering in 1983 as a research associate. Since 1988, he has been an associate professor and was promoted to a professor on February, 2000. During 1991-1992, he stayed at the University of California at Berkeley (UCB) as a visiting researcher. His research fields are control theory and its industrial application, in particular, to motion control, mechatronics, robotics, power electronics, power systems, electric vehicle, etc. He is the member of IEE-Japan, IEEE, JSME, SICE, ISCIE, RSJ, JSST and so on. He received the Best Transaction Paper Award in IEEE Trans. On Industrial Electronics in 1993.

E-mail:hori@hori.t.u-tokyo.ac.jp