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Reform of a motion control system course for developing engineering ability

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ABSTRACT: Methods for solving problems in the *Motion Control System* course are discussed in this article. To improve teaching, it was necessary to reform and innovate, from team building, to classroom and laboratory teaching and curriculum design. A problem-based teaching method was adopted, with emphasis on engineering background, integration of teaching content and updated course content. Also, the curriculum project was designed according to the CDIO method. Innovative experiment teaching content and progressive curriculum design were constructed. Experiments are classified into verification, design, comprehensive or innovative; and an experiment platform was developed. The *segment the whole into parts* method in curriculum design helped students to deepen understanding of teaching content and to grasp the theory and structure of a typical motor control system. After the teaching reform, students' motivation to learn was improved, practical ability was enhanced and the effectiveness of classroom teaching improved. This lays a solid foundation for those who will design, develop and maintain motion control systems.

INTRODUCTION

The Motion Control System course is a key course for students majoring in automation and electrical engineering. Compared with other courses, the motion control system course has the following characteristics: there is a broad and comprehensive coverage of knowledge with engineering theory and practice closely linked. The course covers automatic control theory, motor and drives, power electronics, circuit design, analogue electronics, digital electronics, power electronics and computer control technology. The course deals with electrical systems, power and electronics technologies, software and hardware, components and systems. The content of the motion control system course provides the basis for process control and robot control systems [1].

Abstract concepts are part of the course; systems analysis is complicated, with much mathematics and a great amount of calculation. The teachers are required to have deep and broad knowledge, as well as rich experience in teaching and research. For students, a good foundation obtained from basic courses and strong engineering ability is crucial.

At present, problems have arisen with the traditional teaching process. There is an emphasis on traditional technology, while neglecting advanced technologies. There is concentration on general theoretical analysis and simple experiments, with a lack of description and understanding of complex systems. The updating of course content is too slow and there is a lack of comprehensive and innovative experiments. As the goal of this course is to cultivate applied talent, students need to grasp the analysis, design, installation, commissioning and operation of actual motion control systems. However, it is difficult for students to engage in the field of motion control after graduation, due to excessive theoretical analysis and less actual system experience in the course. Most of the teachers lack the real engineering experience that is important for teaching effectiveness. Finally, the traditional experiments generally only include demonstration and confirmatory experiments to enable the students basically to understand and grasp theory. The experiment teaching is often just a formality and student motivation is not high.

All of the aforementioned problems imply that the course cannot meet the requirement to cultivate innovative, application-oriented talent.

REFORM OF THE MOTION CONTROL SYSTEM COURSE

The goal of the course is to enable students to understand the principles and features of actuators, drivers, controllers, sensors and other components used in the construction of motion control systems. To improve teaching, it is necessary to carry out reform, including teaching team building; teaching in the classroom and in the laboratory, as well as curriculum design, as shown in Figure 1.

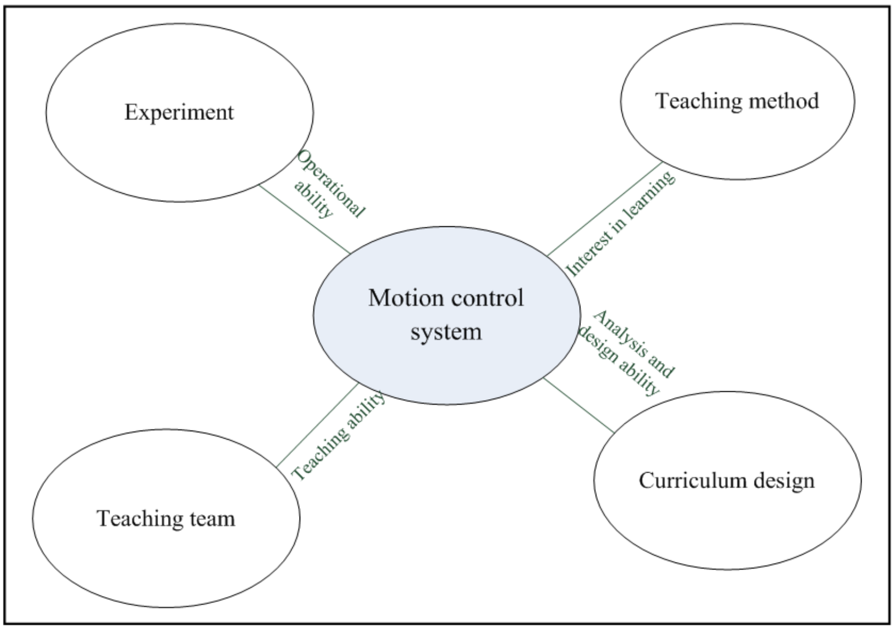

Figure 1: Reform of the Motion Control System course.

Build a Dual-Qualified Teaching Team

Experience of research and engineering practice are critical for teaching the Motion Control System course. As the content of the course is closely related to research and engineering practice, if the teacher has little corresponding actual engineering experience, it will limit the teacher’s depth of understanding of the course content and, as a result, the teaching effectiveness will be affected.

To build a *dual-qualified teaching team* that includes actual engineering experience, a related company was chosen to which to send those teachers without working experience, and where they would take part in product development, production and management. A teacher would spend one or two years gaining engineering experience and grasping the state-of-the-art technology. On the other hand, engineers with good experience were hired to teach part-time. Through such teaching, the team building, as well as the teaching, research and engineering practice, are all greatly enhanced.

Classroom Design

It is well known that good classroom design is important for improving teaching. In classroom design, the focus is on the following aspects: integrating teaching content; adopting progressive teaching methods; and designing the teaching module based on the conceive, design, implement, operate (CDIO) enquiry-based teaching standard [2].

Lay Stress on Engineering Background and Integration of Teaching Content

The purpose of the integration of teaching content is to emphasise the systemic and common or continuity features of motion control systems. As the course involves broad knowledge closely related to other courses, teachers should frequently review the related knowledge to make the teaching content seamless. This will help students to organically merge the knowledge required to understand motion control systems. Both horizontal and vertical continuity is emphasised in the teaching content, which reflects the CDIO concept of integrated curriculum design. However, the main course content is retained, with a moderate reduction of the time spent on abstract theory, and more time spent on the analysis and discussion of new motion control technologies.

The theoretical basis of motion control in new energy generation and robot control technologies is reinforced. There is an increase in the teaching content covering new energy power generation technology, wind power and control technology, motor vehicle principles, and photovoltaic and micro-network technology. Furthermore, through teaching robot controls, students can learn the basic principles of robotics and learn the control methods used in robots.

Combine Theory with Engineering Practice

During teaching, some ordinary drive systems are introduced, such as an air conditioner compressors control, mine hoist control, elevator control system; variable-frequency constant-pressure water supply control system and variable speed wind turbine control system. Through analysing how these control systems work, textbook knowledge was connected to real engineering systems, establishing for students an understanding of real control objects. In this way, students enrich theoretical with practical knowledge and increase their interest in learning.

Before teaching new content, the content already learned is summarised by analysing its strengths and weaknesses, and identifying ways it helps to solve problems. This lays the foundation for teaching new content. Take a single-loop/double loop DC speed control system as an example. There are a variety of schemes to realise such a speed control system; however, it is difficult for students to grasp all of these possible schemes. To solve this problem, the teaching content is based carefully on the following three precepts:

- Integration of teaching and research by converting existing research resources to students' teaching resources.
- Optimisation of the teaching content and teaching mode of the course; expanding and organising the content according to three threads: motor, drive circuit and control strategies. Strengthening the curriculum syllabus by applying new motor simulation technology to the design and analysis of motor drive control systems.
- Guiding students to taking part in research projects to stimulate their interest in learning, and to cultivate their engineering ability in an actual environment.

CDIO-based Teaching Project Design

Classical projects were designed, which were then to be implemented using the CDIO (conceive, design, implement, operate) method [2]. These included a single closed-loop DC (direct current) drive speed control system with/without static error; a speed and current double close-loop DC motor control system; pulse width modulation (PWM) DC motor control system; AC (alternating current) motor speed control systems; a cascade speed control system; and an induction motor VVVF (variable voltage, variable frequency) speed control system.

In addition, new projects were included, such as an intelligent robot controller and a high speed train drive control. To help students master the common control tools, programmable logic converter (PLC) frequency-converters, single-chip microcomputers and digital single processor (DSP) are all used on the projects. Take the single-loop DC speed control system module as an example. First, students dismantle the system, which includes a DC power supply, speed controller, DC motor and tachogenerator. After the students are familiar with, and master, the basic principles of the practical module, they are required to construct a complete single-loop control system and, then, debug and analyse the control performance of the system.

In addition, real enterprise projects are introduced, all closely related to motion control systems, as listed in Table 1.

Table 1: Projects and corresponding teaching content.

Number	Project	Corresponding to the teaching content
1	Electric vehicle speed control system	Principles and methods of DC motor speed control
		Principles of speed sensors
		Speed measurement
2	Extruder control system	Variable voltage and variable frequency
		Servo motor control
		Control DC/AC motor using PLC
		Tension control in motion control system
3	Mine hoist control system	Speed measurement
		Control of AC motor using PLC/DSP
		Variable frequency speed control
4	Carrying robot	Servo motor control
		Stepping motor control
		Position closed-loop servo control
		Speed closed-loop servo control
		Speed and position measurement
5	Wind power generation system	Current, voltage, speed measurement
		Permanent magnet synchronous generator control (start up, stop, normal control)
		Rectifier and inverter

Hybrid Enquiry-based Teaching using Discussion and Problem-based Teaching

Expository teaching was converted to enquiry-based teaching using discussion and problem-based teaching. During teaching, *why* and *how* are emphasised in the classroom. For example, when teaching the closed-loop system, an open-loop system is first considered; students calculate the steady-state performance and judge whether the open-loop system can meet the steady-state performance requirements. If not, students put forward solutions to solve this problem. An example of the approach is the high current problem that appears in the simulation of single-loop speed control systems. Students should find the way to solve this problem, and how to obtain the best starting characteristics, thus, introducing the current double closed-loop system. This teaching method allows students to continue thinking as a class, while closely following the course content [3].

Reform of Experiments

Practice teaching plays a very important role in developing application skills. However, in teaching, theory is often emphasised, while neglecting practice. Practice teaching should be regarded as an extension of theory, and is a direct way to help students to master knowledge.

The main content of students' learning at university is existing theoretical knowledge and a summary of the experience of their predecessors. Through experiments, students can verify the correctness of the theory, and find and solve new problems using their learned knowledge.

Experimental Content

Typically, detailed steps and experimental procedures are given to students. During the experiment, the students only need to be familiar with the experimental device and basic theory, and to conduct simple fault finding. Hence, there is a lack of actual engineering practice.

Experiments are classified as verification, design, comprehensive or innovative.

Combining Experiments with Simulation

The teaching content and curriculum are frequently adjusted to reflect the development of motion control system technology, e.g. adding digital and photoelectric motion control. Also, an experiment platform has been developed for robot practical education. An experiment platform can help students obtain theoretical knowledge by practice, while cultivating teamwork, and their ability in analysing and solving problems. This greatly improves the students' self-confidence and interest in learning. The DC servo control system, AC servo control system, optical digital motion control system and field bus movement control system are also included in the experiments.

Stress Design and Innovative Experiments

Experiment teaching should stress design and innovative experiments. Experiments mobilise a student's initiative, enthusiasm and creativity. Students complete the whole experiment process, from design to operation and report writing. It improves their practical and research ability, as well as promoting innovation and a quality education [4].

The proportion of design and innovative experiments has been increased. A design/innovative experiment may cover knowledge related to others courses. Under the guidance of teachers, students design the speed control program using the theory of electric drive motors, and employ power electronics technology to design the main circuit. They build the mathematical model of the control system using automatic control theory and, then, design the regulator system performance parameters using the engineering design method according to the mathematical model. The controller parameters are verified using Matlab/Simulink. Finally, the system is debugged in the laboratory.

The platform for the experiments is shown in Figure 2 below.

PURPOSE AND CDIO METHOD IN CURRICULUM DESIGN

The curriculum should allow students to grasp the basic theory and structure of a typical motor control system, learn the basic debugging methods, develop their problem-solving skills and apply the knowledge to applications.

In the curriculum design, based on the CDIO method, students are required to integrate disparate knowledge and develop an actual motion control system. This system includes both hardware and software design. The project in the curriculum can be divided into two subgroups: analysis, design and simulation.

For the analysis subgroup, the students are required to determine the schema, design the circuit, calculate and select the components, and design the PCB of the control circuit. For the simulation subgroup, the students construct a simulation model and simulate the control algorithm, taking AC variable speed system vector control and direct torque control as examples. The students improve their computer simulation ability and deepen their comprehension of PWM technology, including sinusoidal PWM (SPWM), constant frequency PWM (CFPWM) and standard variable PWM (SVPWM).

Figure 2: Experiments platform.

The process of project-based curriculum design can be divided into three steps, viz. project design, system implementation and system improvement. In the first step, teachers develop the project with regard to the needs of a company. In the second step, students select the project and work in groups to complete the design. In the third step, the college organises a committee to review the students' design.

In the past, the project took about two weeks to complete and was arranged after the teaching of theory. This made it easy to teach and manage, but the time limit was too onerous. To solve this problem, a decentralised mode of teaching was adopted. The design was implemented in parallel with the teaching of theory. The schema design, software and hardware design, debugging and simulation are implemented, along with teaching theory. Then, the students were grouped to make and test individual modules, as well as combining each module to form a complete system.

EVALUATION OF TEACHING EFFECT

To evaluate the teaching effect, two hundred questionnaires were distributed, to graduate students and students in school, respectively. The questionnaires consisted of five questions answered on a five-point scale, with *5* being the most positive response [5]. The results of the questionnaires are shown in Table 2 and Table 3.

Table 2: Questionnaire results for students in school.

Evaluation content	Score and number of students				
	5	4	3	2	1
Contribute to bridging knowledge between courses	76	20	3	0	1
Deepen understanding of motion control systems	80	16	2	1	1
Satisfied with course content arrangement	76	21	1	1	1
Garnered interest	79	16	2	1	2
Improved understanding of new technologies	81	17	0	1	1

Table 3: Questionnaire results for graduate students.

Evaluation content	Score and number of students				
	5	4	3	2	1
Help to improve future career skills	71	21	7	1	0
Help to enhance engineering practice ability	80	13	4	2	1
Mastered enough solid theoretical foundation and expertise knowledge	76	22	1	1	0
Develop strong engineering and research and development capabilities	77	16	4	2	1
Willing to recommend to lower grades students	80	16	2	2	0

CONCLUSIONS

Motion control systems are characterised by a requirement for strong theoretical foundations and sound engineering practice. The reforms discussed in this article involved the building of a dual-qualified teaching team, integration of teaching content and CDIO project-based teaching. This leads to students acquiring better understanding of abstract theoretical principles, as well as deepening their understanding of knowledge related to motion control systems. By virtue of the course learning content, students will enhance their engineering ability and lay a solid foundation for their future careers.

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