Research teaching applied to automation theory

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ABSTRACT: The teaching of automation theory through research teaching based on experiments with a two-wheeled robot is the focus of this article. The experiments include control system modelling, simulation and control algorithm determination. The results show that research teaching can effectively combine theory and practice. It increases a student's capacity to analyse and solve problems, cultivates innovation and improves a teacher's research and teaching. Research teaching is beneficial to the development of engineering and technology education.

INTRODUCTION

Undergraduate education holds an important fundamental position in training, scientific research and subject development, therefore, it is common to emphasise its teaching in international higher education. Hence, undergraduate engineering and technology teaching is an important measure of a university's level of achievement. China is transitioning from examination-oriented to quality-oriented education and the teaching model is transitioning from passive lecturing to a more creative type of teaching.

Control theory is an important course in the automation discipline. It mainly concerns the laws governing automatic control systems, which has strong theoretical and practical components [1][2]. Practical teaching is an important part of a control theory course, the purpose of which is to combine theory with engineering practice and to effectively train students to analyse and solve problems [3][4]. However, current experiments used in teaching are mainly verification experiments, and these are limited to verifying a single law or conclusion taught in the classroom. Such teaching does not cultivate a student's creativity. Control theory has a background in engineering applications. Designing a research teaching mode based on the application of engineering has become one of the main goals of teaching control theory [5][6].

The research teaching mode still is in initial development but, as demonstrate on their Internet sites, many colleges and universities have set up research teaching modes for control theory. A typical example is Zhejiang University of Technology, with a teaching team led by Professor Yu Li. Their control theory research teaching uses experiments based on an inverted pendulum to combine theory with practice and to produce a more engaging course. The course has become nationally recognised with first-class teaching [7][8]. Other colleges and universities also have explored research teaching - with good results [9-11].

All of the above research results emphasise the importance and necessity of the research teaching model for control theory. The research practical teaching model has been studied; however, the research theory teaching model is still being explored. The theoretical teaching content has to be reformed. Such reformed content would include the establishment of a model of the research object and analysis and design of the control and performance of the object in a simulated, virtual environment. Theory would be combined with practice which, therefore, needs teachers with a relevant research background and experience. The higher qualifications required by teachers has hindered the development of the research teaching model to some extent.

The selection of an engineering research object is particularly important for research teaching. The choice of engineering object can arouse a student's interest in learning and also effectively combine theory and practice. For example, in this article, a two-wheeled robot is used as the engineering object. The student comes to deeply understand

the theoretical research object, while the theory and practical teaching of control theory has been reformed. The research teaching trains students in scientific experimentation and logical thinking in the practical teaching, and improves the students' innovative ability.

THEORETICAL CONTENT OF THE RESEARCH TEACHING MODEL

The content of an automatic control principle course includes the introduction, composition of an automatic control system, modelling of the control system, analysis and design of control systems, etc. The research theory teaching model would use a two-wheeled robot throughout the course. Each stage of theory would be followed by modelling, analysis and controller design of the robot system. Students can master the implementation of various mathematical algorithms through analysis of the robot system using MATLAB simulation software. At the same time, students intuitively can understand the analysis and design of the control system, and reduce the abstractness of control theory teaching.

COMPOSITION OF THE CONTROL SYSTEM

The composition of the two-wheeled robot system is shown in Figure 1. Using the intuitive and interesting characteristics of an actual two-wheeled robot device can stimulate a student's interest in active learning. At the same time, by examining the structure of the two-wheeled robot system, students can discover the difference between the actual system and theory. They also get to know the relationship between the control links, the mechanical parts, signal acquisition and processing, and the actuator.

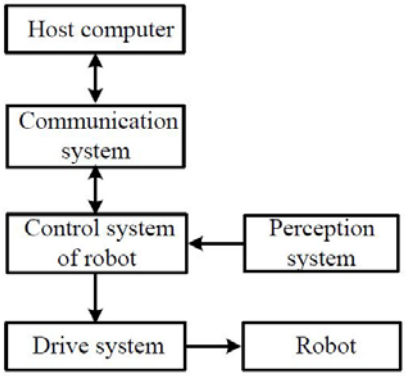

Figure1: Structure of the two-wheeled robot.

MODELLING OF THE CONTROL SYSTEM

Establishing a mathematical model of the two-wheeled robot system is the foundation of control system analysis, controller design and simulation. This requires students first to learn basic mechanical modelling methods. Control system modelling is important but difficult for automatic control systems. It is also an important key to control system analysis and design. Students can understand the common modelling methods and definite the input and output variables of the two-wheeled robot. Hence, they finally understand modelling procedures for the control system. It also lets students understand the reasons for system modelling and linearisation.

ANALYSES AND DESIGN OF THE CONTROL SYSTEM

The control system analysis and design for the two-wheeled robot used the computer aided teaching software MATLAB. First, time domain analysis, root locus analysis and frequency domain analysis are performed for the robot model. Second, the controller for the robot system is designed and the parameters of the controller adjusted until the response curve is satisfactory.

Analysis and design of control systems is at the core of the control theory curriculum. Combining MATLAB simulation software with the robot system allows the relationship between theory and practice to be teased out. The problems and concepts of control systems are developed for students via practical problems. Hence, the teaching of control theory goes from mathematically abstract to concrete with the theoretical knowledge related to an application. Once the relationship between theoretical knowledge and practice is established, students will be stimulated to apply control theory to the solving of engineering problems and this will cultivate their innovative thinking.

CONTROL THEORY EXPERIMENTS

Experiments for the control theory course should develop from the superficial to the deep, and from simple to comprehensive. First, basic verification experiments are designed, followed by comprehensive, design and innovative experiments. The comprehensive, design and innovative experiments can directly impact on outcomes, regardless of the

level of enthusiasm of students. Therefore, designing comprehensive, design and innovative experiments is the basis of developing the research experimental model.

The comprehensive, design and innovative experiments outlined in this article include a proportional integral derivative (PID) two-wheeled robot's motion control using calibration based upon the frequency domain method. The PID controller is the most widely used and successful control method in industry. Therefore, students must master PID control principles, applications and design methods. The comprehensive, design and innovation experiments are based on the two-wheeled robot PID controller. The experiment includes PID controller structure design, as well as PID controller design and zero input response analysis. The experiment requires students to produce a design on their own, and, then, follow the research plan to finally produce the experimental results and correctly handle the experimental conclusions.

Control structure of the freedom balance motion in the two-wheeled robot is shown in Figure 2.

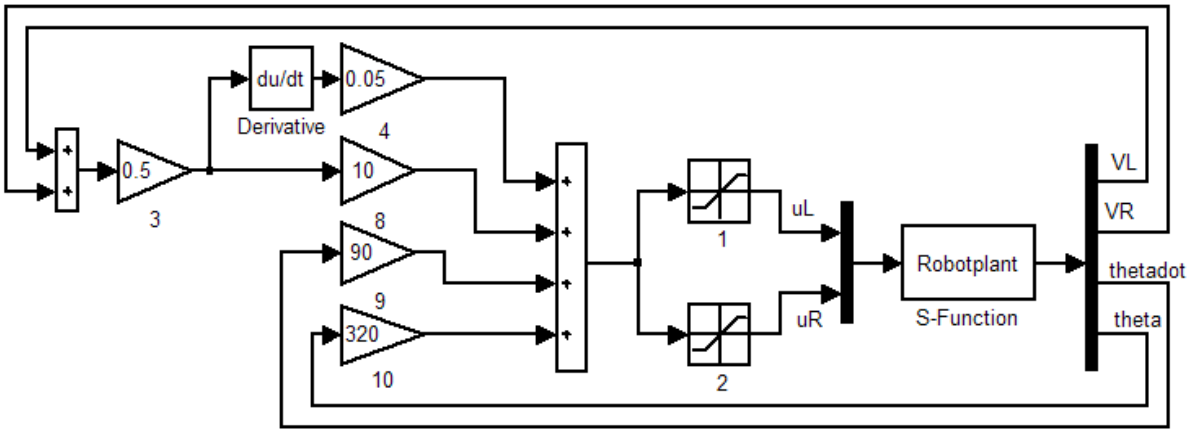

Figure 2: Control structure of freedom balance motion.

Equation (1) describes the action of the PID controller:

$$u_l = u_r = u_1 = k_P\theta + k_D\dot{\theta} + k_{PP}\left(\frac{\dot{\theta}_l + \dot{\theta}_r}{2}\right) + k_{DD}\left(\frac{\ddot{\theta}_l + \ddot{\theta}_r}{2}\right) \quad (1)$$

The angle θ and wheel centre speed are given by Equation (1). The balance control of the robot is realised by the PID controller of the angle θ. However, the output has an oscillation. Students learn the flexibility of designing using a PID controller. Parameter tuning of the PID controller is by trial and error. The ideal parameters for the PID controller tuned by students are k_p = 320, k_D = 90, k_{pp} = 10 and k_{DD} = 0.05. When tuning the PID parameters students reach the conclusion that wheel acceleration feedback can eliminate the oscillation and improve the balance control. However, the robustness will be reduced if the values of k_{pp} and k_{DD} are too large.

Simulation results of angle, angle rate, wheel displacement, wheel rate and motor voltage are shown in Figure 3. Students arrive at the conclusion, based on the learned theoretical knowledge, that the robot has faster response speed, smaller overshoot and steady state error in the range of error band based on the PID controller.

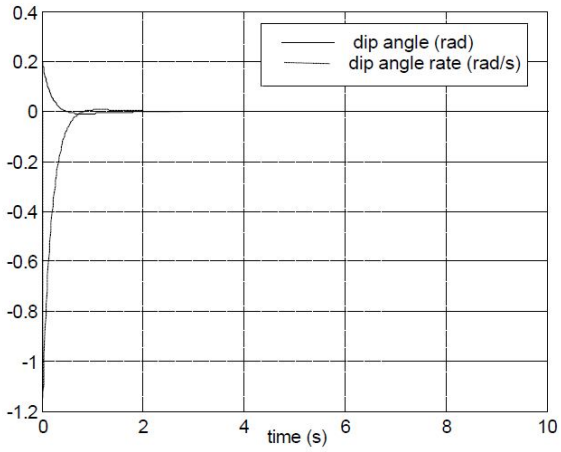

Figure 3: Freedom balance control of robot: a) angle and angle rate.

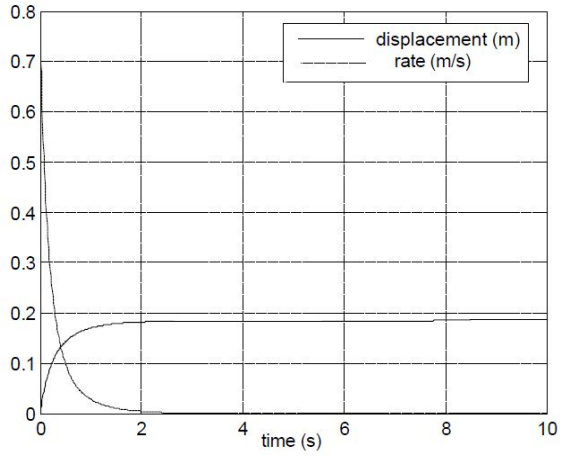

Figure 3: Freedom balance control of robot: b) wheel displacement and rate.

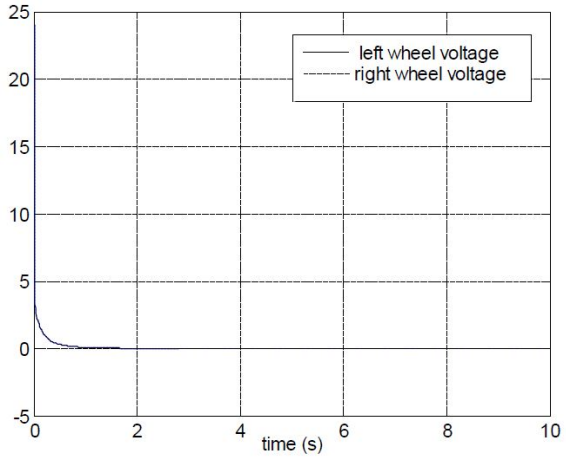

Figure 3: Freedom balance control of robot: c) motor voltage curve.

EFFECT AND EVALUATION OF THE RESEARCH TEACHING MODEL

Effect of Research Teaching

Teaching experience of about one year shows that the research teaching model not only can improve the enthusiasm and initiative of students, but also can promote the transition of students from *they want me to learn* to *I want to learn*, which is beneficial in developing comprehensive and creative abilities. Students universally reflect on the fact that their problem-solving abilities and their innovation is enhanced by research teaching. Seen in the context of higher education, high innovative ability needs to be cultivated to meet the challenges of technology, the economy, society and cultural developments.

Communication exchanges between students and teachers can be enhanced with the research teaching model, to the benefit of both learning and teaching. All of the above show that the research teaching model is worth promoting.

Evaluation of the Research Teaching Model

Compared with traditional teaching, research teaching combines theory and practice. Control problems and concepts are introduced to students through the actual problem itself. This reduces the abstraction of control theory, making it more intuitive and relatively easy to master by students.

The research teaching discussed in this article uses the two-wheeled robot as the teaching platform. Robot control research builds on teachers' scientific research and enables students to understand scientific research.

It is also a new challenge for teachers since it requires them to change from traditional teaching concepts and to update their professional knowledge and research. Research teaching cultivates innovative teaching in universities.

Research teaching is student-oriented flexible education and, therefore, is important in engineering and technology education. The research teaching model provides direction for the reform of engineering and technology education.

CONCLUSIONS

Explored in this article is implementation of the research teaching of control theory into high level undergraduate courses. A two-wheeled robot was used as the basis of control system modelling, simulation, performance analysis and the realisation of control algorithms. Reform of the teaching content was proposed. The research teaching mode combines MATLAB simulation software and control theory to allow students to intuitively understand control systems. The results have shown that research teaching not only inspires students but also improves teaching.

Research teaching can be applied to other university courses. It also enhances students' innovative thinking and it enhances teaching. Research teaching will enrich higher education, and also can promote sustainable development of engineering and technology education.

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