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Enhancing Student Engagement and Intellectual Development through Case-Based Instruction in Modern Control Theory

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Abstract: As technology advances at a breakneck pace, modern control theory has emerged as a vital component within the realm of engineering. This article endeavors to delve into the pedagogical transformation of modern control theory courses, leveraging case studies to align with the evolving educational landscape and nurture the learning interests and cognitive development of students in the contemporary era. By critically examining the challenges inherent in current teaching practices, the article introduces a suite of innovative instructional approaches and strategies designed to enhance students' grasp of theoretical concepts and hone their practical skills.

Keywords: Modern control theory; Course content; Teaching cases; Talent cultivation; Ideological cultivation.

1. Introduction

Modern control theory is an interdisciplinary science that delves into the intricacies of designing control strategies for complex systems, with applications spanning aerospace, industrial automation, and robotics. As technology evolves, traditional teaching methods have become inadequate for fulfilling students' quest for a profound grasp and practical application of modern control theory[1-4].This underscores the urgent need for a pedagogical overhaul in the teaching of modern control theory courses.

2. Course Content of "Modern Control Theory"

Recognized as a cornerstone in the automation domain, Modern Control Theory is pivotal for students. This course is designed to provide a comprehensive understanding of classical control theory's foundational concepts, enabling students to master and internalize fundamental theories, analytical techniques, and design methodologies. It also aims to enhance their capacity to apply these theoretical principles to the analysis and resolution of real-world engineering challenges[6-8].

Leveraging the unique attributes of this course and the diverse strengths of our teaching faculty, we aspire to delve into the philosophical underpinnings of cybernetics. We aim to infuse our curriculum with technological insights, a spirit of craftsmanship, an ethos of innovation, and a sense of teamwork. Our goal is to nurture not only students' emotional intelligence and professional qualities but also instill a profound sense of professional responsibility in engineering[9-10].

3. The Necessity of Cultivating Students' Scientific Thinking in Modern Control Theory

(1) Modern control theory and technology are at the forefront of numerous pivotal fields driving global development. Nurturing a cadre of professionals well-versed in modern control theory, with a global developmental perspective, is crucial for propelling the world's economic progress. The study of modern control theory is inherently challenging, demanding that students possess a robust foundation in mathematics and sharp logical reasoning skills. Embedding control theory principles can assist students in developing sound research methodologies, values, and worldviews, thereby enhancing their overall intellectual caliber.

(2) Guiding students to adopt a proper scientific demeanor is essential. Control theory, being a discipline with practical applications, must align with real-world demands. Integrating case studies that exemplify scientific thinking can steer students towards a correct scientific attitude, encourage them to refresh their knowledge base, sharpen their practical problem-solving skills, and foster the integration of scientific and technological advancements with societal growth. Given the course's strong theoretical and abstract nature, teaching methodologies are revolutionized around the three core tenets of engineering accreditation: adjusting the curriculum to foster innovative talents, which in turn stimulates students' interest in learning and their scientific research mindset.

(3) Fostering students' innovative thinking is paramount. The evolution of control theory intersects with various domains, including mathematics, physics, and computer science, necessitating that students develop innovative thinking capabilities. Infusing ideological and political education into the curriculum can unlock students'intellectual potential and nurture their innovative spirit and creative abilities. A diverse array of teaching strategies, such as the flipped classroom, project-based learning, computer-aided design, and simulation, are employed to emphasize practical instruction. By dissecting exemplary teaching cases and adopting a hybrid online-offline teaching approach, we provide valuable insights that empower students to excel in their academic and professional pursuits.

4. Typical Case Analysis

Case 1: In the Advanced Control course at China

University of Petroleum (Beijing), Professor Yuan Pu, with his extensive 79-80 years of research experience from the early days of China's reform and opening up,has crafted a state feedback predictive control system tailored to the specific demands of chemical control systems. This innovative system has garnered high acclaim from esteemed international figures, including Professor Kalman, the progenitor of modern control theory. Throughout this endeavor, Professor Yuan has played a pivotal role in nurturing a significant pool of advanced control specialists for the Chinese petroleum refining industry.

A midst the global imperative for carbon reduction, the sophistication of automation and intelligence is not only a critical indicator of technological advancement but also a cornerstone for transformation and upgrading, as well as a strategic asset in the pursuit of carbon peak and carbon neutrality goals. Leveraging the distinctive strengths of scientific and technological automation in domains such as big data, cloud services, artificial intelligence, and edge computing, the course enriches its curriculum with relevant teaching cases. This approach not only piques students' curiosity about self-control control theory but also instills in them the scientific mindset necessary to apply control theory to address challenges in chemical control, energy conservation, and emission reduction.

Case 2: Delving into the chapter on frequency response, we bridge the gap between the abstract realm of control theory's frequency characteristic analysis and the practical marvels of skyscraper engineering, specifically the working principles of dampers—those unsung heroes in the battle against wind and seismic forces. By intertwining complex mathematical models and intricate calculations with current events that capture public interest, we transform knowledge into a more relatable, comprehensible, and accessible format. This approach not only fosters students' scientific thinking and engineering problem-solving skills within the control field but also seamlessly integrates research-oriented thinking into professional education. It enhances the appeal and impact of scientific research thinking, nurturing students' innovative spirit, scientific rigor, craftsmanship, and a sense of mission and responsibility.

On May 18, 2021, the SEG Building in Shenzhen was at the center of a viral online debate following its unusual shaking incident. By dissecting this event, we engage in discussions about the windproof and seismic design considerations of high-rise structures. We apply control theory to real-world engineering challenges, thereby bolstering students' practical engineering skills and heightening their awareness of safety issues. This real-world application of theory to practice is a testament to the relevance and power of control theory in addressing contemporary engineering dilemmas.

Figure 1 Shenzhen SEG Building sways

Case 3: In the lecture on the development overview of automatic control theory, we aim to spark students' curiosity and enthusiasm for the subject through compelling real-world examples. Specific Example 1:The triumphant launch of Starship 5 manned spacecraft and the flawless return capsule landing underscore the pervasive role of automatic control technology in global aerospace advancements. These achievements instill in students a profound conviction and a driving ambition to harness the power of control theory for the betterment of humanity. Specific Example 2: By showcasing the critical role of automatic control technology in the signal tracking and communication systems of the Yutu lunar rover, we shed light on its extensive applications in aerospace technology. This helps students grasp the importance and relevance of "Automatic Control Principles" as a cornerstone course within the control discipline. It inspires them to embrace the pioneering spirit of aerospace exploration and fosters a keen interest in the study of control theory, encouraging them to pursue knowledge that can propel technological boundaries and contribute to the grand narrative of space exploration.

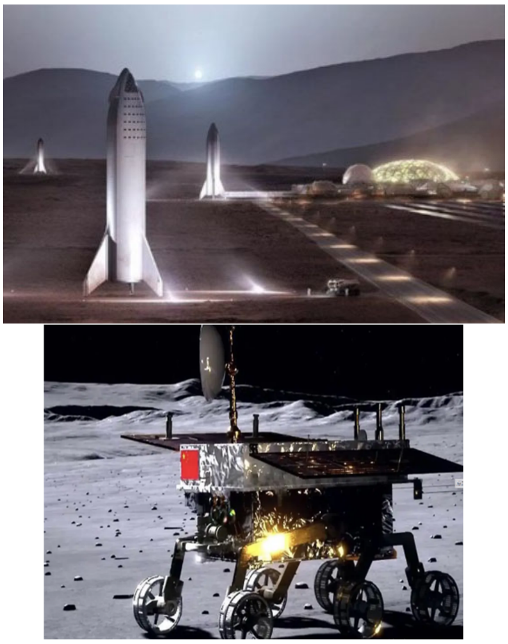

Figure 2 Starship and Yutu lunar rover

Case 4: Modeling Control Systems with Disturbance and Uncertainty. In the context of linear systems, the presence of disturbances, parameter uncertainties, and faults poses significant challenges. This case examines how to develop a comprehensive mathematical model that captures these complexities. Specifically, it focuses on the creation of a linear steady-state system state space model in accordance with the course objectives. The goal is to establish the following state space equations, which are pivotal for enhancing students' comprehension of nonlinear control systems, industrial control systems, and connected vehicle control systems. The development of automotive automatic control systems is crucial, particularly in China, where its importance is manifested in several key areas:

Enhancing Traffic Safety: Autonomous driving technology is anticipated to drastically reduce traffic accidents, thereby improving road safety. Through real-time perception and swift response mechanisms, many accidents attributable to human error can be prevented, leading to a decrease in traffic-related injuries and fatalities.

Boosting Traffic Efficiency: Autonomous vehicles have the potential to enhance traffic flow efficiency by optimizing driving paths and achieving effective intersection management.

Advancing Industrial Growth: The intelligent automobile market is witnessing rapid expansion with an increasing penetration rate, signaling a promising future for the Chinese market. The smart car industry chain is maturing, encompassing a broad range of enterprises from the internet and automotive sectors. The convergence of smartphones and smart cars is becoming increasingly common.

Fostering Technological Innovation: Intelligent driving vehicles represent a significant frontier in automotive technology and industrialization, marking the mainstream trend in future automotive technological innovation. These vehicles rely on environmental perception technology to understand their surroundings and use this information to autonomously control steering and speed via onboard central computers.

Energy Conservation and Emission Reduction: Intelligent driving systems optimize vehicle acceleration, braking, and deceleration patterns, leading to more efficient use of fuel and electricity. Vehicles with intelligent driving capabilities can achieve a 10% increase in fuel economy, with higher levels of automation correlating with greater energy efficiency.

Generating Employment Opportunities: Intelligent connected vehicles not only improve traffic efficiency and reduce accidents but also stimulate the growth of related industries, creating numerous job opportunities.

Supporting Smart City Development: The integration of intelligent connected vehicles with smart transportation systems enables intelligent traffic management, enhancing traffic operation efficiency, and reducing congestion and accident rates.

Strengthening International Competitiveness: The international competitiveness of China's autonomous driving industry is on the rise, with efforts needed in technological innovation, infrastructure development, data collection, and the establishment of laws and regulations to further bolster this growth.

Meeting Consumer Demand: As the economy grows and consumption patterns evolve, the demand for automobiles from households continues to rise. Consumer focus is shifting towards intelligent features, with a staggering 197% growth rate in interest.

By elucidating the significance of mastering control principles for global development, we aim to ignite students' passion for exploring scientific challenges and foster a keen interest in learning.

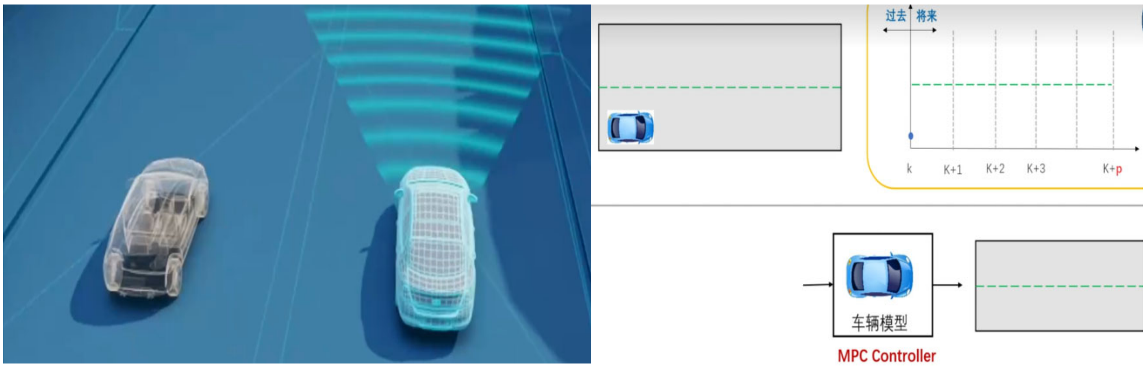

Figure 3. Model Predictive Control and Autonomous Driving

5. Conclusion

This article introduces a case-based teaching methodology and proposes adjustments to the curriculum system, stemming from research and practical experience in the reform of modern control theory education. The objective is to enhance students' grasp of theoretical knowledge and their capacity for practical application. Through a comprehensive overhaul of teaching content and case design, we have integrated the latest advancements in control theory and real-world application examples. This revamp ensures that the curriculum is more aligned with the demands of contemporary industry and scientific research. The updated content not only piques students' curiosity and engagement with the subject matter but also sharpens their skills in tackling real-world challenges. Our approach is designed to stimulate students' passion for mastering modern control theory and to nurture their scientific inquiry and research-oriented thinking.

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