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Exploration and Reform of Signals and Systems Course Construction for Cultivating Engineering Application Capabilities

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Abstract

The signals and systems course is a core component of the electronic information science and technology major, characterized by its strong theoretical foundation and abstract concepts. Under traditional teaching models, students often struggle to establish concrete connections between mathematical derivations and engineering applications. To address this issue, this paper proposes utilizing a self-tracking antenna system, a typical engineering system, as a consistent engineering teaching example throughout the course. It integrates the core theoretical knowledge of "signals and systems" into the analysis, modeling, and simulation practices of this example. By reconstructing a theory-case-practice integrated curriculum, designing blended learning-based teaching activities, and deeply excavating and integrating ideological and political elements, a new teaching model centered on cultivating engineering application capabilities and shaping values has been constructed. Teaching practice indicates that this reform significantly enhances students' learning interests, engineering practical abilities, and comprehensive qualities in solving complex engineering problems, providing a valuable reference for cultivating high-quality talents adapted to modern communication technology development.

Keywords

Curriculum ideology and politics; Engineering case studies; Self-tracking antenna; Signals and systems

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1. Introduction

Signals and systems is an indispensable core professional foundational course for the electronic information science and technology major, serving as a bridge between preceding and subsequent courses. Its primary objective is to cultivate students' abilities to analyze and process signals using mathematical tools, as well as understand and design systems. It also lays a crucial foundation for subsequent courses such as digital signal processing, communication principles, automatic control principles, and radar principles. The course's characteristics, including numerous mathematical formulas and abstract physical concepts, often render students' learning experiences dull and challenging, making it difficult for them to grasp the ultimate purposes and practical values of various transformations and analyses.

Traditional teaching models commonly exhibit a triple emphasis on mathematical derivations while neglecting physical concepts, isolated knowledge points over systematic associations, and theoretical problem-solving over engineering applications. This leaves students in a state of confusion, unable to establish effective knowledge transfer channels or connect classroom learning with future engineering applications and professional development, thereby largely severing the close link between theory and engineering applications and hindering the cultivation of students' engineering application capabilities. It also fails to effectively meet the requirements for cultivating complex engineering problem-solving abilities outlined in engineering education professional accreditation standards [1].

With the in-depth advancement of the new engineering initiative, the demand for cultivating high-quality talents capable of solving complex engineering problems in higher education institutions continues to rise [2,3]. To address the aforementioned teaching challenges, it is essential to introduce comprehensive engineering case studies that can permeate the core knowledge of the course, enabling students to perceive the practical value of theory in solving engineering problems while learning.

This paper employs a self-tracking antenna system as a consistent engineering case study throughout the signals and systems course. Widely applied in satellite communication, radar, and radio astronomy, this system operates by ensuring the antenna's main beam precisely aligns with a moving target in real-time to guarantee high-quality signal reception or transmission [4–6]. It encompasses the complete processes of signal generation, transformation, processing, transmission, and system feedback control, covering signal modulation and demodulation, filtering, system modeling, feedback, and stability analysis [7,8]. The entire tracking loop fully embodies the knowledge of the "signals and systems" course, serving as a concrete manifestation of its content.

2. Curriculum design

2.1. Overall teaching design

Centered around the self-tracking antenna system engineering case study, this paper constructs a theory-case-practice integrated teaching system, streamlining and optimizing the content of the signals and systems course. It breaks away from the traditional mode of isolated chapter-based knowledge explanation, forming three intertwined and parallel teaching mainlines: the theoretical line, the case line, and the practical line, achieving a deep fusion of knowledge transmission and engineering capability cultivation.

The theoretical line aims to concisely explain core concepts, systematically covering the key knowledge of signals and systems to ensure a complete knowledge system and lay a solid foundation for subsequent learning. Following modern educational structural principles, the teaching content is divided into two major sections: signal analysis and system analysis.

The signal analysis section focuses on the time-domain and frequency-domain characteristics of continuous and discrete-time signals, such as convolution operations and Fourier transforms, assisting students in clarifying signal representations and conversions in different domains through formula derivations and graphical demonstrations. The system analysis section delves into the time-domain and frequency-domain responses and stability of linear time-invariant systems, combining practical models like low-pass and high-pass filters to elucidate system input-output characteristics, enabling students to grasp analytical methods and techniques. Simultaneously, attention is paid to the internal connections and logical progressions among knowledge points, guiding students to construct knowledge frameworks and cultivate holistic comprehension abilities.

The case line utilizes the self-tracking antenna system as a carrier, dissecting it into antenna reception, signal processing, and control execution subsystems, and precisely aligning them with theoretical knowledge to correspond abstract theories with specific engineering scenarios, aiding students in understanding the practical application value of theories. When explaining signal analysis, the spatial electromagnetic wave signals received by the antenna subsystem are used as examples to analyze their time-domain waveforms and frequency-domain characteristics, allowing students to perceive the complexity and diversity of actual signals. In the system analysis section, the filter design of the signal processing subsystem is employed to explain how to select types, determine parameters, and analyze processing effects based on performance requirements. By aligning each subsystem of the self-tracking antenna system with the theoretical knowledge points of the course, a correspondence relationship between theory and practice after case integration is formed, as shown in **Table 1**, enabling students to deeply recognize the importance of theoretical knowledge in solving practical engineering problems and enhancing their abilities to analyze and solve practical problems using theoretical knowledge.

The practical line employs MATLAB simulation verification as a platform, utilizing MATLAB/Simulink to construct a simplified simulation model of an antenna angle automatic tracking system. By altering parameters such as signal frequency, filter bandwidth, and system gain, students can observe changes in time-domain tracking curves and frequency-domain spectra, intuitively understanding the guiding role of theory in system performance. Through experiments like setting excessively high gains to induce system oscillations, students deepen their understanding of stability concepts.

Through the intertwined and parallel teaching design of the theoretical line, case line, and practical line, the knowledge of the signals and systems course is no longer confined to mathematical formulas and concepts but transformed into tools capable of solving practical engineering problems, effectively achieving the teaching objective of cultivating students' engineering application capabilities.

2.2. Curriculum-based ideological and political education design

Curriculum-based ideological and political education is an important part of students' course learning. In the teaching of signals and systems, it is essential to deeply explore the ideological and political elements embedded within the course content, integrating the cultivation of abilities to solve complex engineering problems into the entire process of knowledge transmission and skill development,

Table 1. Correspondence between theory and practice after case integration

Course chapter	Theoretical knowledge points	Corresponding points in self-tracking antenna case	Teaching form suggestions
Overview of signals and systems	Continuous-time signal/discrete-time signal, energy signal/power signal	RF signal received by the antenna (continuous), and digital signal after sampling (discrete)	Class summary
Time-domain system analysis	Convolution, system properties (linearity, time-invariance)	Step response of a servo system	Classroom explanation + post-class reflection questions
Fourier series and transform	Frequency spectrum principles, modulation/ demodulation	Spectrum of sum/difference signals, spectral shifting in coherent demodulation	Lecture breakdown with MATLAB-based visualization of spectrum dynamics
Laplace transform	Transfer function of a system, zero-pole representation, stability criteria	Establish an S-domain model for servo systems, analyze transfer functions of the motor and controller, and discuss the impact of pole locations on stability	Symposium & group project
Z-transform	Discrete-time system	In modern digital tracking receivers, after ADC sampling, error signal processing and control algorithms are implemented in the digital domain (DSP/FPGA)	Extended introduction
System frequency domain analysis)	Frequency response, filter	Design of intermediate frequency (IF) filter in receivers, drawing and analysis of open-loop bode plot for servo Systems, with stability and dynamic performance evaluation	Detailed analysis of key cases, simulation experiments

so as to achieve an organic fusion of ideological-political education and professional teaching [9,10].

By combining relevant theoretical knowledge of self-tracking antenna systems, we can mine the underlying principles of Marxist philosophy and guide students to establish a scientific worldview and methodology. When explaining time-domain and frequency-domain analyses of signals, we should clarify that time-domain waveforms represent the phenomena of signal variations, while frequency-domain features reflect the essential attributes of signals, helping students understand the dialectical relationship between phenomena and essence. When analyzing the bandwidth design of loop filters, by comparing the engineering contradictions between noise suppression and dynamic response speed, we can guide students to apply the thinking of focusing on major contradictions to solve practical problems.

Based on the engineering application scenarios of self-tracking antenna systems and in combination with China's achievements in aerospace technology development, we can stimulate students' patriotic enthusiasm and sense of mission. When introducing China's Beidou Navigation Satellite System in the course, we can tell the stories of how researchers overcame technological blockades through perseverance and independent innovation, enabling students to directly perceive the development strength of China's aerospace technology. Considering the current international technological competition situation, we should emphasize the importance of independent innovation in core technologies in the field of signals and systems, guide students to recognize the close connection between professional learning and national technological development, help them establish a lofty ideal of building a strong technological nation, and enhance their sense of responsibility to contribute to the development of China's information technology industry.

The rigor of self-tracking antenna system design could be leveraged to cultivate students' awareness of engineering ethics and the spirit of craftsmanship. When explaining system parameter design, we should emphasize the key impact of indicators such as antenna tracking accuracy and stability on the overall performance of the system, and explain that any parameter calculation errors may lead to tracking failures, which in turn may cause serious consequences such as communication interruptions and mission failures, guiding students to develop a rigorous, meticulous, and excellence-oriented work attitude. By analyzing system failures caused by design oversights in actual engineering cases, we can help students understand the social responsibilities that engineers should bear in technological research and development, strengthen engineering ethics concepts such as reliability and safety, and cultivate students' high sense of professional responsibility and dedication.

The integration of curriculum-based ideological and political education elements involves designing corresponding ideological-political integration points by combining different links of self-tracking antenna system teaching cases, so that value shaping runs through the entire process of theoretical explanation, case analysis, and practical operation. This ensures a deep fusion of ideological-political education with professional knowledge transmission and engineering skill cultivation, forming a synergistic educational effect.

3. Implementation of course teaching

The signals and systems course adopts a blended online-offline teaching mode, incorporating intelligent teaching tools and leveraging advanced technologies such as big data and artificial intelligence [11,12]. Through an online learning platform, personalized learning support and guidance are provided to students, which helps stimulate their learning interest and enthusiasm, and enhances their autonomous learning capabilities. Combined with the online learning platform, the flipped classroom approach is implemented. Before class, students preview the course content via the online platform; during class, teachers guide students in in-depth discussions and practical activities; after class, students review and consolidate their knowledge through the online platform. Teaching activities are designed to form a coherent and interlocking three-stage process encompassing pre-class, in-class, and post-class activities. Additionally, a diversified evaluation system that combines process-based and outcome-based assessments is established, achieving a closed-loop optimization of teaching, learning, and evaluation.

3.1. Theoretical teaching activities

Guided by the main thread of pre-class autonomous preview-in-class in-depth discussion-post-class review and consolidation, a coherent and progressive teaching process is constructed by leveraging the synergistic advantages of the online-offline blended teaching mode.

The pre-class phase centers on online autonomous learning, focusing on the impartation and initial understanding of fundamental knowledge. Teachers upload instructional videos explaining theoretical knowledge to the online learning platform, clearly specifying learning objectives, key points, and difficulties. Simultaneously, they provide background materials related to self-tracking antenna system cases for the upcoming class, guiding students to gain a preliminary understanding of engineering scenarios. Online quiz questions are set to assess students' self-learning outcomes. Through data feedback from the platform, teachers can accurately identify students' knowledge weaknesses and adjust the focus of in-class teaching accordingly, ensuring that offline instruction is more targeted.

The in-class phase takes place in the offline classroom, emphasizing ability cultivation and value shaping. Teachers deliver in-depth explanations of difficult content identified from pre-class feedback. Combining self-tracking antenna system cases, they design group discussion topics, guiding students to engage in solution design and debate using knowledge such as frequency-domain analysis and S-domain modeling. This collaborative inquiry process enhances students' ability to solve engineering problems. Meanwhile, elements of curriculum-based ideological and political education are integrated. Through case studies, such as China's breakthroughs in satellite tracking technology, value guidance is provided, achieving the simultaneous advancement of knowledge acquisition and ideological-political education.

The post-class phase relies on online expansion to facilitate knowledge internalization and transfer application. Students are required to complete MATLAB/Simulink simulation assignments related to self-tracking antenna systems, write experimental reports, and outline the application logic of theoretical knowledge in engineering practice. They participate in themed discussions on the platform, sharing problems encountered during simulations and their solutions, deepening their understanding of the knowledge system. Teachers promptly grade assignments and respond to discussions through the online platform, guiding students to translate classroom learning into practical abilities to solve engineering problems.

3.2. Construction of experimental platform

To enhance the practical teaching quality of the signals and systems course, this paper focuses on constructing a practical teaching platform centered around the core content of self-tracking antenna systems from the perspective of teaching modes. An open experimental teaching mode was adopted. Teachers prepare experimental guidelines in advance, clearly defining experimental objectives such as "optimizing the anti-interference performance of self-tracking systems," and providing optional experimental projects, including hardware debugging and software simulation using MATLAB/Simulink, along with outcome requirements. Students autonomously select experimental content, design experimental plans with reference to teacher-provided materials, including parameter settings, step planning, and data collection methods. During experiments, teachers offer guidance both online and offline, promptly addressing technical challenges. Upon completion, students submit reports and outcomes. Teachers evaluate them from dimensions such as plan innovation and operational standardization, provide improvement suggestions, and organize group discussions on experimental results to cultivate students' autonomous learning and innovative spirit.

3.3. Teaching evaluation

Teaching evaluation adopts a combination of formative and summative assessment. In formative assessment, process-based evaluation is incorporated into the grading system, focusing on students' routine performance and learning process. Through methods such as online learning data analysis, simulation assignments, group discussion participation, and experimental reports, students' learning progress is comprehensively evaluated. This approach helps to provide a holistic and objective reflection of students' learning situations, stimulates their learning interest and enthusiasm, and offers references for their future academic and career development.

Summative assessment is conducted through final exams, with exam questions including application-based problems related to engineering cases. This evaluation method comprehensively assesses students' attainment of knowledge, skills, and overall competencies. Special emphasis is placed on the feedback role of evaluation. Through timely analysis of learning data, personalized tutoring and support are provided to address students' difficulties. Additionally, feedback on teaching reforms is collected through student evaluations of teaching and questionnaires, enabling continuous improvement of teaching methods.

4. Evaluation of course teaching effectiveness

Since the initiation of curriculum development oriented toward engineering education professional certification, the signals and systems course has achieved remarkable results through teaching reforms that incorporate engineering case studies. According to a questionnaire survey, over 75% of students believe that the teaching model using engineering case studies enhances their learning interest and practical abilities. Performance analysis indicates that the average grade of students in the reform-oriented class has increased by 16%, with a noticeable rise in the rate of excellent course design projects. Post-course follow-up interviews reveal that students have generally developed a deeper understanding of the connection between signals and systems theory and aerospace engineering practices, leading to increased appreciation for the course.

The integration of curriculum-based ideological and political education has effectively inspired a sense of mission and learning initiative among students. Meanwhile, the diversified assessment system has reduced end-of-term pressure, encouraging students to focus more on daily learning and ability development. Teachers have reported improved classroom participation and teaching engagement, though they have also noted that innovative teaching approaches demand greater time investment and professional expertise from instructors. Based on student evaluations of teaching and questionnaire feedback, students generally express high satisfaction with the curriculum-based ideological and political education, teacher capabilities, and teaching methods, fully demonstrating the positive role of teaching reforms in enhancing learning engagement, interest, and overall effectiveness.

5. Conclusion

This paper has utilized the self-tracking antenna system as a through-line engineering case study for the course, signals and systems. Teaching practice has demonstrated that this reform has yielded significant educational outcomes. From a systematic perspective, this engineering case study links all core knowledge points of the signals and systems course, helping students construct a comprehensive knowledge network of signals and systems rather than isolated mathematical formula-based knowledge points. From the perspectives of cutting-edge relevance and practicality, this engineering case study, derived from current engineering applications in the aerospace field, has greatly enhanced students' learning interest and national mission awareness. From the standpoint of deepening theoretical understanding, applying abstract knowledge such as Fourier transforms, Laplace transforms, Z-transforms, and system functions to solve specific engineering problems in the self-tracking antenna system enables students to truly grasp their physical meanings and engineering values. From the perspective of cultivating thinking abilities, this engineering case study encompasses a wide-bandwidth system ranging from radio frequency signal processing to low-speed servo control, requiring students to approach engineering problems from multiple perspectives, including signal flow, energy flow, and information flow, thereby fostering their analytical and design capabilities for engineering problems.

In summary, the exploration and reform of curriculum development using engineering case studies, represented by the self-tracking antenna system, have provided an effective pathway for transforming the signals and systems course from a theory-oriented to an engineering capability-oriented approach. This is of significant importance for cultivating innovative engineering and technical talents who meet the requirements of engineering education professional certification for solving complex engineering problems.

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