2024 Volume 2, Issue 2
Signal and Information Processing
ISSN: 2630-4805

Design and Practice of Advanced and Innovative Experimental Schemes for the "Digital Signal Processing" Course

Xu Chen[1,2,3], **Zhifeng Yao**[1,2,3]*, **Huaibo Song**[1,2,3]
[1]Northwest A&F University, Xianyang 712100, Shaanxi Province, China
[2]Key Laboratory of Agricultural IoT, Ministry of Agriculture and Rural Affairs, Xianyang 712100, Shaanxi Province, China
[3]Shaanxi Provincial Key Laboratory of Agricultural Information Perception and Intelligent Service, Xianyang 712100, Shaanxi Province, China

***Corresponding author:** Zhifeng Yao, yzfeng@163.com

Abstract:

"Digital Signal Processing" is a practical basic course in electronic information majors, and its experimental practice is a powerful complement to classroom teaching. There is an urgent need to add challenging advanced experiments based on existing experiments to enhance students' innovation abilities. This paper integrates the course content, designs advanced and comprehensive experiments, and combines independent development with group cooperation in an orderly manner according to the teaching arrangement. The results show that this scheme can solve the problem of the loose connection between theory and application in teaching, effectively improve students' practical skills, and meet the requirements of the new engineering education philosophy and engineering professional certification specifications.

Keywords:

Digital Signal Processing
Experimental scheme design
Innovation and entrepreneurship ability
Speech signal analysis

Online publication: December 16, 2024

1. Introduction

Since the release of the "Implementation Opinions on Deepening the Reform of Innovation and Entrepreneurship Education in Higher Education Institutions," universities across the country have made it an important research topic to enhance and promote the innovative qualities and entrepreneurial abilities of college students. With the continuous strengthening of innovation and entrepreneurship education in higher education, significant progress has been made in improving education quality and promoting students' comprehensive development, greatly pushing forward graduates' entrepreneurship, employment, and service to the country's modernization. However, there are still practical issues in current higher education, such as the loose integration of innovative and entrepreneurial educational concepts with professional courses and knowledge, the disconnection from practical content, the singularity of teaching methods, and the weak pertinence and effectiveness [1-3]. Therefore, as teachers in higher education in the new era, it is necessary to closely integrate the training orientation and educational goals of innovative talents, carry out teaching reforms on key professional basic courses and their practical links, strengthen innovation ability education in the process of imparting professional knowledge, introduce advanced, innovative, and comprehensive experiments into course experiments, and cultivate students' innovative practice abilities.

"Digital Signal Processing," as one of the core courses in the field of information processing, is a compulsory course for electronic information engineering majors and is widely used in modern communications, digital control, and speech and image processing [4-7]. The course content involves many mathematical derivations and calculations, which are highly theoretical and difficult to understand and master. The traditional teaching model still focuses on indoctrination, where students simply receive book knowledge and cannot connect theory with application, greatly limiting the improvement of students' innovation abilities [8,9]. Agricultural and forestry universities are born and thrive because of agriculture, but at present, their subject layout is not limited to agriculture and has gradually moved towards a comprehensive path of multidisciplinary intersection. Based on this, the teaching of "Digital Signal Processing" should be closely integrated with the characteristics of agricultural and forestry universities, focusing on the goal of cultivating innovative talents. The learning of course knowledge points should be organically integrated into advanced and innovative comprehensive experiments, emphasizing the combination of theory and experiment, guiding experiments with theory, strengthening theory through experiments, promoting students' deep understanding and mastery of knowledge, improving students' hands-on ability and teamwork spirit, and realizing the cultivation of innovative practice abilities throughout the entire process of education and teaching.

2. Experimental scheme system design

The design of advanced and innovative comprehensive experiments should be based on improving students' ability to think and solve problems [10,11], focusing on the key and difficult points of the course content. The main goals and ideas are as follows:

Firstly, we need to deeply integrate teaching content, break content barriers, pay attention to distinguishing it from related course content, uniformly coordinate and organize, design project cases with moderate difficulty and strong comprehensiveness, and deepen students' understanding of course knowledge points.

Secondly, it is necessary to integrate the course learning process with solving practical problems, design targeted project cases for students to complete in groups, stimulate students' interest in learning in the process, and encourage students from different groups to actively participate in exchanges and discussions, cultivating their collaboration spirit and communication skills while improving their practical skills.

Thirdly, guided by independent learning, we allow students to explore and cooperate to think about problem-solving methods in the experimental process, fundamentally improving their ability to analyze and solve problems.

2.1. Design ideas

Based on the above concepts to organize teaching, on the basis of verification experiments, combining the key and difficult knowledge in "Digital Signal Processing," we increase the proportion of comprehensive and advanced experimental projects, develop comprehensive project cases, and use this as an entry point to explore speech signal processing, image signal analysis, and other content related to this course. These techniques are combined with teaching content to form comprehensive training projects.

To better mobilize students' enthusiasm and initiative in learning and enhance the real effect of teaching, this article adopts a combination of software and hardware in the practical teaching links, organically integrating classroom and after-class experiments. Comprehensive experiments with diverse forms are designed and developed, including general experiments, systematic verification experiments, and comprehensive application experiments, in areas such as audio analysis, processing, and recognition. The content tends to be project-oriented and engineering-oriented, dedicated to cultivating college students' practical innovation abilities and meeting national talent training goals.

2.2. Content design

(1) Optimizing the content system and highlighting knowledge understanding and application abilities: Focusing on basic theories and engineering applications for the electronic information engineering major training program at Northwest A&F University, relying on the "basic concepts, basic theories, and basic methods" in the teaching content, using verification experiments as a bridge, and led by comprehensive and advanced experimental projects, we reorganize and optimize the original teaching content. The knowledge framework of the "Digital Signal Processing" course is organized as shown in **Figure 1**. By combining horizontal and vertical associations, we establish mind maps and knowledge graphs, delete repetitive and outdated content, add comprehensive experimental cases with strong applicability, and form a curriculum system that serves the cultivation of electronic information students in agriculture and forestry in the new era.

(2) Improving teaching methods and enhancing the cultivation of innovative thinking skills: We incorporate the results of graduation projects and innovative entrepreneurial projects related to "Digital Signal Processing" into the classroom, drawing on teachers' own scientific research experience and existing practical cases to feed back into teaching. For specific knowledge points in the course, we fully explore their historical backgrounds and practical applications and timely internalize the latest industry development status and scientific research achievements into teaching content, such as research on audio enhancement methods based on generative adversarial networks, voiceprint recognition methods, and fault diagnosis methods. The design scheme for the experimental content is shown in **Figure 2**. It adopts heuristic and seminar-style teaching methods, combining theory and experiments

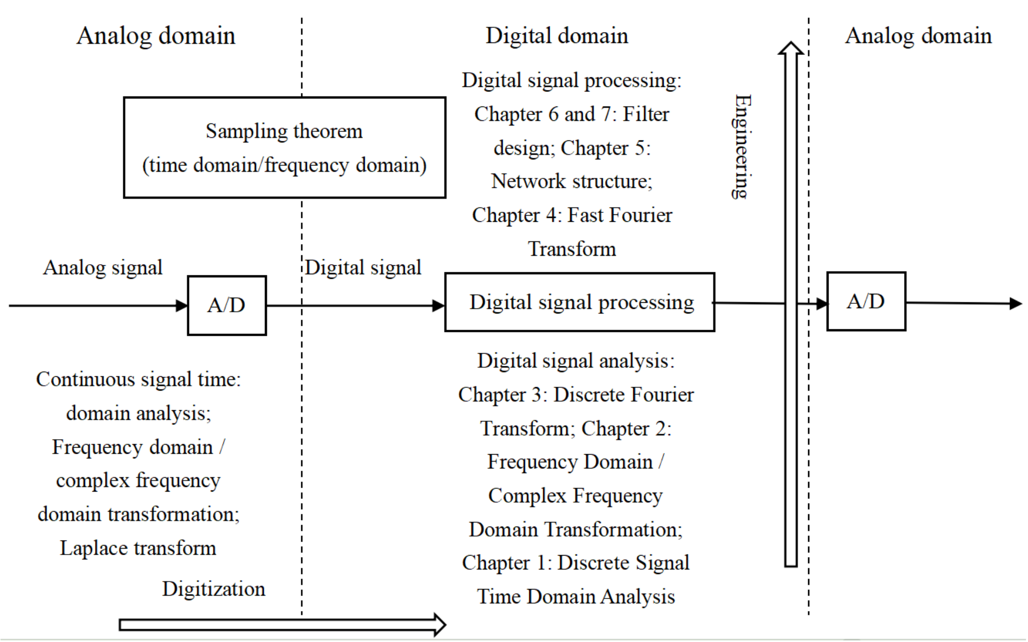

Figure 1. Knowledge framework of digital signal processing

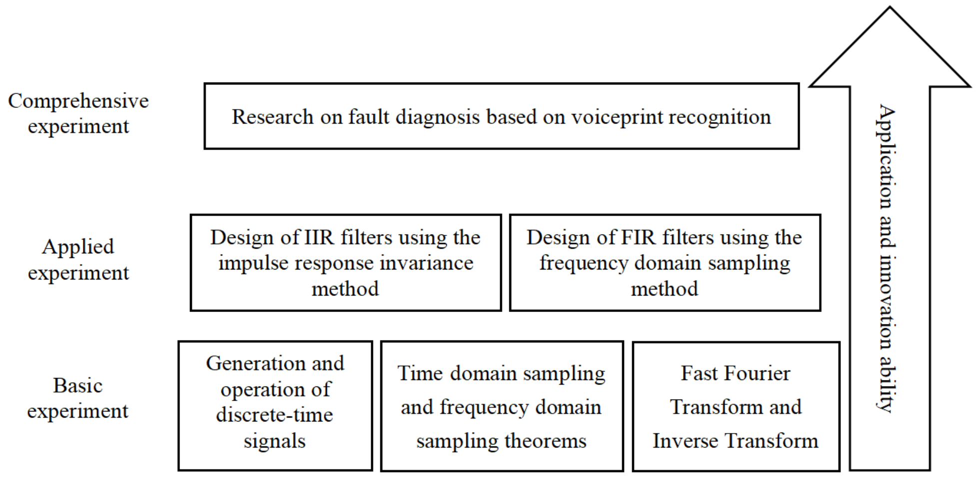

Figure 2. Experimental content design scheme

closely to stimulate students' innovative thinking and enhance their ability to solve complex problems.

(3) Linking theory with practice and strengthening practical skills based on a project-driven approach: Case-based and project-based teaching guided by teachers can deepen students' understanding and mastery of knowledge points, stimulate students' enthusiasm for learning, and make abstract theoretical learning more vivid. Therefore, we design and develop comprehensive practical projects that are problem-oriented, use group discussion as a mode, focus on student development as the leading and central aspect, and aim to enhance students' collaborative spirit. We guide students to exercise their critical thinking skills in problem-solving through "self-study + discussion." During the practical process, the instructor only provides guidance from the sidelines, allowing students to independently think through the basic ideas and then collaborate to complete group tasks, thereby truly mastering the theoretical knowledge in the textbook.

3. Teaching organization of the experimental section

Based on the aforementioned experimental plan, the progressive and innovative experimental design comprises three parts: basic verification experiments, applied advanced experiments, and comprehensive innovative experiments, aiming to comprehensively enhance students' application and innovation abilities.

3.1. Basic verification experiments

The primary characteristic of these experiments is their relatively straightforward content, focusing on the consolidation and observational verification of theories to deepen students' understanding and mastery of key and difficult concepts. Hence, the first fundamental knowledge point from the textbook is selected: the generation and operation of discrete-time signals, as well as crucial theorems connecting the analog and digital domains—time-domain sampling and recovery, and the Fast Fourier Transform, which facilitates the application of digital signal processing methods. Although some of the experiments are relatively simple, they hold particular significance within the overall course knowledge system, thus requiring students to complete them independently. Simultaneously, to prevent plagiarism, customizable elements are incorporated into the design and implementation of the experiments. The design of the verification experiments is outlined in **Table 1**.

Table 1. Content of basic verification experiments

Experiment name	Specific content
Generation and Operations of Discrete-Time Signals	Introduction to the concept of discrete-time signals; Representation of typical discrete signals such as unit sample signals, unit step signals, sine and cosine signals, etc., enabling students to observe the waveforms generated by different discrete signals and grasp their characteristics; Completion of operations such as addition, multiplication, shifting, and flipping among discrete-time signals, recording and analyzing the changes in waveforms after operations. Based on this, signal autocorrelation and cross-correlation will be included as a supplementary learning section to enhance students' self-study capabilities.
Time Domain Sampling Theorem and Recovery	Observe and record the simulation waveforms of data sources, sampling pulses, sampled, and recovered discrete-time signals; analyze the impact of different sampling frequencies on time domain sampling, and intuitively understand the meaning of Nyquist's sampling definition; use sinc function programming to achieve interpolation and reconstruction of sampled signals, deeply understand the reasons for signal distortion and the principles of anti-aliasing filters.
Fast Fourier Transform and Its Inverse Transform	Utilize modular design methods to reproduce principles such as radix-2 decimation, multiplication by twiddle factors, complex number summation, and multiplication by coefficients followed by summation; observe waveform changes after each step to enable students to understand the implementation ideas of the Fast Fourier Transform; on this basis, achieve the Inverse Fast Fourier Transform through two conjugate calculations and multiplication by 1/N; implement the computation process of the Fast Fourier Transform through programming, allowing students to grasp the specific implementation steps of butterfly operations.

3.2. Design-based advanced experiment

The design-based experiment mainly focuses on the practical aspect of filter design. On one hand, by building a simulation system to design digital filters for both infinite and finite impulse inputs, the functionality of the filters can be observed and analyzed through input signals and the simulation system. On the other hand, by programming different filter designs, students can transition from perceptual understanding to theoretical application. The specific design content mainly includes the design of IIR digital filters using the impulse response invariance method and the design of FIR digital filters using the frequency sampling method.

Taking the experiment of designing an FIR digital filter using the frequency sampling method as an example, let's briefly introduce the design and implementation of the overall experimental scheme. Recall the core theorem of this course—the frequency sampling method. That is, if the sequence x(n) has a length of M, then only when the number of frequency domain sampling points N ≥ M, can we have

$$X_N(n) = IDFT[X(k)] = x(n) \tag{1}$$

When the frequency domain sampling theorem is satisfied (N ≥ M), the inverse discrete Fourier transform (IDFT) of the N-point frequency domain sampling sequence X(k) is the original sequence x(n). Therefore, it is possible to recover X(z) and $X(e^{j\omega})$ from X(k).

$$X(Z) = \frac{1}{N}\sum_{k=0}^{N-1} X(k)\frac{1-Z^N}{1-W_N^{-k}Z^1} \tag{2}$$

Among them, X(k) = H(z)$|z = e^{j\frac{2\pi}{N}k}, k=0,1,2\cdots,N-1$, We can rewrite formula (2) as

$$X(Z) = (1 - Z^N)\frac{1}{N}\sum_{k=0}^{N-1}\frac{X(k)}{1-W_N^{-k}Z^1} = X_e(z)\frac{1}{N}\sum_{k=0}^{N-1} X_k(z) \tag{3}$$

Among them $H_e(z) = 1 - Z^N$, $H_k(z) = \frac{X(k)}{1-W_N^{-k}N^1}$

From this, we can extend to its first application, namely, the frequency sampling structure of the FIR system H(z). The frequency sampling structure consists of a cascade of a comb filter and N parallel first-order IIR networks [12]. Based on the above results, the stability and correction methods are analyzed to enable students to grasp extended thinking from basic theorems to applications.

The main content of this experiment is derived from the basic concepts of frequency sampling and recovery. It involves selecting sampling points on the desired ideal filter frequency response curve and then completing the design of the FIR digital filter through interpolation formulas. Based on the stability of the network structure and correction methods, students are asked to complete the basic design and draw the schematic diagram of the correction method principles independently, as shown in **Figure 3**. This enhances students' understanding and

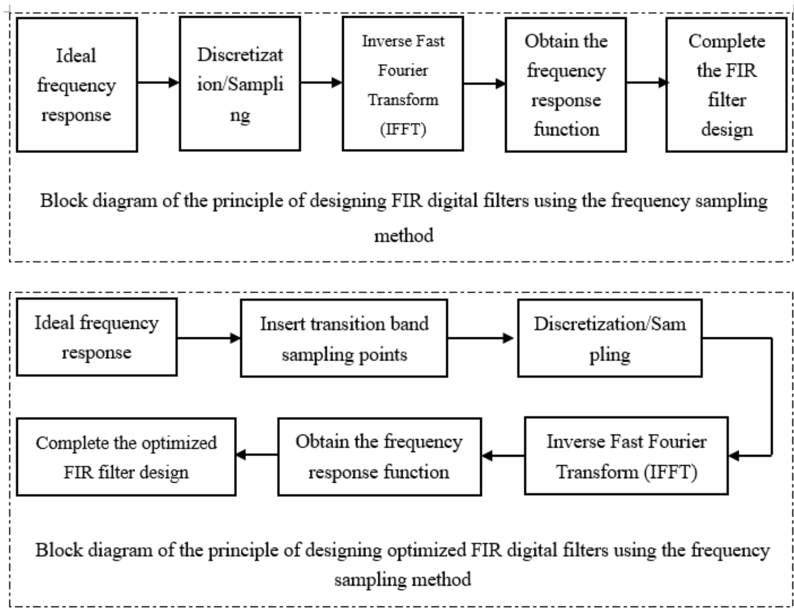

Figure 3. Block diagram of the experimental principle for designing filters using the frequency sampling method

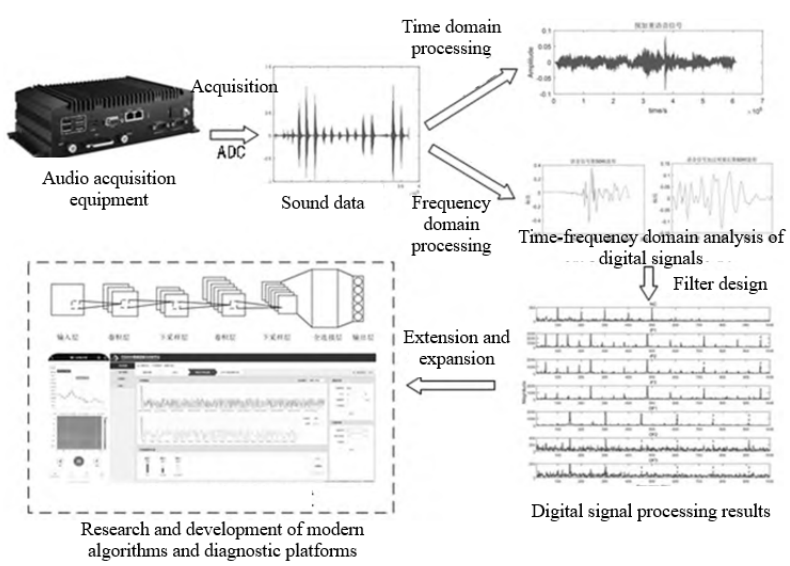

Figure 4. Design ideas for comprehensive experimental content

mastery of optimized design methods.

After completing the construction of the block diagram on the simulation page, we visually observe the input and output waveforms. By adjusting the filter design parameters, we observe and analyze their impact on the changes in the output frequency response curve waveform, and compare the effects on filter performance before and after optimization. Finally, through reference code, students will understand the design ideas of the entire experiment, master the programming implementation methods of FIR digital filters, and establish their holistic and comprehensive understanding of the content of different chapters of the course.

3.3. Comprehensive innovative experiment

Comprehensive innovative experiments mainly originate from engineering applications and have a certain level of advancement and expansibility. They require students to comprehensively apply the theoretical knowledge learned in the course, especially the relevant knowledge involved in basic and design experiments. The comprehensive experiment designed for this course is a study on fault diagnosis of components based on sound recognition. The overall experimental design ideas and key steps are shown in **Figure 4**.

The experimental data comes from noise signals collected from key areas inside the vehicle's cockpit during previous research. This data includes gear whine, reducer knock, gear impact, and abnormal valve system sounds. The specific experimental content involves utilizing knowledge gained from the course to perform pre-emphasis, framing and windowing, fast Fourier transforms, and power spectrum calculations on the sound signals. Then, through a combination of Mel filters and cepstral coefficients, the characteristics and types of abnormal sounds are analyzed to achieve the solution of Mel cepstral coefficients. Given the nature of this experiment, it is conducted in teams of two to three students. The final step involves organizing the experimental results and completing an experimental report. Based on this, students can continue to explore further courses such as digital image processing, pattern recognition, and artificial neural networks. They can utilize wavelet transforms or machine learning algorithms to further detect and diagnose faulty sounds. Additionally, using knowledge from embedded systems courses and comprehensive practical experiences, students can develop and implement diagnostic systems. Clearly, this experiment requires the integrated application of fundamental theoretical knowledge from multiple courses, such as the time-domain sampling theorem, Fourier spectrum analysis, FIR digital filter design, and short-time energy calculation. It also involves the comprehensive application skills of related prerequisite and subsequent courses. If students are interested, they can continue to improve the research and development of the diagnostic platform using relevant knowledge from embedded courses and comprehensive practices. Therefore, this experiment can comprehensively test students' mastery and application of knowledge, stimulate their innovation and creativity, provide them with a preliminary understanding of solving practical engineering problems, and enhance their ability to solve complex problems and collaborate in teams, as outlined in the course objectives.

4. Conclusion

Higher education, facing the backgrounds of emerging engineering and agricultural disciplines, must undergo reforms in engineering education and talent cultivation systems. Correspondingly, the curriculum system also needs to align with the changes and development of industrial and economic structures driven by technological innovation in the new era. Electronic information, as a professional discipline closely related to social and technological advancements, should have its core courses designed to meet the objectives of cultivating interdisciplinary talents in the new era. This paper explores a new model centered on students' active learning, focusing on engineering accreditation requirements, and completes the design and implementation of advanced experimental programs. Although it has achieved certain results, it is essential to incorporate more comprehensive design cases in future teaching practices, enabling students to freely choose topics that interest them. Continuously updating and improving experimental content with the times is also crucial.

Funding

(1) Ministry of Education Industry-Education Integrated Co-training Project "Design and Application of Advanced Experimental Projects for the Course 'Digital Signal Processing'" (220505078131047)

(2) Ministry of Education Industry-Education Integrated Co-training Project "Exploration of Reform in Electrical and Electronic Experimental Teaching System in Agricultural and Forestry Universities Under the Background of New Engineering Disciplines" (220603335094316)

Disclosure statement

The authors declare no conflict of interest.

References

[1] Xu Y, Zhu K, 2021, Exploring the Integration Points of Ideological and Political Education in the Course of “Digital Signal Processing.” Education Teaching Forum, (07): 117–120.

[2] Yang Y, Xu P, Wu X, 2022, Exploration and Practice of Modular Teaching Reform in Digital Signal Processing Courses. Journal of Liaoning University (Natural Science Edition), 49(02): 183–188.

[3] Dai K, 2023, Teaching Practice of Digital Signal Processing Courses. Electronic Technology, 52(03): 270–271.

[4] Zhang H, Yu L, Xiao J, et al., 2022, Analysis and Teaching Practice of the Digital Signal Processing Course System. Journal of Higher Education, 8(35): 124–127.

[5] Kang S, 2022, Discussion on the Teaching Methods of “Digital Signal Processing” under the Background of New Engineering. China New Telecommunications, 24(20): 63–65.

[6] Wang K, Gan H, Guo T, et al., 2022, Design and Implementation of a Multi-level Digital Signal Processing Experiment System. Computer Knowledge and Technology, 18(21): 8–10.

[7] Pan Z, Song Y, Yu Y, 2022, Design of Ideological and Political Teaching Methods for the “Digital Signal Processing” Course in Applied Undergraduate Education. Education Teaching Forum, (15): 129–132.

[8] Jiang Y, Yan Y, Huang Q, et al., 2020, Exploration of Teaching Reform in Digital Signal Processing Courses Based on Engineering Education Professional Certification. Journal of Nanchang University of Aeronautics (Natural Science Edition), 34(04): 112–117 + 122.

[9] Kong L, 2020, Research on Curriculum Reform Based on Innovation and Entrepreneurship Ability Training—Taking the Digital Signal Processing Course as an Example. University Education, (11): 129–131.

[10] Wang Q, Fu L, Wang L, 2020, Construction of “Digital Signal Processing” Course Oriented to Engineering Practice. Journal of Electrical and Electronic Education, 42(04): 128–133.

[11] Liu W, 2019, Exploration and Practice of Teaching Reform in “Digital Signal Processing” Courses Based on Virtual Simulation. Journal of Qilu Normal University, 34(01): 34–41.

[12] Ding Y, Gao X, 2022, Digital Signal Processing (5th Edition), Xidian University Press, Xi’an, 161–164.