Research on the Project-Based Teaching Reform of "Fundamentals of Digital Television Technology" for the Ultra-High Definition Video Industry

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Abstract: *The development of the ultra-high definition video industry drives the reform of the "Fundamentals of Digital Television Technology" course. Starting from the evolution characteristics of ultra-high definition technology, this study analyzes the reconstruction logic of the course knowledge system driven by the iteration of resolution, color gamut, frame rate, and coding standards, and establishes the coupling relationship between the industrial technology chain and teaching units. Accordingly, this study designs a project-based hierarchical architecture based on the acquisition and processing workflow of ultra-high definition signals, constructs modular task clusters centered on coding and transmission technologies, and sets acceptance criteria that integrate subjective and objective evaluation indicators. This study proposes an inquiry-based teaching process guided by the technical link, identifies technical difficulties and breakthrough paths in coding algorithms, transmission adaptation, and system integration, and constructs a formative evaluation mechanism based on project completion. This research provides a reform path for adapting the digital television technology course to the needs of the ultra-high definition video industry.*

Keywords: *Ultra-High Definition Video; Digital Television Technology; Project-Based Teaching; Curriculum Reconstruction; Evolution of Coding Standards; Technical Link*

Introduction

The ultra-high definition video industry, characterized by 4K/8K, high dynamic range, and high frame rate, drives the upgrade of the entire link system and puts forward requirements for reforming the traditional structure of the "Fundamentals of Digital Television Technology" course. The current course has problems of disconnection from industry frontiers in areas such as sampling and quantization, the evolution of coding tools, and transmission protocol configuration, making it difficult for students to establish an end-to-end technical understanding. The necessity of carrying out project-based teaching reform oriented to industry needs is reflected in the need to reconstruct the principles and mechanisms in the course content, to design project systems around the technical chain in the teaching model, and to match the progressive logic of difficulties and establish a completion-based evaluation mechanism in the teaching process. Starting from the evolution of industrial technology, this study systematically designs the teaching system and process organization methods, providing theoretical support and a framework for curriculum reform.

1. Logical Basis of the Evolution of Ultra-High Definition Video Industry Technology and the Reconstruction of Course Content

1.1 Mapping of the Ultra-High Definition Video Technical Architecture to the Course Knowledge System

1.1.1 Reconstruction of Sampling and Quantization Principles Under the Improvement of Resolution

The leap of ultra-high definition video resolution to the 4K/8K level drives a step change in sampling frequency, quantization precision, and data throughput. The video signal digitization section in the course must reconstruct the application scenarios of the Nyquist sampling theorem, analyze the impact of spatial sampling patterns on aliasing effects under higher pixel density, and remodel the change in quantization noise distribution introduced by a quantization depth of 10 bits and above, thereby extending sampling and quantization from theoretical formulas to the level of system design constraints.

1.1.2 Update of the Color Processing Module Driven by Wide Color Gamut and High Dynamic Range

The BT.2020 color gamut has been significantly expanded, and the PQ curve and HLG curve introduced by high dynamic range change the traditional gamma correction mechanism. The course's content on colorimetry and color space conversion needs to update the color gamut mapping algorithm, the chroma subsampling mode, and the color volume description method, so that students can master the representation method of wide-color-gamut color signals and understand the influence mechanism of luminance level division under high dynamic range on video signal quantization.

1.1.3 Constraints of High Frame Rate Video Streams on Encoding Parameter Configuration

Ultra-high definition video generally adopts high frame rate specifications from 50fps to 120fps, and the increased sampling density in the time dimension imposes higher requirements on the temporal redundancy removal capability of encoding algorithms. The motion estimation and compensation module in the course needs to introduce high-frame-rate characteristic-based motion vector field analysis, inter-frame prediction mode selection strategies, and temporal hierarchical encoding structure design, so that students can understand the reshaping of the trade-off relationship between encoding complexity and compression efficiency caused by the increase in frame rate.

1.2 Iteration of Core Modules in Digital Television Technology from the Perspective of Standard Dynamic Evolution

1.2.1 Evolution of Coding Tools from H.264 to H.266 and Their Embedding in the Course

The evolution of coding standards from H.264/AVC to H.266/VVC introduces tools such as quad-tree nested multi-type tree block partitioning, affine motion compensation, and adaptive loop filtering. The video coding principles section in the course needs to disassemble these tools into teachable algorithm modules, including block partitioning strategy optimization, motion model parameter estimation, and adaptive adjustment of filter coefficients, so that students can understand the algorithmic evolution logic behind the improvement of coding efficiency.

1.2.2 Teaching Transformation of Modulation and Multiplexing Technologies in Next-Generation Transmission Standards

Next-generation transmission standards such as ATSC 3.0 and DTMB-A adopt the combined scheme of LDPC coding and high-order QAM modulation, and introduce time-frequency domain interleaving and multi-physical layer pipe technologies. The channel coding and modulation module in the course needs to transform the performance analysis of the BICM architecture, the code rate adaptation mechanism, and the layered modulation technology into a computable channel capacity model, so that students can master the matching relationship between physical layer parameter configuration and channel conditions[1].

1.2.3 The Driving Role of Standard Text Updates on the Design of Course Experiment Platforms

Standard text updates, accompanied by test vector changes and reference software iterations, impose dynamic adaptation requirements on the course experiment platform. The course needs to construct a modular experimental framework that transforms the encoding parameter set, bitstream syntax structure, and decoding conformance requirements specified in the standard text into configurable experimental tasks, enabling students to reproduce key technical improvements during the standard evolution process by adjusting experimental parameters.

1.3 Analysis of the Coupling Relationship Between the Industrial Technology Chain and Course Teaching Units

1.3.1 Correspondence Between RAW Format Processing at the Acquisition End and the Principle of Video Digitization

The RAW format output of ultra-high-definition cameras includes Bayer array data, black level correction information, and lens shading compensation parameters, and its processing flow directly corresponds to the principle of video signal digitization in the course. The teaching unit needs to technically map the steps of RAW format linearization, demosaicing algorithm, and white balance correction to the sampling theorem and color restoration model, enabling students to understand the impact of front-end acquisition quality on subsequent encoding and transmission links.

1.3.2 The Correlation Between Rate-Distortion Optimization in the Encoding and Transmission Link and the Channel Coding Module

The encoder seeks a balance between bit rate and distortion through a rate-distortion optimization algorithm, and this optimization objective is coupled with the error protection mechanism of channel coding. The course needs to establish a joint source-channel coding analysis framework, which performs a correlation analysis between the rate control strategy at the encoding end and the constellation diagram design as well as the interleaving depth selection at the modulation end, enabling students to grasp the influence mechanism of cross-layer optimization on the end-to-end video transmission quality.

1.3.3 The Connection Between High Dynamic Range Mapping at the Decoding and Display End and Terminal Color Management Technology

The restoration of ultra-high-definition video on terminal display devices relies on a tone mapping algorithm to convert the high dynamic range video to the capability range of the display device. The decoding and display modules in the course need to cover technical contents such as content-based adaptive tone mapping, the description of the display device's color gamut boundary, and metadata parsing along with mapping parameter extraction, enabling students to understand the technical path for color information fidelity when the decoding end and the display end work collaboratively.

2. Project-Based Teaching System Design for the "Digital Television Technology Fundamentals" Course

2.1 Project Hierarchy Architecture Based on the Ultra-High-Definition Signal Acquisition and Processing Workflow

2.1.1 RAW Format Parsing and Preprocessing Project Level at the Acquisition End

The bottom layer of the project hierarchy architecture focuses on the original acquisition link of ultra-high-definition video signals. It requires students to process the RAW format files output by the camera, parse the arrangement pattern of the Bayer array, and implement black level compensation, lens shading correction, and linearization processing algorithms. This project level enables students to establish a quantitative understanding of the output characteristics of the sensor through pixel-level operations, comprehend the sources of noise and the correction methods during the conversion from optical signals to electrical signals, and provide quality-controllable input data for subsequent video processing links.

2.1.2 Video Signal Digitization and Color Space Conversion Project Level

The middle level focuses on the digitized representation of video signals and the conversion of color spaces. The project tasks at this level include reconstructing full-color images from the preprocessed RAW data through a demosaicing algorithm, performing white balance adjustment and color correction matrix operations, and finally completing the conversion from the sensor RGB space to the BT.2020 wide color gamut space. This level emphasizes the integration of colorimetry principles and numerical calculation methods, enabling students to master the mapping relationships of pixel values in different color spaces as well as the methods for describing the color gamut boundary.

2.1.3 High Dynamic Range Synthesis and Quantization Coding Project Level

The high level of the project architecture focuses on the synthesis and quantization coding of high dynamic range video. Students need to process multiple exposure image sequences, generate high dynamic range video frames through exposure fusion algorithms, implement luminance mapping based on the perceptual quantization curve, and finally configure quantization parameters according to ultra-high-definition coding standards. This level combines high dynamic range imaging technology with the front-end processing of video coding, enabling students to understand the influence mechanism of luminance level division on coding efficiency.

2.2 Construction of a Modular Task Cluster Centered on Video Coding and Transmission Technologies

2.2.1 Coding Parameter Configuration and Rate-Distortion Optimization Task Module

The core module of the modular task cluster focuses on the parameter configuration and rate-distortion optimization of the video encoder. Students need to adjust the encoder's quantization parameters, GOP structure, number of reference frames, and rate control mode according to the characteristics of the ultra-high-definition video sequence, and analyze the influence of different parameter combinations on the bit rate of the output bitstream and the peak signal-to-noise ratio of the reconstructed video. This module enables students to establish the ability to apply rate-distortion theory in the actual configuration of the encoder through parameter scanning and performance curve plotting.

2.2.2 Encoding Tool Combination Selection and Algorithm Complexity Analysis Task Module

Targeting multiple encoding tools in the ultra-high-definition encoding standard, the task module requires students to selectively enable a combination of tools such as extended block partitioning depth, affine motion compensation, and adaptive loop filtering according to the characteristics of the video content, and to measure the changes in encoding time, decoding complexity, and compression efficiency under different tool combinations. This module enables students to understand the trade-off between the complexity of the encoding algorithm and its compression performance through comparative experiments of tool switching, and to master the optimization methods of encoding strategies for specific video content.

2.2.3 Transmission Protocol Adaptation and Bitstream Encapsulation and Parsing Task Module

The task module focuses on the transmission adaptation link of the encoded video bitstream. Students need to encapsulate the ultra-high-definition video bitstream into container formats suitable for different transmission scenarios, configure streaming media protocol parameters, and simulate bitstream parsing and error concealment mechanisms under network packet loss conditions. This module combines transmission protocol characteristics with the bitstream syntax structure, enabling students to understand the influence of transport layer parameter configuration on the reconstruction quality at the decoding end and to grasp bitstream adaptation strategies for different channel conditions[2].

2.3 Setting of Project Outcome Acceptance Criteria Integrating Subjective and Objective Evaluation Indicators

2.3.1 Setting of Objective Quality Evaluation Indicators Based on Coding Parameter Combinations

The first dimension of the project outcome acceptance criteria takes the objective quality evaluation indicators as its core. It defines the calculation methods for the peak signal-to-noise ratio, the structural similarity index, and the video multi-method assessment fusion indicator for the coding tasks completed by students, and specifies the acceptable thresholds for these indicators under different coding parameter combinations. This criterion constrains the reasonable range of coding parameters through quantitative indicators, provides a unified numerical benchmark for the horizontal comparison of student outcomes, and eliminates the interference of subjective factors in outcome evaluation.

2.3.2 Setting of Subjective Quality Evaluation Indicators Oriented Toward the Display Terminal

The second dimension of the acceptance criteria introduces the subjective quality evaluation method. It designs a subjective scoring process for the display effect of ultra-high-definition video with reference to the double-stimulus continuous quality-scale method specified in Recommendation ITU-R BT.500. Students play back the encoded video sequences on specific display devices, and the evaluators give scores based on the image edge sharpness, color accuracy, motion smoothness, and high dynamic range luminance levels. This dimension emphasizes the correlation between the terminal display quality and the encoding parameters.

2.3.3 Setting of Comprehensive Evaluation Indicators for Coding Efficiency and Transmission Robustness

The third dimension of the acceptance criteria integrates the indicators of coding efficiency and transmission robustness. It calculates the subjective score per unit bit rate as a comprehensive measure of coding efficiency, and simultaneously designs a network packet loss simulation environment to measure the decoding success rate and error concealment effect of the bitstream under error-prone conditions. This evaluation indicator links the encoder output quality with the adaptability of the transmission channel, thereby expanding the outcome evaluation of student projects from a single quality dimension to a comprehensive dimension that integrates the collaborative optimization of efficiency and robustness.

3. The Organizational Logic and Effectiveness Evaluation of the Project-Based Teaching Process

3.1 Design of Inquiry-Based Teaching Segments Oriented by the Technical Chain

3.1.1 Design of the Inquiry Segment for Analyzing the Influence of Coding Parameters

The teaching segment revolves around the influence mechanism of ultra-high-definition video coding parameters on the quality of the output bitstream. Students adjust variables such as quantization parameters, rate control modes, and GOP structures to observe the reconstructed image differences of the same video sequence under different coding configurations. This segment guides students to establish the mapping relationship between the coding parameter space and the rate-distortion performance surface, enabling them to discover the nonlinear correlation between the quantization step size and the subjective perceptual quality during the parameter scanning process, and to develop the ability to explore the underlying logic of the coding algorithm.

3.1.2 Design of the Inquiry Segment for Transmission Protocol Adaptation Strategies

Aiming at the transmission requirements of ultra-high-definition video streams under different network environments, the teaching segment requires students to analyze the applicable scenarios of UDP and TCP protocols in video transmission, design an adaptive bitrate switching strategy, and configure forward error correction parameters. Students test the transmission effects of different protocol combinations under simulated network bandwidth fluctuations and packet loss conditions, explore the coupling relationship between transport layer parameter settings and the buffer status of the decoding end, and establish a quantitative correlation between protocol characteristics and the transmission quality of video streams.

3.1.3 Design of the Inquiry Segment for the Tone Mapping Algorithm at the Display End

The teaching segment focuses on the tone mapping process of high dynamic range video on standard dynamic range display devices. Students need to implement mapping algorithms based on global mapping, local adaptive mapping, and content analysis, and compare the performance of different algorithms in terms of luminance compression, contrast preservation, and color saturation control. This segment enables students, through algorithm implementation and effect comparison, to explore the matching mechanism between the luminance response characteristics of the display end and the human visual perception.

3.2 The Progressive Difficulty and Breakthrough Paths of Key Technologies in the Project Process

3.2.1 Identification of Difficulties at the Encoding Algorithm Level and the Parameter Optimization Path

At the initial stage of the project process, the technical difficulties are concentrated at the encoding algorithm level. Students, facing the high computational complexity and bit rate control accuracy requirements brought by ultra-high-definition video, need to identify the restrictive relationships among the motion estimation search range, the block partitioning depth, and the number of reference frames on encoding speed and compression efficiency. The breakthrough path constructs a joint optimization objective function of encoding complexity and distortion, guides students to adopt a hierarchical search strategy and early termination decision conditions, and adjusts the relevant parameter thresholds in the encoder configuration file, thereby achieving a balance between encoding efficiency and resource consumption.

3.2.2 Identification of Difficulties at the Transmission Adaptation Level and the Protocol Configuration Path

In the middle stage of the project process, the technical difficulties shift to the transmission adaptation level. Students need to cope with the requirement of smooth bitstream transmission under network bandwidth fluctuations, identify the dynamic matching relationship between the selection of bitrate switching timing and the buffer length, as well as the trade-off mechanism between the redundancy of forward error correction coding and the channel bit error rate. The breakthrough path guides students to design a buffer status feedback-based adaptive bitrate algorithm, establishes a quantitative correlation between the transmission protocol parameters and the playback continuity at the decoding end by adjusting the bitrate ladder of video segments and the switching threshold parameters.

3.2.3 Identification of Difficulties at the System Integration Level and the Path for Collaborative Parameter Optimization

In the later stage of the project process, the technical difficulties escalate to the system integration level. Students face the collaborative configuration problem among encoding parameters, transmission parameters, and display parameters, and need to identify the influence mechanism of the superposition of encoding loss, transmission error, and display mapping on the final viewing quality. The breakthrough path guides students to construct an end-to-end quality evaluation model, analyze the interaction effects of parameters from each link through experimental design methods, and adopt the response surface methodology to search for the optimal combination of the encoding quantization step size, the forward error correction redundancy, and the tone mapping curve parameters, thereby achieving full-link quality optimization from the source to the display.

3.3 Construction of a Formative Evaluation Mechanism Based on Project Completion

3.3.1 Setting of Phased Evaluation Indicators for the Completion of Coding Tasks

The first level of the formative evaluation mechanism focuses on the phased completion of coding tasks. It sets quantitative evaluation indicators for the coding parameter configuration files, rate-distortion curve data, and coding log files submitted by students. The evaluation indicators include the syntactic correctness of the encoder configuration file, the logical rationality of the quantization parameter settings, the accuracy of the BD-rate calculation value in the rate-distortion curve, and the degree of conformity between the coding time and the target deviation. The quantitative assessment of the phased products forms a quantitative description of the students' mastery level in the coding link.

3.3.2 Process Recording and Quantitative Analysis of the Completion of Transmission Tasks

The second level of the evaluation mechanism focuses on the completion process of transmission tasks. It records the students' parameter adjustment trajectories during the configuration of transmission protocols, the selection of bitstream encapsulation formats, and the simulation of network environments. By analyzing the packet loss rate variation curve during the bitstream transmission process, the triggering frequency of decoder error concealment, and the statistical values of playback continuity, the evaluation mechanism forms a process-based assessment of the completion of transmission tasks. This level emphasizes the recording of the correlation between the parameter adjustment paths and the experimental results, enabling the evaluation outcome to reflect the students' depth of understanding of transmission principles.

3.3.3 Integrity Assessment of Technical Documentation and Code Specifications Throughout the Entire Project Cycle

The third level of the formative evaluation targets the technical documentation and code implementation specifications throughout the entire project cycle. It assesses the completeness and standardization of the coding algorithm description documents, the parameter experiment design reports, and the source code comments submitted by students. The evaluation criteria include the logical reasoning of the technical documentation regarding the basis for coding parameter selection, the standard presentation of experimental data charts, the rationality of code module division, and the semantic clarity of variable naming. The quality assessment of the documents and code reflects the students' technical expression ability and the degree of engineering thinking formation during the project execution process.

Conclusion

This research focuses on the demands of the ultra-high-definition video industry and constructs a project-based teaching reform framework for the "Digital Television Technology Fundamentals" course. At the level of content restructuring, this research analyzes the mapping relationship between the ultra-high-definition technical architecture and sampling quantization, color processing, and coding parameters, traces the standard evolution path from H.264 to H.266, and establishes the coupling association between each link of the industrial technology chain and the teaching units. At the level of system design, this research constructs a three-level project architecture based on the acquisition and processing workflow, forms a modular task cluster centered on coding parameter configuration and transmission protocol adaptation, and sets multidimensional acceptance criteria that integrate objective indicators, subjective scoring, and transmission robustness. At the level of process evaluation, this research designs an inquiry-based segment oriented by the technical chain, identifies the technical difficulties and optimization paths for encoding algorithms and system integration, and constructs a formative evaluation mechanism based on task completion, process recording, and technical specifications. Future research can explore the embedding of AI coding tools, the integration of VR and ultra-high-definition teaching scenarios, and the dynamic update mechanism oriented toward next-generation standards.

References

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