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 has changed the content of the "Fundamentals of Digital Television Technology" course. With the progress of ultra-high-definition technology, this paper studies the reconstruction logic of the course knowledge system based on iteration in resolution, colour gamut, frame rate and coding standards, and establishes a coupling relationship between the industrial technology chain and teaching units. Based on the above, this paper puts forward a project-based hierarchical structure for the acquisition and processing workflow of ultra-high-definition signals, organises modular task clusters according to coding and transmission technologies, and sets both subjective and objective acceptance criteria. Under the leadership of the technical link, inquiry-based teaching will be used to explore technical problems and find good solutions in coding algorithms, transmission adaptation, system integration, etc., and a formative assessment system based on project completion will be established. Given the high-definition video demand of the public, this paper will propose a reform plan to change the development direction of digital television technology.*

Keywords: *Ultra HD Video, Digital Television Technology, Project-based Teaching, Curriculum Reconstruction, Evolution of Coding Standards, Technical Links*

Introduction

With the development of 4K/8K Ultra HD video, high dynamic range and high frame rate in the video industry now, all links in the system need to be strengthened, and the traditional structure of the "Fundamentals of Digital Television Technology" course must be reformed. The current course does not cover the latest developments in the field of sampling and quantization at the forefront of the industry, changes in coding tools and transmission protocol configuration, etc., so students have been unable to obtain all-round technical knowledge. With the rise of project-based teaching reform in the industry, we need to change the basic ideas and ways of teaching course content, design project systems based on the technical chain in the teaching model, and align the progressive logic of difficulties with a completion-based evaluation system during teaching. With the development of industrial technology, this paper will systematically introduce the teaching system and forms of organisation for teaching to provide theoretical support and a framework for curriculum reform.

1. Logical Basis of the Evolution of Technology in the Ultra-High Definition Video Industry and 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

As the resolution of Ultra High Definition videos has reached 4K and 8K, so too have the demands for sampling frequency, quantization precision and data transmission. The digitalisation part of the video signal in this course should reconstruct the application scenarios of the Nyquist sampling theorem, analyze the effect of spatial sampling patterns on aliasing at high pixel densities, model the change in the distribution of quantization noise due to a quantization depth of 10 bits or more, and extend 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

BT.2020 has been extended to some extent, and the PQ curve and HLG curve in high dynamic range are not the same as traditional gamma correction. The content of the course on colourimetry and colour space conversion needs to be updated to include the colour gamut mapping algorithm, chroma subsampling mode and colour volume description method; students should be able to learn how to represent wide-colour-gamut colour signals and understand the mechanism of influence for luminance level division under high dynamic range in video signal quantization.

1.1.3 Constraints of High Frame Rate Video Streams on the Selection of Encoding Parameters

Generally speaking, high-definition videos have a relatively high frame rate, about 50fps to 120fps, and due to the increased sampling density in the time dimension, they have higher demands on the temporal redundancy removal ability of encoding algorithms. The Motion Estimation and Compensation module in the course should have the characteristics of high-frame-rate motion vector field analysis, selection strategies for inter-frame prediction modes, design of the temporal hierarchical encoding structure, etc., to help students learn how the trade-off between encoding complexity and compression efficiency changes with an 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

Coding standards have gone from H.264/AVC to H.266/VVC, and with them many new tools have been added, such as quad-tree nested multi-type tree block partitioning, affine motion compensation and adaptive loop filtering. The principles of video coding in the course should be broken down into teachable algorithm modules, such as optimisation of the block partitioning strategy, motion model parameter estimation and adaptive adjustment of filter coefficients, so that students can learn about the algorithmic evolution logic behind the improvement in coding efficiency.

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

The new transmission standards are ATSC 3.0 and DTMB-A, and they have added LDPC coding, high-order QAM modulation, time-frequency domain interleaving, multi-physical layer pipe technology, etc. The channel coding and modulation module in the course should take the performance analysis of the BICM architecture, the code rate adaptation mechanism and the layered modulation technology, convert them into a computable channel capacity model, and have students learn about the correspondence between physical layer parameter configuration and channel conditions[1].

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

Update the standard text, modify the test vectors and revise the reference software, and then dynamically switch to the course experiment platform. A modular experimental framework should be set up in the course to convert the set of encoding parameters, bitstream syntax structure and decoding conformance requirements specified in the standard text into configurable experimental tasks, and students can reproduce the main technical improvements in the evolution of the standard by changing 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 stage and the basic idea of video digitalisation

The RAW format output of an ultra-high-definition camera contains Bayer array data, black level correction information and lens shading compensation parameters, and its processing flow is in line with the principle of video signal digitalisation in this chapter. Technically map the steps of RAW format linearization, demosaicing algorithm and white balance correction in the teaching unit to the sampling theorem and color restoration model so that students can learn how the quality of the front-end acquisition affects the subsequent encoding and transmission links.

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

The Rate-Distortion Optimisation Algorithm is used to trade off bit rate and distortion, and the optimisation objective is combined with that of channel coding error protection. The course will build a joint source-channel coding analysis framework to connect the rate control strategy at the encoding end with the design of the constellation diagram and the selection of interleaving depth at the modulation end, and students will be able to learn about the effect of cross-layer optimisation on the overall quality of video transmission.

1.3.3 The Link between High Dynamic Range Mapping at the Decoding and Display End and Terminal Colour Management Technology

Tone mapping is needed to display high-definition video on a small screen; that is to say, the large dynamic range of the video must be reduced, and it needs to be compressed into a small range that can be displayed on the screen. The decoding and display modules in the course should cover technical content such as content-based adaptive tone mapping, the description of the colour gamut boundary of the display device, and metadata parsing with mapping parameter extraction, so that students can learn the technical path of colour information fidelity at the end of decoding and display by working together.

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

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

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

At the bottom of the project hierarchy is the original acquisition link of the ultra-high-definition video signal. The RAW-format files obtained from the camera need to be processed, the arrangement pattern of the Bayer array should be parsed, and then algorithms for black-level compensation, lens shading correction and linearization are applied. At the level of this project, students will be able to learn about the quantitative characteristics of the output from a sensor through pixel-level operations, be introduced to noise sources and correction methods in the conversion of optical signals to electrical signals, and obtain quality-controlled input data for the next stage of video processing.

2.1.2 Video Signal Digisation and Colour Space Conversion Project Level

The middle part is to handle the digitalisation of video signals and conversion of colour spaces. At present, the goal of this project is to construct a full-colour image from the pre-processed RAW data by means of a demosaicing algorithm, apply white balance correction and colour correction matrix operations, and finally complete the conversion of the sensor RGB space to the BT.2020 wide colour gamut space. At this level, students need to learn the basic ideas of colourimetry and numerical calculation; they should be able to find out how to map pixel values in different colour spaces and how to describe the boundary of the colour gamut.

2.1.3 High Dynamic Range Synthesis and Quantisation Coding Project Level

At the top of the project architecture is the synthesis and quantisation coding of High Dynamic Range (HDR) video. The student needs to process a large number of sequences of exposure images, generate high-dynamic-range video frames with exposure-fusion algorithms, apply luminance mapping according to the perceptual quantization curve, and finally set quantization parameters in accordance with the coding standards for ultra-high-definition. At this time, high dynamic range imaging technology is combined with the front-end processing of video coding to have students learn about the effect mechanism of luminance level division on coding efficiency.

2.2 Construction of a Modular Task Cluster Based on Video Coding and Transmission Technology

2.2.1 Coding Parameter Configuration and Rate-Distortion Optimization Task Module

The first part of the modular task cluster is to set the parameters and optimise the rate-distortion for the video encoder. Adjust the quantization parameters, GOP structure, number of reference frames and rate control mode of the encoder according to the characteristics of the ultra-high-definition video sequence, and analyze the effect of different combinations of these parameters on the bit rate of the output bitstream and the peak signal-to-noise ratio of the reconstructed video. Help students learn how to apply the rate-distortion theory in daily life and sketch the performance graph of encoders by changing parameters.

2.2.2 Selection of Encoding Tool Combination and Algorithm Complexity Analysis Task Module

There are many encoding tools in the ultra-high-definition encoding standard, so for the task module, students need to select a combination of these tools according to the characteristics of the video content, such as the degree of extended block partitioning, affine motion compensation and adaptive loop filtering, and then measure the changes in encoding time, decoding complexity and compression efficiency under different combinations of these tools. Students will be able to compare the complexity and compression efficiency of various encoding algorithms by carrying out comparative experiments with tool switching in this module, learn to optimise encoding strategies for all kinds of videos, and gain practical experience.

2.2.3 Adaptation of Transmission Protocol and Bitstream Encapsulation and Parsing Task Module

The Task module is added to the link of the encoded video bitstream. The student needs to put the ultra-high-definition video bitstream in a container that can be used for all kinds of transmission, set parameters for streaming media protocols, and simulate bitstream parsing and error concealment in the presence of network packet loss. This module will present the attributes of the transmission protocol and the structure of the bitstream, help students learn how changes in the configuration of the transport layer parameter affect the reconstruction quality at the decoding end, and study bitstream adaptation strategies under different channel conditions[2].

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

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

The first index in the criteria for accepting the project result is an objective quality assessment indicator. Set the calculation method for the peak signal-to-noise ratio, the structural similarity index and the fusion indicator of the video multi-method assessment for the coding tasks students have completed, and specify the acceptable thresholds for these indicators under all combinations of coding parameters. First, according to the purpose and goals of the institution, set a general range for the number of students' grades in the horizontal comparison and avoid arbitrary changes in the evaluation criteria.

2.3.2 Setting of Subjective Quality Evaluation Indicators Based on the Display Terminal

The second type of an acceptance criterion is a subjective quality judgment method. To find out how much people believe that ultra-high-definition video displays are good, the double-stimulus continuous quality scale method of Recommendation ITU-R BT.500 will be used. Students play back the encoded video sequences on some display devices, and then evaluators will give scores based on the sharpness of the image edges, colour accuracy, smoothness of motion and high dynamic range luminance. The above show the relationship among the quality of the end display and the encoding parameters.

2.3.3 Setting of All-round Evaluation Indicators for Coding Efficiency and Transmission Robustness

The third kind of acceptance criterion is the combination of the coding efficiency index and the transmission robustness index. Calculate the subjective score per unit bit rate as the overall index of coding efficiency, and at the same time build a network packet loss simulation environment to determine the decoding success rate and error concealment effect of the bitstream in the presence of errors. Based on the above indices, we will consider both the quality of the encoder output and the adaptability of the transmission channel; therefore, the scope of evaluation for student projects will be extended from a single dimension of quality to an all-encompassing one that includes the joint optimisation of efficiency and robustness.

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

3.1 Design of Inquiry-Based Teaching Segments Based on the Technical Chain

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

The teaching content will be to learn how the parameters of ultra-high-definition video coding affect the quality of the output bitstream. Change the quantization parameter, rate control mode, GOP structure, and so on, then observe how much the reconstructed image differs in a specific part of the video with different coding parameters. Therefore, the students have built a map of the coding parameter space and the rate-distortion performance surface, and they have observed that the quantization step size is not directly related to subjective perceptual quality; thus, they have developed an interest in learning more about the logic of the coding algorithm.

3.1.2 Design of the Inquiry Segment for Adaptation Strategies of Transmission Protocol

Based on the transmission requirements of ultra-high-definition video streams in various network environments, the teaching section will have students learn about the use cases of UDP and TCP protocols for video transmission, design an adaptive bitrate switching scheme, and set up forward error correction parameters. Students will observe the performance of all combinations of protocols under various network conditions, such as changes in network bandwidth and packet loss; they will also learn how to modify transport layer parameters to affect the buffer state at the decoding end and determine the extent of impact of each protocol on the quality of video transmission.

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

The teaching content is Tone Mapping of High Dynamic Range Video for Standard Dynamic Range Displays. Based on the world map, local adaptation maps and content analysis should be performed first, and then mapping algorithms are used to compare the results of all these algorithms in terms of luminance compression, contrast preservation and colour saturation control. Students can carry out algorithms and observe the results in this part to learn about the correspondence between the luminance response characteristics of a display end and human vision.

3.2 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 beginning of the project, the technical problem is at the level of the encoding algorithm. Students need to know that there is a high computational complexity and a need for accurate bit-rate control in ultra-high-definition video; thus, they should determine the trade-off relationship among the motion estimation search range, the depth of block partitioning and the number of reference frames, encoding speed and compression efficiency. BreakthroughPath is a combination of the goals of encoding complexity and distortion, so it can be used to employ a hierarchical search strategy and early-termination conditions, modify the corresponding parameter thresholds in the encoder configuration file, etc., to achieve a trade-off between encoding efficiency and resource consumption.

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

At the middle stage of the project, the technical problem is now at the level of transmission adaptation. Students need to meet the demand for continuous bitstream transmission in the face of network bandwidth fluctuations, determine how to change the correspondence relationship between the selection time of bit rate switching and buffer size, and learn how to trade off the redundancy of forward error correction coding with the channel bit error rate. The first way is to have students design a buffer-status feedback-based adaptive bitrate algorithm and determine how to keep up with the decoding speed at the decoding end by changing the bitrate ladder of video segments and modifying threshold parameters according to transmission protocol parameters.

3.2.3 Identification of Problems in the System Integration Stage and Path for Collaborative Parameter Optimization

Towards the end of the project, there have been some serious technical problems in the entire system. Students need to solve the problem of collaborative configuration for encoding parameters, transmission parameters and display parameters, and determine the influence mechanism of the superposition of encoding loss, transmission error and display mapping on the final viewing quality. First, build a general quality evaluation model based on the breakthrough path; then, through experimental design, find out how the parameters in each link are related; finally, use a response surface method to find the best combination of tuning for encoding quantization step size, forward error correction redundancy and tone mapping curve parameters to improve the quality of the whole link from source to 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 assessment mechanism is to check the progress of the coding tasks. Set quantitative evaluation criteria for the configuration files of coding parameters, rate-distortion curve data and coding log files submitted by students. The four evaluation indices are the syntactic correctness of the encoder configuration file, the logical rationality of the quantization parameter setting, the accuracy of the BD-rate calculation value in the rate-distortion curve, and how close the coding time is to the target deviation. Quantitative evaluation of the phased products provides a quantitative description of the students' learning results 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 is the completion process of transmission tasks. Record the paths of parameters modified by students in the configuration of transmission protocols, selection of bitstream encapsulation formats and simulation of network environments. According to the variation curve of the packet loss rate during bitstream transmission, it can be determined how often decoder error concealment is triggered, and based on the statistical values of playback continuity, a process-based evaluation mechanism for the success of transmission can be established. The above stage is to record the correlation among the paths of parameter adjustment and experimental results, and the evaluation results can show how well students have grasped the principles of transmission.

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

The third level of formative assessment will be the technical documents and code implementation specifications for all stages of the project. Determine whether the coding algorithm description documents, parameter experiment design reports and source code comments provided by the students are complete and uniform. The items in the assessment are: the reason for choosing the basis of the coding parameters in the technical documentation, the standard form of experimental data charts, the rationality of code module division, and the semantic clarity of variable names. The quality of the documents and code can show how well students can express themselves technically and how much engineering thinking they have developed in the project.

Conclusion

In light of the high-definition television requirements of the Chinese people, a project-based teaching reform plan for the course "Fundamentals of Digital Television Technology" has been developed in this paper. In terms of the restructuring of content, this paper will examine the mapping relationship between the ultra-high-definition technical architecture and sampling quantization, color processing and coding parameters, trace the standard evolution path from H.264 to H.266, and determine the coupling association among all links in the industrial technology chain and teaching units. At this time, for system design, we will establish a three-level project structure based on the acquisition and processing workflow, create a modular task cluster for coding parameter configuration and transmission protocol adaptation, and set up all kinds of acceptance standards, such as objective indicators, subjective scores and transmission stability. Process evaluation at this level will add an inquiry-based section in line with the technical chain to determine if there are any technical problems, and the best way to deal with encoding algorithms and system integration will be decided; a formative assessment system based on task completion, process recording and technical specifications will also be established. In the future, we will integrate AI coding tools with VR and ultra-high-definition teaching environments to create an intelligent and adaptive system that meets the needs of the new generation, and this paper will present one such case.

References

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