Analysis of 4K HDR Technology Development, Production, and Broadcasting Workflow Post-Print

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Abstract

As demands for television program broadcast quality continue to increase, 4K technology, representing a new stage in the development of broadcast television technology, has gradually gained widespread application in television program production. Consequently, how to properly execute 4K HDR video production and broadcasting has become a critical issue facing many television stations. Accordingly, this paper provides a brief overview of the current development status of 4K HDR technology, examines the production and broadcasting workflow for 4K HDR video, and finally identifies several issues requiring attention in 4K HDR production and broadcasting, with the aim of promoting the broader application of 4K HDR technology.

Full Text

Analyzing the Development, Production, and Broadcasting Workflow of 4K HDR Technology

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Abstract

With continuously rising demands for television program quality, 4K technology has emerged as the next evolutionary stage in broadcasting and is gradually finding widespread application in television production. Consequently, effective 4K HDR video production and broadcasting has become a critical challenge for many television stations. This paper provides a brief overview of the current development status of 4K HDR technology, examines the production and

broadcasting workflows for 4K HDR video, and concludes by highlighting key issues requiring attention in 4K HDR production and broadcasting, aiming to facilitate the broader adoption and application of 4K HDR technology.

Keywords: 4K HDR technology; production workflow; broadcasting workflow

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While 4K technology significantly enhances horizontal and vertical video resolution, the overall quality improvement remains limited due to the numerous factors affecting two-dimensional moving image quality. However, applying 4K HDR technology not only improves resolution but also transforms color gamut, brightness, and gamma, thereby comprehensively upgrading video image quality. This proves immensely valuable for producing and broadcasting high-quality television programs.

1. Development Status of 4K HDR Technology

4K HDR technology represents the integration of 4K resolution and High Dynamic Range (HDR) imaging. The 4K component increases video resolution to 3840$×$2160, delivering sharper images, while HDR provides substantially greater dynamic range and image detail than conventional imaging by synthesizing the best-exposed Low-Dynamic Range (LDR) images across different exposure times into a single visually striking HDR image. Overall, the ultra-high-definition clarity enabled by 4K technology and HDR' s ability to faithfully render details in both dark and bright areas demonstrate strong complementarity in enhancing video quality. Their fusion creates a superior viewing experience and has gained widespread adoption in television production, filmmaking, and even security surveillance applications. For instance, numerous live galas hosted by local television stations in recent years have employed 4K HDR technology, dramatically improving overall broadcast quality. However, despite its growing adoption, HDR remains a technical specification with multiple competing standards—including HDR10, Dolby Vision, and HLG—that have yet to achieve full standardization. This fragmentation creates compatibility issues between different HDR standards, posing obstacles to further development of 4K HDR technology.

2. 4K HDR Video Production Workflow

The production process for 4K HDR video begins with establishing clear basic technical standards to guide the entire workflow. These typically include specifications for resolution, dynamic range, file packaging format, and other parameters, as detailed in Table 1 .

During the shooting phase, camera menus must be properly configured according to these technical standards, including shooting format and frame rate. If post-production color grading is planned, LOG standard modes should be selected. For Sony cameras such as the PMW-F55 and PXW-FS7, S-LOG3 is rec-

ommended. When HDR grading capabilities are unavailable in post-production, HLG (gamma curve) and BT.2020 (color space) options should be selected directly.

Following shooting, footage undergoes color grading using specialized software systems to create HDR images. Using the DaVinci Resolve system as an example—owing to its powerful real-time RGB processing capabilities that enable primary and secondary color correction with RGBY processing at every node, allowing adjustment of chrominance, luminance, and saturation—the workflow proceeds as follows. First, footage files are imported into DaVinci Resolve, with projects created according to file formats. Next, color space settings are configured, including input color space/gamma curve, output color space/gamma curve, and peak brightness values for the main display, thereby determining the quantization range of the output image. After completing these settings, the colorist enters the grading interface [Figure 1: see original paper], places footage on the timeline, and performs primary and secondary color correction to restore proper color and brightness [FIGURE:2-FIGURE:4]. Primary correction adjusts black and white levels, exposure, contrast, and white balance to achieve precise, realistic images that align with the creator' s intent while enhancing visual fluidity and consistency. Secondary correction focuses on adjusting overall atmosphere and tone, typically involving personalized and localized grading. To ensure successful grading, DaVinci' s built-in waveform scopes are used to monitor adjustments and control peak brightness. After grading, Final Cut Pro can be used to produce the HDR video by creating a new library, changing its properties to wide-gamut HDR, and completing the final output.

Additionally, HDR standards can be categorized into several types, including Dolby Vision, HDR10, HLG, and SL-HDR1, each with distinct production workflows. For Dolby Vision specifically, production begins with color grading to create a 1,000-nit HDR master. After importing the final footage and XML, parameters such as highlight levels, ambient light, color system, color gamut, minimum brightness, and gamma must be adjusted. Metadata is then generated through frame-by-frame analysis. Because Dolby Vision images are unique—each shot carries corresponding metadata that enables accurate content presentation on compatible devices—the created metadata must be embedded into the video signal (SDI) for transmission to content mapping units. This metadata subsequently maps the HDR signal to specific SDR targets for output to SDR reference monitors. Finally, using HDMI Tunneling, the HDR grading results from the color system are output directly to televisions, enabling perfect presentation of the high-dynamic-range, wide-color-gamut footage on consumer displays. This approach preserves rich color pixels while enhancing overall image quality.

3. 4K HDR Video Broadcasting Workflow

For television stations, broadcasting 4K HDR video programs demands high technical standards, necessitating careful workflow adjustments to ensure suc-

cessful transmission. First, because 4K ultra-high-definition switching rhythm differs significantly from HD and SD, broadcast operations should employ equipment such as the Sony HDC-4300, which offers greater depth of field at the same aperture to facilitate rapid focusing. Second, to create optimal conditions for HDR production, the HLG_{BT}.2100 curve and BT2020 color space should be adopted, complemented by 4K HDR subtitle machines to ensure proper subtitle rendering.

4. Key Considerations in 4K HDR Production and Broadcasting

4.1 Lighting and Shadow Control

Since 4K HDR can faithfully reveal details in both highlights and shadows, it may expose lighting details previously invisible in HD footage, sometimes compromising overall image quality. Therefore, 4K HDR production requires comprehensive consideration of lighting and shadow control, with strict requirements for lighting design on subjects, props, and objects to prevent quality degradation from overlooked lighting details.

4.2 Color Overflow Management

During HDR video production, high color saturation can easily exceed display limits under the traditional Rec.709 color space, significantly degrading image quality. While conventional HD workflows address this by reducing highlights and raising shadows, 4K HDR' s expanded adjustment space in Rec.2020 allows further highlight and shadow manipulation. However, directly increasing overall saturation using traditional HD methods often causes color overflow [Figure 5: see original paper]. To resolve this, 4K HDR production should enhance dynamic range color latitude (gamut) during primary grading to improve out-of-gamut images [Figure 6: see original paper], while synchronously adjusting luminance and chrominance signals and modestly increasing overall saturation based on actual conditions. This ensures subject saturation meets requirements while preventing large-scale color overflow. Although minor overflow may still occur, it can be addressed through localized adjustments during secondary grading. Additionally, compared to other colors, red, pink, and blue hues exhibit higher overflow probability in HDR video, requiring multi-stage adjustments for individual control of these color ranges.

4.3 Noise Control

During shooting, subjects often face insufficient or poor lighting conditions. To compensate, photographers typically increase brightness through aperture and shutter adjustments, which reduces depth of field and makes focus control difficult, ultimately introducing noise from underexposure. Addressing this requires not only post-production adjustments to chrominance and luminance signals but also capturing images in the mid-to-highlight exposure range whenever possible

to minimize highlight detail loss, maximize sensor performance, and achieve optimal signal-to-noise ratio.

In conclusion, as HDR and 4K technologies continue evolving, 4K HDR video production and broadcasting will inevitably become the mainstream standard in the film and television industry. Effective integration of these technologies requires familiarity with 4K HDR production and broadcasting workflows while remaining vigilant regarding issues such as noise control and color overflow.

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Note: Figure translations are in progress. See original paper for figures.