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A Survey on Applications of High Dynamic Range Technologies in Consumer Electronic Devices

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Abstract: High dynamic range (HDR) technology is one of various research topics in computer vision technologies, which has been actively being applied to cutting-edge consumer electronics products such as premium UHDTV, premium smart phones and etc. In case of consumer camera devices or mobile camera phones, HDR scene capture mode is commonly provided by combining differently-exposed images with standard dynamic range (SDR). In consumer premium TVs, there exist two kinds of HDR processing technologies: one is a tone mapping (TM) to render HDR content on SDR display, and the other one is an inverse tone mapping (iTM) to render a SDR content on HDR display. Especially, in the case of HDR ton mapping, some metadata for adjusting radiometric difference between a reference mastering display and various consumer TV displays were standardized as well as HDR signal encoding method. Currently there exist various organizations related to HDR standards: UHD-Alliance, SMPTE, CTA, ITU-R, MPEG, DVB and etc. Those HDR standard ecosystem members include movie studio, broadcasting, OTTs, TV/STB manufacturers, and etc. They have made efforts to create a next big opportunity of brand-new HDR technology on the basis of 4K UHD media. We will here review HDR technologies, standards, delivery system, and its CE industry trends.

Keywords: CE products, High Dynamic Range (HDR), Display, Mobile phones, UHD TV, and HDR standards.

1. INTRODUCTION

Nowadays the CE industry is moving from traditional content display/imaging devices with Standard dynamic range (SDR) capability to premium content display/imaging devices with High dynamic Range (HDR) capability, because all stakeholders in content distribution ecosystem want to boost the sale of both premium 4K UHD TVs and premium content services, by applying the HDR technologies for the innovation of the traditional TV value chain. Thus, they all, in content production, distribution, and display & rendering are making efforts to build new HDR open standard platform. Up to date, several standards for HDR format have been suggested, and CE display/imaging device manufacturers are trying to adopt those HDR standards into their premium CE products such as UHD TV, UHD STB, Premium PC game monitor, cutting-edge mobile phone, and etc. For the application of HDR capability into CE display/imaging products, there exist two main HDR technologies: HDR down-conversion (or tone mapping), and HDR up-conversion (or inverse tone mapping), [1], which will be discussed briefly in a later section.

In this paper, we provide the up-to-date trends and details for HDR technologies, standards, and CE device applications. More specifically, in the section 2, we discuss the concept of HDR compared to that of SDR, and then review HDR technologies including the HDR tone mapping and inverse tone mapping. In the section 3, we summarize some industry standards for HDR and introduce a representative open-platform based HDR delivery ecosystem. In the section 4, CE industry trends for promoting brand-new HDR CE devices are reviewed. Lastly, our conclusion is provided.

2. HDR TECHNOLOGY

2.1 HDR versus SDR

Human eyes with ultra-high dynamic range (10^{-6}~10^{8} nits) and ultra-wide color gamut (corresponding to CIE 1931 chromaticity diagram's horse shoe's area) can sense correctly very dark black scene and very bright highlights, robustly, while a consumer legacy camera or display could capture or render an SDR image with narrow color gamut, as shown in Table 1, [1]. Traditional legacy content standards and ecosystems have been developed focusing on the SDR specification, based on the old CRT display.

Table 1 Comparison of SDR and HDR [1].

Items	SDR	HDR
Peak luminance	~500 nits	1K~10K nits
Camera DR	50dB	120dB
Display CR	1:1K	1:1000K
Quantization	8b to 10b	FP or variable
Color Gamut	BT.709/sRGB	BT.2020/P3
Fidelity	Display-limited	As good as HVS

As shown in Fig. 1, HDR content can express more details and more natural colors, well, compared to legacy SDR content.

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Fig. 1 A pair of SDR and HDR images.

As we can see in Fig. 1, the HDR image appears to be even clearer and more colorful than the SDR image.

2.2 HDR: TONE MAPPING (TM)

As shown in Fig. 1, HDR tone mapping is a HDR-to-SDR down-conversion technology, which needs to render real-life-like HDR contents with high dynamic range and wide color gamut (e.g: mastered on a reference display with peak luminance 4,000nits and BT.2020 color) well onto a limited SDR display with relatively lower dynamic range and smaller color gamut (e.g: peak luminance 100nits and BT.709 color). This tone mapping can be considered to be “color volume mapping of HDR to SDR” in a wide sense. Thus, a number of such studies have been proposed to make the original HDR content on the reference display and the tone-mapped SDR content on the SDR display have perceptually similar visual appearance.

2.3 HDR: INVERSE TONE MAPPING (iTM)

As shown in Fig. 1, HDR inverse tone mapping is to synthesize pseudo-HDR content from legacy SDR content. As is commonly known, the legacy SDR content does not have enough information such as visual details and colors over the highlight and black image region. Thus, this SDR-to-HDR reconstruction belongs to a kind of ill-posed problems. In the area of camera imaging devices, to solve this problem, some computational photography technologies were developed by capturing differently exposed multiple camera images and combining them without occurrence of ghost artifacts [1]. Recently, some unique approach was proposed to reconstruct similar camera raw image (as a kind of HDR image) by using its corresponding JPEG image and some camera ISP parameters (as a metadata), which enables convert the JPEG image into the original camera raw image [4].

On the other hand, in the TV domain, in general there is no useful camera capturing information within the legacy SDR content, some heuristic rules or assumptions on such highlight and black information are applied for effective and automatic HDR up-conversion.

3. HDR STANDARDS AND SYSTEMS

3.1 HDR TV Standards

All content service ecosystem members including studios, OTTs, TV/STB manufacturers, and etc. needed to prepare brand-new open standards for HDR as a next big thing to current UHD media service [2][3][5][6]. As listed in Table 2, several standards have been formulated for every aspect of HDR content production, distribution, and display. More specifically, **the UHD-Alliance** is as follows:

- Resolution: 3840 x 2160
- EOTF: SMPTE ST 2084 (PQ)
- Color: 10 bit, BT.2020 (Representation),
  Display reproduction (DCI-P3 90%)
- Valid DR: 0.05~1000nits (LCD),
  0.0005~540 nits (OLED)

And **the HDR10 media profile** is as follows:

- EOTF: SMPTE ST 2084 (PQ)
- Color: 4:2:0, 10 bit, BT.2020
- Metadata: SMPTE ST 2086 , (MaxFALL, MaxCLL)

Table 2 Some HDR TV standards [2][3][5][6].

Organizer	HDR
SMPTE	- ST 2084: PQ EOTF (10-/12-bit quantization of absolute luminance) - ST 2086: static metadata (to mastering display & contents) - ST 2094: dynamic (content-dependent) metadata
ITU-R	- BT.2020: wide color gamut for UHD TV system - BT.2390-0: requirements of HDR television systems
CTA	- guidelines for a TV, monitor, or projector as and HDR-compatible display - HDR10 media profile
UHD-A	- a multi-industry alliance for ULTRA HD PREMIUM standards and certification promotion - HDR10 media profile
BDA	- new UHD BD specs for HDR, - mandatory: HDR10 media profile

3.2 HDR10 Delivery System

The HEVC Main 10 profile compression is enough for the delivery of 10 bit 4:2:0 format HDR10 video. This open platform is not a complete standard, but a collection of technologies and specifications [2][3][5][6]. In Fig. 2, the OOTF (Optical optical transfer function) block conducts live or offline color-grading, yielding a SMPTE ST 2086 static metadata (global info about mastering display and mastered content), and the pre-processing block does the 10bit quantization, color conversion and chroma subsampling. The display adaptation block in the TV side of Fig. 2, performs some color volume mapping to minimize the difference between the mastering display and play-back display.

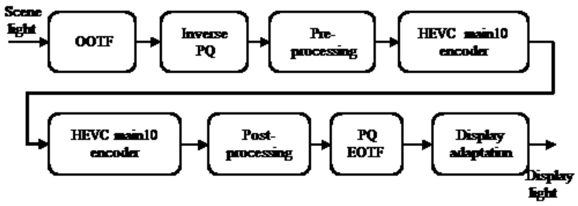

Fig. 2 The HDR10 based HDR Delivery System.

4. HDR MEDIA CE DEVICES

At first, the HDR technology has been studied in the area of graphics engine and camera imaging. As mentioned earlier, already camera industry started to release consumer cameras with a functionality of automatic HDR image capture based on use of multi-frame post-processing SW technology or HDR sensor-based HW technology. In the case of using the HDR sensor, the HDR imaging technology has been being considered to be a core technology for the development of self-driving car. On the other hand, in case of the TV industry, to boost the sale of both premium 4K UHD TVs and premium content services, HDR technologies have been actively adopted into traditional TV value chain since 2014. Currently, STB industry also began to handle the HDR content service on its STB device. Furthermore, some smart-phones manufacturers enabled play HDR content services on their mobile display with HDR capability.

Fig. 3 Examples of the HDR CE devices.

5. CONCLUSIONS

As a next big thing to current 4K UHD media, High dynamic range (HDR) technologies are employed actively into CE display/imaging products. This trend helps to boost the market size of premium CE visual products like 4K UHD TV, cutting-edge smart phones, HDR content streaming services, and etc. First of all, all HDR content service ecosystem members have got together to build HDR open standards (e.g: HDR10 media profile adopted by UHD-Alliance) and to make, distribute, and display HDR contents (/movies) according to the open standards. Basically, these standards handle the case of HDR down-conversion of rendering the original HDR contents graded on a reference mastering display onto a playback display with relatively lower dynamic range and color gamut. Thus, several parameters such as luminance and color info about the mastering display and mastered content were standardized as a metadata (e.g: SMPTE ST 2086 or SMPTE ST 2094). Additionally, to minimize bandwidth of HDR contents distribution, first the HDR content is converted into corresponding SDR content and some metadata, and then the SDR content is compressed by HEVC Main10 profile, along with its metadata. In the display side, the decoded SDR content and its metadata are used to reconstruct the original HDR content. On the other hand, the amount of HDR premium contents available are absolutely insufficient, compared to the case of the legacy SDR contents. Thus, SDR-to-HDR reconstruction (or inverse tone mapping) without metadata have been studied hard. However, since the resulting HDR appearance is not satisfactory, new alternative approach for effective inverse tone mapping is required.

For the success of HDR media services and products as a mainstream in the CE market, new cutting-edge HDR display panel technologies as well as the mentioned HDR signal processing technologies should be developed seamlessly being closely coupled.

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