On the Consideration of New Color Space for Next Generation Media

Du Sik Park, Seo Young Choi, Ho Young Lee, Yun Tae Kim, Ji Young Hong and Chang Yeong Kim
Multimedia Lab, SAIT, Samsung Electronics, Yongin, Gyeonggi-do, 446-712, Korea
Tel.:82-31-280-6615, E-mail: dusikpark@samsung.com

Keywords: UHDTV, 3D-TV, Color Space, Wide Gamut, Display Referred Space

Abstract

The current study introduces a new color space applicable to next-generation media such as UHDTV and 3D-TV systems that are in the middle of development. Display referred approach was taken into account rather than scene referred approach for deriving a new RGB-primary set forming the new color space. The reproducible color range generated by the newly suggested RGB-primary set encompasses almost entire real-world surface colors with a very good efficiency.

1. Introduction

Original scenes captured using video cameras are generally recorded and processed according to the encoding schemes defined by world-wide agreed technical standards. For producing and internationally exchanging HDTV programs, Recommendation ITU-R BT. 709 is currently used by television communities [1]. This mainly defines reference RGB primaries forming a reproducible color region (color gamut), an opto-electronic transfer function for perceptually uniform coding, and conversion matrices creating luminance-like and color-difference signals that are further used for compression.

Beyond HDTV, Ultra High-Definition TV (UHDTV) and 3D-TV are considered to be future TV systems and to be able to offer an improved visual experience to viewers, especially, in the aspect of realistic sensation and faithful reproduction of visual information. In the case of UHDTV, these benefits can be achieved by providing a wide field of view covering all of the human visual field due to UHDTV characteristics having a very large size display greater than at least 60 inches with four or sixteen times higher pixel resolutions (3840×2160 or 7680×4320) than HDTV. Flat panel displays such as LCD and AMOLED will be promising candidates for handling this large size and high resolution.

ITU-R BT.709 previously introduced was established based on CRT displays' intrinsic properties and so its color gamut is not large enough to encompass the real-world surface colors' gamut [2]. At present, the color gamut of flat panel displays tend to be larger than that defined in ITU-R BT.709 due to deeper RGB-primary set, multi-primary color addition to RGB or enhancing color gamut of backlight for LCD etc. [3-7]. This indicates that a new color space is required for next-generation displays such as UHDTV and 3D-TV applications whose contents will be rendered on flat panel displays, not a CRT. Not only reflecting this point, but also considering other technical issues, standardization activities for UHDTV and 3D-TV broadcasting systems are currently in process within International Telecommunication Union Radiocommunication Sector (ITU-R). Therefore, the present work attempted to derive a new RGB primary set for a new color space that will be appropriate for the future media.

2. Methods

Real-world surface color data – Pointer's 576 gamut boundary colors in 1980 and ISO's Standard Object Color Space (SOCS) database in 2003 – were used to derive a new RGB-primary set suitable to next-generation media and to evaluate the derived set [8,9]. Both data sets of Pointer and SOCS were obtained by measuring a huge number of natural and artificial objects' colors. Pointer developed the real surface-color gamut under CIE illuminant C from 4089 high-chroma samples. ISO collected a total number of 53499 of large reflectance and transmittance source data for existing objects in the world and produced the SOCS database.

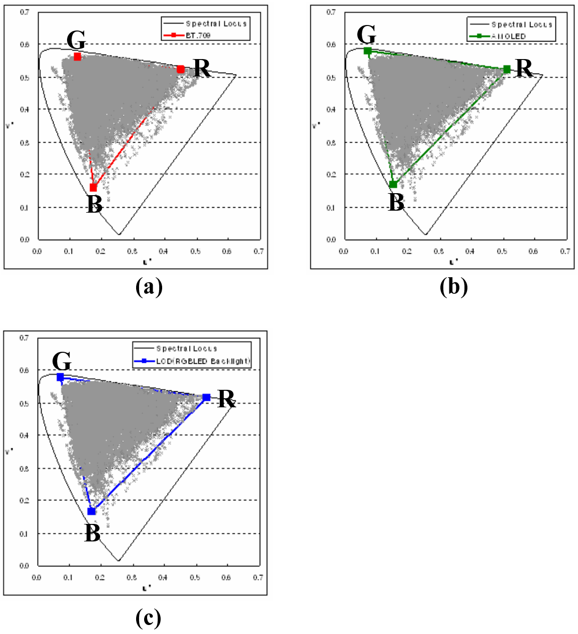


Fig. 1. Comparison of the real surface colors (×) in the CIE u′v′ diagram with (a) the gamut of ITU-R BT.709 (—), (b) the reproducible color range by the AMOLED (—), and (c) the reproducible color range by the LCD equipped with an RGBLED backlight (—).

Figures 1(a) – 1(c) compare the real surface colors of Pointer and SOCS database with the reproducible color gamut of ITU-R BT.709, AMOLED and LCD in the CIE u'v' chromaticity diagram. The RGB primary data of the AMOLED and the LCD given in figures 1(b) and 1(c) were obtained by measuring the RGB primary colors of the AMOLED and the LCD equipped with an RGBLED backlight that were produced by Samsung. The gamut of ITU-R BT.709 in Figure 1(a) cannot cover all the real surface colors particularly in green-blue and red-blue regions. It is however examined in figures 1(b) and 1(c) that the AMOLED and the LCD, which will be used to present UHDTV or 3D-TV contents in the near future, can encompass majority of the real surface colors. This indicates that a new color space for UHDTV or 3D-TV systems should include a great portion of the real surface colors.

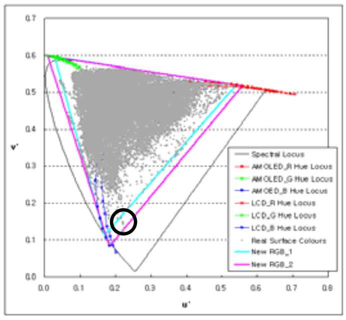


Fig. 2. The real surface colors (●), the RGB hue locus of the AMOLED (■, ■, ■) and the LCD equipped with a RGB LED backlight (□, □, □), and the reproducible color ranges by two derived RGB-primary sets 1 (cyan line) and 2 (magenta line) in the CIE u′v′ diagram.

TABLE 1. Chromaticity coordinates (CIE u′v′) for the two derived RGB-primary sets.

New RGB-primary set	Red	Green	Blue
1	0.540, 0.519	0.028, 0.595	0.168, 0.112
2	0.557, 0.517	0.009, 0.597	0.183, 0.082

The two key factors were therefore employed to establish new RGB primaries shaping a new color space for the future displays: (1) the overlapped gamut region between the real surface colors' gamut and the gamut generated by a new RGB-primary set should be the maximum, and (2) the position of new RGB primaries should be placed to be close to the constant hue lines of the RGB primaries of the AMOLED and the LCD. Two candidates for the new RGB-primary set were selected in accordance with these two factors. Figure 2 shows two sets of the reproducible color gamut created by the two selected new RGB primaries 1 and 2 in the CIE u'v' diagram, which are symbolized using cyan and magenta triangles respectively. Table 1 introduces the chromaticity coordinates of these two RGB primary sets. The constant hue lines of the RGB primaries of the AMOLED and the LCD are also seen in Figure 2. Individual data points (open or filled squares) on each of the constant hue lines have different chroma values but identical hue. The grey points in Figure 2 represent the real surface colors composed of Pointer and SOCS database. The reproducible color gamut from the RGB-primary set 1 indicated by cyan line excludes few colors marked by a black circle which fall into very low lightness range but possess high chroma interval, whereas that indicated by magenta line covers all the real surface colors.

3. Results and discussion

The two RGB-primary sets 1 and 2 determined in the previous section were evaluated in terms of gamut coverage (see Eq. (1)) and gamut efficiency (Eq. (2)) in the comparison with a reference gamut. The reference gamut was established for the current study from the real surface colors (Pointer and SOCS database) and the reproducible colors by the RGB primaries of two flat-panel displays (the AMOLED and the LCD in figures 1 (b) and 1(c)), and of three standard color spaces (ITU-R BT.709, Adobe RGB [10], and NTSC [11]). The gamut-coverage and -efficiency were obtained by computing a gamut boundary and then gamut volume in the three-dimensional CIELAB space. The segmentation maxima method was adopted to calculate the gamut boundary [12]. In the computation of the CIE $L^*a^*b^*$ values, D65 was used as a reference white.

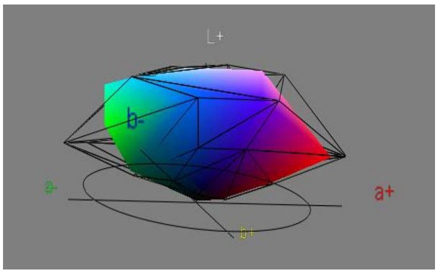
$$Gamut\ Coverage = \frac{target\ gamut \cap reference\ gamut}{reference\ gamut} \quad (1)$$

where target gamut is the gamut generated from the new RGB primary set, reference gamut is the gamut created from the real surface colors, the flat panel displays and the standard color spaces, the numerator represents overlapped volume between the target gamut and the reference gamut, and the denominator indicates the reference gamut's volume.

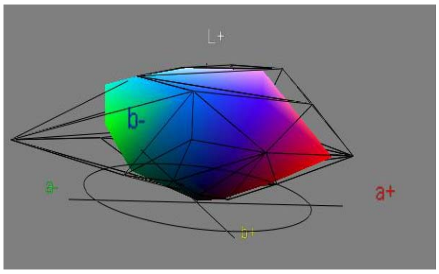
$$Gamut\ Efficiency = \frac{reference\ gamut}{tartet\ gamut} \quad (2)$$

where the numerator and the denominator represent the reference gamut's volume and the target gamut's volume respectively. If the reference gamut's volume is larger than target gamut's volume, the inverse ratio of Eq. (2) is calculated for the gamut efficiency.

The gamut coverage describes how much the target gamut covers the reference gamut made of natural and artificial colors available in the world. The gamut efficiency shows how efficiently the target gamut encompasses the reference gamut. The computed gamut-coverage and -efficiency were 98 % and 74 % for the RGB primary set 1 indicated by cyan line, and 98 % and 63 % for the RGB primary set 2 represented by magenta line in Figure 2. Figures 3(a) and 3(b) illustrate these differences in the reproducible color gamut by the two RGB-primary sets (symbolized by black wire) against the reference gamut (symbolized by solid). The two sets of the black-wire gamut are seen to cover the reference gamut equally well, i.e. 98%. It is however examined that the black-wire gamut in Figure 3(a) surrounds the solid gamut more efficiently with smaller non-overlapped volume between them than that in Figure 3(b). Therefore, the RGB primary set 1 (indicated by cyan line in Figure 2 and black wire in Figure 3(a)) can be considered to be appropriate for the future media such as UHDTV and 3D-TV applications.



(a)



(b)

Fig. 3. Comparison of the reference gamut (solid) with (a) the gamut (black wire) created by the new RGB-primary set 1 indicated by cyan line in Figure 2 and (b) the gamut (black wire) generated by the new RGB-primary set 2 indicated by magenta line in Figure 2.

The colors which are able to be presented by additively mixing the chosen RGB primary set 1 were quantized according to the encoding scheme defined in ITU-R BT. 709. The quantization interval was then computed using average and maximum of color-difference values (ΔE^*_{ab} in CIELAB) occurring from all possible combinations of consecutive quantized levels. The calculated quantization interval using 8-bit length was average ΔE^*_{ab} of 0.7 and maximum ΔE^*_{ab} of 2.3. These results are comparable with the quantization interval for ITU-R BT. 709 having average ΔE^*_{ab} of 0.5 and maximum ΔE^*_{ab} of 2.0.

Considering ITU-R BT. 709 is used all over the world for HDTV broadcasting applications, it can be concluded that the newly suggested RGB-primary set having the comparable quantization interval to ITU-R BT.709's will not cause noticeable contour artifacts.

4. Summary

The present work introduced a new RGB primary set forming a new color space applicable to next-generation media such as UHDTV and 3D-TV systems. As the world-wide agreed standard for HDTV systems, ITU-R BT. 709, was proposed based on the CRT's characteristics, the current work took account of the flat panel displays' properties, which will be used to present UHDTV and 3D-TV contents. Additionally, a real-world surface-color database was also considered in the determination of an appropriate RGB-primary set.

The color region reproduced by the newly proposed RGB-primary set could cover up to 98 % of the reference gamut with high gamut-efficiency of 74 %. The hue of the derived RGB-primary colors was located as close as that of both the AMOLED and the LCD. It was also demonstrated that the colors reproduced using the proposed RGB-primary set could be quantized with similar quantization-error to that occurred in ITU-R BT.709.

5. Future Works

Only part of the new color space for next-generation media such as UHDTV and 3D-TV systems was given in the current study; specification of colorimetric values (XYZ) for new RGB primaries. This can be expressed as a matrix relating device-dependent RGB signals to device-independent XYZ signals. Hence, the same RGB signals generated by different video cameras can be assigned to have identical colorimetric values if the camera RGB signals are transformed to the XYZ values according to that matrix.

The remaining part of the new color space is to define an encoding scheme for creating luminance-like and color-difference signals that can be used for compressing the size of the image corresponding to the original scene captured by a video camera. In the compression stage, two color-difference signals that generally mean 'Yellow-Blue' and 'Red-Green' differences are sub-sampled whereas luminance-like signals are maintained. If the color-difference signals include luminance information due to incomplete separation between luminance-like and color-difference signals, more visible artifacts tend to be viewed from the resulting images after compression. Therefore, the future work aims to derive a new conversion method through which an accurate separation (zero crosstalk) between luminance-like and color-difference signals is achieved. If there is no crosstalk between these signals, sub-sampling rates using the color-difference signals can be increased than the existing 4:2:2 or 4:2:0 sub-sampling case. This can contribute to improve compression ratio for UHDTV and 3D-TV applications having much more visual-information to be recorded/transmitted than HDTV systems.

6. References

1. Recommendation ITU-R BT. 709-5 (2002).
2. T. Matsumoto et al., *SID'06 Technical Digest*, p.1130 (2006).
3. J. Someya et al., *SID'06 Technical Digest*, p.1134 (2006).
4. D. S. Park et al., *The 1st Int. WS on IMQA*, p. 24 (2005).
5. H. W. Ok et al., *ICIP*, p. III-980-3 (2005).
6. C. Y. Kim et al., Proc. SPIE, p. 6058E-1, (2005).
7. L. Beke et al., J. Elec. Imag. **17[2]**, p. 0230112-1 (2008).
8. M.R. Pointer, *Col. Res. Appl.,* **5[3]**, p.145 (1980).
9. ISO/TR 16066 (2003)
10. Adobe® RGB Color Image Encoding, Adobe Systmes Incorporated (2005).
11. SMPTE 170M-2004 (2004).
12. J. Morovic et al., *Col. Res. Appl.,* **25[6]**, p.394 (2000).