Subjective Evaluation Due to Desaturation of Primary Colors of UHD Display

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ABSTRACT

It has been considered that changes in the primary colors of the display affect the color reproduction when the color gamut is extended to UHD. In this study, using a wide color gamut image how the color impression of the image changes when the saturation of the three primary colors of the display is changed independently was evaluated. The results showed that differences in the saturation of the primary colors had effect on the perception of the colors in the image when the image contained a lot of red and green colors.

1 Introduction

The standard for UHD displays, which has become widespread in recent years, is called BT.2020, and is defined as having higher resolution, wider color gamut, and high dynamic range than the current BT.709 standard for HD imaging devices, which dramatically increases the amount of information [1][2].

UHD display are being considered not only for use in the media and other entertainment fields, but also for use in medical, industrial, and other fields that require strict color management. It is considered important for displays used in the entertainment field to give a good impression to users. However, displays used in the medical and industrial fields are used by the human, that it can be reproduced accurately for a human observer that will make the observer perceive the reproduction as looking like the original is required[3].

With the shift from HD to UHD color gamut, the saturation of primary colors has increased. Since the color displayed on a display is determined by the intensity ratio of the primary colors of the display, the change in chromaticity of the primary colors from HD to UHD affects the color reproduction when the same image is displayed.

In a previous study, a subjective evaluation of the effect of decreasing the three primary colors saturation of all pixels on of a display was conducted [4][5].

In this study, the three primary colors of the display were changed independently, and the change in the impression of the color of the image was evaluated using a UHD-compatible display. From the evaluation results, the change in perception of image color change and each primary color of the display were examined, when the saturation of each of the primary colors of the display was decreased.

2 Saturation reduction method

2.1 Colors displayed on the display

The colors displayed on a display are made by the three primary colors, RGB. In the XYZ color system defined by CIE, colors can be expressed as XYZ stimulus values, and additive color mixing is established among stimulus values. Therefore, an arbitrary color displayed on a display corresponding to the input gray scale is converted to XYZ tristimulus using Equations 1 and 2.

$$\begin{cases} R_s = \left(\frac{R_{tone}}{MaxTone}\right)^{\gamma} \\ G_s = \left(\frac{G_{tone}}{MaxTone}\right)^{\gamma} \\ B_s = \left(\frac{B_{tone}}{MaxTone}\right)^{\gamma} \end{cases} \quad (1)$$

$$\begin{pmatrix} X_{out} \\ Y_{out} \\ Z_{out} \end{pmatrix} = \begin{pmatrix} X_R & X_G & X_B \\ Y_R & Y_G & Y_B \\ Z_R & Z_G & Z_B \end{pmatrix} \begin{pmatrix} R_s \\ G_s \\ B_s \end{pmatrix} \quad (2)$$

The display's tone value is converted to a signal value that matches the gamma characteristics of the display using Equation 1. The signal values of the display are converted to the XYZ tristimulus values using Equation 2.

In Equation 1, Rtone, Gtone, Btone, Rs, Gs, Bs, MaxTone, and γ are the RGB input gray scale, RGB signal value, maximum gray scale value, and gamma value, respectively. Rs, Gs, and Bs in Equation 2 are the converted RGB signal values, and Xj, Yj, and Zj (j =R, G, and B) are the XYZ tristimulus values when the highest tone of the primary colors of the display is displayed, respectively. Xout, Yout, and Zout are XYZ tristimulus values of the output color, respectively.

$$\begin{pmatrix} R_s \\ G_s \\ B_s \end{pmatrix} = \begin{pmatrix} X_R & X_G & X_B \\ Y_R & Y_G & Y_B \\ Z_R & Z_G & Z_B \end{pmatrix}^{-1} \begin{pmatrix} X_{in} \\ Y_{in} \\ Z_{in} \end{pmatrix} \quad (3)$$

By Equation 3, which uses the XYZ tristimulus values before saturation reduction, the signal value of after saturation reduction is obtained.

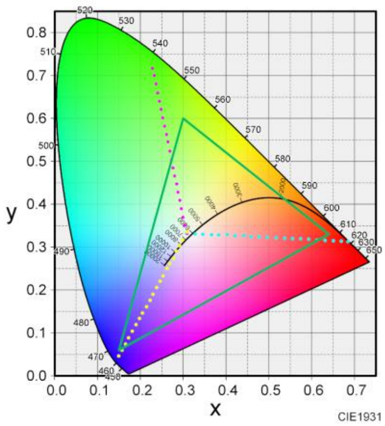


Figure1. Chromaticity transition of primary colors and comparison with BT.709

2.2 Decrease in saturation of the primary colors

In order to obtain the XYZ tristimulus values of the primary colors of the display after saturation reduction, the saturation is changed on the xy chromaticity diagram using equation 4.

$$\begin{cases} x' = x - (x - xw) \times t & (0 \le t \le 1) \\ y' = y - (y - yw) \times t & (0 \le t \le 1) \end{cases} \quad (4)$$

In Equation 4, x, y, x', y', are the chromaticity coordinates of the original color, the chromaticity coordinates after saturation reduction. In Equation 4, xw, yw, and t are the chromaticity coordinates of white color, and the saturation reduction rate, respectively. As the ratio of the saturation reduction rate t increases, the chromaticity coordinates of the original color become closer to those of the white color.

The obtained xy chromaticity coordinates are converted to XYZ tristimulus values using Equation 5, and the XYZ tristimulus values after saturation reduction are obtained.

$$\begin{cases} X = \frac{x}{y} Y \\ Z = \frac{1-x-y}{y} Y \end{cases} \quad (5)$$

Since the stimulus value Y is luminance, the Y before saturation reduction is used to keep unchanged.

Figure 1 shows the chromaticity coordinates of the primary colors when the saturation reduction rate t is varied from 0 to 100% in 5% steps.

Figure 2 shows the transition of luminance of the primary colors when the saturation reduction rate is varied from 0 to 100% in 5% steps.

From the figure1, figure2, it is confirmed that when the saturation of the primary colors is decreased, the saturation decreases at a constant level and the luminance is maintained at a constant level.

2.3 White balance processing

By reducing the luminance of one of the primary colors and adding the luminance of the other two primary colors, the saturation is reduced while maintaining the luminance.

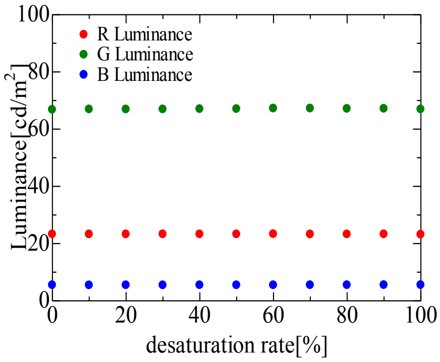


Figure2. Luminance change when the saturation of the primary colors is reduced.

When an image is converted without processing the other two primary colors compensation, the XYZ tristimulus values of the primary colors changes, which causes a problem of color temperature change. For this reason, the color temperature of white color is kept constant by using Equation 6 to keep the color temperature and luminance of white color constant.

$$\begin{cases} C_0' = \frac{S_0 \times C_0 + S_1 \times C_1 + S_2 \times C_2}{S_0} \\ C_1' = \frac{(S_0 - S_1) \times C_1}{S_0} \\ C_2' = \frac{(S_0 - S_2) \times C_2}{S_0} \end{cases} \quad (6)$$

C_0, C_1, and C_2 in Equation 6 indicate the XYZ tristimulus values of the primary colors before saturation change, respectively. C'_0, indicates the XYZ tristimulus value of the primary color whose saturation is decreased, and C'_1 and C'_2 indicate the XYZ tristimulus value of the primary color whose saturation is not decreased, respectively. S_0 is the signal value of the primary color that was decreased when saturation was decreased, and S_1 and S_2 are the signal values that were added when saturation was decreased. In Equation 6, subtraction is performed for the primary colors added to the rest of the primary color whose saturation was reduced by the amount added. Since the saturation is decreased to keep the luminance of the primary colors constant, the luminance decreases when white is displayed.

For this reason, the luminance of white color is kept constant by dividing by the signal value of the saturation to be reduced.

Figure3 shows the transition of the chromaticity coordinates of colors of R, G, B, Y, C, M, and W when the saturation processing is executed.

3 Decrease in saturation of the evaluation image

The parts of standard images used for subjective evaluation are shown in the figure4[6].

For four different patterns images, the saturation of each primary color was reduced by 0%, 10%, 20%, 25%, 30%, 35%, 40%, 45%, and 50%, respectively. A total of 100 pictures were created.

(a) (b) (c)

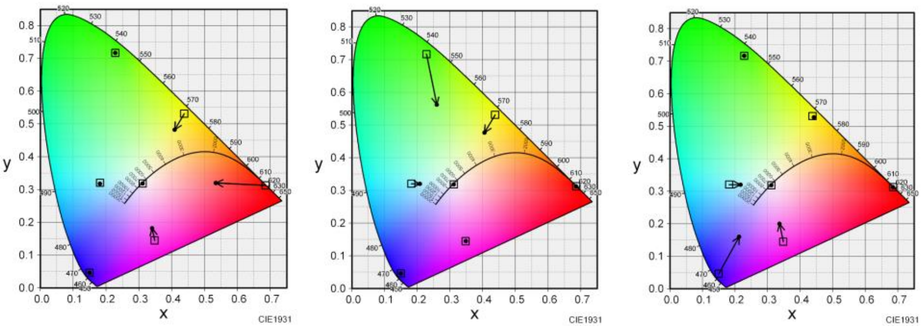


Figure3. Saturation changes when saturation is reduced by 40%. (a) Decrease red saturation by 40% (b) Decrease green saturation by 40% (c) Decrease blue saturation by 40%

(a) (b) (c) (d)

Figure4. Evaluation image. (a)Flowers (b)Moss (c)Butterflies (d) Stained Glass

Table1 Evaluation contents

Rating	Evaluation Words
5	The color difference is not perceived
4	The color difference is perceived, but it is not annoying
3	The color difference is perceived, but it's not noticeable
2	The color difference is annoying , but it is tolerable
1	The color difference is annoying, but it is intolerable

4 Subjective evaluation

4.1 Subjective evaluation method

Using the images before and after the decrease in saturation, subjective evaluation was conducted to see how people perceive the difference in color when the saturation is decreased.

The double-stimulus impairment scale method was used as a subjective evaluation method[7]. A total of 100 sets of images are presented to 21 subjects. The subjective evaluation was done twice, the first time having the subjects get used to the test and the room brightness, and the results of the second time were used as the experimental data.

First a reference image was shown to the subject for 3 seconds. Next, an achromatic image was shown to the subject for 3 seconds. Then the subject was shown an image with reduced saturation. Finally, the achromatic image was shown and evaluated by the subject.

The order of the images and the rate of decrease in saturation are presented to the subjects in a random order, so that the psychological effects on the subjects depending on the order of presentation are averaged out. Subjective evaluation was done twice per subject.

The first evaluation was done to let the subject get used to the environment, and the result of the second evaluation was used as the experimental data.

The rating values of the subjective evaluation are shown in Table 1. Since the reference image was processed to maintain not only the saturation but also the white balance, the subjects were asked to answer the evaluation terms, which were set in five levels, whether they could recognize the difference in colors, including the difference in saturation and the difference in brightness.

4.2 Results

The results of the mean opinion score (MOS) for each color, each image, and each saturation reduction rate are shown in Figure5.

From the subjective evaluation, no difference in color was perceived even when the saturation was decreased up to 10% of each primary color. When saturation was reduced by more than 20%, the perception of color differences is greater in images that contained more colors with reduced saturation.

In addition, when the saturation of red was decreased, the decrease in saturation was perceived more clearly than when the saturation of the other primary colors was decreased.

When compared to the BT.709 gamut, the saturation is equal when the saturation of the primary colors R, G, and B of the display is reduced to approximately 25%, 40%, and 10%, respectively. When the saturation of red was reduced, the difference in color was clearly perceived in images with high saturation colors, such as "Flowers" and "Butterflies". The change in saturation was perceived less clearly in images with low saturation colors. When the saturation of green was reduced by 40%, the difference in color was perceived more clearly in images that contained more green colors. The images fewer green colors showed less perceived color difference. When the saturation of blue was reduced by 10%, the perceived difference in color was small in all images.

The human eye perceives a greater difference between the colors displayed in HD and UHD when green and red with high saturation are displayed.

In the previous study, when the saturation was decreased for three primary colors, the change in perception of the decrease in saturation was different depending on the picture pattern[4][5]. As in the previous study, the perception of the difference in color was smaller in the "Stained Glass" image than in the other images when the saturation was decreased.

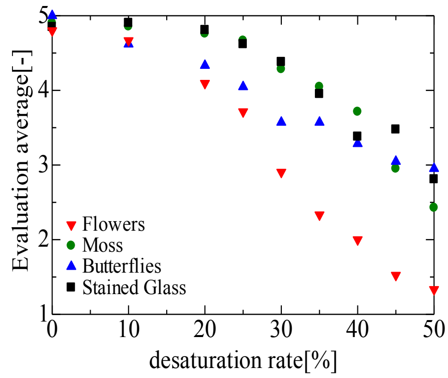
5 Conclusions

In this study, a subjective evaluation was conducted to investigate the changes in the perception of the human eye in response to the changed color saturation of displays due to the shift from HD to UHD color gamut.

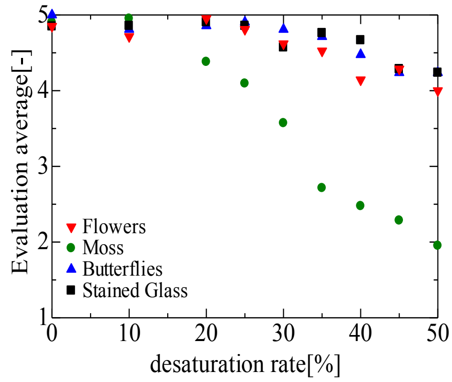
The saturation of the red and green primary colors of the UHD was larger than that of HD. From the subjective evaluation, when image containing many red and green colors, the difference in saturation of the primary colors has a strong effect on the perception of the colors in the image.

Currently available UHD-compatible displays differ in the saturation of the primary colors for each display. Therefore, when an image containing many red and green colors is displayed, it is considered that differences in saturation affect the color perception of images viewed by humans for each display.

(a)



(b)



(c)

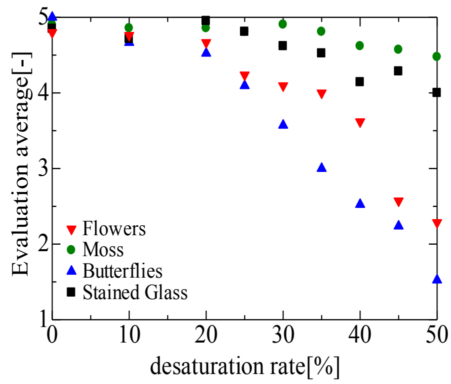


Figure5. MOS of subjective evaluation results by 21 subjects. (a) MOS when red saturation is reduced. (b) MOS when green saturation is reduced. (c) MOS when blue saturation is reduced.

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