Subjective evaluation of required area of color gamut for preferred color reproduction using a laser light source display

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Abstract

This paper describes a result of subjective evaluation of color gamut required for preferred color reproduction by using a display with laser light sources. The results indicate three matters: (1) the maximum chroma of the required color gamut on a display is found in several hues; (2) the maximum chroma changes depending on image contents; (3) it is expected that the color gamut required for preferred color reproduction is correlated with the pseudo-optimal colors.

In this evaluation, test images were presented on a laser light source display in a dark room with varying chroma values. Evaluation was made with five-grade score. The scores were expected to decrease after exceeding a certain chroma. The chroma level was the limit of the color gamut required for preferred color reproduction.

We evaluated six kinds of images with different hue of red, green, and blue with two lightness levels. For each color, one image was of a natural object, such as a leaf, sky and a rose. The other was of an artificial object, specifically a ball shape. The objects of each image consisted of similar colors.

Introduction

The color gamut of displays continues to increase with enabling colors to be represented on displays more vividly than ever before. In some cases, however, the colors are too vivid to result in an unnatural look. As a consequence, subjects of great interest have been focused on finding a color gamut necessary for displaying vivid colors that look natural, and various findings on this subject have been reported [1]~[6].

We reported the results of subjective evaluation of a color gamut required for a preferred color reproduction on a wide gamut display using the Adobe RGB color space. It was found that the Adobe RGB gamut was not wide enough and a wider gamut display had to be used for this purpose [7].

Our last paper described the result of subjective evaluation by using a pseudo ultra-wide gamut display. The color gamut of the display was wider than optimal colors in some areas with high lightness. The results indicate that the maximum chroma of the required color gamut is near optimal color in the high lightness areas [8]. But the last study could not reveal the gamut in the lower lightness areas.

In this study, we have conducted evaluations subjectively by using a display with laser light sources which has wider color gamut than the Adobe RGB and the gamut of the pseudo ultra-wide gamut display especially in the area with lower lightness. And it has the top level extent of color gamut among all displays.

Subjective Evaluation

Procedure of evaluation

Figure 1 shows the conditions of the subjective evaluation. In this evaluation, test images were shown on a laser light source display in a dark room with varying chroma values. Evaluation was made with five-grade score (5: Excellent, 4: Good, 3: Fair, 2: Poor, 1: Bad). Subjects were permitted to answer using decimals. The scores were expected to decrease after exceeding a certain chroma level. The chroma level was the limit of the color gamut required for preferred color reproduction.

The subjective evaluations were conducted as follows.

step 1. Adaptation to the viewing condition (5 minutes)
step 2. Evaluation of the practice images (5 images)
step 3. Evaluation of the test images (38 images)

In step 1, subjects were viewing a gray image (J=50) for five minutes to adapt the luminance of display. The practice images in step 2 were selected from the test images. The subjects were not told that the images were for practice. The test images in step 3 were presented in random order. After each image, the subjects viewed a gray image before looking at the next image to reduce the temporal contrast effect.

Thirty people cooperated for our experiments (15 male and 15 female, ages 20-25).

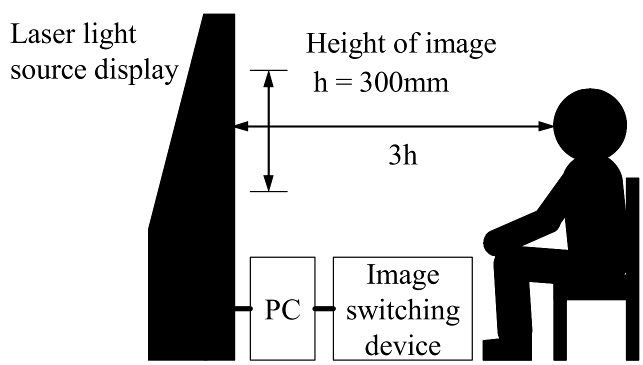

***Figure 1**. Conditions of subjective evaluation*

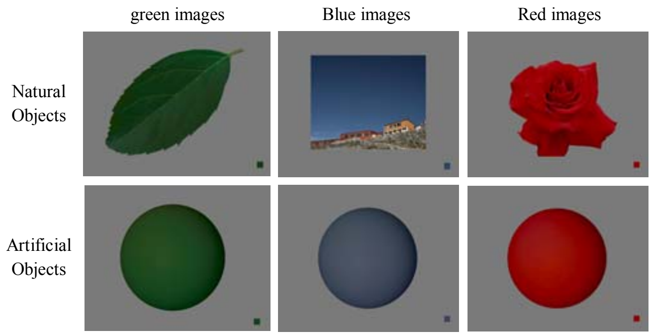

Figure 2*. Test images*

Table 1: The average colors of the test images

Color (object)	Light- ness	Hue (deg)	Chroma
Green	J = 60	h = 141	C = 25 ~ 115 (7 levels)
(leaf / ball)	J = 25	h = 140	C = 20 ~ 64 (7 levels)
Blue	J = 70	h = 205	C = 25 ~ 73 (7 levels)
(sky / ball)	J = 30	h = 250	C = 30 ~ 88 (7 levels)
Red	J = 60	h = 32	C = 25 ~115 (5 levels)
(rose / ball)	J = 30	h = 32	C = 20 ~ 64 (5 levels)

Test images

Figure 2 shows the test images used in this evaluation. We evaluated six kinds of images with different hue of red, green, and blue with two lightness levels.

For each color, one image was of a natural object, such as a leaf, sky and a rose. The other was of an artificial object, specifically a ball shape. The objects of each image consisted of similar colors and the amount of surface area of the objects in the images was also made to be similar.

The background was gray (with a lightness of CIECAM02 J=50) to regulate adaptation of the eyes and the contrast effect between the object and the background.

Figure 3-[A], 4-[A] and 5-[A] show the average colors of the test images using the CIECAM02 color space. The parameters of CIECAM02 were set to those of a dark condition. The thin and thick black lines were represented the color gamut of Adobe RGB and the laser light source display. In all hues of the test images, the gamut of the laser light source display was wider than that of an Adobe RGB display.

Table 1 shows details of the color of the test images. Five or Seven levels of chroma were set for each hue and the test images were prepared.

Color transformation of Test images

The colors of the original images were transformed so that its average color matched the target color. Its luminance was adjusted in XYZ color space to keep tone of image naturally. Its chroma and hue were adjusted in CIECAM02 color space because CIECAM02 had high uniformity of color appearance.

The Color transformation was conducted as follows for the test images.

- step 1. The colors of the original image were transformed into XYZ (CIE 1931).
- step 2. XYZ was transformed into X'Y'Z' to adjust the luminance of the average color. Specifically Y was multiplied by a ratio of the target luminance to the average luminance of original images. X and Z were multiplied by the same constant.
- step 3. X'Y'Z' were transformed into JCh (CIECAM02).
- step 4. C and h was transformed into C' and h' to adjust the average color of images to the target color. Specifically its chroma C is multiplied by a certain constant, and the hue h was shifted by a constant value.
- step 5. JC'h' was transformed to X"Y"Z".
- step 6. X"Y"Z" was transformed to RGB for a laser light source display.

In step 6, if the colors of any given pixel were outside the Adobe RGB gamut, the colors of the image were compressed to fall within the gamut. The same color compression was applied to all test images of the same hue.

Results and discussions

Gamut required for a preferred color reproduction

Figure 3-[B], 4-[B] and 5-[B] show the experiment scores of test images. The white points are represented the scores of the natural object images and the black points are the scores of the artificial object images.

The scores of the green leaf images (J=60) have decreased after exceeding a certain chroma level. It has been expected that the chroma level was the limit of the color gamut required for preferred color reproduction. The similar feature has been found in the results of the blue sky images (J=30), the red rose images (J=60) and the red ball images (J=60). In the four images, the scores have shown significant differences in the average chroma of images.

The thick gray line of the figure 3~5 shows the optimal color which is a gamut of theoretical object colors. In the red rose images (J=60) and the red ball images (J=60), the chroma with best score has been near optimal color. The features correspond to that of our last study. But in the green leaf images (J=60) and the blue sky images (J=30) the chroma with best score has been lower than the optimal color.

Correlation with the pseudo-optimal colors

The gamut of optimal color is wider than that of realistic objective colors because the spectral reflectance function of optimal color is allowed to have discontinuous value. If the color gamut required for preferred color representation is empirically-derived, there is a possibility that the chroma with best score is correlated with the gamut of realistic objective colors.

The thin and dashed lines show the pseudo-optimal colors. They represent the gamut of realistic objective colors [9]. The parameter δ is correlated with a change of reflectivity with wavelength of lights. It becomes smaller, the spectral reflectance function becomes smoothly and the gamut of pseudo-optimal color becomes narrower. The pseudo-optimal color of $\delta = 0.03$ contains about 100% of the colors of SOCS which is a database of object colors. And the pseudo-optimal color of $\delta = 0.01$ contains almost 90% of SOCS [10] [11].

In the red rose images (J=60) and the red ball images (J=60), the chroma with best score has been higher than the pseudo-optimal color ($\delta = 0.03$). On the other hand, in the green leaf images (J=60) and the blue sky images (J=30) the chroma with best score has been lower than that of the pseudo-optimal color ($\delta = 0.01$). The features might be caused by that green leaf and blue sky are memory colors.

Conclusions and future directions

This paper describes a result of a subjective evaluation of color gamut required for preferred color reproduction by using a display with laser light sources. The result indicates that the maximum chroma of the required color gamut is found in several hues but the chroma changes depending on image contents. It is expected that the color gamut required for a preferred color reproduction is correlated with the pseudo-optimal colors.

In our next study we will conduct evaluations subjectively about more colors and contents to reveal a correlation between a color gamut required for preferred color reproduction and a pseudo-optimal color.

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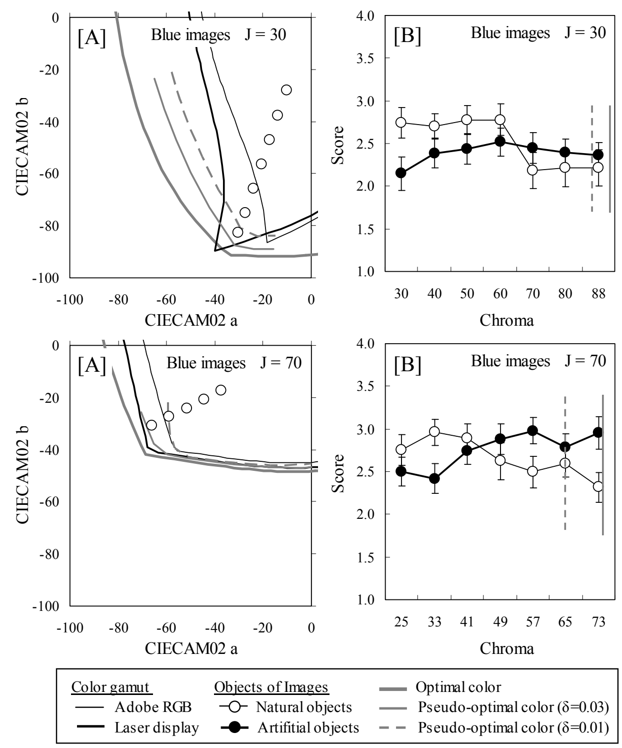

Figure 4. *Average colors of blue images [A] and evaluation results [B]*

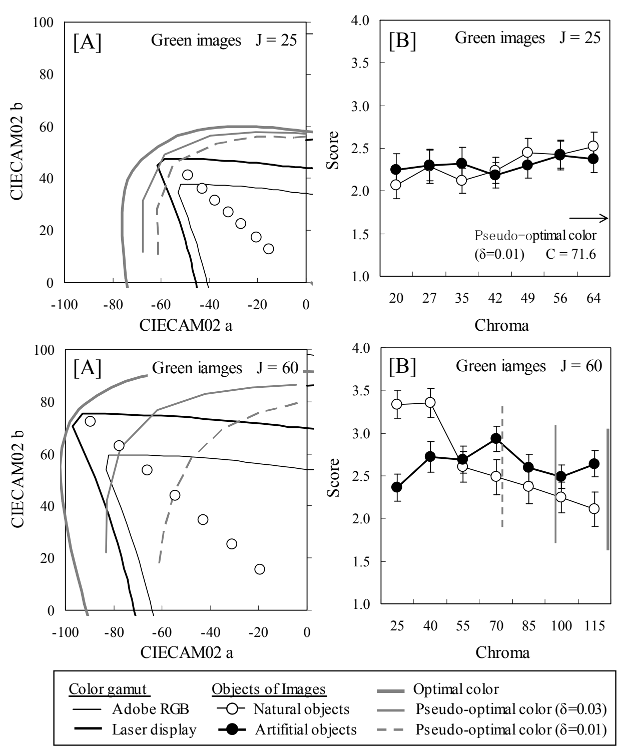

Figure 3. *Average colors of green images [A] and evaluation results [B]*

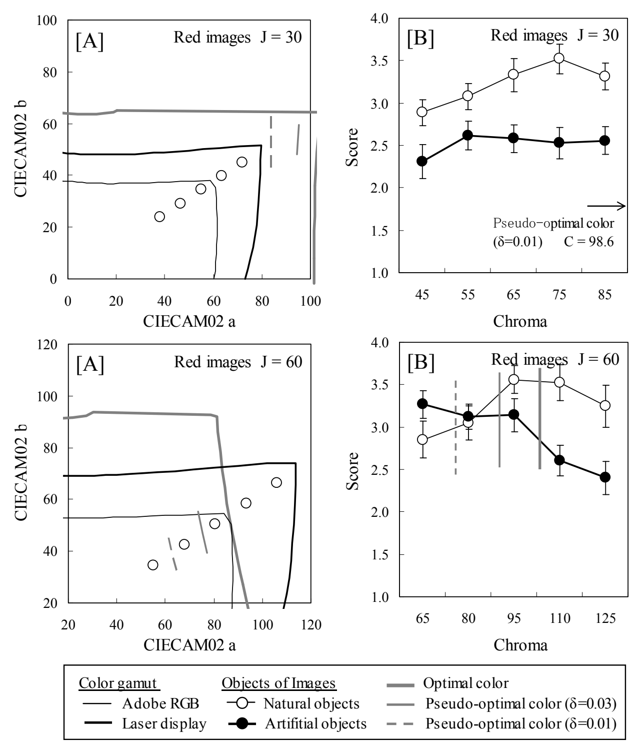

Figure 5. *Average colors of red images [A] and evaluation results [B]*

References

[1] T. Nishimura, M. Ohta, "Preferred Color Reproduction of Color TV Images", TELEVISION GAKKAISHI, 28, 623 (1974).
[2] T. Hirokawa, M. Inui, T. Morioka and Y. Azuma, "Gamut Expansion by Using Object Color Database", Proc. Color Forum JAPAN 2006, pg. 39 (2006).
[3] Y. Kwak, J. Hong, D. S. Park, "Preferred memory and accent colors shown on a display", Jour. SID, 15, 649 (2007).
[4] S. Wen, "A method for selecting display primaries to match a target color gamut", Jour. SID, 15, 1015 (2007).
[5] Y. Hisatake, A. Ikeda, H. Ito, M. Obi, Y. Kawata and A. Maruyama, "The Ergonomics Requirement for Reproducible Area of Color Chromaticity in Electronic Displays", Proc. 13th IDW, pg. 2301 (2007).
[6] S. Ichikawa, Y. Shimodaira, "Acceptable Color Gamut of Images Based on Subjective Evaluation", IEICE technical report, Electronic information displays 107(453) pg.105-108 (2008).
[7] T. Kitano, M. Kanai, H. Kasahara, Y. Koyama, T. Abe, "Evaluation of the preferred color reproduction on a wide color gamut display", Proc. Annual Meeting of SPSTJ 2007, pg.94-95 (2007)
[8] M. Kanai, T. Kitano, H. Kasahara, K. Fukasawa, T. Abe, "Subjective evaluation of required color gamut for preferred color reproduction using pseudo ultra-wide gamut display", Proc. NIP24, pg.616-619 (2008)
[9] N. Ohta, "A Simplified Method for Formulating Pseudo-Object Colors", Color Res. Appl., Vol.7, pg.78-81 (1982)
[10] ISO/TR 16066:2003 "Standard object colour spectra database for colour reproduction evaluation (SOCS) " (2003)
[11] T. Fujine, T. Kanda, Y. Yoshida, M. Sugino, M. Teragawa, Y. Yamamoto, N. Ohta, "Theoretical Limit of Objective Colors and Real Objective Colors", ITE technical report, CE2007 pg.57-64 (2007)

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