Subjective evaluation of required color gamut for preferred color reproduction using pseudo ultra-wide gamut display

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Abstract

This study reports on the results of the subjective evaluation of a color gamut required for a preferred color reproduction using a pseudo ultra-wide gamut display. The results indicate three things: (1) pseudo ultra-wide gamut displays are equivalent to conventional displays in terms of appearance and are useful for subjective evaluations; (2) the maximum chroma of the required color gamut is near optimal color; (3) the maximum chroma changes depending on image contents.

In this evaluation, test images were presented on a display with varying chroma values and subjects were asked to evaluate their preference of the images. The scores were expected to decrease after reaching and exceeding a certain chroma. The thresholds were the limits of the color gamut required for preferred color reproduction.

The test images consisted of natural object images and artificial object images. The images were red, yellow, green, purple, and magenta with high luminance.

These images were displayed on a pseudo ultra-wide gamut display, based on Adobe RGB display and the adaptation luminance of white point was set to 60% of the maximum luminance. Therefore, the display used in this experiment was able to display some colors out of Adobe RGB gamut in a higher luminance. Additionally, its color gamut was wider than optimal colors in some areas.

Introduction

The color gamut of displays continues to grow increasingly wider enabling colors to be represented on displays more vividly then ever before. In some cases, however, the colors are too vivid, resulting in an unnatural look. As a consequence, efforts 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], [2], [3], [4], [5].

In a previous study, we reported the results of a subjective evaluation of a color gamut required for a preferred color reproduction on a display using the Adobe RGB color space. It was found that the Adobe RGB gamut was not wide enough and a wider gamut display was needed for this purpose.

In this study, we use a method to expand the gamut reported by Heckaman et al [6]. We refer to a display that uses this method of gamut expansion as a "pseudo ultra-wide gamut display (PWGD)". Heckaman used this to evaluate HDR rendering. We believe that the PWGD can also be used to evaluate a display's required color gamut. But this method employs luminance adaptation; it is therefore necessary to confirm whether luminance adaptation has an influence on subjective evaluations.

The purpose of this study is to evaluate the following 2 points using results of the subjective evaluations.

1. The equivalence between the PWGD and a conventional display.
2. The color gamut required for a preferred color reproduction using the PWGD.

Pseudo ultra-wide gamut display (PWGD)

Figure 1 illustrates the principles of the PWGD. In this display, the adaptation luminance of the white point was set below its maximum luminance. The displayed images were processed so that the luminance of all display colors was lowered the rate of the adaptation luminance. The details of this process are described in section 3-3.

Without experiencing the actual maximum luminance of the display the subjects perceived the adaptation luminance of white as the display's maximum luminance. The color gamut of the display was expanded in areas with high luminance. In this way we were able to make the subjects perceive a wider color gamut than the actual color gamut of the display.

In this study, we used an Adobe RGB display (EIZO ColorEdge CG21) and set the adaptation luminance to 60% of its maximum luminance.

Figure 4 shows the color gamut of the PWGD on the CIECAM02 color space. The parameters of CIECAM02 were set to the values of dark room. The color gamut of the PWGD was wider than that of the optimal colors of certain hues.

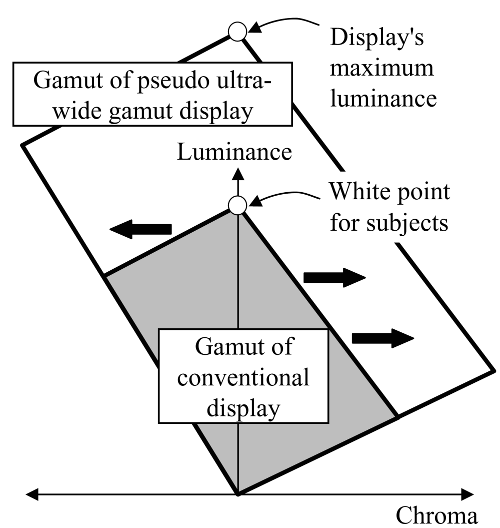

***Figure 1**. Mechanism of pseudo ultra-wide gamut display*

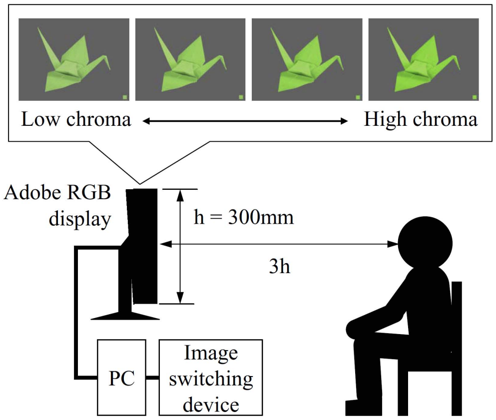

***Figure 2**. Conditions of subjective evaluations*

Subjective Evaluation

Overview of Evaluation

Figure 2 shows the conditions of the subjective evaluation. In this evaluation, test images were presented on a display with varying chroma values and subjects were asked to evaluate the images using a five-grade scale (5: Excellent, 4: Good, 3: Fair, 2: Poor, 1: Bad). Subjects were permitted to answer using decimals.

The scores were expected to decrease after reaching and exceeding a certain chroma level. The thresholds were the limits of the color gamut required for preferred color reproduction.

In this study, we conducted two subjective evaluations: one using a PWGD and one using a conventional display. In a subjective evaluation, if the PWGD is equivalent to that of the conventional display, the results of the two evaluations should be the same.

Test images

Figure 3 shows the test images used in this evaluation. The images consisted of two images for each hue. The hues were red, yellow, green, purple, and magenta with high luminance (see Table 1).

For each color, one image was of a natural object, such as a flower or leaf. The other was of an artificial object, specifically an Origami 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.

Figure 4 shows the average colors of the test images using the CIECAM02 color space. In most hues of the test images, the gamut of the PWGD was wider than that of the conventional display. Six levels of chroma were set for each hue and the test images for the PWGD were prepared. In the common color gamut of two displays the test images for the conventional display were also prepared. A CIECAM02 model was employed so that the colors of the test images had the same appearance on both displays.

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.

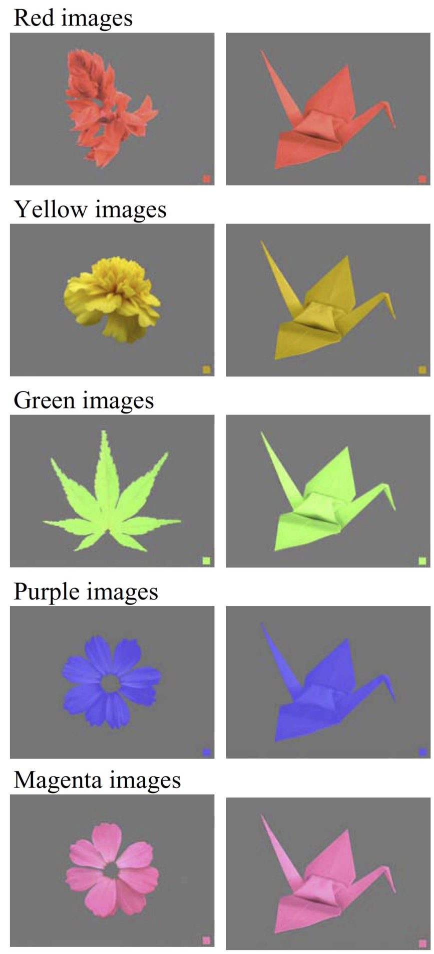

***Figure 3**. Test images with natural objects on the left, artificial objects on the right.*

Color transformation for PWGD

The test images were prepared for both PWGD and conventional displays. Color transformation was conducted as follows for both types of test images.

- step 1. The colors of the original image (Adobe RGB) were transformed into JCh (CIECAM02). The parameters of CIECAM02 were set to match those of a dark room.
- step 2. JCh was transformed into J'C'h' so that the average color of the test image matched the target color. Its lightness J and chroma C were multiplied by a constant, and the hue h was shifted by the same value.
- step 3. J'C'h' was transformed to XYZ (CIE 1931).
- step 4. The XYZ values of test images used for the PWGD were multiplied by 0.6.
- step 5. XYZ was transformed to Adobe RGB.

In step 5, 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.

Method of evaluation

The subjective evaluation was divided in two sections: the PWGD and the conventional display. The order of steps was random. Both were conducted in a dark room. Between the two sections the subjects adapted their eyes in the illumination room to reset the adaptation luminance. Each section consisted of the steps below.

- step 1. Adaptation for five minutes (viewing a gray image [J=50])
- step 2. Evaluation of the practice images (5 images)
- step 3. Evaluation of the test images (60 images in the PWGD section, 36 images in the conventional display section)

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 (J=50) before looking at the next image to reduce the temporal contrast effect. 30 subjects participated in the evaluation (15 male, 15 female, ages 21-26).

Results

Equivalence of PWGD

Figure 5 shows the results of this subjective evaluation. The vertical axis shows the average score and the horizontal axis shows the average chroma of objects. On the whole, the scores of the PWGD were similar to those of conventional displays.

Table 1 shows the results of the analysis of variance and the coefficient of correlation between the two types of displays. In most hues, the comparison showed no significant difference and a high coefficient of correlation. These results indicate that the PWGD is equivalent to the conventional display in terms of appearance and that it is useful for the subjective evaluation of the color gamut required for a preferred color reproduction.

The coefficient of correlation of the green images is comparatively low. This is because the scores of the green images were not varied with the chroma lowering the S/N.

The reason the comparison showed significant differences in the purple images was not clear. We suspect that since the lightness of the purple images was lower than that of the other images, the contrast and the number of tonal gradations decreased.

Required color gamut for preferred color reproduction

Figure 5 shows that the scores for all images except yellow images decreased after reaching and exceeding a certain chroma. This indicates that colors with a higher chroma than the threshold are perceived as unnatural. And the thresholds are the maximum chroma of the color gamut required for preferred color reproduction. The maximum chroma is near optimal color. It's possible, then, that there is a relationship between the maximum chroma and the optimal color.

Figure 5 also shows that the maximum chroma changes depending on image contents. The natural object images were higher than the artificial object images. This contrasts with the color gamut of natural objects being smaller than the artificial objects. More study is needed to find this cause.

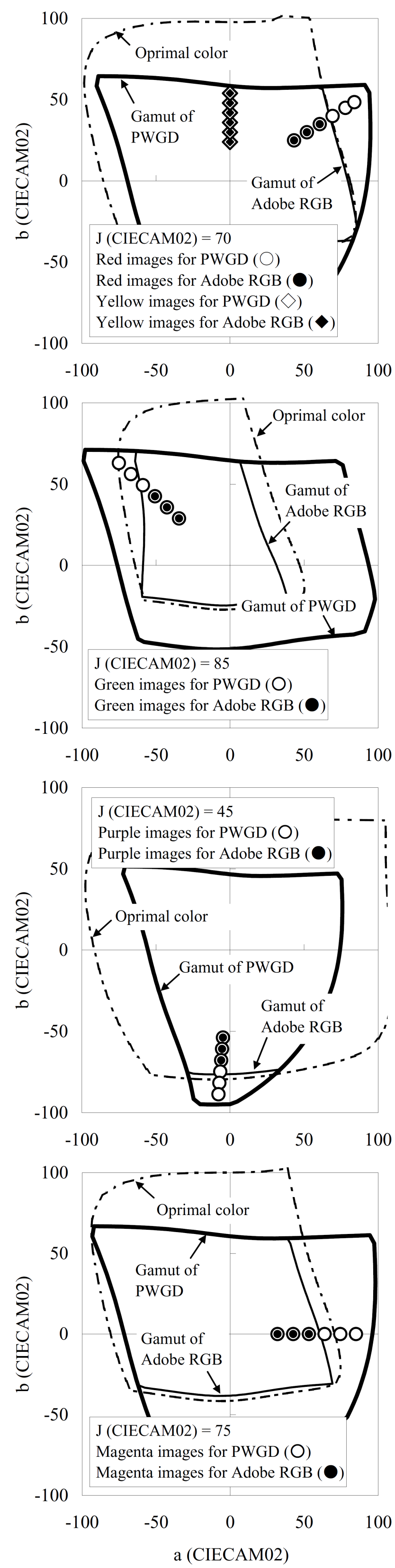

***Figure 4**. The average color of the test images and the gamut of displays*

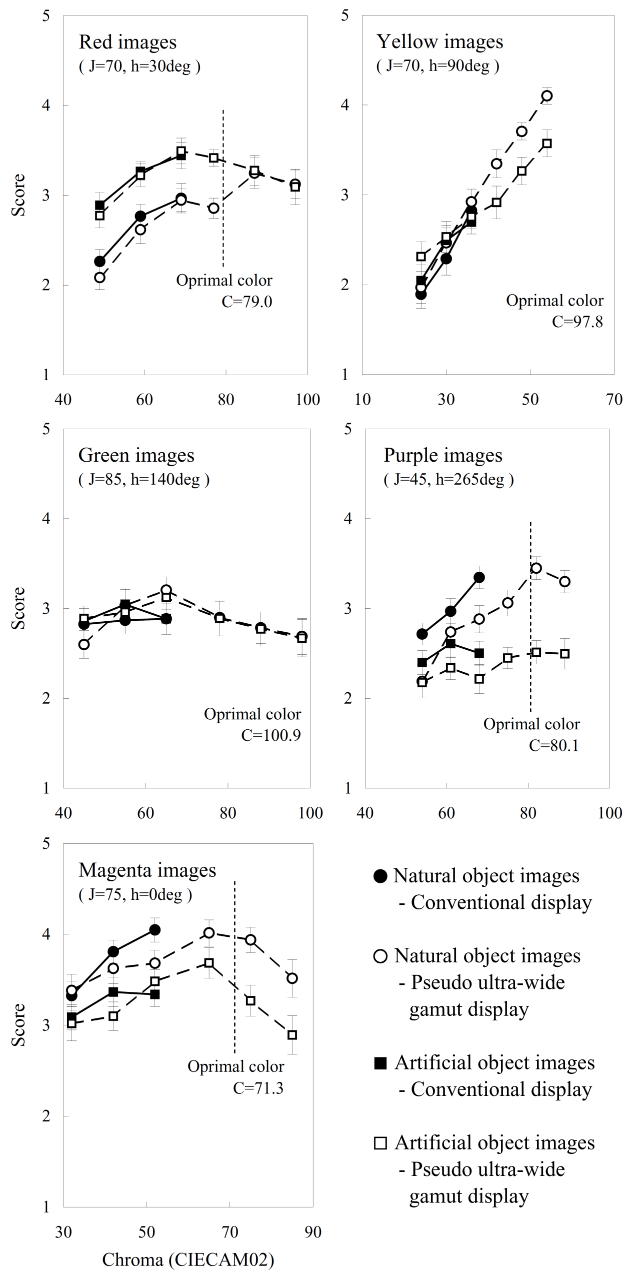

***Figure 5**. Experiment results (chroma vs. scores)*

Table 1: Correlation between pseudo ultra-wide gamut display and conventional display

Color	Light-ness	Hue (deg)	Significant difference	Coefficient of correlation
Red	J = 70	h = 30	NA	0.997
Yellow	J = 70	h = 90	NA	0.976
Green	J = 85	h = 140	NA	0.265
Purple	J = 45	h = 265	Yes	0.930
Magenta	J = 75	h = 0	NA	0.843

Conclusion

This study reports on the results of the subjective evaluation of a color gamut required for a preferred color reproduction using a pseudo ultra-wide gamut display. The result indicates the following.

1. The pseudo ultra-wide gamut displays are equivalent to conventional displays in terms of appearance and are useful for subjective evaluations.
2. The maximum chroma of the required color gamut is near optimal color.
3. The maximum chroma changes depending on image contents.

Since a pseudo ultra-wide gamut display was used, this study reports the color gamut required for preferred color reproduction in areas with high luminance. Our next study will be a subjective evaluation using other wide gamut displays and evaluating in areas with low luminance.

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Author Biography

Masashi Kanai received his MS in physics from Tokyo Institute of Technology (1999). Since then he has worked in the Corporate Research and Development Division at Seiko Epson. His work has focused on the development of color matching technology for displays.

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Kenji Fukasawa received his BS in electronics from the University of Yamanashi (1985). Since then he has worked in the Corporate Research and Development Division at Seiko Epson. His work has focused on the development of color matching technology for color devices. He is a group leader.

Takao Abe received his PhD in industrial chemistry from the University of Tokyo (1976). He joined Konica Corporation that same year and left Konica in 2003. He is now a full professor of Shinshu University in Japan. His main activities have been in the science and technology of imaging materials. He is now President of the Society of Photographic Science and Technology of Japan.