Visualization of Observer Variability in Color Appearance on Wide Color Gamut Display

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ABSTRACT

A method for simulating color appearance in natural images for color-normal observer having non-CIE standard color matching functions was presented. The observer variability can be visually recognized by observing the original and simulated images on the same display. The simulation results clearly showed large differences in wide color gamut displays.

1. Introduction

Currently wide color gamut is one of the key technologies in the development of high picture quality displays. Displays employing Display P3 (DCI-P3) color gamut, which is wider than conventional Rec. 709 (sRGB), are already available on the market and research on quantum dot technologies and laser-based technologies[1] has been active to meet Rec. 2020 color gamut. Wide color gamut, however, increases the degree of observer metamerism[2,3]. Observer metamerisms is the phenomena that a metameric color pair for one color-normal observer is mismatch for another color-normal observer. Observer metamerism occurs due to variations in the color vision characteristics of different observers. The variations in the color vision characteristics are caused by various factors, such as lens optical density, macular pigment optical density, and cone photopigment sensitivity. It can be expressed as differences in color matching functions (CMFs). Various experimental and simulation studies on observer metamerism have been reported. For example, Park et al.[4] investigated the effect of color gamut and peak luminance on observer metamerism using computer simulation. Several studies have visually shown observer variability for uniform color images (patches), but very few for natural images[2,5]. In display device development and content production, it is important to understand individual differences in color perception on display. This paper presents a method to simulate for the CIE standard observer the color appearance of the natural images for color-normal observer whose CMFs differs from the standard and show it on the sRGB display.

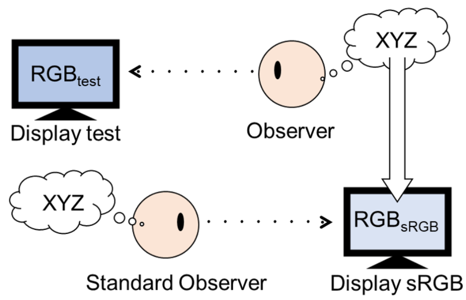

Fig. 1 Concept of simulation

2. Methods

Figure 1 shows a concept of the simulation method. Firstly, XYZ tristimulus values of a test image produced for the standard observer are calculated using a given observer's CMFs and the spectral power distributions (SPDs) of a test display. Then RGB values are calculated from the XYZ values with CMFs of the standard observer and SPDs of the sRGB display. In order to reproduce the simulated image on the sRGB display, the color gamut of the test image is adjusted so that the XYZ values of the test image are within the sRGB color space for various CMFs. The followings are the detailed procedure.

The test image is the gamut adjusted sRGB image. The XYZ values of the test image on the sRGB display, XYZ_{org}, are calculated using the color matching function of the CIE 2° 1931 standard observer, CMF_{std}, the spectral power distribution of the sRGB display, SPD_{sRGB}, and the pixel values of the test image, RGB_{org}.

$$\begin{pmatrix} X_{org} \\ Y_{org} \\ Z_{org} \end{pmatrix} = 683 \cdot \mathrm{CMF}_{\mathrm{std}} \cdot \mathrm{SPD}_{\mathrm{sRGB}} \cdot \begin{pmatrix} R_{org} \\ G_{org} \\ B_{org} \end{pmatrix} \qquad (1)$$

The pixel values RGB_{test} for expressing XYZ_{org} to the standard observer on the test display having SPD_{test} is calculated as follows.

$$\begin{pmatrix} R_{test} \\ G_{test} \\ B_{test} \end{pmatrix} = (683 \cdot \mathrm{CMF_{std}} \cdot \mathrm{SPD_{test}})^{-1} \cdot \begin{pmatrix} X_{org} \\ Y_{org} \\ Z_{org} \end{pmatrix} \qquad (2)$$

The tristimulus values XYZ_{ind} of RGB_{test} shown to an individual observer having $\mathrm{CMF_{ind}}$ on the test display is obtained from the following equation.

$$\begin{pmatrix} X_{ind} \\ Y_{ind} \\ Z_{ind} \end{pmatrix} = 683 \cdot \mathrm{CMF_{ind}} \cdot \mathrm{SPD_{test}} \cdot \begin{pmatrix} R_{test} \\ G_{test} \\ B_{test} \end{pmatrix} \qquad (3)$$

Finally, RGB_{sim} for XYZ_{ind} stimulus on the sRGB display can be obtained using $\mathrm{CMF_{std}}$ and $\mathrm{SPD_{sRGB}}$ as follows.

$$\begin{pmatrix} R_{sim} \\ G_{sim} \\ B_{sim} \end{pmatrix} = (683 \cdot \mathrm{CMF_{std}} \cdot \mathrm{SPD_{sRGB}})^{-1} \cdot \begin{pmatrix} X_{ind} \\ Y_{ind} \\ Z_{ind} \end{pmatrix} \qquad (4)$$

When the RGB_{sim} values are displayed on the sRGB display, it simulates how the individual observer perceives color of the test image. Variability in color appearance among the observers can be recognized by simultaneously displaying the reproduced image with RGB_{sim} and the original test image on the sRGB display.

3. Simulation Examples

Various color-normal CMFs and SPDs are required in the calculation. Saker et al.[6] and Asano et al.[7] proposed categorical CMFs based on the CIE 2006 physiological model. In the present study, the Park's 5 categorical CMFs[5] generated based on Asano's method were used. Figure 2 shows CMFs used in the simulation. Observer 1 is the same as the CIE 2006 physiological observer. In the simulation, displays having sRGB, P3, and Rec. 2020 color gamut were assumed.

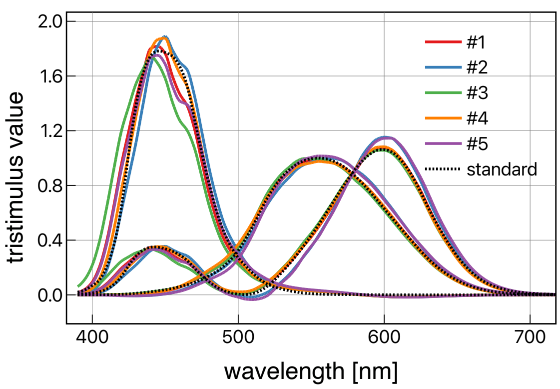

Fig. 2 Individual CMFs and CIE 1931 2° standard CMFs used in the simulation.

Fig. 3 Test images

Fig. 4 Simulation results for the test image 1.

Fig. 5 Simulation results for the test image 2.

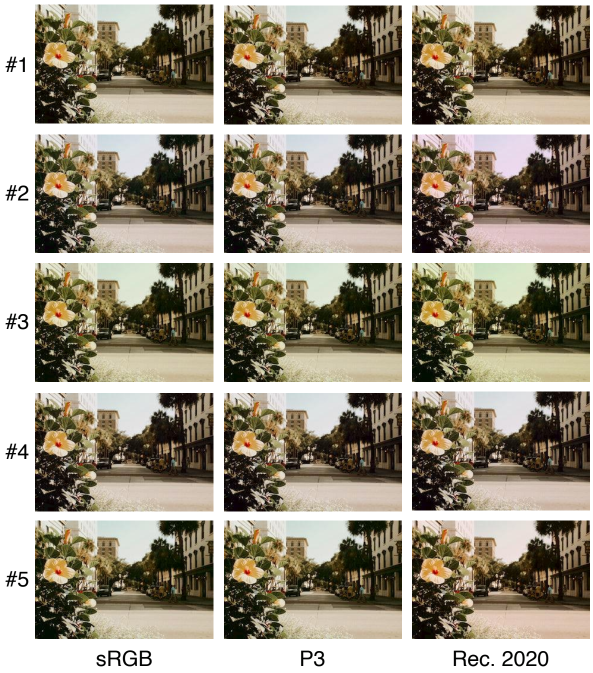

Fig. 6 Simulation results for the test image 3.

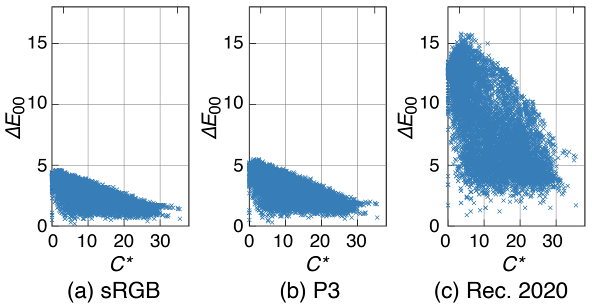

Fig. 7 Color difference ΔE_{00} vs. chroma C^* of pixels in test image 1 for observer 2.

The SPDs were also the data provided by Park. The peak luminance of the displays was assumed to be the same, white point was D65, and the gamma of the sRGB display was 2.2. Figure 3 shows test images.

Figures 4 - 6 show the simulation results for the five observers. Some images turn pinkish or greenish. This comparison clearly shows the variability in color appearance. There are differences among the observers in all displays and the degree of the difference becomes larger as the gamut becomes wider. Figure 7 shows chroma C^* of each original pixel in the test image 1 *vs.* color difference ΔE_{00} between the original and simulated images for observer 2. As reported elsewhere, the lower the saturation, the larger the difference. Figure 8 compares maximum ΔE_{00} between the original and

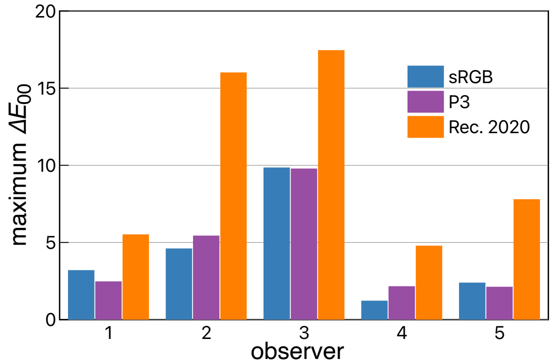

Fig. 8 Maximum color difference ΔE_{00} for the test image 1.

simulated images for test image 1. It can be found from the Figs. 7 and 8 that intra-observer variation between sRGB and P3 displays is small, but it increases significantly with Rec. 2020 display. Inter-observer difference in Rec. 2020 display is large.

4. Conclusions

This paper introduced the method visually showing how the colors in the image appear to the individual observer. It is easy to recognize that the wider the color gamut, the larger the individual differences in color appearance. Although we never know exactly another person's perception, the method can help to understand the variability in color appearance. This is important in the development of displays and the creation of content.

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