Color Categories in Various Color Spaces

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Abstract

Using color names is one of the most important tools to communicate color information. We carried out a color naming experiment, where subjects were asked to sort 292 Munsell color samples under various light sources into eleven basic colors defined by Berlin and Kay. The experimental results were represented in various color spaces, the Munsell color space, the CIE (x, y) chromaticity diagram, the CIELAB space and the CIECAM97s (J, C, h) space. Performance of these color spaces for representing color names will be discussed.

Introduction

Color names are frequently used to communicate color information in every day life. Also color naming is useful to categorize objects and recognize them. Berlin and Kay[1] have mentioned that in fully developed languages there are precisely eleven basic color names. Mapping these color names in a certain color space would be very useful for many color industry fields including color imaging. Boynton and Olson[2] provided quantitative information concerning the locations of basic colors in the OSA space. Color appearance of the object is, however, influenced by viewing conditions such as the illumination, the surround and viewing size, etc. On the other hand, attributes of color appearance such as brightness, hue, and colorfulness, and also color names are independent of the viewing condition. Mapping color names in a viewing-condition-independent color space would be very useful for many application field of color industry. In this study, I try to map color names in various color spaces, Munsell color space, the (x, y) chromaticity diagram, the CIELAB space and the CIECAM97s (J, C, h) space. Performance of these color spaces for representing color names will be discussed.

Categorical Color Naming Experiment[3]

In order to specify the regions of basic color names under various adaptation conditions, categorical color naming experiments were carried out using a variety of color chips under many kinds of light sources.

The set of JIS (Japanese Industrial Standard) color chips specified with the Munsell Color System is used for the experiment. We used 292 color chips consist of samples found at even value V, even chroma C, and hue H labeled 5 and 10. The size of each color chip was 5.5×7 cm, and it was put on an N5 gray background. The stimuli were viewed at an angle of about 45˚ at a distance of 50 cm.

Nine light sources used for the present study were a fluorescent lamp (D65) as a simulator of CIE standard illuminant D65, a cool white fluorescent (W), a three-band type fluorescent warm white (EX-L), three-band type fluorescent neutral (EX-N), a halogen (IL), a high pressure sodium (NH), a metal halide (MHL), a high pressure mercury (H), and a fluorescent high pressure mercury lamp (HF). The range of the correlated color temperature was from 1880K to 6700K. The illuminance was 1000 lux for all illuminants.

Subjects were asked to sort samples into eleven basic color categories specified by Berlin and Kay[1]. These colors are *red*, *green*, *yellow*, *blue*, *orange*, *pink*, *purple*, *brown*, *white*, *gray* and *black*. Sorting of color samples under each illuminant was repeated three times for each subject in different experimental sessions.

Four Japanese students with normal color vision examined by the Ishihara plates participated in the experiment as subjects.

Color Name Regions in Color Spaces

Color samples sorted into the same color category consistently for all three trials under each illuminant are selected for each subject. Color samples selected from four subjects were not much different from subject to subject. In order to examine consensus colors, we extracted color samples named with a same color by at least three out of four subjects.

Munsell Color Space

The Munsell Color System is based on principles of color perception. Munsell color chips are selected to represent scales of constant hue, chroma, and lightness; each one spaced uniformly in accordance with the perception of an observer under a certain illuminant, usually the CIE illuminant C. Since various light sources are used in our experiment, we use the Munsell Color System merely as a coordinate system for color samples in the present study.

Figure 1 shows color name regions in the Munsell hue circle under the D65 fluorescent lamp, the high-pressure mercury lamp H, and the halogen lamp IL. It seems that there is not much difference among these three graphs, as if the color constancy held. If you look it precisely, however, some differences exist clearly, particularly between the mercury lamp H and the other two lamps.

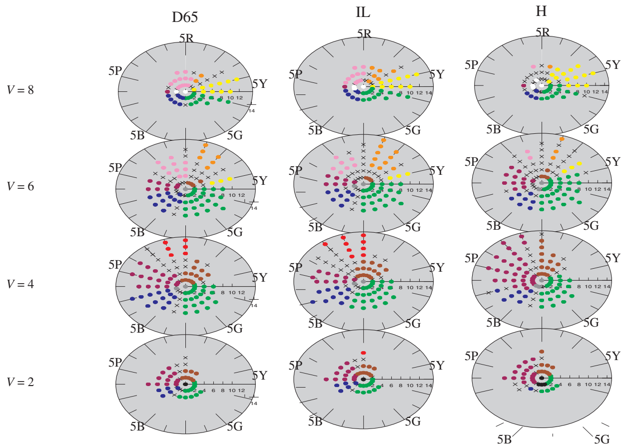

Figure 1. Color name regions in the Munsell hue circle for typical three illuminants: D65, IL and H.

CIE 1931 (*x*, *y*) Chromaticity Diagram

This CIE 1931 colorimetric system is based on color matching experiments. Color is specified with the tristimulus values; *X*, *Y*, *Z*. Since the tristimulus values are obtained by wavelength integration of product of spectral reflectance of color samples, the spectral power distribution of illuminant and the color matching function, the chromaticity coordinates of a color chip are changed with light sources. As you can easily imagine, color name regions in the (*x*, *y*) diagram are greatly depends on light sources. Fig. 2 shows color name regions obtained with color chips of the Munsell value *V*=4 in the (*x*, *y*) diagram for the same illuminant as Fig. 1.

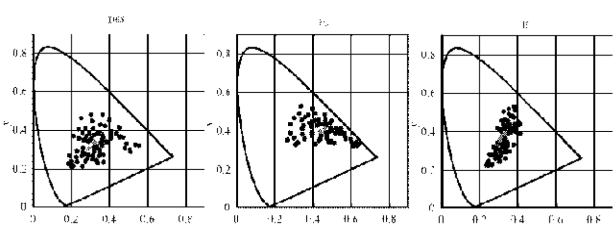

Figure 2. Color name regions in the (x, y) *diagram.*

CIE 1976 (*L*a*b**) Uniform Color Space

Tristimulus values specify the color match of a material for a specific illumination and viewing, but do not incorporate how we respond visually to color differences. A number of linear or nonlinear transformations of tristimulus space have been derived to improve the correlation between Euclidean distance measurements and perceived color differences. Among these attempts, the CIE *L*a*b** uniform color space has been the most commonly used in many industrial fields.

The CIELAB models the visual system in three ways. Firstly, The CIELAB takes account of chromatic adaptation by normalizing the tristimulus values to the reference white of the illumination (i.e., X/X_n, Y/Y_n, and Z/Z_n). Secondly, the nonlinear transform (cube-root exponent) is designed to model the compressive response typically found between physical energy measurements and perceptual responses. Finally, these signals are combined into three response dimensions roughly corresponding to the white-black or light-dark (*L**), red-green (*a**), and yellow-blue (*b**) responses of the opponent-color theory of color vision.

Figure 3 shows color name regions in the (*a**, *b**) diagram for color samples of which lightness *L** are between 35 and 55 under the same three light sources as Fig. 1. Color name regions of blue and purple among these three light sources slightly overlapped with each other.

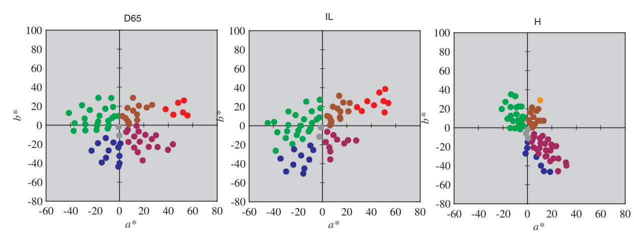

Figure 3. Color name regions in the (a*, b*) *diagram.*

CIE 1997 Color Appearance Space

In order to allocate the basic color name regions in a viewing-condition independent color space, we applied the CIE Color Appearance Model (CIECAM97s)[4] to our data. The lightness *J*, the chroma *C* and the hue angle *h* of the CIECAM97s output were calculated for all color samples which were consistently sorted in a same color name under each illuminant. Fig. 4 shows color name regions in the hue circle of the CIECAM97s for color samples of which lightness *J* are between 35 and 55 under the same three light sources as Fig. 1. Although the color gamut varies with the illuminant, the color name regions do not seem to be overlapped among different light sources.

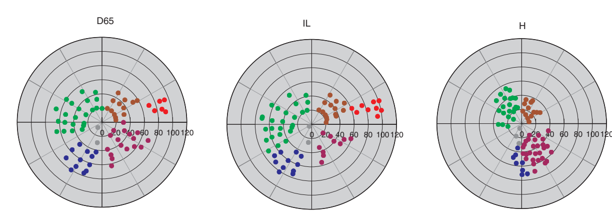

Figure 4. Color name regions in the hue circle of the CIECAM97s.

Figure 5 shows the basic color name regions in the hue circle of the CIECAM97s space at four different lightness levels. Each color name region was determined with an OR-region for all light sources. Although some regions of the color name such as black and gray seem to be overlapped with each other, they are separated in lightness. It is found that the eleven basic color name regions are clearly separated in the CIECAM97s space with each other. This means that the CIECAM97s provide a good prediction of color names under various light sources.

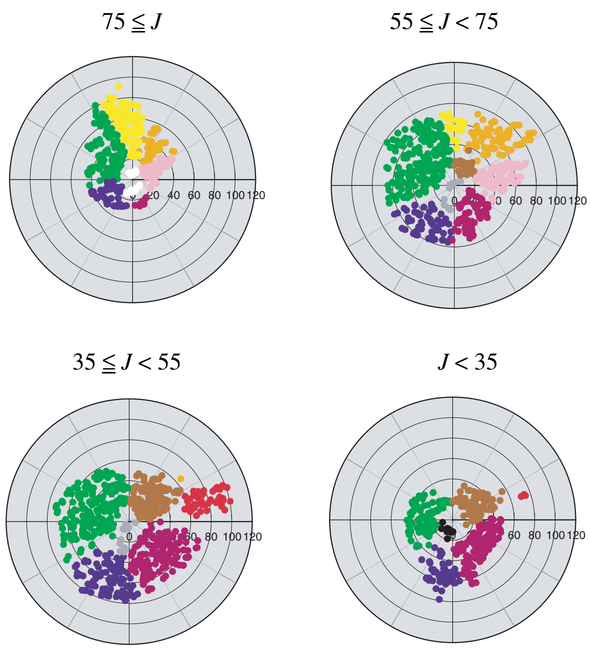

Figure 5. Color name regions in CIECAM97s space.

Conclusion

We compare the performance of four color spaces, the Munsell System, the CIE 1931 XYZ, the CIE 1976 L*a*b*, and the CIECAM97s for specification of color name. It was found that among these color spaces, the CIECAM97s provide the prediction of color names under various light sources.

References

1. B. Berlin and P. Kay *Basic color terms: The universality and evolution*, Berkeley: University of California Press, 1969.
2. R. M. Boynton and C. X. Olson, Locating basic colors in the OSA space, *Color Res. Appl.*, **12**, 94-105, (1987).
3. H. Yaguchi, Y. Takahashi and S. Shioiri, Basic categorical colors in the CIECAM97s space, *Proc. of AIC Midterm Meeting,* , Warsaw, pp.49-54, (1999).
4. M. R. Luo and R. W. G. Hunt,. The structure of the CIE 1997 Colour Appearance Model (CIECAM97s), *Color Res. Appl.*, **23**, 138-146, (1998).

Biography

Hirohisa Yaguchi received his B.E. degree in Photographic Engineering from Chiba University in 1974 and a Ph.D. in Information Processing from Tokyo Institute of Technology in 1980. From 1982 to 1986 he was a Research Associate at the National Research Council of Canada. In 1986, he joined Faculty of Engineering, Chiba University where he is now a Professor at Department of Information and Image Sciences. His research has primary focused on color vision and visual science. He is a member of IS&T, ISCC and OSA. He has been active in the International Commission of Illumination (CIE) and the International Association of Color (AIC). He is currently an Associate Editor of Color Research and Application.