Categorical Color Rendering of Various Light Sources

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ABSTRACT

We propose a new color rendering index based on categorical color name rather than color difference. Subjects were asked to sort 292 Munsell color samples under 14 separate illuminants into eleven basic colors. The distributions of color category in the Munsell Color Space were different from one illumination to another. In order to quantify the category overlap for two different illumination conditions, an evaluation method for the categorical color rendering was developed. Assuming the D65 fluorescent illumination as a reference illuminant, the comparison was made between the condition of the D65 fluorescent illumination and each of the other 13 illumination conditions. The order from best to worst rate by the index of categorical color rendering does not completely agree with the general color rendering index.

KEYWORDS: COLOR, COLOR APPEARANCE, COLOR PERCEPTION, COLOR RENDERING, LIGHT SOURCE

1. INTRODUCTION

If an identical object is illuminated with different light sources, the color may sometimes appear different one another. For example, an object that appears red under a tungsten lamp may appear orange under a white fluorescent lamp. Such a case, rendering of the color may be judged to be unsatisfactory, because even the same object is differently categorized in color name. The color name plays an important role in many practical situations, such as color communication, color signaling, color coding, color cognition and so on. Since the color name is considered to one of the attributes of color appearance and the color name itself may be independent of the viewing condition, the use of color names is very useful method to communicate color information.

Currently, we use the CIE color rendering index or the CIE metamerism index for evaluating color rendering quality. These indices are, however, based on color difference between colors illuminated under a testing lamp and a reference illuminant. The purpose of the present study is to take account of color categorization rather than color difference in evaluating the practical color rendering property of various light sources.

2. EXPERIMENTS

Experimental Materials

The set of JIS color chips specified with the Munsell's Color Order System is used for the experiment. We employed 292 color samples which consists of all samples found at even value levels , even chroma levels, and hue labeled 5 and 10. The size of each color chip was 5.5 x 7 cm, and it was put on an N5 gray background.

Light sources

The fourteen light sources used for the present study were fluorescent lamp (D65) as a simulator of CIE standard illuminant D65, cool white fluorescent (W), three-band type fluorescent "warm white" (EX-L), three-band type fluorescent "neutral" (EX-N), narrow band red radiation fluorescent (R100), narrow band green radiation fluorescent (G100), combined narrow band 55% green and 45% red radiation fluorescent (G55R45), combined narrow band 80% green and 20% red radiation fluorescent (G80R20), halogen (IL), low pressure sodium (NX), high pressure sodium (NH), metal halide (MHL), high pressure mercury (H), and fluorescent high pressure mercury lamp (HF). The illuminance was 1000 lux for all illuminants.

Categorical Color Naming

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.

Subjects

Three subjects with normal color vision checked by the Ishihara plates participated in the experiment.

3. RESULTS

Color samples sorted into the same color category consistently for all three trials under each illuminant are plotted in the Munsell Color Space. Figure 1 shows these color categories in the Munsell Hue-Chroma diagram for color samples with Value 6 under all illuminants from the subject NU. The distributions of color category for the fluorescent lamps D65, EX-N, EX-L, W, G55R45, G80R20, the metal halide lamp MHL and the halogen lamp IL were very similar with each other. On the other hand, color categories for the fluorescent lamp R100, G100, fluorescent high pressure mercury lamp HF, low pressure sodium NX, high pressure sodium NH and high pressure mercury H were different from one illumination to another. Similar results were obtained for the other samples and from the other subjects.

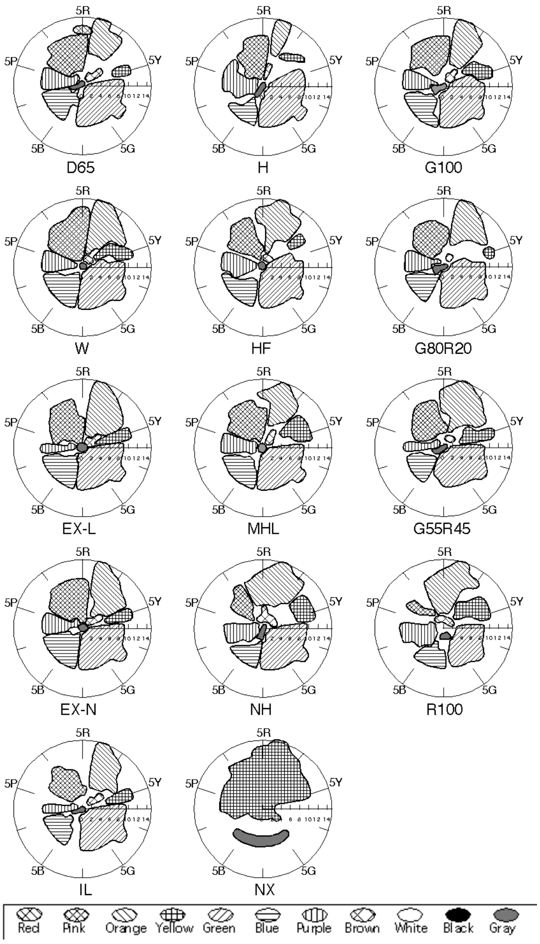

Figure 1. Categorical color name regions in the Munsell Color Space for each illuminant condition.

4. CATEGORICAL COLOR RENDERING

In order to quantify the category overlap for two different illumination conditions, an evaluation method for the categorical color rendering was developed. The idea of the method proposed here is similar to *percent overlap* developed by Boynton, Fargo and Collins [2]. Assuming the D65 fluorescent illumination as a reference illuminant, the comparison was made between the condition of the D65 fluorescent illumination and each of the other 13 illumination conditions. At first, samples sorted into the same color category consistently for all three trials under the D65 fluorescent illumination was selected. Then among these selected samples (let the number be N_{D65}), we count the number (N_s) of samples under each illumination sorted into the same category as in the D65 fluorescent illumination condition consistently for three trials. Also we count the number (N_d) of samples sorted into a different category consistently for three trials. The categorical color-rendering index proposed here was defined as $100(N_s - N_d)/N_{D65}$. Figure 2 shows categorical color-rendering indices for 13 illuminants. These data are derived from the mean for three subjects.

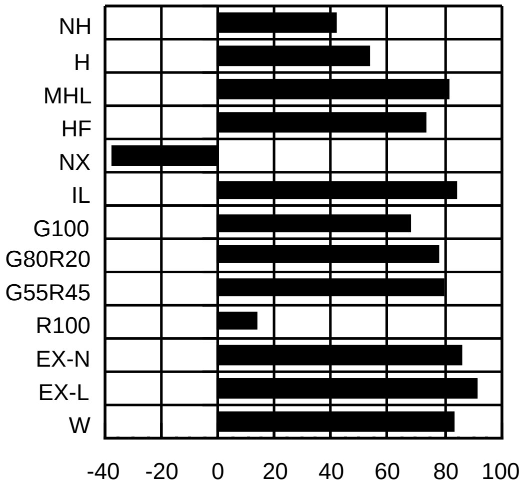

Figure 2. Categorical color-rendering indices for 13 illuminants.

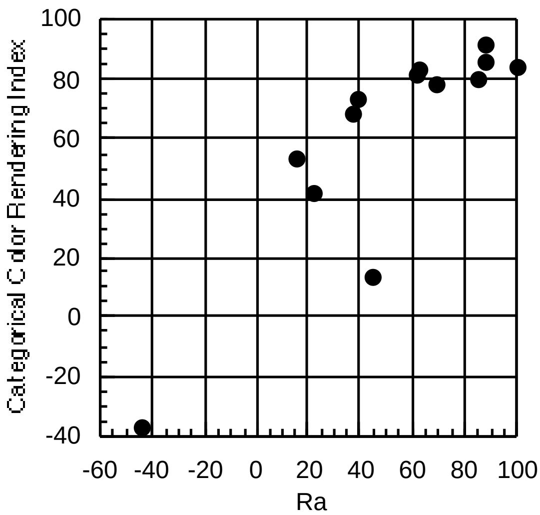

Figure 3. Relation between categorical color-rendering index and the CIE general color rendering index.

Figure 3 shows the categorical color-rendering indices as a function of the CIE general color rendering index, *R*a. The order from best to worst rate by the categorical color-rendering index does not completely agree with *R*a. It could be said that illuminants of which *R*a is higher than about 60 shows a similar performance for categorical color cognition and they are ranked in high categorical color-rendering indices from 80 to 90.

5. CATEGORICAL COLOR REGIONS IN CIECAM97s 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) [3] 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. Figure 4 shows the basic color name regions in the (*h*, *C*) diagram of the CIECAM97s space. Each color name region was determined with an OR-region for all illuminants except for three colored lamps of R100, G100 and NX, then an AND-region for all three subjects was taken. 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.

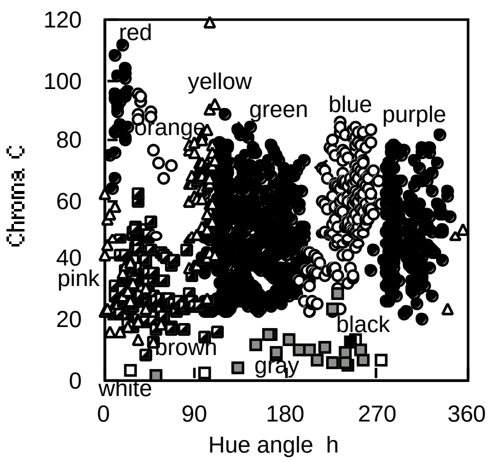

Figure 4. Eleven basic color name regions in the CIECAM97s space.

6. CONCLUSIONS

We propose a method for evaluating the practical color rendering property which takes account of color categorization rather than color difference. The present study, furthermore, shows that the CIECAM97s can predict the color name for any color sample under any illuminant. We are going to propose a new categorical color rendering index based on the CIECAM97s at the CIE 99 meeting.

REFERENCES

1. BERLIN B and KAY P: *Basic color terms: The universality and evolution*, Berkeley: University of California Press, 1969.
2. BOYNTON RM, FARGO L and COLLINS BL: Categorical color rendering of four common light sources, *Color Res. Appl.*, **15**, 222-230, 1990.
3. LUO MR and HUNT RWG: The structure of the CIE 1997 Colour Appearance Model (CIECAM97s), *Color Res. Appl.*, **23**, 138-146, 1998.

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