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PRACTICAL DESIGN OF SPECTRAL POWER DISTRIBUTIONS WITH PREFERABLE COLOR APPEARANCE OF LED LIGHT SOURCES

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Since high-luminance blue LEDs have been mass-produced in 1993, we got three primary color LEDs, red, green and blue. After the epoch, we can make various colors with LEDs, then the application fields of LEDs for light sources are greatly expanded. In the first stage of the LED era, LED was used in limited way such as sign illuminations or signal lamps because of high luminances but insufficient lumens. But recently, LEDs are used for not only such auxiliary lighting purposes but also general lighting fields. In the near future, it will be sure that the day will come when LEDs will be replaced to fluorescent lamps which are currently main light sources in the world.

One of the characteristics of the spectral distribution design of LED light sources is that the design will be accomplished by mixing only the LED's spectral power distributions to be mixed, because LED's spectral power distribution does not have the mercury emission lines in the visible range (about 405,436,546,578nm) like a fluorescent lamp's spectral power distribution.

From another point of view, because we are familiar for more than 60 years with the light of a fluorescent lamp which has the spectral power distribution composed of the mercury emission lines in the visible range and the phosphor emissions, it might be supposed that we see un-experienced color appearance changes under LED light sources which are composed of only the LED emissions.

Various studies on color rendering properties of light sources have so far been done. For example, there are many reports related to color preference (flattery index, Acceptability index) by Judd and Pracejus, and the relationship between color rendering and perceived brightness and the feeling of contrast. Recently TC1-69 "Color Rendition by White Light Source" has tried to develop a new metric instead of CIE color rendering indices, the TC members have carried out the various experiments about fidelity and preference of color appearance by various light sources.

As for the types of white LEDs, there are four main methods as follows;

- (1) Mixing of red, green, blue LED
- (2) UV emitting LED + red, green, blue phosphor
- (3) Blue LED + yellow phosphor
- (4) Blue LED + red, green phosphor

In these methods, the type (3) is mainly used for LED white light sources because of high efficiency and large amount of lumen output. However, the LED by the type (3) has insufficient power distribution in red region, so color appearance of especially red color objects seems no good. In order to improve this problem, the color improved LED lamps have developed by adding red phosphor to the type (3).

LED lamps for general lighting have just started to be developed and the performance will be expected to increase from now on. It is very important that we investigate what the ideal spectral power distribution of LED lamp for general lighting will be.

The purpose of this study is to find out the ideal spectral power distribution of white LED lamps to improve color appearance. In this report, it will be shown the results of theoretical simulation about color rendering changes and the results of the subjective evaluating experiment on color appearance when a red LED, a green LED, a blue LED are added to the white LED lamp of the type(3).

The general color rendering index Ra and the correlated color temperature of the white LED lamp used for calculation is 59, 4820 K. The lights of a red, green and blue LED were added to the white LED light remaining the chromaticity of the color of the light. Ra, the special color rendering index R9, and the gamut area ratio of the area surrounded by No.1-8 of CIE test colors illuminated by the test illuminant to the area illuminated by the reference illuminant are calculated. Also the gamut area ratio of No.9-12 of CIE test colors is calculated in the same way.

As the example of the results, it was shown that Ra, R9 and the gamut area ratio when mixed at the appropriate lumen ratio of white: red: green: blue. By adding red, green, blue LED to the white LED, Ra improved to 90 from 59 and R9 to +42 from -89. The gamut area of the test color No.1-8 and No.9-12 illuminated by the mixed light is over 100 when the reference (black body of 4820K) gamut area equals 100. These results show that the white light with the mixed red, green, blue lights can achieve an color saturation effect to show color objects more vivid than under the reference illuminant. The test color No.9 illuminated by the mixed light is plotted greatly outward than illuminated by the reference illuminant on the u^*v^* chromaticity diagram, so it will be supposed that red color objects will be seen much saturated under the test light.

The subjective experiment on the change of color appearance under the test LED lights with adding some mixture ratios of red LED, green LED, and blue LED to the white LED of the type (3) was carried out. The results show that the saturation of color objects was observed higher under the test light and the appearance of illuminated area was looked more beautiful and more clarified. Especially, it was confirmed that the saturation increase effect of vivid red color objects was large. In addition, the test light which has less illuminance because of the improvement of color rendering properties than the reference light, obtained nearly the same brightness with that of the reference because brightness feeling (subjective brightness perception) is improved by saturation increasing effect. It was clear that white LED light sources with more comfortable lighting effects will be able to be achieved by adding appropriate spectral power distribution to a red region, a green region, and a blue region on the spectral power distribution of white LED now generally used.