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독립적으로 조도변경가능한 LED 조명 색상제어 알고리즘

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A Color Control Algorithm for LED Lights with Independently Changeable Illuminance

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Abstract - This paper presents a color control algorithm for LED lights with independently changable illuminance. The proposed algorithm adjusts the light intensity to obtain a desired color with alterable illuminance. To verify the validity of the proposed algorithm, it was applied to control of a RGBW LED module. The achieved color temperature range of the module was from 3000K to 7500K, and the illumination one was from 500 lux to 1500 lux.

I. Introduction

Light emitting diode (LED) lightings have a great potential in the future due to its long lifetime and small size [1]. Especially, an LED lighting composed of the red, green, and blue (RGB) LEDs can change its light color. To achieve a desired color, the light intensities of each red, green, and blue LEDs should be controlled by the color mixing theory [2]. The pulse-width modulation (PWM) dimming is widely used to regulate the light intensity of LEDs. The LED light intensity can be changed linearly by the PWM dimming signal.

A color control method has been reported in [3] to obtain a relation matrix between tristimulus values and PWM dimming duty ratio. Each elements in the relation matrix of each LEDs, however, can be determined by measuring tristimulus values at various dimming levels. Since this method processes a number of experiment data, this may causes errors. The independent control of light intensity of LEDs maintaining a color temperature is hard to realize due to the non-linear relationship between the tristimulus values and light intensity.

This paper presents an alternative color control algorithm which changes the color by simply setting a color axis of a desired color. The desired light intensity can be independently controlled.

In Section II, the background of the color mixing theory is described. The proposed color change algorithm is explained in Section III. Section IV presents the experimental results with an LED lighting which adopts the proposed algorithm.

II. Chromaticity Coordinate Change

Different wavelengths of light cause different excitation levels to human eyes. To quantify this feature the Commission Internationale de L'Eclairage (CIE) standardized the eye sensitivity function $V(\lambda)$. This function is also known as the luminous efficiency function of optical power to luminous flux.

The human eyes distinguish color based on three main colors, red, green, and blue. The CIE defines the relative spectral sensitivity of the three primary color, $\bar{x}(\lambda)$, $\bar{y}(\lambda)$, $\bar{z}(\lambda)$. These are referred as the color matching function. The green spectral sensitivity $y(\lambda)$ is generally identical to the eye sensitivity function $V(\lambda)$ [4].

With three reference colors, any color in the triangle area which is made of the three colors can be generated. According to additive color mixing theory, the coordinate of mixed colors is linear-combination of the coordinates of each sources in the CIE x-y color space.

III. LED Color Change Algorithm

Fig. 1 shows the block diagram of the color change process. The input vector that denotes the desired light involves three parameters. x_m and y_m are the color coordinate of the desired light in CIE 1931 color space, and I is the illuminance value that specify the brightness of the light. The output vector consists of four PWM dimming duty ratios for each LEDs. There is a linear relationship between the illuminance and dimming value for each LEDs. The desired color can be achieved by the proper combination of the light intensity.

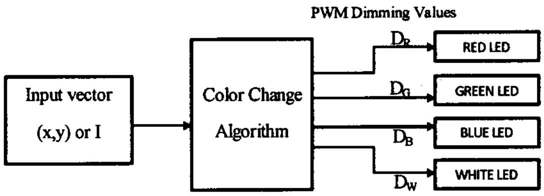


Fig. 1 Block diagram of RGBW LED color change algorithm

The color temperature can be controlled easily using the proposed color control algorithm. The illuminance can be varied without changing the color.

The color change process can be divided into two parts: a linear function between PWM dimming duty ratio and illuminance of respective LEDs, and a relation from CIE 1931 color diagram to illuminance of each LEDs.

There is a linear relationship between the illuminance and PWM driving duty ratio of respective LEDs. The illuminance has the direct proportional relation to the driving current. The desired illuminance can be expressed by the following equations. The coefficient matrix C_1 and C_2 depend on the characteristic of LEDs. I is the illuminance of LED lights while D means the PWM duty ratio. The subscript R, G, B, and W mean the color of LED.

$$\begin{bmatrix} I_R \\ I_G \\ I_B \\ I_W \end{bmatrix} = [C_1] \begin{bmatrix} D_R \\ D_G \\ D_B \\ D_W \end{bmatrix} + [C_2] \quad (1)$$

From (1), the illuminance of each LEDs can be determined by the input vector. The color coordinate of mixed color can be expressed by the following equation:

$$\begin{bmatrix} x_m \\ y_m \\ I_m \end{bmatrix} = \begin{bmatrix} \frac{x_r - x_m}{y_r} & \frac{x_g - x_m}{y_g} & \frac{x_b - x_m}{y_b} & \frac{x_w - x_m}{y_w} \\ \frac{y_r - y_m}{y_r} & \frac{y_r - y_m}{y_g} & \frac{y_r - y_m}{y_b} & \frac{y_r - y_m}{y_w} \\ 1 & 1 & 1 & 1 \end{bmatrix} \begin{bmatrix} I_R \\ I_G \\ I_B \\ I_W \end{bmatrix} \quad (2)$$

The matrix A is shown as follows:

$$A = \begin{bmatrix} \frac{(x_r - x_m)}{y_r} & \frac{(x_g - x_m)}{y_g} & \frac{(x_b - x_m)}{y_b} & \frac{(x_w - x_m)}{y_w} \\ \frac{(y_r - y_m)}{y_r} & \frac{(y_r - y_m)}{y_g} & \frac{(y_r - y_m)}{y_b} & \frac{(y_r - y_m)}{y_w} \\ 1 & 1 & 1 & 1 \end{bmatrix} \quad (3)$$

It need to employ the generalized inverse matrix. The condition for generalized inverse matrix of any m×n matrix is that the rank of the matrix is either m (right generalized inverse) or n (left generalized inverse). In this RGBW color change algorithm, A is a 3×4 matrix. As the x coordinate and y coordinate of RGBW LED are different, there is no row with all the variables zero. The rank of the matrix A equals 3. The right generalized matrix is shown as:

$$A^{-1} = A^{T}(AA^{T})^{-1} \quad (4)$$

The whole color change algorithm can be automatically implied by a digital control system.

IV. Experimental Results

In order to verify the color accuracy with color change algorithm, an experimental set up had been built. Fig. 2 shows the schematic of an RGBW LED light source. In the experimental system, we used LUXEON LED which provided the color coordinate on the date sheet.

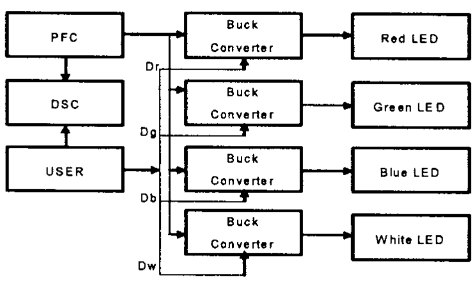
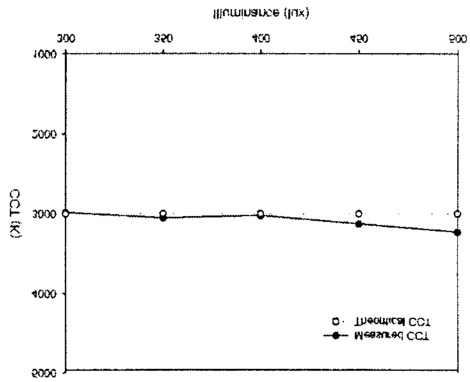


Fig. 2 Schematic of RGBW LED source

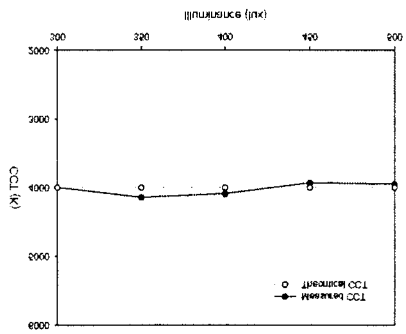
LED module set was constructed by ten red LEDs, ten green LEDs, ten blue LEDs and ten white LEDs. The LEDs were mounted on the heat sink.

The four independent buck converters operating at a constant switching frequency drived the RGBW LED. The LED drivers using HV3402 as the driving chip to offered a constant peak current value for four LED sets. The color change system was implemented in a digital control board using "C" language, which supplied the enable signal for drivers with the PWM turn-on and turn-off waveform. There was a 4x4 keyboard in the digital control board to input the desired color. Users can simply achieve the required color by just inputting the color coordinate and brightness value. There was also a serial port inside the DSP control board which can communicate with the computer through RS232.

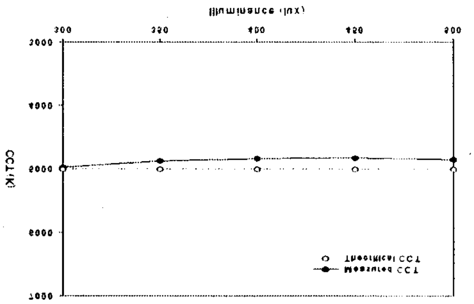
The experimental set up as described was used to verify the performance of the color change algorithm. The whole control and drive system were first calibrated at a fixed temperature by adjusting four respective driving current for red green blue and white LEDs. The KONICA MINOLTA CL-200 colorimeter was used to test the color coordinates and illuminance of the achieved color. Figure 3 shows the verified color performance of the control system. The color deviation was T≤ 100K with iluminance level of 70%. The achieved illuminance value shows in Figure 4.The illuminance change was less than 2% under the color temperature from 3000 K to 7500K.



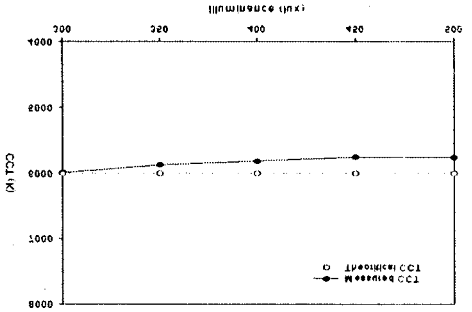
(a) Color temperature = 3000 K



(b) Color temperature = 4000 K

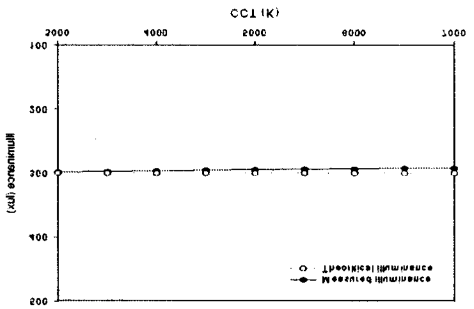


(c) Color temperature = 5000 K

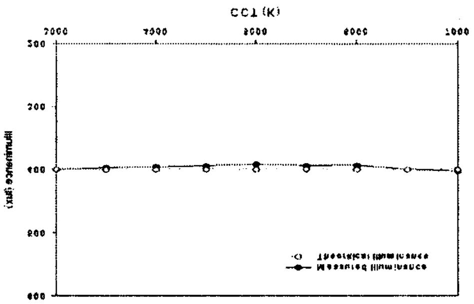


(d) Color temperature = 6000 K

Fig. 3 Measurement illuminance maintaining color temperature



(a) Illuminace = 300 lux



(b) Illuminance = 400 lux

Fig. 4 Measurement color temperature maintaining illuminance

V. Conclusion

RGBW LED has a large potential in lighting application, especially to get the instant colors. However, due to the device aging and sensing nonlinearity, the accuracy and system complexity is still a difficult task. A digital color change system without various sensors has been proposed in this paper. The system can achieve the desired color dynamically and reduce the complexity for using feedback control loops.

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