Journal of
Information Technology & Software Engineering

Tamura et al., J Inform Tech Softw Eng 2017, 7:5
DOI: 10.4172/2175-7866.1000218

Short Communication
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Image Color Conversion by Illumination

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Abstract

We developed a software program to imitate the color of an object within the range of sRGB on a PC display. The obtained colors were converted from the picture information taken under a white light source, such as D65. Other, arbitrary light sources such as natural sunlight or standard illuminants, could be used in addition to the test illumination. Judging from the sample of the converted pictures, the software functions quite well.

Keywords: Color conversion; D65; Illumination; Picture; Simulation; Spectrum

Introduction

In the case of illumination conditions for pictures used in Internet sales, there may be claims that the colors of the products shown are different from that initially ordered. Therefore, it is important to represent products correctly, according to the illumination environment of the display on the electronic devices. An electronic picture of a scene taken under illumination S_1 (for example, white illumination light) is called here the "original picture". One of the issues to solve is to reproduce the same scene under different illumination S_2 (test illumination light), by calculating the original screen data. Being able to estimate spectral reflectivities of substances and reproduce a real color image based on the RGB picture taken under illumination S_1 and S_2 is important. In this study, chromatic adaptation was not considered in the process of picture generation. For picture generation, color impressions were imitated immediately after the illumination had been changed. To determine whether the test illumination light was appropriate for the actual scene as seen visually by a human observer, an evaluation simulation program using picture information was developed. Several strategies were proposed to predict colorimetric values of objects under an arbitrary illuminant from an RGB image [1-4]. They could minimize the error of measured color data analytically and determine the optimum colorimetric value of objects. Murakami and other groups have also reported another methods using an ill-conditioned inverse problem in vector space [5-8]. Therefore, we extrapolated from the previous work [9], utilized characteristic vectors to analyzed the principal components of spectral reflectivities, and simulated the visibility of the objective color under the various illuminations in this report.

Development of the Program

A program running on Windows with the following functions and features was developed in Visual C++Ver. 6. A picture taken under illumination similar to D65 or auto white balance set to D65, was used as the original picture for evaluation. Thus, the reference illuminant was regarded as D65. The picture could be displayed on a PC screen in bitmap format. The monitor to display the picture corresponded to sRGB. The chromaticity coordinates of the picture were within the range of sRGB. One original picture and converted picture under the white illumination light (S_1) and test illumination light (S_2), respectively, were indicated on the PC display to allow comparison of visual images of both colors. In summary, (1) obtain the digital value of each pixel, (2) convert the digital value to XYZ value under S_1, (3) convert the XYZ value under S_1 to XYZ value under S_2, (4) convert the calculated XYZ value to a digital value, (5) indicate the converted color on the display. In steps (2) and (4), sRGB was used. In step (3), the corresponding procedure of tristimulus values between light source color and the object color and the process of tristimulus value conversion according to illumination change, were included.

The color of the display was the light source color and the tristimulus values specified in sRGB corresponded to the light source color. To imitate the color of an object on the display, we had to determine the relationship between the objects and both light source color and object color. Illumination in this report was indicated as S. The tristimulus values of the object color were indicated as X_{obj}, Y_{obj}, and Z_{obj}, respectively. The tristimulus values of the display corresponding to these are X, Y, and Z, respectively. The corresponding relation was indicated in formula 1.

$$X = \alpha X_{obj},\ Y = \alpha Y_{obj},\ Z = \alpha Z_{obj} \quad (1)$$

Furthermore, it is reasonable to assume that the tristimulus value of a white object under illumination S corresponds to the maximum luminance of the light source color with chromaticity coordinates of illumination S on the display. To determine the coefficient α, the maximum achievable brightness was introduced. The coordinate axis of a rectangular coordinate system, shown in Figure 1, was the luminance of a three primary color display system. Point R indicated the red primary color point, G the green primary color point, and B the blue primary color point position. Point W was the position of white balance. Color generated by the mixture of the primary color display system was the inner area of the rectangular parallelepiped, as shown in Figure 1. The chromaticity coordinates of illumination S were indicated as (x_I, y_I). Color with constant chromaticity showed a straight line trace starting from the origin. The straight line g indicated the chromatic series of the same chromaticity as the illumination S. Point P indicated the position of the straight line g, where it crossed with the surface of the rectangular parallelepiped. Point P was the color with chromaticity coordinates (x_I, y_I) and corresponded to the color of maximum brightness that can be used with the display system. The brightness was

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Received November 28, 2017; **Accepted** December 14, 2017; **Published** December 21, 2017

Citation: Tamura S, Okamoto Y, Shigeri Y (2017) Image Color Conversion by Illumination. J Inform Tech Softw Eng 7: 218. doi: 10.4172/2175-7866.1000218

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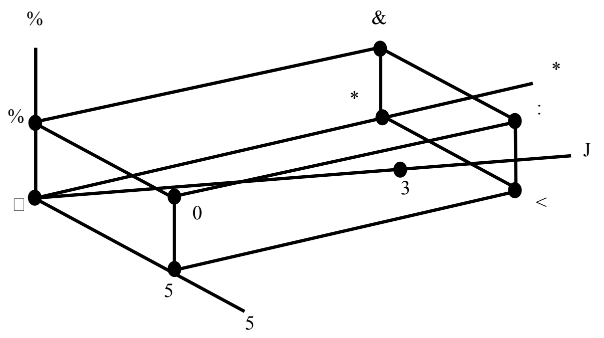

Figure 1: Orthogonal coordinate system of three primary colors (RGB). Point B (blue primary color point), G (green primary color point), and R (red primary color point). Point W was the position of white balance.

indicated as L_I and named as the maximum achieved luminance. The color of a white object under illumination S corresponded to point P. The stimulus value Y_{obj} of the white object under illumination S was 100. On the other hand, the stimulus value Y of a light source color of point P was L_I. Formula 2 was determined using L_I.

$$\alpha = L_I/100 \quad (2)$$

Here we describe the method to estimate the tristimulus value under test illumination. In this case, the tristimulus value of the object color under reference illumination was given when the illumination was switched from the reference illumination to the test illumination. The reference illumination here was D65. The test illumination was optional, but its spectral distribution should be required. The estimation method was based on the spectral reflectance of the object color. First, the spectral reflectance of the object was estimated from the tristimulus value of the object color under reference illumination. Second, the tristimulus value under the test light source was calculated from the estimated spectral reflectance and the spectral distribution of the test illumination. In this calculation, two spectral reflectances of the reference illumination and the test light source, and the main component vector of the object color, were used. The spectral reflectance of the object color was assumed to be expressed well by the following formula 3 in the area where the color chart existed.

$$\rho(\lambda) = \mathrm{k}_1\, \rho_1(\lambda) + \mathrm{k}_2\, \rho_2(\lambda) + \mathrm{k}_3\, \rho_3 \qquad (3)$$

Where, $\rho_i(\lambda)$ (i=1, 2, 3) represented the three main characteristic vectors extracted by principal component analysis from the class of spectral reflectance of the standard color chart. When formula 3 was used, the tristimulus value (Xs, Ys, Zs) under reference illumination of object color could be converted to the tristimulus value (Xt, Yt, Zt) under test illumination (formula 4).

$$\begin{bmatrix} Xt \\ Yt \\ Zt \end{bmatrix} - \begin{bmatrix} Xt_1 & Xt_2 & Xt_3 \\ Yt_1 & Yt_2 & Yt_3 \\ Zt_1 & Zt_2 & Zt_3 \end{bmatrix} \begin{bmatrix} Xs_1 & Xs_2 & Xs_3 \\ Ys_1 & Yt_2 & Ys_3 \\ Zs_1 & Zs_2 & Zs_3 \end{bmatrix}^{-1} \begin{bmatrix} Xs \\ Ys \\ Zs \end{bmatrix} \qquad (4)$$

Here, Xs_i, Ys_i, Zs_i was the tristimulus value of reference illumination $\rho_i(\lambda)$ and Xt_i, Yt_i, Zt_i was the tristimulus value under test illumination $\rho_i(\lambda)$. The object color used was extracted from the 1569 different kinds of colors in JIS Z8721. A variance-covariance matrix specimen was specified among wavelengths for these spectral reflectance data. The characteristic value and characteristic vector using the matrix were obtained and numbered in order of larger characteristic value. Table 1 indicated the contribution ratio and cumulated contribution ratio in the first four components. The total contribution ratio reached ≥ 99% with the first three components. Therefore, fluctuation of spectral reflectance could be fully approximated using these three components. Formula 3 worked well to estimate spectral reflectance. Figure 2 indicated three characteristic vectors.

Application of the Program

The operation of the above program could be summarized as follows. (1) Start the program and select the bitmap file to convert from the file open menu. The specified picture was displayed on the left part of the client area. (2) Select the test illumination in the "test illumination" menu. A light bulb, daylight of various correlated color temperatures, the light spectrum of environment light and other various artificial sources for color evaluation were preset for test illumination. Furthermore, the spectral distribution of the light source could be given to set the user-specified optional illumination. (3) Select test illumination to display the converted picture on the right half of the client area. Figure 3 shows the simulation result of an earthenware

Component	Contribution ratio (%)	Total contribution ratio (%)
1	81.427	81.427
2	13.603	95.030
3	4.178	99.208
4	0.374	99.582

Table 1: Contribution ratio.

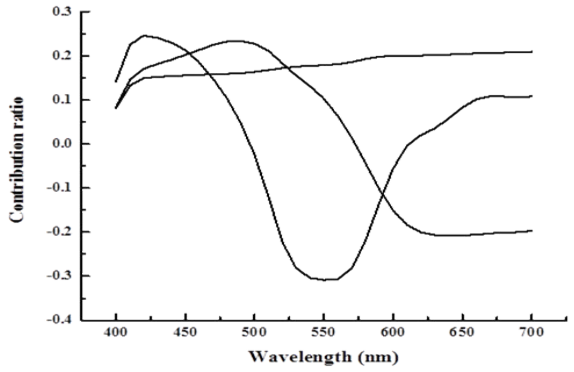

Figure 2: Three characteristic vectors.

Figure 3: Example of picture conversion (earthenware pot). Right bottom was a converted picture.

Figure 4: Example of picture conversion (gold-painted porcelain). Original picture (left) and converted one (right).

Figure 5: Example of picture conversion (Chinese phoenix). Original picture (left) and converted one (right).

pot when the metal halide lamp (HP5) was selected. Figure 4 showed the original picture of a gold-painted porcelain (left) and converted pot under a light environment at a color temperature of 15,000°C (right). Figure 5 shows the original picture of a Chinese phoenix (left) and one converted (right) under the mixed illumination (D65 + 470 nm blue LED).

Conclusion

We developed a software program to imitate the color of an object (under white light source) to that under different illumination. Judging from the sample of the converted pictures, our software theoretically could work. For various marketplaces, our software would be expected to reduce the gap between the standard illumination condition and arbitrary light source condition for commercial products.

Acknowledgment

This research was supported by LIXIL JS Foundation (15-14), Foundation for Promoting Personal Mobility and Ecological Transportation and JSPS KAKENHI Grant Number 26350693 (to S. Tamura and Y. Shigeri). We thank Prof. Leslie Sargent Jones (Appalachian State University) for her careful reading of the manuscript.

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