An Illumination-Adaptive Colorimetric Measurement Using Color Image Sensor

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SUMMARY An image sensor for a use of colorimeter is characterized based on the CIE standard colorimetric observer. We use the method of least squares to derive a colorimetric characterization matrix between RGB output signals and CIE XYZ tristimulus values. This paper proposes an adaptive measuring method to obtain the chromaticity of colored scenes and illumination through a 3×3 camera transfer matrix under a certain illuminant. Camera RGB outputs, sensor status values, and photoelectric characteristic are used to obtain the chromaticity. Experimental results show that the proposed method is valid in the measuring performance.

key words: CIS, ALC, chromaticity, camera characterization

1. Introduction

Generally, a Color Image Sensor (CIS) is used to capture an image and has output signals of RGB from CIE XYZ tristimulus. A camera characterization matrix is easily derived by least squares polynomial modeling between RGB output signals of a camera and XYZ tristimulus values of objects. We first surveyed the camera characterizations in the standard environments, and then determined one of them suitable to a certain illuminant for improving measuring performance of a CIS. We could apply a CIS to measure the chromaticity of colored scenes without any preprocessing. The proposed method enables us to predict ambient chromaticity including illuminations and objects using camera output signals and photoelectric characteristic under various illuminants. Experimental results prove more accurate measurement of illuminant and objects' chromaticity in complex scenes. Improved measurement of ambient using CISs can be effectively applied to a variety of areas such as image processing to compensate phenomena of HVS (Human Visual System).

2. Colorimetric Characterization

Camera characterization methods can be divided into two general categories; spectral sensitivity-based method, and color target-based method. With spectral sensitivity-based characterization, the camera spectral sensitivity needs to be measured using specialized apparatus, such as a monochrometer and radiance meter. A relationship between the camera spectral sensitivity and CIE Color Matching Functions (CMFs) needs to be found. This relationship can be used to transform the camera RGB values into XYZ values. As such, the basic concept of color target-based characterization is to use reference targets containing a certain number of color samples. These color samples are imaged by a camera and measured by a spectrophotometer to obtain the RGB values and their corresponding XYZ values. However, color target-based characterization is more widely used, as it only requires a target, which makes it more practical. Plus, polynomial regression is adopted for model derivation. Device characterization by polynomial regression with least squares fitting has already been adequately explained by many other researchers [1]–[3].

We derived transfer characterization of a CIS using variable polynomial regression with the method of least squares. This method is widely used to derive the camera transfer characterization because only XYZ values and RGB output signals are needed. The matrix of transformation between XYZ tristimulus for N color samples and corresponding camera RGB outputs is shown in Eq. (1). (on condition that RGB values are in proportion to XYZ values)

\[
\begin{bmatrix}
 R_1 & R_2 & \ldots & R_N \\
 G_1 & G_2 & \ldots & G_N \\
 B_1 & B_2 & \ldots & B_N \\
\end{bmatrix} =
\begin{bmatrix}
 a_{11} & a_{12} & a_{13} & | & X_1 & X_2 & \ldots & X_N \\
 a_{21} & a_{22} & a_{23} & | & Y_1 & Y_2 & \ldots & Y_N \\
 a_{31} & a_{32} & a_{33} & | & Z_1 & Z_2 & \ldots & Z_N \\
\end{bmatrix}
\]

(1)

Both camera RGB outputs and corresponding XYZ tristimulus are 3×N matrices but camera transfer characterization is 3×3 matrix. So we used a procedure known as the method of least squares to find camera characterization in this overdetermined system [4]. The best characterization matrix is determined as the one that minimizes the color difference over all color samples. Finally, a 3×3 camera characterization matrix (Mc) is derived as shown in Eq. (2) by using the method of least squares.

\[
\begin{bmatrix}
 a_{11} & a_{12} & a_{13} \\
 a_{21} & a_{22} & a_{23} \\
 a_{31} & a_{32} & a_{33} \\
\end{bmatrix} =
\begin{bmatrix}
 R_1 & R_2 & \ldots & R_N \\
 G_1 & G_2 & \ldots & G_N \\
 B_1 & B_2 & \ldots & B_N \\
\end{bmatrix}
\begin{bmatrix}
 X_1 & X_2 & \ldots & X_N \\
 Y_1 & Y_2 & \ldots & Y_N \\
 Z_1 & Z_2 & \ldots & Z_N \\
\end{bmatrix}^T
\]

(2)

3. Improved Measuring Performance Using Multi-Mc

The image signal processing block diagram of a CMOS CIS

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The camera has different colorimetric characterizations according to the white balance established by photographing conditions. Auto White Balance (AWB) automatically adjusts variations of image color caused by various light sources, using the average value of color difference signals from a rectangular area on a screen, which can be set independently from the ALC (Auto Luminance Control) function. Therefore, AWB function should be deactivated for the purpose of a colorimeter. Also Gamma function is off for a linear relationship between XYZ values and RGB values. A CIS is set up as follows:

1. AWB function: OFF;
3. Gamma correction: OFF.

ALC is constituted with Auto Exposure Shutter (AES) and Auto Gain Control (AGC). AES automatically controls shutter speed to assure optimal exposure as object's brightness changes, and AGC changes digital and analog gain according as a luminance level.

We first obtained a standard camera transfer matrix ($M_{C50}$) by least squares solution through camera RGB values and measured chromaticity in the illuminant D50 (5000 K). CIS controls ALC register status to maintain camera output values within constant ranges. ALC register status offer information about shutter ratio, analog and digital gain ratio. So we can get a weighted factor $K_L$ for a luminance level as Eq. (3).

$$K_L = f \left( \text{shutter ratio, digital gain, analog gain} \right)$$

The process to predict the chromaticity of a certain illuminant and colored scenes under that illuminant is as follows. We sampled some data from camera Bayer outputs to reduce computing burden. The camera RGB values are nonlinearly normalized to compensate for nonlinear characteristic of RGB channels through Eqs. (4), (5) because even if a gamma function of a CIS is off internally, photoelectricity characteristic from XYZ tristimulus to RGB values isn’t exactly linear. Next XYZ tristimulus are calculated as Eq. (6).

$$R_N = \frac{K_R \times R^\gamma}{2^n - 1}$$
$$G_N = \frac{K_G \times G^\gamma}{2^n - 1}$$
$$B_N = \frac{K_B \times B^\gamma}{2^n - 1}$$
$$K_i = \frac{(2^n - 1)^{y_i}}{2^n - 1} \quad \text{for } i = R, G, B$$

where $R_N, G_N, B_N$ are nonlinearly normalized values from RGB camera outputs, $K_i$ is an weighted factor obtained from ALC register status, $K_R, K_G, K_B$ are factors for normalization of output values (maximum of value = 1), $n$ is a bit-depth ($n = 8$), and $\gamma_R, \gamma_G, \gamma_B$ are exponential values of nonlinearity for each RGB channel.

Generally chromaticity of illuminants is located near the black body locus in the chromaticity diagram and chromaticity of a white patch is similar with the chromaticity of illuminants. It is important to seek white pixels from camera outputs of complex scenes. So luminance data ($Y$) from RGB values are used to find pixels of white or bright gray level of camera outputs because those pixels have higher luminance in the complex scene. After sorting camera outputs as luminance $Y$, we get upper 10% pixels to find white or bright gray level. Then the CCT (Correlated Color Temperature) of illumination is estimated using basis characterization matrix obtained under the illuminant of D50 ($M_{C50}$).

After estimating the illuminant using single characterization matrix, we selected the closest characterization matrix of the CIS similar to the present viewing environment among 3 characterization matrices ($M_{CA}, M_{C50}, M_{C65}$) obtained under representative illuminations of D50, D65, and A. Finally, we could estimate more precise chromaticity of illumination and objects through the selective $M_c$. This method will be referred to as the illuminant-adaptive multi-$M_c$. The proposed design flow is illustrated in Fig. 2. The proposed estimation process is summed up as followings:

1. Estimating $XYZ$ tristimulus from $RGB$ values using $M_{C50}$ (basis matrix);
2. Selecting high luminance pixels corresponding to upper 10% of $Y$;
3. Estimating CCT of illumination from selective samples (rough estimation by $M_{C50}$);
4. Selecting one of characterization matrices ($M_{CA}$,
5. Estimating chromaticity of illumination and chromaticity of various colors in scenes (precise estimation by selective $M_c$).

4. Experimental Results

We evaluated the measuring performance of the proposed method with two points of view: illuminant chromaticity and object’s chromaticity. First, we evaluated the ability to predict chromaticity of 13 colors in the Macbeth color checker, red, green, blue, cyan, magenta, yellow, orange, purplish blue, moderate red, purple, yellow green, orange yellow, and white in 3 kinds of illuminants, D50, D65, and A. Color differences were evaluated in term of the chromaticity errors, $\Delta u'v'$ to check the performance of the proposed method quantitatively. Comparisons of average color differences between single-$M_c$ and multi-$M_c$ are shown in Table 1. Color differences using multi-$M_c$ are improved at 10% from 0.0200 to 0.0180 in illuminant D65 and 36% from 0.0256 to 0.0164 in illuminant A.

Second, we inspected estimation performance of illumination from complex scenes under some illuminants. The average color differences of illuminant estimation are compared in Table 2 between single-$M_c$ and multi-$M_c$. The rate of improvement is about 20%.

In conclusion, the proposed method enables us to estimate illuminants and chromaticity of reflecting objects accurately by using multi-characterization under various environments.

5. Conclusions

In this paper, we proposed a new method to obtain chromaticity of colored scenes including illuminations from output signals of a CIS. We can measure the chromaticity of complex scenes and various illuminants using the proposed method. The experimental results demonstrate that the proposed method effectively measures those. As an application of measuring performance of a CIS, this paper presents an estimation technique using multi-characterizations to estimate chromaticity more accurately than using single-characterization under various environments. The estimated chromaticity for ambiance can produce optimum conditions for image capture systems in various viewing conditions. Moreover the proposed method can be used to control CISs to optimize image conditions including contrast, brightness offset, color saturation, gamma, and white balance.

References