

ILLUMINATION ESTIMATION BASED ON VALID PIXEL SELECTION IN HIGHLIGHT REGION

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ABSTRACT

This paper proposes a method for estimating the illuminant chromaticity using the distributions of camera responses obtained by a CCD camera in a real-world scene. Illuminant estimation using a highlight method is based on the geometric relation between a body and its surface reflection. In general, the pixels in a highlight region are affected by an illuminant geometric difference, camera quantization errors, and the non-uniformity of the CCD sensor. As such, this leads to inaccurate results if an illuminant is estimated using the pixels of a CCD camera without any preprocessing. Accordingly, to solve this problem, the proposed method analyzes the distribution of the CCD camera responses and selects pixels using the Mahalanobis distance in highlight regions. The use of the Mahalanobis distance based on the camera responses enables the adaptive selection of valid pixels among the pixels distributed in the highlight regions. Lines are then determined based on the selected pixels with r-g chromaticity coordinates using a principal component analysis (PCA). Thereafter, the illuminant chromaticity is estimated based on the intersection points of the lines. Experimental results using the proposed method demonstrated a reduced estimation error compared with the conventional method.

1. INTRODUCTION

Color constancy is the part of the human visual system that derives the intrinsic reflectance properties of objects that are independent of extrinsic parameters, such as the illumination, viewing direction, surface orientation, and surrounding colors. In the case of humans, the original color of an object under an arbitrary illuminant is estimated as an integrated judgment. However, an input device, such as a camera, is unable to discriminate the features of the original input responses, thus illuminant estimation is needed to replicate the visual ability of humans[1-2].

Lee[3] proposed a method for estimating the illuminant chromaticity by analyzing regions with a chromaticity

change, i.e. for highlight regions in an image, the chromaticity distribution of the highlight region makes a line, and if there are more than two lines, the cross point is assumed to be the illuminant chromaticity. However, since conventional methods basically estimate an illuminant with either a synthetic or optimal image, it is difficult to obtain a good result for a real-world scene, as the camera responses include quantization errors and non-uniform CCD sensors. To overcome this problem, Lehmann [4] recently proposed an illuminant estimation method for real-world scenes that uses additional captured images to compensate for camera noise. Yet this method cannot be applied when additional captured images are unobtainable. Therefore, this paper proposes an illumination estimation method using the Mahalanobis distance that considers the camera response distribution within a single image.

2. ILLUMINATION ESTIMATION USING HIGHLIGHT REGION

Illumination estimation using a highlight region is based on using the illuminant information captured by the chromaticity distribution of the pixels in a highlight region. The method is relatively straightforward and most frequently used, as an illumination can be estimated based on the output response without any specific camera optics. The camera input response is represented by the following equation:

$$C = \int E(\lambda)S(\lambda)R(\lambda)d\lambda \quad (1)$$

where C is the RGB value of the camera response, $E(\lambda)$ is the spectral power distribution, $S(\lambda)$ is the sensitivity of the camera, and $R(\lambda)$ is the surface reflectance. Equation (1) can also be divided by the interface reflectance and body reflectance, and described by the dichromatic reflection model and as follows:

$$C = \alpha(\theta)C_S + \beta(\theta)C_B, \quad (2)$$

where θ is determined based on the difference between the illuminant orientation and the normal vector for the surface, α, β are the geometrical factors, and C_S and C_B are the interface reflectance and body reflectance of the object, respectively. Thus, equation (1) can be represented as follows:

$$C = \alpha(\theta) \int E(\lambda)R(\lambda)d\lambda + \beta(\theta) \int E(\lambda)R(\lambda)d\lambda. \quad (3)$$

Equation (3) is described using RGB values,

$$\begin{pmatrix} R \\ G \\ B \end{pmatrix} = \alpha(\theta) \begin{pmatrix} R \\ G \\ B \end{pmatrix}_I + \beta(\theta) \begin{pmatrix} R \\ G \\ B \end{pmatrix}_B, \quad (4)$$

where the interface reflectance part I is considered the same as the illumination irradiating the object in the scene. Equation (4) is described using chromaticity coordinates as follows:

$$\begin{pmatrix} r \\ g \end{pmatrix} = \begin{pmatrix} \frac{R}{R+G+B} \\ \frac{G}{R+G+B} \end{pmatrix}. \quad (5)$$

The dichromatic reflectance model is then represented using the following r-g chromaticity coordinates:

$$\begin{pmatrix} r \\ g \end{pmatrix} = \alpha(\theta) \begin{pmatrix} r \\ g \end{pmatrix}_I + \beta(\theta) \begin{pmatrix} r \\ g \end{pmatrix}_B. \quad (6)$$

In equation (6), the relationship between the illumination and the surface reflectance is indicated by geometrical factors, and at this point, the line is made based on a Hough transform.

Lehmann[4] recently proposed a method of illumination estimation for real-world scenes that uses additional captured images to compensate for camera noise. Lehmann's method, Color Line Search (CLS), consists of three steps as follows: First, highlight regions are automatically selected and their pixels transformed into chromaticity coordinates. Second, the color lines are determined according to the dichromatic reflectance using a Hough transform. Third, a consistency check is applied based on a corresponding path search of the image domain. However, we attempt to estimate the illumination using a single image without the additional images required by the CLS method. As such, based on surveying the distribution of a cluster and considering the CCD camera response in a highlight region, the following

method is proposed for valid pixel selection in a highlight region.

3. PROPOSED METHOD FOR VALID PIXEL SELECTION

Although an image is taken accurately, the image also includes the non-uniformity of the CCD sensor, electrical signal unstableness, and camera noise. Therefore, the camera response to a Gretag-Macbeth Color-Checker with r-g chromaticity coordinates under a D65 illuminant was investigated using a Sony DSC-D700 CCD camera in a dark booth. Figure 1(a) shows the 240 uniform color patches of the Gretag-Macbeth Color-Checker. Although ideally each color patch should be uniform, the RGB values of the captured image varied due to the non-uniformity of the camera response, as shown in figure 1(b),

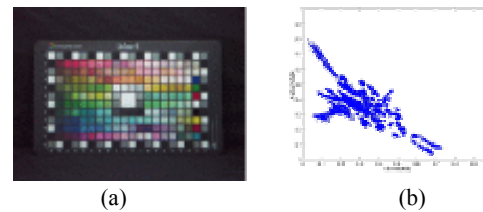


Figure 1. Distribution of CCD camera response in r-g chromaticity coordinates; (a) Gretag-Macbeth color checker and (b) response distribution in r-g chromaticity coordinates.

where the non-uniformity of the RGB response induced a cluster of r-g chromaticity coordinates, rather than a single point. Also, the distribution of the highlight-region responses was similar to an ellipse. Figure 2 shows distribution of pixels of highlight region.

As such, in the proposed highlight method, the covariance of the cluster is used to define the Mahalanobis distance, then the average value of the Mahalanobis distance among the 240 patches is used as the threshold T to select valid camera responses, which was 0.9129 in this paper. A block diagram of the proposed algorithm is shown in figure 3. First, an input image is segmented into highlight regions based on the RGB intensity, and the size of each region is 20×20 pixels.

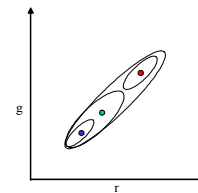


Fig. 2. Distribution of the same Mahalanobis distance for representatives in the highlight region.

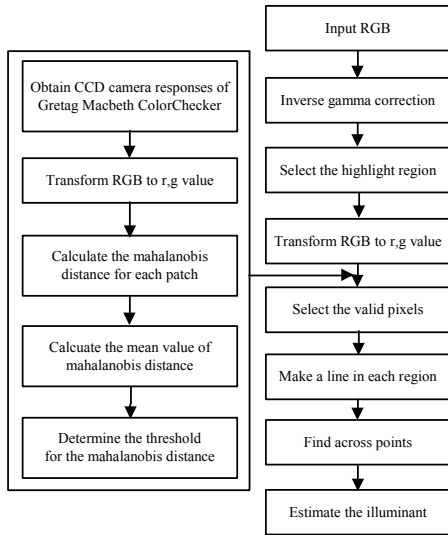


Figure 3. The block diagram of proposed algorithm.

Based on the r-g chromaticity coordinates, an (r,g) value is calculated for each pixel in a highlight region using equation (5). Three representative values are then determined based on the intensity in each highlight region to effectively describe the feature of the cluster. New populations are selected in advance using the established threshold as a criterion for the three representative values. To obtain the threshold value, the standard deviation between the mean of the camera response and the cluster of color tones for each Gretag-Macbeth Color-Checker patch is calculated, then the threshold is defined as the Mahalanobis distance for a pixel with the standard deviation of the color tone. The total color tone is then expanded based on calculating the mean value for the Mahalanobis distance in each patch. As a result, valid pixels are selected from among standard representatives in a highlight region.

Generally, the pixels in a highlight region form an elliptical shape based on their r-g chromaticity coordinates. Thus, representatives need to be determined for selecting valid pixels from a highlight region. As such, we use Wandell's method to determine cluster representatives. A cluster is divided by 0~30%, 0~70%, and 70~100% according to the intensity of the chromaticity coordinates, and each representative is determined based on the mean of the chromaticity values in each region. Therefore, valid pixels are selected within the Mahalanobis distance of the standard representatives.

The Mahalanobis distance indicates the relation between clusters or the relation between a cluster and a pixel,

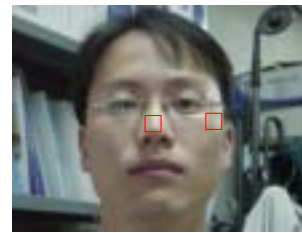
$$d = \sqrt{(S - \bar{S})^T \Sigma^{-1} (S - \bar{S})} < T, \quad (7)$$

where d is the Mahalanobis distance between an arbitrary pixel and the centroid, S is the location vector of an arbitrary pixel, \bar{S} is the mean vector of the training set, T is valid threshold for noise and Σ is the variance-covariance matrix for the training set. Based on the distance calculated using equation (7), pixels are then selected that are close to the cluster's shape in a highlight region. This means that valid pixels are selected based on the Mahalanobis distance after analyzing the distribution of the CCD camera responses.

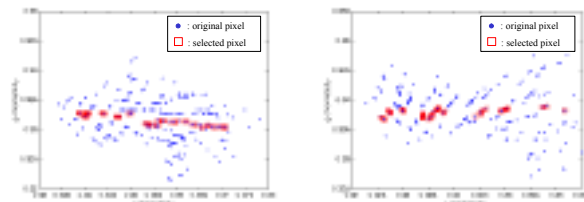
4. EXPERIMENTS

The proposed method was evaluated using a Sony DSC-D700 CCD camera, which was calibrated prior to the experiments. The image size was 640×480 , the shutter speed was set to $1/45s$, and the f-number was fitted to 2.4. Experiments were based on four illuminants (Day, A, U30-TL84, and CWF) in the Gretag-Macbeth Judge II Booth. To compare the results, the pixels selected in the highlight regions were compared with the lines based on the chromaticity coordinates. In addition, the estimation error and reproduced images were compared for a quantitative result.

Consequently, the images reproduced using the proposed method were visually more similar to under the standard illuminant than those reproduced using the conventional method. In addition, the proposed method was able to accurately estimate the illuminant using only a single real-world image. Figure 4 shows the pixels selected after applying the proposed algorithm, where the pixels were selected using the average Mahalanobis distance based on the distribution of the camera response.



(a)



(b)

(c)

Figure 4. Pixel distribution of highlight regions (•) and selected pixels (□); (a) test image, (b) pixels of nose region, and (c) pixels of cheek region.

Figure 4(a) shows a nose region, while figure 4(b) shows a cheek region, and the circles (•) denote the pixels selected in highlight region, whereas the squares(□) denote the pixels selected using the proposed algorithm. Although the pixels in the highlight regions were distributed based on chromaticity coordinates, the pixels selected using the proposed method represented a cluster.

It is able to calculate the estimation error of the conventional and proposed method. The images were also reproduced under standard illumination using the illumination estimation results for CLS method and proposed method. Therefore, we can compare with reproduction image under a standard illumination visually. Figures 5~7 show the images reproduced using the two methods. In figure 5(b), a reddishness appears in the white patch region, which is absent in figure 5(c), making it similar to the standard image. As comparing with a white patch and total tone of color in figure 6 (b) and 6(c) we are able to confirm that proposed method is better. It is difficult to discriminate the images of two methods in case of CWF illumination, because an error of illumination estimation is small relatively in figure 7. Table 1 shows the quantitative results, which confirm that the proposed method reduced the estimation error for all illuminations. The estimation error was calculated as follows:

$$E = \sqrt{\Delta r^2 + \Delta g^2}. \quad (8)$$

Table 1. Comparison of estimation error according to the illuminations.

	Gray world assumption	CLS method	Proposed method
A	0.0914	0.0424	0.0342
U30-TL84	0.0611	0.0730	0.0523
CWF	0.0434	0.0121	0.0092

5. CONCLUSIONS

This paper proposed a more accurate method for illuminant estimation based on considering the distribution of the CCD camera responses in a real-world image. The proposed method analyzes the statistical data for the CCD camera responses, calculates the Mahalanobis distance for the camera responses, then selects pixels based on the relation between the Mahalanobis distance and the cluster feature in a highlight region. In experiments, the images reproduced using the proposed method were visually more similar to under the standard illuminant than those reproduced using the conventional method. In addition, the illuminant was accurately estimated using only a single real-world image.

6. ACKNOWLEDGEMENT

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7. REFERENCES

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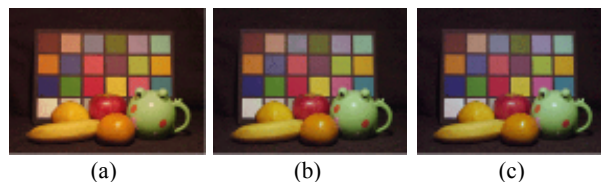


Figure 5. Results of image reproduction; (a) test image under A illumination, (b) reproduction image after estimating illumination using CLS method, and (c) reproduction image after estimating illumination using proposed method.

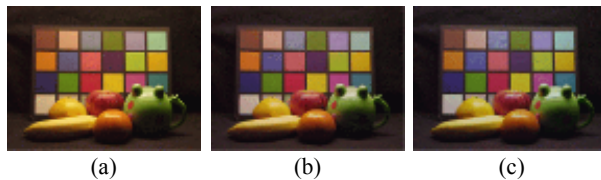


Figure 6. Results of image reproduction; (a) test image under U30-TL84 illumination, (b) reproduction image after estimating illumination using CLS method, and (c) reproduction image after estimating illumination using proposed method.

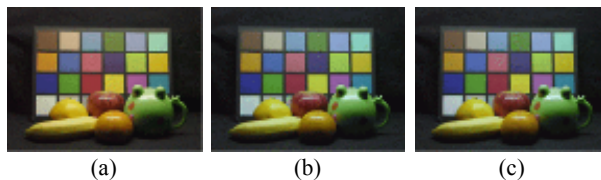


Figure 7. Results of image reproduction; (a) test image under CWF illumination, (b) reproduction image after estimating illumination using CLS method, and (c) reproduction image after estimating illumination using proposed method.