Estimation of Illuminant Chromaticity Based on CCD Camera Response Distribution in a Real-World Image

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Abstract

This paper proposes a method for estimating the illuminant chromaticity using the distributions of the 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.

Illuminant Estimation Method

Color constancy is the attempt to derive the intrinsic reflectance properties of objects, which are independent of extrinsic parameters, such as illumination, viewing, direction, surface orientation, and surrounding colors. In the case of human beings, 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 feature of an illuminant, as it only records the features of the original input responses. As such, there is a need for illuminant estimation to replicate the visual ability of humans. Illuminant estimation methods[1-4] can be classified according to whether they use spectral reflectance or a tri-stimulus. The basic approach using spectral reflectance was originally designed by Maloney et. al.[1] The spectral reflection from an object surface comes from the multiplication of the body and the surface reflection. Therefore, the spectral reflectance of an illuminant can be estimated using an analysis of this multiplication formula. D'Zmura et. al.[2] proposed general linear and bilinear models to extend Maloney's approach based on the combination of multiple illuminants and multiple surfaces and the relationship between these two factors. Plus, Tominaga[3] proposed illumination estimation using singular value decomposition.

In contrast, Land's Retinex theory[4] is the basic approach using a tri-stimulus input along with the grey world assumption that the average vector for the three channels is assumed to be the illuminant chromaticity for the scene or image. Other approaches using highlights have also been considered. Lee[5] proposed a method to estimate 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 camera responses include quantization errors and non-uniform CCD sensors. To overcome this problem, Lehmann(color line search: CLS) recently proposed an illuminant estimation method for real-world scenes that uses additional captured images to compensate for camera noise.[6] Yet, it is still difficult to apply this method to a real situation. Therefore, this paper proposes an illuminant estimation method using the Mahalanobis distance that considers the camera response distribution within a single image.

Mahalanobis Distance Method

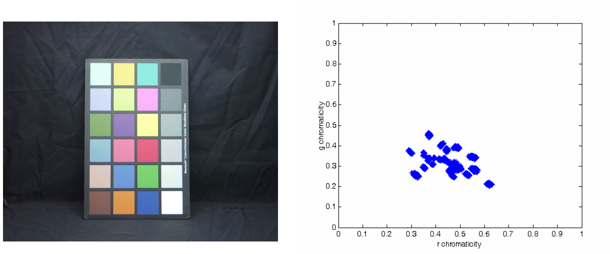
The Mahalanobis distance indicates the relation between clusters or the relation between a cluster and a pixel, where d is the Mahalanobis distance between an arbitrary pixel and the centroid, S is the location vector of an arbitrary pixel, $\overline{S}$ is the mean vector of the training set, and Σ is the variance-covariance matrix for the training set.

$$d = \sqrt{(S-\bar{S})^T \sum^{-1}(S-\bar{S})} \tag{1}$$

where T is transpose. Based on the distance calculated using Eq. (1), pixels are 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.

Illuminant Estimation Based on CCD Camera Responses

Although an image is taken accurately, the image also includes the non-uniformity of the CCD sensor, electrical signal unstableness, and camera noise.[7] Figure 1 shows the distribution of the camera responses for a Macbeth ColorChecker with r-g chromaticity coordinates under a D65 illuminant with a Sony DSC-D700 CCD camera.



(a) *(b)*

Figure 1. Camera response of real-world image; (a) Macbeth ColorChecker under D65, (b) the distribution in r-g chromaticity coordinates.

Figure 1(a) shows the 24 uniform color patches of the Macbeth ColorChecker. Although ideally each color patch should be uniform, the RGB values of the captured image vary due to the non-uniformity of the camera response. This characteristic is shown in figure 1(b). The non-uniformity of the RGB responses induces a cluster of r-g chromaticity coordinates, rather than a single point. Also, the distribution of the highlight region responses is similar to an ellipse. 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 24 patches is used as the threshold value to select valid camera responses. The block diagram of proposed algorithm is shown in Figure 2. First, an input image is segmented into highlight regions based on the RGB intensity, and the size of each region is 20×20 pixels. A (r, g) value is calculated for each pixel in a highlight region using r-g chromaticity coordinates. Three representative values are then determined based on the intensity in each highlight region to describe the feature of the cluster effectively.

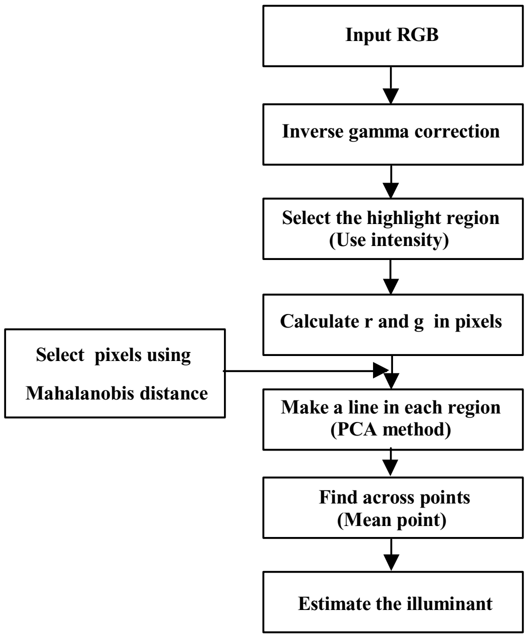


Figure 2. Block diagram of proposed algorithm.

These three regions are then segmented using the intensity of 0~30%, 0~70%, and 70~100%. The representative values are the defined average value for each segmented region. Then, a new population is composed using the Mahalanobis distance as the threshold. Finally, the r-g chromaticity coordinates are used to create a line by applying the selected pixels to the PCA method, and the intersection point of the lines is the illuminant.

We detected a line in the cluster using a statistical characteristic. Principal component analysis is the method to determine a single line for the pixels of highlight in the r-g chromaticity coordinates. For an arbitrary vector population,

$$X = [x_1 \ x_2 \ \cdots \ x_n]^T, \tag{2}$$

the mean vector of this population is defined as follow

$$m_x = E\{x\}, \tag{3}$$

and the covariance of the vector is

$$C_x = E\{(x-m_x)(x-m_x)^T\}. \tag{4}$$

A line in the highlight region is determined using the significant eigen-value of C_x. Therefore, we able to a line in the highlight region after the covariance value of highlight pixels is calculated and the vector of the significant eigen-value is selected.

Experiments

Prior to the experiment, the camera calibration was completed. Figure 3 shows the image under illuminant A. Four highlight regions were identified based on the intensity. The intensity threshold of the highlight regions was 2.7 times the mean intensity of the image.[8] The selected regions were then sorted according to their intensity.

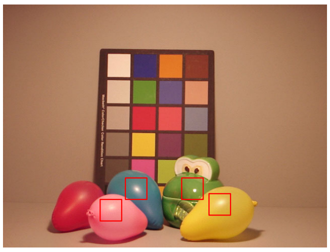
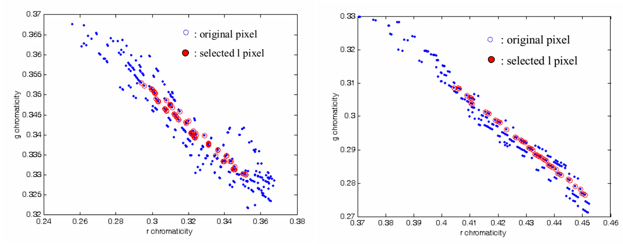


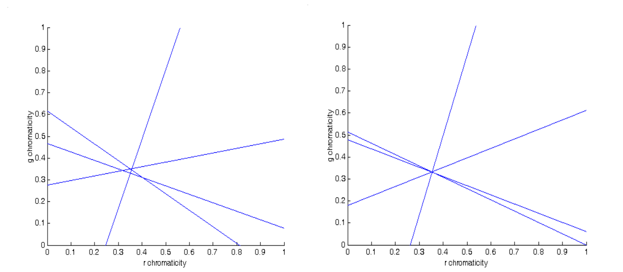
Figure 3. Selected highlight regions in a real-world image

Figure 4 shows the selected pixels after applying the proposed algorithm, where the pixels were selected using the average Mahalanobis distance based on the distribution of the camera response. Figure 4(a) shows a cyan region, while figure 4(b) shows a pink region. The lines are created from the selected pixels, the open circles(o) are the pixels selected using the proposed algorithm, and the filled circles(●) are the pixels selected using CLS method.



(a) *(b)*

Figure 4. Selected pixels highlight regions; (a) cyan region, (b) pink region.



(a) *(b)*

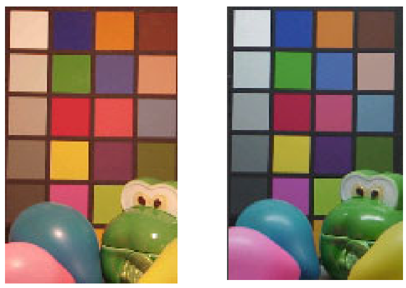
Figure 5. The intersection points from the lines; (a) CLS method, (b) proposed method.

Table 1. Comparison of RMSE

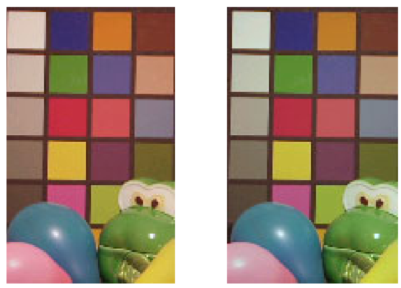
	CLS method	Proposed method
RMSE	0.0385	0.0096

Figure 5 shows the lines from the pixels. Figure 5(a) shows the lines when using CLS method, while figure 5(b) shows the lines when using the proposed method. The (r, g) value of the real-world image was (0.3932, 0.3278), the (r, g) value using CLS method was (0.3561, 0.3381), and the (r, g) value using the proposed method was (0.3881, 0.3197).

Table 1 shows a comparison of the RMSE between CLS method and the proposed method, where the proposed algorithm produced a better result than CLS method. Thereafter, the illuminant chromaticity was estimated based on the intersection points of the lines, and von Kries's model used to reproduce the image with the estimated illuminant. Figures 6(a) and 6(b) show a real-world image under illuminant A and illuminant D65, respectively, and the reproduction images using the conventional method and proposed method are shown in figures 6(c) and 6(d), respectively. The proposed method was more similar to under the standard illuminant, due to excluding the influence of camera noise. As such, the experimental results demonstrated that the proposed method could estimate an illuminant using a single real-world image without additional captures.



(a) *(b)*



(c) *(d)*

Figure 6. The result of image reproduction; (a) test image under A illuminant, (b) a measured image under D65 illuminant, (c) a reproduction image using CLS method, (d) a reproduction image using proposed method.

Conclusion

This paper proposed a more accurate method for illuminant estimation based on considering the distribution of CCD camera responses in a real-world image. The proposed method analyzes statistical data for 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. Finally, the illuminant is estimated from the selected pixels. In experiments, the reproduction image resulting from the proposed method was visually more similar to under the standard illuminant than that from the conventional method. In addition, the illuminant was accurately estimated using only a single real-world image.

Acknowledgement

This work was supported by grant no. M10203000102-02J0000-04810 from the National Research Laboratory Program of the Korea Ministry of Science & Technology.

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Biography

Yeong Ho Ha received the B. S. and M. S. degrees in Electronic Engineering from Kyungpook National University, Taegu, Korea, in 1976 and 1978, respectively, and Ph. D. degree in Electrical and Computer Engineering from the University of Texas at Austin, Texas, 1985. In March 1986, he joined the Department of Electronic Engineering of Kyungpook National University, as an assistant professor, and is currently a professor. Dr. Ha served as TPC co-chair of 1994 IEEE International Conference on Intelligent Signal Processing and Communication Systems. He is now chairman of IEEE Taegu section and president of Korea Society for Imaging Science and Technology. He is a senior member of IEEE, and a member of Pattern Recognition Society and Society for IS&T. His main research interests are in color image processing, computer vision, and digital signal and image processing.