Illuminant Conversion Using Iterative Variation Method

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Abstract

In recent years, the rapid development of the Internet has allowed people at home to access large amounts of image data stored on web servers throughout the world. Significant value can be added by estimating the illuminant at the time of acquisition, and convert to the image under a desired illuminant source. There have been studies about illuminant estimation. All of these algorithms perform illuminant estimation in an original image. This paper stands on a slight different point of view from these existing studies. The purpose of the study is to obtain an image illuminated by a desired one. In the proposed algorithm, the conversion is performed from an image whose illuminant is unknown to the image whose illuminant is the desired one. In the conversion process, the illuminant estimation is performed relative to the desired one, and the problem dimensions are reduced.

The problem is formulated by an optimization problem framework of a cost function and some constraints and for the solution, a variation method is applied iterative.

1.Introduction

In recent years, the rapid development of the Internet has allowed people at home to access large amounts of image data stored on web servers throughout the world. Also, it is common practice to use color images obtained using peripheral equipment such as digital cameras which have recently become extremely popular. The growing demand for color images has been accompanied by increased popularity of an application called photoretouch software which is capable of applying desired conversion adjustments to color images. These features can correct characteristics of color images at the time of acquisition without the need to rescan images. These features are significant advantages of digital imaging. Further value can be added by estimating the the illuminant at the time of acquisition, and convert to the image under a desired illuminant source. For example, color images of important cultural assets can be obtained from the web. Users can further enjoy the images by manipulating them so that appear to be taken under particular illuminant conditions. Such an image conversion system will add value by allowing manipulation of the images of important cultural assets that cannot be touched physically. Users wish to realize this process effectively, therefore automatic processing is being sought so that it is only necessary to designate the desired illuminant source.

There have been studies about illuminant estimation for the applications described. The gamut mapping algorithm[1] (Foryth, Finlayson), the Maloney-Wandell algorithm[2] (Maloney, Wandell), MAR algorithm[3] (Cheng, Lee) have been proposed. All of these methods perform illuminant estimation. This paper approaches the problem with a slightly different point of view from these existing body of studies. The purpose of the study is to obtain an image illuminated by a desired one, and convert from an image whose illuminant is unknown to the image whose illuminant is the desired one. As in the conversion process illuminant estimation is essential, the illuminant estimation is performed relative to the desired one. For the purpose of this study, there is an advantage in the framework in reducing the problem dimensions. The relationship between an image and its converted image is described by a cost function and constraints. For the optimization of the cost function on the constraints, the variation method is the most suitable. In the framework, a procedure of sequential determination of parameters is included, so an iterative variation method has been developed for the problem.

Experimental results show the validity of the proposed method.

2.Algorithm

In the proposed algorithm, the conversion is performed from an image whose illuminant is unknown to the image whose illuminant is the desired one. In the conversion process, the illuminant estimation is performed relative to the desired one, therefore constraints between a before-conversion image (image 1) and an after-conversion image (image 2) are posed on. The relationship between image 1 and image 2 is described by a cost function and three constraints. The cost function is based on the least mean square of the prediction error by using a chromatic adaptation model. For the optimization of the cost function on the constraints, the variation method is the most suitable. In the framework describing the chromatic adaptation, the three parameters are included. The chromatic adaptation parameters and three coordinates of an illuminant are mutually convertible and the problem dimension itself is three.

For the optimization of the cost function on the constraints, the variation method is the most suitable. In the framework, a procedure of sequential determination of parameters is included, so an iterative variation method has been developed for the problem.

Three constraints are posed on for the three dimensional problem. The constraints on the variation method are based on the assumptions that (I)constancy on the average intensities in two images (image 1, image 2), (II)constancy on the intensities of two illuminant sources (a designated and in an original image) and (III)constancy on the chromaticity variances in two images (image1, image2). The assumption (III) is based on that the color of an illuminant shifts all of color coordinates in an image, but do not vary the chromaticity variance.

The iterative variation method is described bellow. The assumption (I)(II) are included in the variation method, but the assumption (III) is not included in the variation method because of its non-linearity. By the iterative variation method, candidates of the optimum solution are derived on a one-dimensional space (three parameters minus two constraints), and the optimum solution is selected in the space using the assumption (III). Let $y = \frac{Y}{X+Y+Z}$, $\left(X_W^*, Y_W^*, Z_W^*\right)$ be illuminant coordinates of image 1, and image 2, respectively. $\left(X_W^*, Y_W^*, Z_W^*\right)$ is to be designated, and $\left(X_W, Y_W, Z_W\right)$ is to be estimated. The cost function of the variation method is as follows:

[Cost function]

$$f\left(k_L, k_M, k_S\right) = \left\| \begin{bmatrix} X_W^* \\ Y_W^* \\ Z_W^* \end{bmatrix} - \begin{bmatrix} X_w^{'} \\ Y_w^{'} \\ Z_w^{'} \end{bmatrix} \right\|^2, \tag{1}$$

where

$$\begin{bmatrix} X_w^{'} \\ Y_w^{'} \\ Z_w^{'} \end{bmatrix} = M \begin{bmatrix} X_w \\ Y_w \\ Z_w \end{bmatrix}$$

$$M = \begin{bmatrix} m_{11} & m_{12} & m_{13} \\ m_{21} & m_{22} & m_{23} \\ m_{31} & m_{32} & m_{33} \end{bmatrix},$$

$$m_{11} = 0.74k_L + 0.26k_M,$$
$$m_{12} = 1.32k_L - 1.32k_M,$$
$$m_{13} = -0.15k_L - 0.05k_M + 0.2k_S,$$
$$m_{21} = 0.14k_L - 0.14k_M,$$
$$m_{22} = 0.26k_L + 0.74k_M,$$
$$m_{23} = -0.03k_L + 0.03k_M,$$
$$m_{31} = 0,$$
$$m_{32} = 0,$$
$$m_{33} = k_S.$$

where

M: chromatic adaptation matrix.[4]

The chromatic adaptation model predicts color appearance under different illuminants, and the cost function of equation (1) evaluates the prediction error.

The constraints of the variation method based on the assumptions are as follows:

[Constraint 1]

$$C = \frac{1}{N}\sum_i Y_i - \frac{1}{N}\sum_i \left(m_{21}X_i + m_{22}Y_i + m_{32}Z_i\right) = 0, \tag{2}$$

where

i : pixel index in an image,

N: number of pixels in an image.

[Constraint 2]

$$Y_w = Y_w^* \tag{3}$$

[Constraint 3]

$$\frac{1}{N}\sum_i \left(\sqrt{X_i^2 + Y_i^2} - Av\right)^2 = \frac{1}{N}\sum_i \left(\sqrt{\left(X_i^{'}\right)^2 + \left(Y_i^{'}\right)^2} - Av^{'}\right)^2, \tag{4}$$

where

$$Av = \frac{1}{N}\sum_i \sqrt{X_i^2 + Y_i^2},$$

$$Av' = \frac{1}{N}\sum_i \sqrt{\left(X_i^{'}\right)^2 + \left(Y_i^{'}\right)^2}.$$

The constraint 2 is used in equation (1). Based on the cost function and the constraint 1, the Lagrange function is constructed as follows:

$$F(k_L, k_M, k_S, \mu) = f(k_L, k_M, k_S) - \mu \cdot C(k_L, k_M, k_S) \tag{5}$$

where

μ : Lagrangean unknown parameter.

First order derivatives on equation (5) about k_L, k_M, k_S, μ derive the following equations:

$$\begin{aligned}
\frac{\partial F}{\partial k_L} &= \frac{\partial f}{\partial k_L} - \mu \frac{\partial C}{\partial k_L} = 0, \\
\frac{\partial F}{\partial k_M} &= \frac{\partial f}{\partial k_M} - \mu \frac{\partial C}{\partial k_M} = 0, \\
\frac{\partial F}{\partial k_S} &= \frac{\partial f}{\partial k_S} - \mu \frac{\partial C}{\partial k_S} = 0, \\
\frac{\partial F}{\partial \mu} &= \frac{\partial f}{\partial \mu} - \mu \frac{\partial C}{\partial k_L} = 0,
\end{aligned} \tag{6}$$

where

$$\frac{\partial f}{\partial k_L} = (2A1^2 + 2B1^2)k_L + (2A1 \cdot A2 + 2B1 \cdot B2)k_M + (2A1 \cdot A3 + 2B1 \cdot B3)k_S + 2A1 \cdot A4 + 2B1 \cdot B4,$$

$$\frac{\partial f}{\partial k_M} = (2A1 \cdot A2 + 2B1 \cdot B2)k_L + (2A2^2 + 2A2^2)k_M + (2A2 \cdot A3 + 2B2 \cdot B3)k_S + 2A2 \cdot A4 + 2B2 \cdot B4,$$

$$\frac{\partial f}{\partial k_S} = (2A1 \cdot A3 + 2B1 \cdot B3)k_L + (2A2 \cdot A3 + 2B2 \cdot B3)k_M + (2A3^2 + 2B3^2 + 2C1^2)k_S + 2A3 \cdot A4 + 2B3 \cdot B4 + 2C1 \cdot C5,$$

$$\frac{\partial f}{\partial k_\mu} = 0,$$

$$\begin{aligned}
A1 &= -0.74X_w - 1.32Y_w + 0.15Z_w, \\
A2 &= -0.26X_w + 1.32Y_w + 0.05Z_w, \\
A3 &= -0.2Z_w, \\
A4 &= X^*{}_w, \\
B1 &= -0.14X_w - 0.26Y_w + 0.03Z_w, \\
B2 &= 0.14X_w - 0.74Y_w - 0.03Z_w, \\
B3 &= Y^*{}_w, \\
C1 &= -Z_w, \\
C2 &= Z^*{}_w.
\end{aligned}$$

$$\begin{aligned}
\frac{\partial C}{\partial k_L} &= -\frac{1}{N}\sum_i \left(0.14X_i + 0.26Y_i - 0.03Z_i\right) \\
\frac{\partial C}{\partial k_M} &= -\frac{1}{N}\sum_i \left(-0.14X_i + 0.14Y_i + 0.03Z_i\right) \\
\frac{\partial C}{\partial k_s} &= 0
\end{aligned}$$

By solving four linear equations of (6), parameters k_L, k_M, k_s are determined on an initial point of (X_w, Y_w, Z_w). Using the resultant k_L, k_M, k_s in the following equation (7),

$$\begin{pmatrix} X_W \\ Y_W \\ Z_W \end{pmatrix} = M^{-1} \begin{pmatrix} X_W^* \\ Y_W^* \\ Z_W^* \end{pmatrix}, \tag{7}$$

the optimized (X_W, Y_W, Z_W) is obtained. The optimized (X_W, Y_W, Z_W) is applied to the cost function iterative. The iteration starts with the initial value of $(X_W(0), Y_W(0), Z_W(0))$. The n-th $(0 \le n)$ solution $(X_W(n), Y_W(n), Z_W(n))$ is applied to the cost function, and the *(n+1)*-th solution $(X_W(n+1), Y_W(n+1), Z_W(n+1))$ is derived by the variation method. Until enough large N, $(n \le N)$ the procedure is applied iterative.

As described, the solution of the method exists on a one dimensional line segment. The line segment is the shrieked space from three dimensional space including possible illuminant coordinates. In the one dimensional space, the constraint 3 is applied to evaluate the optimum solution.

The convergence of the algorithm can be proved easily because the cost function is a quadric function.

3.Experiments

Experiments were performed to confirm the validity of the proposed method.

In the experiments, images whose illuminant condition was known a priori were used to estimate the precision. Figure 1 and 2 show the results of the proposed algorithm. Figure 1(a) was originally taken under the D65 illuminant and converted to the desired A illuminant. Figure 1(b) was originally taken under the A illuminant and converted to the desired D65 illuminant. Figure 2(a) was originally taken under the D65 illuminant and converted to the desired A illuminant. Figure 2(b) was originally taken under the A illuminant and converted to the desired D65 illuminant.

Figure 3 through 6 show the results on the XZ color coordinate (Y=100) using the algorithm. The initial points in the iterative algorithm were 336 equally spaced points in the range of $50 \le X \le 160$, $0 \le Z \le 250$. The iteration was terminated when the modified values of k_L, k_M, k_s were less than 10^{-5}. Figure 3 through 6 correspond to Figure 1(a), 1(b), 2(a), 2(b), respectively. The solution results of the iterative variation method is on the line segment. The three dimensional problem with two constrains is reduced to one dimensional space. Candidates for the optimal solution are on the line segment. The triangle dots on the line segment are the optimal solution determined among the candidates by using the constraint 3. The square dots indicate the original illuminant to be estimated.

The estimation errors of the illuminants in the XYZ coordinate is 7.86%, in the case of Figure 3, 0.22% in the case of Figure 4, 13.4% in the case of Figure 5, and 0.20% in the case of Figure 6. These results show the validity of the proposed method.

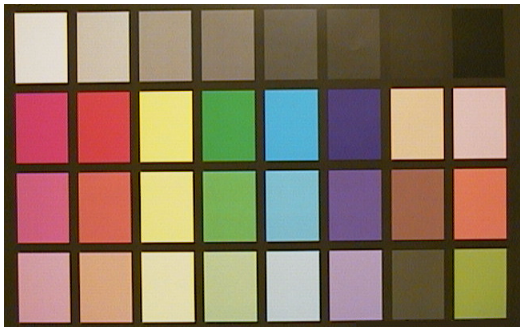

Figure 1 (a) Converted image. (The original illuminant is the D65 and converted under the A.)

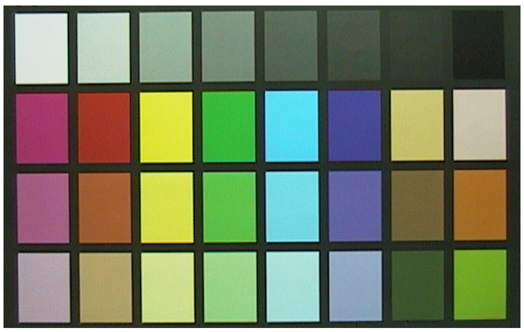

Figure 1(b) Converted image. (The original illuminant is the A and converted under the D65.)

Figure 2 (a) Converted image. (The original illuminant is the D65 and converted under the A.)

Figure 2(b) Converted image. (The original illuminant is the A and converted under the D65.)

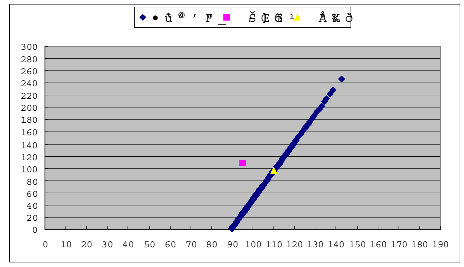

Figure 3 Solution result for Figure 1(a).

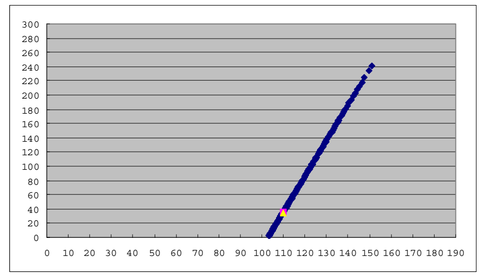

Figure 4. Solution result for Figure 1(b).

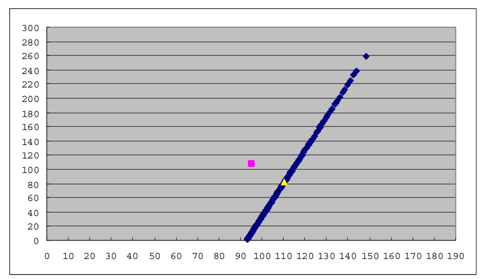

Figure 5. Solution result for Figure 2(a).

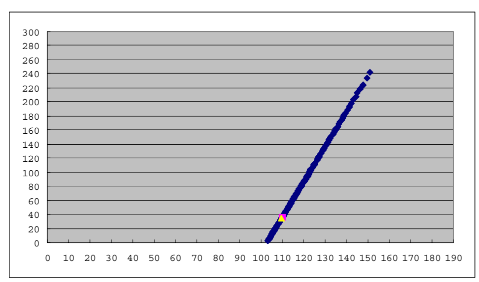

Figure 6. Solution result for Figure 2(b).

4.Conclusions

In the proposed algorithm, the conversion was performed from an image whose illuminant was unknown to the image whose illuminant was the desired one. In the conversion process, the illuminant estimation was performed relative to the desired one, and the problem dimensions were reduced.

The problem was formulated by an optimization problem framework of a cost function and some constraints and for the solution, a variation method was applied iterative.

Experiments were performed to confirm the validity of the proposed method. In the experiments, images whose illuminant condition was known a priori were used to estimate the precision. Though the purpose of the study was to obtain an image illuminated by a desired one, the estimation errors were evaluated because the precision of the estimation error directly effects on converted images. The results of the errors were 0.20% to 13.4%. These results have shown the validity of the proposed method.

References

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Biography

Dr. Nobuhito Matsushiro received his Ph.D degree from the University of Electro. Communications, Tokyo, Japan in 1996. He is a visiting scientist in Rochester Institute of Technology, NY, USA.