Illuminant Estimation of Natural Scene Using the Sensor Correlation Method

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ABSTRACT

This paper describes practical algorithms and experimental results using the sensor correlation method. We improve the algorithms to increase the accuracy and applicability to a variety of scenes. First, we use the reciprocal scale of color temperature, called "mired", in order to obtain perceptually uniform illuminant classification. Second, we propose to calculate correlation values between the image color gamut and the reference illuminant gamut, rather than between the image pixels and the illuminant gamuts. Third, we introduce a new image scaling operation with an adjustable parameter to adjust overall intensity differences between images and find a good fit to the illuminant gamuts. Finally, the image processing algorithms incorporating these changes are evaluated using a real image database.

1. INTRODUCTION

The estimation of scene illumination from image data is important in many fields of color science, computer vision, image processing, color imaging, image reproduction, and image database retrieval. Given the inescapable limitation on estimating the illuminant spectral-power distribution, it is reasonable to classify the illuminant as belonging to one of several likely types. The classification approach rather than the estimation approach is simple for data processing, stable for computation, and appropriate for applications such as photography. In a previous paper [1], we built on earlier illuminant classification methods [2] to estimate the illuminant color temperature. Our illuminant classification was to restrict the estimation to a set of blackbody radiators. Color temperature classification provides simple specification of many common light sources. That , which we called sensor correlation, used a scaled version of the red and blue sensor responses to classify scene illuminant by color temperature.

The present paper describes practical algorithms and experimental results using the sensor correlation method. We improve the algorithms to increase the accuracy and applicability to a variety of scenes. The wide range of application of the improved algorithms is confirmed using a data set of natural images under different illuminants.

2. ILLUMINANT SET AND COLOR TEMPERATURE

Blackbody radiators are used frequently to approximate scene illuminants in commercial imaging, and we classify scene illuminants according to their blackbody color temperature. The color temperature of a light source is defined as the absolute temperature (in kelvin K) of the blackbody radiator. For an arbitrary illuminant, the correlated color temperature is defined as the color temperature of the blackbody radiator that is visually closest to the illuminant. The correlated color temperature of a scene illuminant can be determined from the CIE (x, y) chromaticity coordinates of the measured spectrum [3]. The spectral radiant power of the blackbody radiators as a function of temperature T (in K) is described by the formula

$$M(\lambda) = c_1 \lambda^{-5} \{\exp(c_2/\lambda T) - 1\}^{-1}, \qquad (1)$$

where $c_1 = 3.7418 \times 10^{-16}$ Watts-m^2 and $c_2 = 1.4388 \times 10^{-2}$ Watts-K and λ is wavelength (m). Differences in the scale of color temperature do not correspond to equal perceptual color differences. Judd's experimental report [4] suggested that visually equally significant differences of color temperature correspond more closely to equal differences of reciprocal color temperature. The unit on the scale of micro-reciprocal degrees ($10^6 K^{-1}$) is called "mired". The blackbody radiators are written as a function of reciprocal temperature $T'(=10^6/T)$ as

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$$M(\lambda) = c_1\ \lambda^{-5}\ \{\exp(c_2 T'/\lambda) - 1\}^{-1}. \tag{2}$$

3. DEFINITION OF ILLUMINANT GAMUTS

The scene illuminant classification algorithms use a set of reference illuminant gamuts to define the anticipated range of sensor responses. To create the reference illuminant gamuts, we used a database of surface-spectral reflectances. The image data are obtained using a Minolta camera (RD-175) with known sensor responsivities. Hence, the sensor responses can be predicted using

$$\begin{bmatrix} R \\ G \\ B \end{bmatrix} = \int_{400}^{700} S(\lambda) M(\lambda) \begin{bmatrix} r(\lambda) \\ g(\lambda) \\ b(\lambda) \end{bmatrix} d\lambda, \tag{3}$$

where S(λ) is the surface-spectral reflectance function and r(λ), g(λ), and b(λ) are the spectral-sensitivity functions and M(λ) is the scene illuminant. The Minolta camera can be operated in one of two modes. One mode is appropriate for imaging under tungsten illumination (say illuminant A), and a second mode is appropriate for imaging under daylight (D65). Operating in the high blue sensor gain improves the performance of the scene illuminant classification. Hence, all analyses throughout this paper were performed in this mode. The scene illuminants for classification are blackbody radiators spanning 118 mired (8500K) to 400 mired (2500K) in 23.5 mired increments.

The illuminant gamuts are defined on the RB plane. The (R, B) sensor plane is a reasonable choice for the blackbody radiators because their illuminant gamuts differ mainly with respect to this plane. The boundary of the illuminant gamut is obtained from the convex hull of the set of (R, B) points. Figure 1 shows the illuminant gamuts of the blackbody radiators in the (R, B) plane in two ways. In Figure 1 (left) gamuts are depicted at equal spacing in reciprocal color temperatures, while in Figure 1 (right) gamuts are depicted in equal spacing of color temperatures, spanning from 2500K to 8500K in 500K increments. The illuminant gamuts separated by equal reciprocal color temperature steps are better separated than those separated in equal color temperature steps.

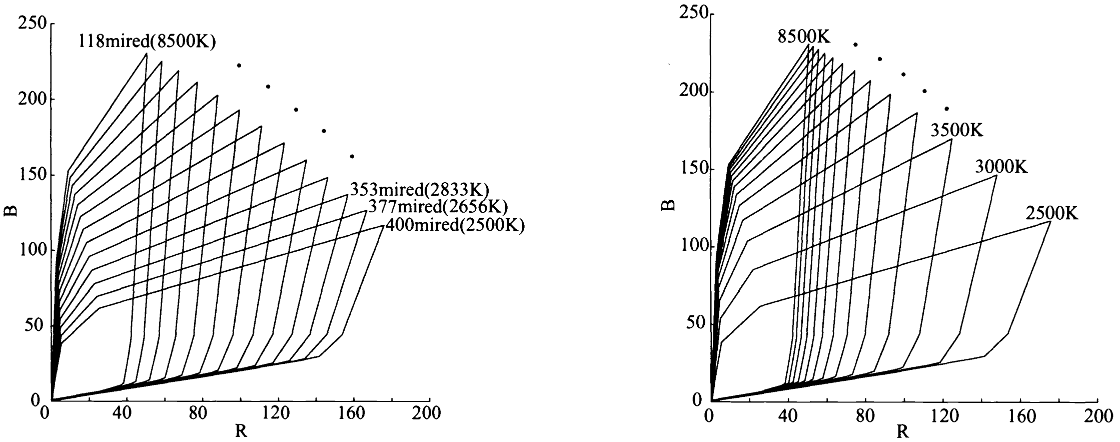

Figure 1 Illuminant gamuts for blackbody radiators in equal intervals of 23.5 mired (left) and 500K (right)

4. GAMUT-BASED ILLUMINANT CLASSIFICAITON

4.1 Image gamut

In the pixel-based classification proposed in a precious paper [1], image data are converted to the binary histogram in which holes and sparse clusters are possible. Therefore it is inevitable that the correlation function is sometimes unstable and not unimodal. To solve this problem, we propose using the convex hull of the image data to determine an image gamut in the RB plane. A correlation value is then computed between the image gamut and the illuminant gamut. The gamut-based correlation differs from the pixel-based correlation in that the calculation presumes that interior points might all have been present in the scene. A practical correlation value is computed from the area of the gamuts as

$$r_i = A_{Ii} \Big/ \sqrt{A_I A_i}\,, \qquad (i=1, 2, \ldots, 13) \tag{4}$$

where A_I is the area of an image gamut, A_i are the area of the ith illuminant gamut, and A_{Ii} is the area of the overlap between the image and illuminant gamuts.

For example, Figure 2 shows the synthesized image consisting 18 chromatic patches of the Macbeth Color Checker. Figure 3 shows the plot of the (R, B) pixel values for Figure 2 and the image gamut, where the solid curve represents the convex hull of (R, B) values and the surrounded region by this curve represents the image gamut.

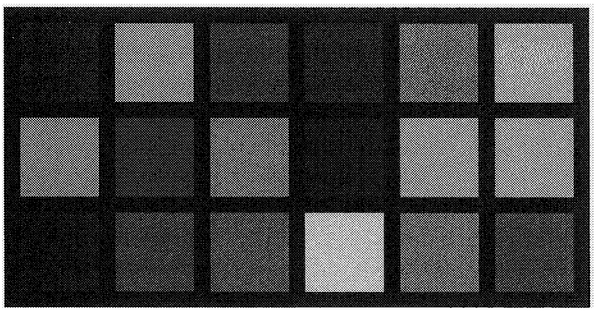

Figure 2 Synthesized mage of the chromatic color patches.

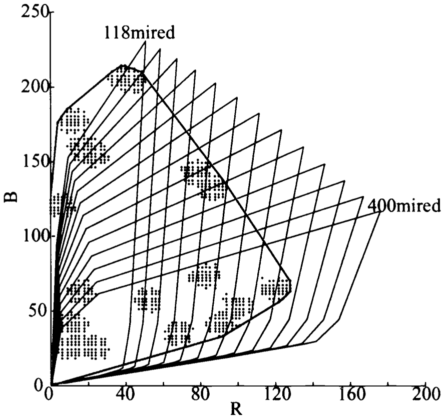

Figure 3 Plot of the (R, B) pixel values and image gamut.

4.2 Image scaling

The sensor correlation method requires a scaling operation that compensates for intensity differences between images. This scaling operation is equivalent to placing a neutral density filter in the light path or adjusting the exposure duration. Scaling preserves the shape of the image gamut and the relative intensity information within an image. To scale the data, we define I_i as the i^{th} pixel intensity,

$$I_i = \left(R_i^2 + G_i^2 + B_i^2\right)^{1/2} \tag{5}$$

and let I_{max} be the maximal value of the intensity over the image. Then to scale the intensity across different images, we divide the sensor RGB values by the maximum intensity,

$$(R, G, B) = \left(R / I_{\max}, G / I_{\max}, B / I_{\max}\right). \tag{6}$$

Bright image regions contribute much the illuminant information. This is especially true if nearly white surfaces are present in the scene, in which case these image regions mainly determine the color temperature estimate. However, if there is no bright surface, the scaling operation converts dark surfaces into bright image regions, and the estimation accuracy decreases. Hence, the selection of a proper scaling parameter is an important element of the algorithm.

In the initial formulation of the sensor correlation algorithm, we chose the scaling parameter based on a set of properties of the brightest pixels. Since then, we have discovered a better normalization method that is illustrated in Figures 4 and 5. Figure 4 shows the convex hulls of the (R,B) pixel values of the image in Figure 2. These convex hulls are each scaled by a different normalization parameter, k. A set of these image gamuts were used to generate the correlation functions shown in Figure 5; each curve shows the function for a different parameter k. To select a value k, we compute all of these gamuts and then choose the peak correlation over all the functions. In this example, the peak correlation occurs for $k=0.8$ and a reciprocal color temperature of 212 mired (4722K). This normalization procedure can be applied to any image.

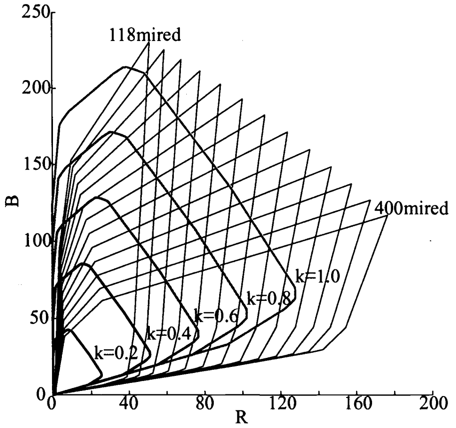

Figure 4 Convex hulls with different normalization parameter.

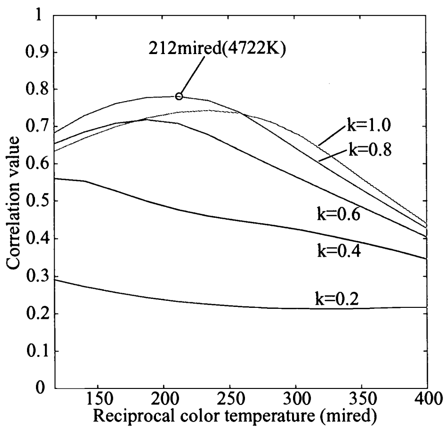

Figure 5 Correlation functions for different normal parameters.

5. EXPERIMENTAL RESULTS

We have evaluated the proposed algorithm using a database of images for indoor scenes. Figure 6 shows a set of 12 images of scenes photographed under a halogen lamp in our laboratory. This illuminant has a correlated color temperature near 3100K. The estimate of scene illuminant was obtained and the difference between the estimate by the image and the direct measurement by the spectroradiometer was calculated in the reciprocal color temperature unit (mired). The proposed modifications improve the estimates for all images except image 5, where bright texture on the shirt has random fluctuations of pixels. The difference between estimates and direct measurement is 6.3 mired on average.

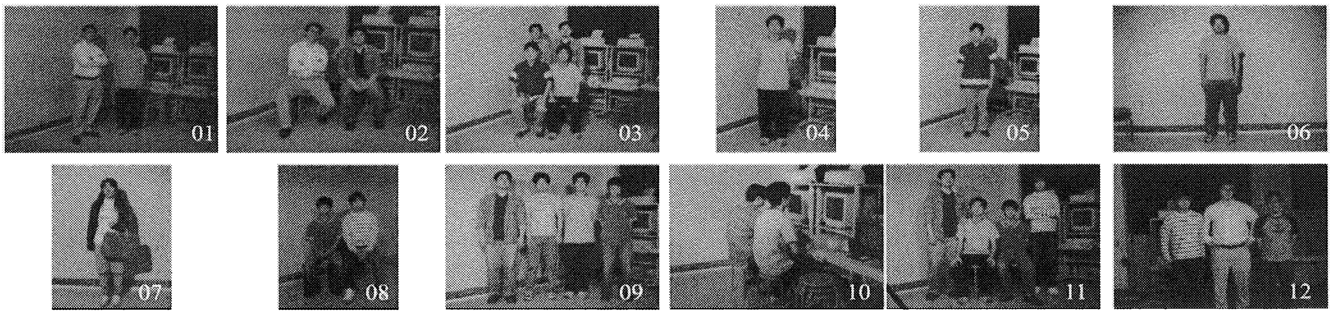

Figure 6 Set of images of indoor scenes under a halogen lamp.

6. CONCLUSIONS

We have described improvements of our research on the sensor correlation method for illuminant. First, the reciprocal scale of color temperature should be used to achieve perceptually uniform illuminant classification. Second, we proposed that a gamut-based correlation value should be calculated between an image gamut and the reference illuminant gamuts. Third, we have proposed a new normalization operation that makes classification performance independent of image intensity. Finally, the applicability of the improved algorithm was shown using real images.

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