Color temperature transformation of high dynamic range images

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ABSTRACT

Estimation and correction of color temperature of digital images are basis of white balance adjustment after image acquisition stage. White balance is one of the most important image processing techniques for subjective image quality enhancement. Correction of color temperature is applied for white balance adjustment or for changing the mood of a picture. A picture taken under the daylight can be changed to have a mood of sunset or cloudy day, for example.

We evaluate color temperature transformation of high dynamic range images in linear and log domain, and we conclude that linear domain transformation shows better results.

Keywords: high dynamic range image, color transformation matrix, color correction.

1. Introduction

Digital camera images are quite different from the irradiance of 3D scenes on the image plane, since camera responses are designed to be nonlinear to enhance the contrast. Therefore, camera image intensities are not true value of relative radiance in the scene. Because of nonlinear mapping of camera sensors, it is hard to process images for our own purposes. A typical digital camera acquires an image employing CCD or MOS sensors and ADC (analog to digital converter) to digitize intensity information. Nonlinear characteristics are introduced during this process. Image sensors have limited dynamic range; therefore it shows cut off range and saturation range. Debevec and Malik [1] proposed a method to obtain high dynamic range images from many picture with different exposure.

Color temperature is illuminant light color of the observed scene. It is the main factor that determine mood of the image or picture. Technically, color temperature unit is K(Kelvin) and if color temperature is low the image looks reddish and give warm mood. In contrast, high Kelvin temperature image is bluish. Therefore, user's impression about image is determined by color temperature.

This paper we convert color temperature and compare color temperature transformation method in linear scale and log scale.

2. Color Temperature Transformation

In this section, we will briefly describe high dynamic range imaging briefly, and then introduce color transformation. We will derive a color transformation matrix between two different color temperatures.

2.1Estimation of high dynamic range images

First of all, we need to estimate the camera response curve which is nonlinear. There are a large number of conventional estimating methods. In this paper we employ Debevec and Malik estimation method, a non-parametric representation using a smoothness constraint [1]. Input of this algorithm is a number of same scene photographs taken with different shutter speed. With these differently exposed images the proposed algorithm can recover the camera response curve from same sample pixel values. And algorithm generates a high dynamic range radiance by weighted average of many images with different shutter speed. This high dynamic range radiance is recovered using nonlinear characteristics of the sensor obtained with the algorithm.

Figure 1. High dynamic image in linear scale (Left), and linear scale (Right) under D65 illumination.

2.2 A color transformation matrix

Suppose we have two images taken under two different lighting conditions. For example, if we want to convert an image from 6500K Daylight to 2500K 'A light', we need reference images taken under controlled illumination. We used test images of Macbeth color checker which has 24 colors. And then we take 24 points of pixel values that represent each color's intensity (Fig.2). To find a transformation matrix, calculate the relationship between 24 sample points intensities of each color channel. We employed red, green, and blue color coordinates. Using Debevec algorithm we can obtain a high dynamic image in log domain(fig.1).

If we compare two reference images in log domain using linear transformation model, we obtain a 3x3 conversion matrix, Q(log), which is a log domain transformation matrix between log domain image as shown in equation (1) . R, G, and B are column vectors of image data. On the other hand, log domain image can be mapped to linear domain image. Q(linear) is a 3x3 linear domain transformation matrix between linear domain pictures as in equation (2). Linear domain transformation seems to be a reasonable choice; however, it emphasizes bright regions while ignoring dark areas since they have very small brightness values. Log domain processing has a merit of reducing the intensity ratio of bright to dark regions. We compare the two transformation methods in this paper.

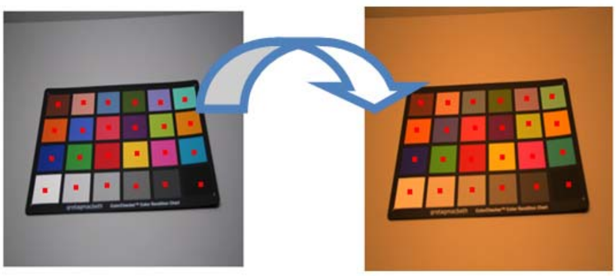

Figure 2. Concept of making color transformation matrix (Convert D65 image to A light image)

$$[R_A \quad G_A \quad B_A]_{\ln E} = Q_{\log}[R_{Day} \quad G_{Day} \quad B_{Day}]_{\ln E} \qquad (1)$$

$$[R_A \quad G_A \quad B_A]_E = Q_{linear}[R_{Day} \quad G_{Day} \quad B_{Day}]_E \qquad (2)$$

To calculate Q matrix, we use pseudo inverse which results in minimum mean square solution.

$$Q_{\log} = [R_A \quad G_A \quad B_A]_{\ln E}^{-1} \times [R_{Day} \quad G_{Day} \quad B_{Day}]_{\ln E} \qquad (3)$$

$$Q_{linear} = [R_A \quad G_A \quad B_A]_E^{-1} \times [R_{Day} \quad G_{Day} \quad B_{Day}]_E \qquad (4)$$

$[R_A \quad G_A \quad B_A]_{\ln E}$ represents Red, Green, Blue intensity of whole pixels in A light log domain. E means irradiance.
$[R_{Day} \quad G_{Day} \quad B_{Day}]_{\ln E}$ represents Red, Green, Blue intensity of whole pixels in Daylight log domain. After calculate (3),(4).We can obtain two kinds of 3x3 transformation matrices(5),(6).

3. Experiment and Result

In this section, we evaluate the performance of the suggested transformation matrix. Our experiment is to convert an image from D65 (Daylight,6500K) to 'A light' (2800K). First, we estimate the camera response function with a non-parametric representation and generate a high dynamic range radiance image(Fig.1). Second, we convert image color temperature using obtained transformation matrix two domains, linear and log domain. And then calculate error of converted image to compare the two conversion method.

3.1 Estimation of camera response curve

We have 12 digitized images of Macbeth color checker from same vantage point with different known exposures under D65 (6500K) and A light(2800K) luminance. Figure 3 shows known exposure photos with various shutter speeds: 1/125, 1/100, 1/80, 1/60, 1/50, 1/40, 1/30, 1/25, 1/20, 1/15, 1/10, and 1/8 sec. Camera we have used for the experiment is Canon 350D. From sample points of 12 photographs, we can obtain a nonlinear camera response curve (Fig.4) and high dynamic range radiance image. We set smoothness term lambda to 20. Through this processing we obtain camera nonlinear curve and a high dynamic range image.

High dynamic image is a log domain image, since the sensor response curve is log domain. To get a linear domain image, we need to apply exponential function.

Figure 3. 12 pictures taken under D65 (Daylight) with different shutter speed.
(1/125, 1/100, 1/80, 1/60, 1/50, 1/40, 1/30, 1/25, 1/20, 1/15, 1/10, 1/8sec)

3.2 Color temperature conversion

Obtained color transformation matrix is applied to the result image of section 3.1(Fig.1).Two domain matrices are:

$$Q_{\log} = \begin{pmatrix} 0.8177 & -0.0116 & -0.1308 \\ 0.2207 & 0.8765 & 0.04 \\ 0.0628 & -0.0393 & 0.5786 \end{pmatrix} \qquad (5)$$

$$Q_{linear} = \begin{pmatrix} 1.2082 & 0.0321 & 0.0136 \\ 0.2828 & 0.5454 & -0.011 \\ -0.0633 & -0.0386 & 0.1755 \end{pmatrix} \qquad (6)$$

Please note that linear domain result (Fig.6) is darker than log domain result (Fig.5). Theses intensity problem is solved by scaling process.

Table 1. Error between converted image and ground truth.

	Max error	RMS error	Red RMS	Green RMS	Blue RMS
$\ln E_A - (\ln E_{Day}) \times Q_{\log}$	2.01	**0.52**	0.19	0.23	0.43
$\ln E_A - \ln(E_{Day} \times Q_{linear})$	1.84	**0.32**	0.20	0.16	0.19
$E_A - \exp(\ln E_{Day} \times Q_{\log})$	31.65	**7.87**	7.40	2.44	1.12
$E_A - E_{Day} \times Q_{linear}$	30.06	**6.54**	6.16	2.03	0.71

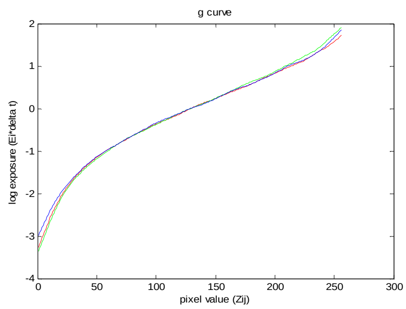

Figure 4. Nonlinear Camera response curve each color channel.

(a) (b) (c)

Figure 5. Converted color temperature images from D65 to A light in log domain.
(a)D65 log image (b) $\ln(E_{day} \times Q_{linear})$ (c) $(\ln E_{day}) \times Q_{\log}$

(a) (b) (c)

Figure 6. Conversion of color temperature from D65 to A light in linear domain
(a) D65 linear image (b) $\exp(\ln E_{day} \times Q_{\log})$ (c) $E_{day} \times Q_{linear}$

3.3 Comparison of error

For quantitative comparison of two color temperature conversion methods, we calculate the error in each domain. Compare converted images, from ‘D65’ to ‘A light’, and ground truth image taken under ‘A light’ luminance. Through this process, we observe which domain transform matrix is better and close to the ground truth. Ground truth data is real ‘A light’ photograph.
Table 1. shows an error between transformed ‘A light’ and ground truth ‘A light’ image. It is important to calculate and compare the error in the same domain.
For this experiment we compare rms (root mean square) error. Using Q(linear) matrix image shows smaller rms value compared to the color temperature change calculated in log domain. In linear domain, image which multiply Q(linear) has lower rms than Q(log).
Accordingly, linear domain conversion matrix, Q(linear) generates an image closer to the ground truth than Q(log) matrix image.

4. Conclusion

Using Debevec and Malik method, we estimate nonlinear camera response curve and obtain a high dynamic image from a number of images with different shutter speed. And then we convert color temperature of digital images proposed by a 3x3 color converting matrix in log and linear domain. With this matrix, we convert color temperature in two domains, log and linear domain.
We show color converting results visually and mathematically. Subjective evaluation of linear domain image is slightly darker than a log domain image. However, scaling process can solve this problem without any difficulty. After error analysis, color temperature transformation in linear domain results in better image similar to the ground truth. Therefore, we conclude that color correction and transformation should be applies in linear domain after correction of non linear response of a camera.

5. References

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