Correcting for non-uniform illumination when photographing the mural in the royal tomb of Amenophis III (III) Correcting mural images

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Abstract

We have been attempting to digitize murals at the royal tomb of Amenophis III. When photographing the murals, two strobe lights with an umbrella were used to provide uniform illumination. Nonetheless, the illumination was still somewhat non-uniform. We corrected for this non-uniform illumination by applying an illumination model, which we evaluated using images with white patches and images of the model mural without white patches. The illumination model was then extended to two light sources and applied to images of the actual mural. The corrected images were observed to be more uniformly illuminated.

Introduction

The tomb of Amenophis III, one of the pharaohs of ancient Egypt, is located in the Valley of the Kings in Luxor, Egypt. The burial chamber is 8.2 m wide, 15.4 m long, and 3.1 and 4.7 m high. And the Amduat is painted on the four walls. We have been attempting to create a full-size digital image of this mural, which are accessible to many researchers in the world and can be displayed on computer displays[1,2,3]. We took 99 images (small-size images) of each position of the mural with a 21 mega pixel camera. These 99 small-size images were stitched, and a 500 mega pixel image (middle-size image) was produced. From these middle-size images, we are attempting to produce a full-scale large-size image corresponding to the entire area of each of walls, north, south, east, and west.

To avoid non-uniform illumination, the mural was illuminated with diffuse light from two strobe lights using umbrellas positioned on either side. However, this still does not provide highly uniform illumination. We are currently attempting to correct this non-uniformity by applying a illumination model[4,5].

Illumination model

If we assume a strobe and an umbrella as a point light source located at a longer distance (Fig. 1), an inverse-square relationship holds for the reduction in the intensity of this virtual light source placed at the longer distance. The illuminance E at any point (x, y) on the mural will then be given by:

$$E = \frac{p}{d^2} = \frac{p}{(x-x_0)^2 + (y-y_0)^2 + d_0^2} \tag{1}$$

where p is the luminous intensity of the light source, d is the distance between the point light source and the point (x, y), x_0 and y_0 are the coordinates of the foot of a perpendicular of the point light source to the wall, and d_0 is the distance between the point light source and the mural as shown in Fig.2. We named this model the Point Light Source (PLS) model. To compensate for the non-uniformity, the illuminance at each point (actually, at each pixel) is corrected by a target illuminance or the illuminance at a standard point (pixel) using a model equation. The coordinates used to specify each point are not its actual spatial coordinates but the location of the pixel in the stored image. Since it is difficult to measure the illuminance, the tristimulus value Y, evaluated from the digital RGB values for a location which is assumed to have the same reflectivity in the photographed image, is employed as a relative value.

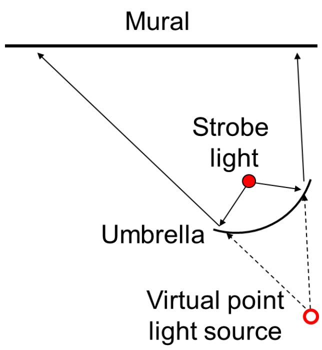


Fig.1 Illumination model in which illumination, provided by light from a strobe light reflected from an umbrella, is assumed to act as a virtual point light source.

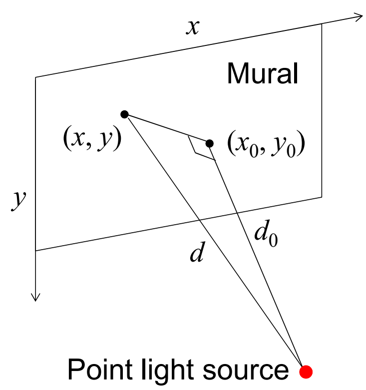


Fig.2 Geometric arrangement of a light source and a mural

Verification of illumination model using white patch images

A model mural (2.4 m wide × 1.6 m high) was created from a set of photographs taken in a preliminary survey and used to verify the effectiveness of the illumination model. Thirty five white patches were attached to the model mural and a lighting was set up to illuminate it solely from the right-hand side. The white patches were then removed and the model mural was photographed again under the same conditions. The tristimulus value Y was obtained using the sRGB space from the digital RGB values in the white patches in the image[6], becasue the image was saved with sRGB mode.This Y value was the relative illuminance value E. The four constants p, x_0, y_0, and d_0 used in the PLS model were calculated by nonlinear optimization using the tristimulus value Y on the location coordinates (x, y) of the 35 white patches and at the respective locations. In other words, a relative luminous intensity p, the location (x_0, y_0) and the distance d_0 were estimated. The RGB digital values of each pixel in the original image were transformed to the tristimulus values XYZ, and then the XYZ values at each location of the pixel were corrected based on the relative illuminance value Y at that location. The corrected XYZ values were then reverse-transformed to RGB values. The illuminance of the white patches of the image were corrected by the pixel-by-pixel color correction. The illuminance of the white patches were also corrected by the following two-dimensional second-order polynomial, which is used in trend removal and non-uniform illumination of microscopic images[7,8].

$$E = ax^2 + bxy + cy^2 + dx + ey + f \tag{2}$$

We call this model the SOP model. Fig. 3 shows original and corrected images, and also shows the tristimulus value Y before and after the correction based on the white patches. Fig. 3 shows that the large variation in the tristimulus values Y prior to correction is greatly reduced after correction. The illuminance of the white patches in the image corrected by using the PLS model are nearly the same, which confirms that the illumination model selected in this study is effective.

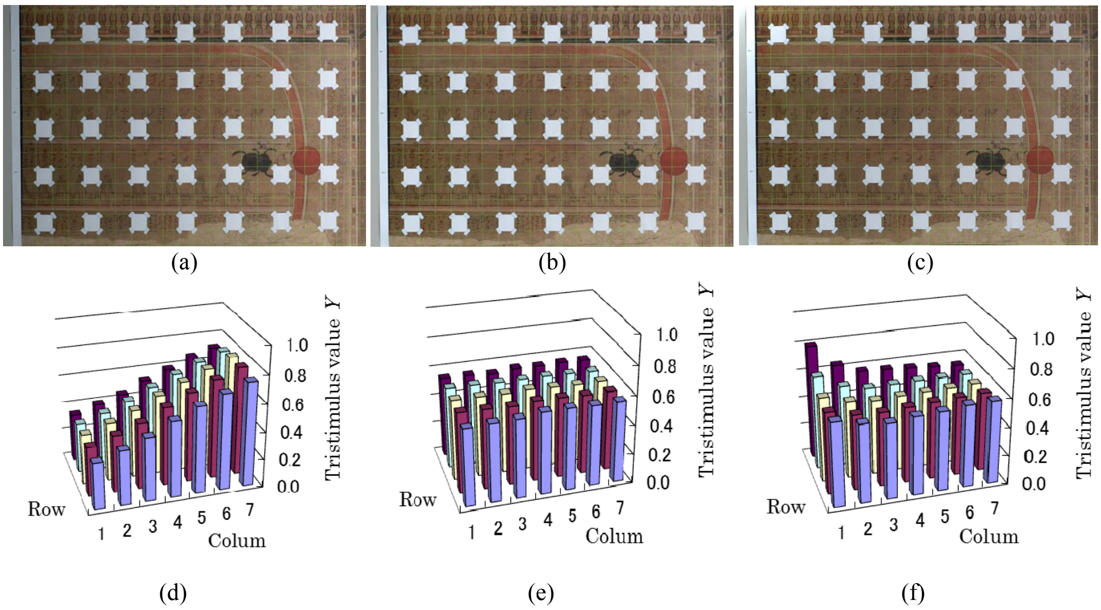


Fig.3 Original image illuminated solely from the right-hand side (a), and images corrected by using the proposed model (PLS model) (b), and two-dimensional second-order polynomial model (SOP model) (c). The lower figures (d), (e) and (f) show tristimulus values Y of white patches of the above images (a), (b) and (c), respectively. Standard deviations σ are 0.143, 0.007 and 0.055, respectively.

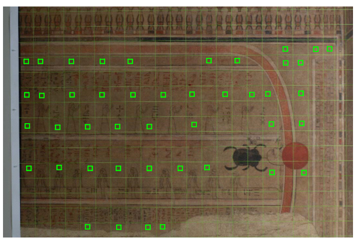
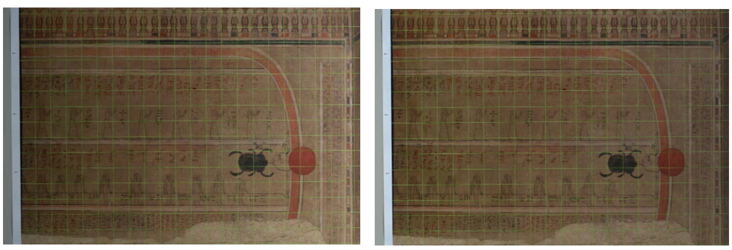


Fig.4 Extraction of backgrounds having nearly the same color



(a) (b)

Fig.5 The original image of the model mural (a), and an image corrected by using PLS model (b)

Verification of the illumination model on an image without white patches

The white patches used in the test of the illumination model were unable to be applied to an ancient monument such as the mural at the royal tomb. Instead, background regions having nearly the same color were used. Forty four nearly uniform background regions were extracted manually (indicated by green squares in Fig. 4). The four constants employed in the illumination model were calculated using the digital *RGB* values for each square region and the correction was applied to the non-uniformity in the illumination. The original image and an image corrected by using PLS model are shown in Fig.5. The corrected images were observed as uniformly illuminated. Fig. 6 shows the tristimulus values Y before and after correction. The horizontal axis shows the background image number, beginning from the upper left corner and proceeding to the right, then down to the lower right corner. The standard deviation of tristimulus values of the background of the corrected image is approximately 1/4 of that of the original image. This confirms that the correction successfully eliminated non-uniformity using the background of the image.

Application to the mural images

The photography was performed using two lights on the right and left sides, so the proposed illumination model, PLS model, was extended to two sources as follows:

$$E = \frac{p_1}{(x-x_1)^2+(y-y_1)^2+d_1^2} + \frac{p_2}{(x-x_2)^2+(y-y_2)^2+d_2^2} \quad (3)$$

The subscripts 1 and 2 indicate the constants indicating virtual point light sources 1 and 2, respectively. A constant a is introduced as ambient illuminance, i.e. bias, to the model.

$$E = \frac{p_1}{(x-x_1)^2+(y-y_1)^2+d_1^2} + \frac{p_2}{(x-x_2)^2+(y-y_2)^2+d_2^2} + a \quad (4)$$

The later model, the PLS model with ambient illuminance, is named the PLSA model. We also tried to use the SOP model, because equations for single and double light sources have the same form as shown in the following.

$$\begin{aligned} E &= E_1 + E_2 \\ &= a_1x^2 + b_1xy + c_1y^2 + d_1x + e_1y + f_1 \\ &\quad + a_2x^2 + b_2xy + c_2y^2 + d_2x + e_2y + f_2 \\ &= ax^2 + bxy + cy^2 + dx + ey + f \end{aligned}$$

The middle-size images are 16 bits 500 mega pixels TIFF images, and are too large to correct the non-uniform illumination, becasue library softwares, e.g. OpenCV which we are using to process an image, cannot process an image of over 1 GB. Therefore, instead of actual middle-size images, 20 mega pixel JPEG images were used. Fig. 7 presents four JPEG images of East wall, which images were corrected by using three models, i.e. PLS, PLSA and SOP models. It is found that the lower area of image (a) is very dark, because of non-uniform illumination. This image is the worst non-uniform image in these four images, and also one of worst images in all middle-size images.

The backgrounds were extracted manually from the four images to be used at computation of the values of constants employed in the illumination models. Fig. 8 shows 65 uniform background regions extracted from Fig. 7(a). The values of constants were determined from these background colors by the nonlinear optimization process described in the previous section. The values converged due to this process sometimes varied depending on different initial values. In some calculations, the value was converged into negative values for the relative luminous intensity p and ambient illuminance a employed in the PLS and PLSA models. The values of the constants providing the least square error were adopted.

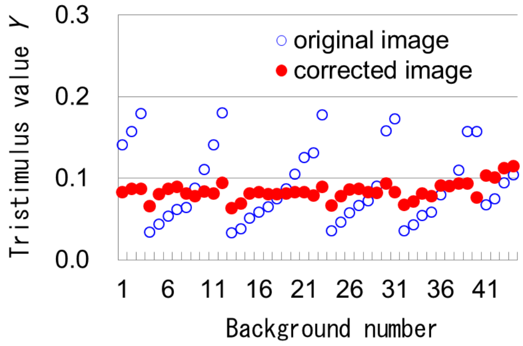


Fig.6 Tristimulus values Y of backgrounds in original and corrected images shown in Fig.3. Standard deviations σ are 0.046 and 0.011, respectively.

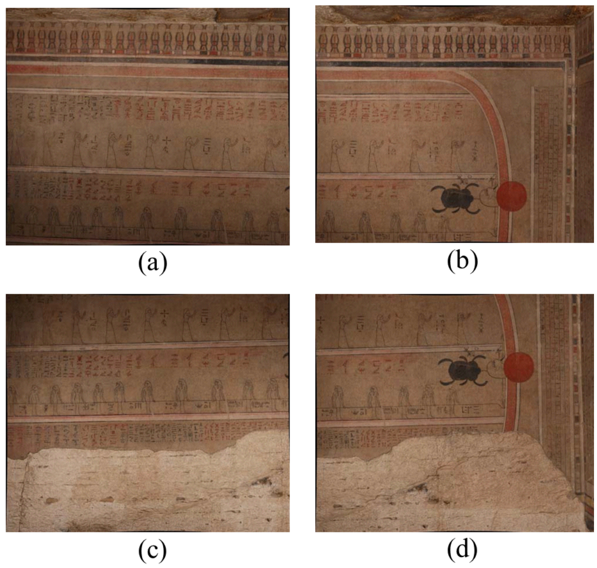


Fig.7 Four images of East wall

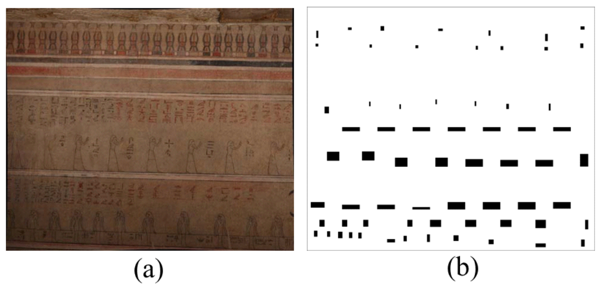


Fig.8 An example of extracted background which is assumed to have the same color. (a) is identical to the image of Fig.7a, and (b) is an extracted background image from (a).

Table 1 Standard deviations of tristimulus values Y of background for original and corrected images. Ratio is $\sigma_{cal} / \sigma_{org} \times 100$.

Image	Original		PLS model		PLSA model		SOP model
	σ_{org}	σ_{cal}	ratio(%)	σ_{cal}	ratio(%)	σ_{cal}	ratio(%)
a	0.0418	0.0122	29	0.0082	20	0.0141	34
b	0.0276	0.0138	50	0.0130	47	0.0152	55
c	0.0503	0.0139	28	0.0132	26	0.0141	28
d	0.0263	0.0088	34	0.0066	25	0.0109	41
mean			35		30		40

To evaluate the effects of correction, standard deviations of tristimulus values of the extracted backgrounds of original and corrected images were calculated based on three models, and are shown in Table 1. The PLSA model shows the best result, namely the average standard deviation of the original image was reduced to approximately 30% . The images corrected for Fig.7 by using the PLSA model are shown in Fig.9. It is found that the dark lower area of the image of Fig.7(a) was improved and shows nearly the same brightness as other areas. However the bottom area in the left side of the image is brighter than other areas, which means over correction. Backgrounds were unable to be extracted from delamination areas observed in Figs.7(c) and 7(d). Since these areas were not reflected in the computed values of constants, brightness of the corrected delamination area slightly differs between Figs.7(c) and 7(d). Background of the delamination area should be measured and used to compute the constants in the near future to avoid such differences.

Tristimulus values Y of backgrounds of the original image and the image corrected by using the PLSA model, i.e. Fig.7 (a) and Fig.9 (a) respectively, are shown in Fig.10. The correction reduced the standard deviation of tristimulus values Y from 0.042 to 0.008. Stitched images from original images, shown in Fig.7, and corrected images, shown in Fig.9, are shown in Figs.11 (a) and (b), respectively. The over correction area in image of Fig.9 (a) was not used for stitching. Slightly dark area is observed in the left middle area of Fig.11 (a), but not in Fig.11 (b). The stitched image Fig.11 (b) from corrected image is observed to be more uniformly illuminated.

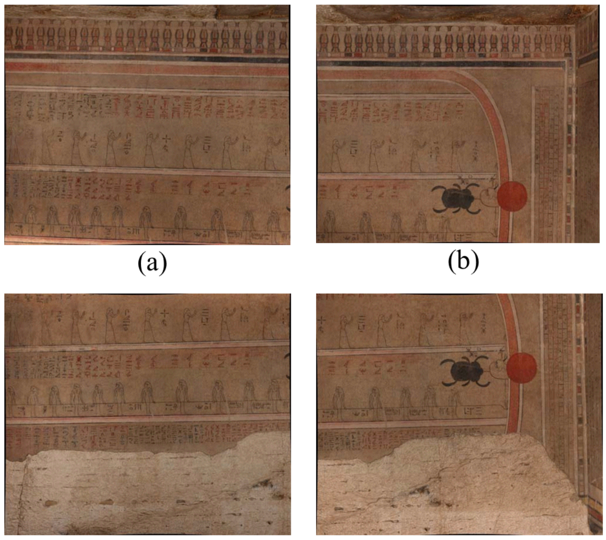


Fig.9 Corrected images of original images shown in Fig.7 by using PLSA model

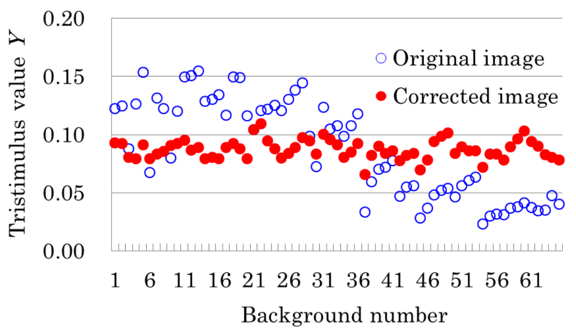


Fig.10 Tristimulus values Y of original and corrected images by using PLSA model. Standard deviations σ of original and corrected images are 0.042 and 0.008, respectively.

Summary

An illumination model for photography was constructed and its effectiveness was examined using a model mural illuminated by imbalanced illumination from one side. The illumination model was extended to the actual use of photography with illumination from two sides and applied to the image of the actual mural. It was confirmed that the non-uniformity in illumination was reduced. This procedure will be applied to all actual middle-size images.

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(a)

(b)

Fig.11 Stitched images from original images (a) and corrected images by using PLSA model (b)

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Author Biography

Masao Inui received his M. Eng. from Chiba University in 1973 and joined the University staff there in the same year. In 1986, he joined Konica Corporation, where he advanced to the position of Chief Research Associate. In 1993, he received his Ph.D. from Chiba University, and in 1998, Dr. Inui took a professorship at Tokyo Polytechnic University. His special interests include image analysis, evaluation, design, and processing. He is a member of the IS&T, The Royal Photographic Society, The Society of Photographic Science and Technology of Japan and The Color Science Association of Japan.