

Color Gamut Mapping based on Mahalanobis Distance for Color Reproduction of Electronic Endoscope Image under Different Illuminant

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Abstract

In this paper, a color difference is defined instead of the conventional color differences to evaluate gamut-mapping techniques for electronic endoscope images reproduced on CRT under environmental illuminant. This color difference is defined from Mahalanobis distance by using covariance matrices for differences of metric lightness, chroma and hue angle. The covariance matrices for endoscope images were obtained by psychophysical experiments. We compared the resultant matrices with those for natural scenes, and found the color difference was customized for the electronic endoscope images well.

Introduction

In recent years, an electronic endoscope has been widely used to diagnose gastrointestinal diseases. The color of gastrointestinal mucosa gives significant information for diagnosis of many diseases such as gastritis and cancer. With the advance of telecommunication system, the electronic endoscope images can be sent to the remote sites for diagnosis through the computer networks. The physician can send images to another hospital and ask specialists for the diagnosis. The endoscope images are generally viewed by physician in dark environment of an operating room. It is necessary to consider the influence of environmental illuminant on the appearance when the images are viewed in an another room such as a meeting room, because diagnosis by specialists is mainly based on the appearance of color.

The method to predict the color appearance on CRT under environmental illuminant has been already proposed using color appearance model[1]. However, the gamut-mapping for the image that cannot be reproduced in the gamut of CRT brings a serious change to the color appearance of the predicted image. The gamut-mapping should ensure that the appearance of the reproduction is as close to the predicted image as possible.

There are various gamut-mapping techniques such as lightness mapping, chroma mapping, and combined lightness and chroma mapping[2-7]. It is necessary to evaluate the mapping techniques to select the suitable one, because it depends on the color gamut of each device and each image to be displayed. Subjective testing is often used to evaluate the mapping technique. However, it is difficult to test subjectively for many kinds of mapping techniques. Objective evaluation is required to evaluate the mapping technique.

Color differences in uniform color spaces[8] such as CIELAB or CIELUV were designed for color patches in whole visible range, not for electronic endoscope images. For computer generated images, Katoh and Itoh[7] customized the color difference in CIELAB color space using psychophysical techniques. However, it does not use the correlation among the lightness, chroma and hue angle. The CIE 1994 total color-difference[9] takes into account the correlation between hue and chroma in the estimation of weighting functions. However, it does not use the correlation between lightness and hue, lightness and chroma.

In this paper, a color difference is defined to evaluate the gamut-mapping techniques to map the predicted electronic endoscope images under various illuminants. The color difference is defined by Mahalanobis distance using covariance matrix on differences of metric lightness, chroma and hue angle between original image and processed images that is equivalently perceptible with original image. The differences are obtained by psychophysical experiments changing the metric lightness, chroma and hue angle of the electronic endoscope images, and the color difference takes into account the correlation among the lightness, chroma and hue angle. We also compare the resultant matrices with those of natural scenes. Simple gamut compression techniques are evaluated objectively based on the resultant color difference in our system.

Color Reproduction Method for Endoscope Images under Environmental Illuminant

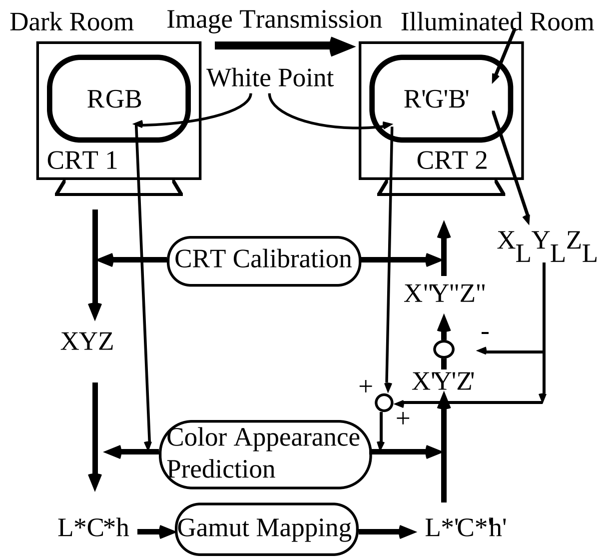


Figure 1. Color reproduction system of electronic endoscope image under different illuminant

Figure 1 shows a schematic diagram of a color reproduction method to reproduce the appearance of endoscope images on CRT under various illuminants. The *R*, *G*, *B* original endoscope image is transformed to *X*, *Y*, *Z* tristimulus values using the characteristics of the CRT in the dark environment. Chromatic adaptation model by Fairchild[10,11] is applied to *X*, *Y*, *Z* values and the predicted color appearance are represented in CIELUV *L**, *C**, *h* color space[8]. The gamut-mapping is performed to adjust the *L**, *C**, *h* values on CRT 1 to the *L*'*, *C*'*, *h'* values on CRT 2 under various illuminants. Then, inverse chromatic adaptation is performed to get *X'*, *Y'*, *Z'* values adapted in the illuminant. The X_L , Y_L, Z_L tristimulus values of the reflected light on CRT surface are subtracted from *X'*, *Y'*, *Z'* to give *X"*, *Y"*, *Z"* tristimulus values of emitted light on CRT surface. Finally, the *X"*, *Y"*, *Z"* is transformed to the device dependent *R,' G '*, *B'* values that are displayed on CRT 2. X_L, Y_L, Z_L can be calculated from the spectral reflectance of the CRT surface and spectral radiance of the illuminant.

The measurement of spectral reflectance of the CRT depends on the viewing angle, so it was assumed that the electronic endoscope images are displayed on the center of the CRT and the observer watches the images in a fixed position in front of the CRT. The spectral reflectance of the CRT was obtained by dividing the amount of radiant power reflected on CRT by the amount of radiant power reflected on the standard diffusing reflector. The scattering of light inside the CRT was ignored. The spectral reflectance was calculated for three kinds of illuminants to examine the illuminant dependence of the spectral reflectance as shown in Fig. 2, under "A", "Cool white" and "Day light." The spectral reflectance has approximately the same shape for these three kinds of illuminants. The resultant X_L, Y_L, Z_L values are shown in the Table 1.

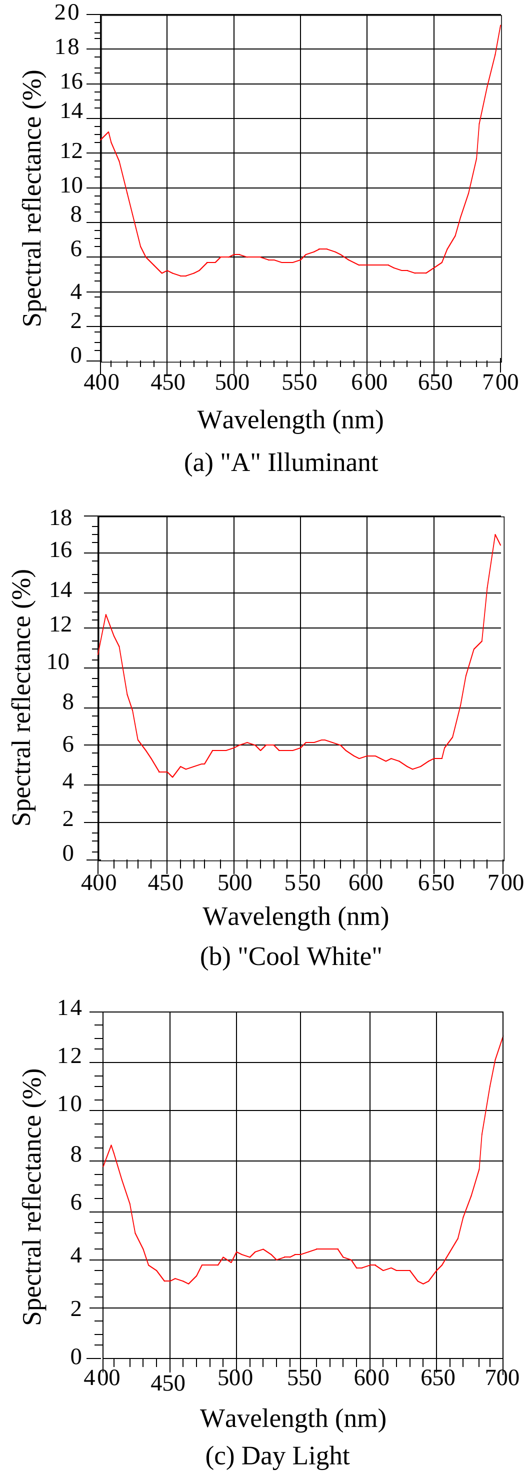


Figure 2. The spectral reflectance of CRT display under various Illuminants; (a) "A" Illuminant, (b) "Cool White", and (c) "Day Light".

The chromatic adaptation on CRT in a dark environment occurs on the white point of the CRT. In the case of illuminated CRT, Katoh considered mixed chromatic adaptation[1]. He found that human visual system

Table 1. XL, YL, XL tristimulus values of reflected light on CRT under various illuminants

illuminant	"A"	"Cool White"	"Day Light"
X_L	6.24	5.84	1.88
Y_L	5.52	5.83	2.95
Z_L	3.68	4.07	4.24

is 60% adapted to CRT white point and 40% to the ambient light. However, as Katoh stated, the degree of adaptation depends on the time of observation and the distance from the CRT. In the medical systems, it is difficult to reproduce the same experimental conditions used by Katoh. Then, we assumed that chromatic adaptation on CRT in the illumination occurs on the white point on the CRT where the tristimulus values are added due to the environmental illuminant .

Color Difference Based on Mahalanobis Distance for Electronic Endoscope Images

Definition

A color distance based on Mahalanobis distance[12] is defined by using covariance matrix for differences of metric lightness, chroma and hue angle between original image and processed image that is equivalently perceptible with original image. The Mahalanobis distance makes the influence of the distribution of each attribute uniform and is defined in a color space as follows;

$$d = \begin{bmatrix} \Delta L & \Delta C & \Delta h \end{bmatrix} \begin{bmatrix} V_{LL} & V_{LC} & V_{Lh} \\ V_{CL} & V_{CC} & V_{Ch} \\ V_{hL} & V_{hC} & V_{hh} \end{bmatrix}^{-1} \begin{bmatrix} \Delta L \\ \Delta C \\ \Delta h \end{bmatrix}$$

$$= \begin{bmatrix} \Delta L & \Delta C & \Delta h \end{bmatrix} \begin{bmatrix} W_{LL} & W_{LC} & W_{Lh} \\ W_{CL} & W_{CC} & W_{Ch} \\ W_{hL} & W_{hC} & W_{hh} \end{bmatrix} \begin{bmatrix} \Delta L \\ \Delta C \\ \Delta h \end{bmatrix}$$

where V_{LL}, V_{CC}, V_{hh} are the variances of metric lightness, chroma, hue angle, respectively. On the other hand, $V_{LC}(V_{CL})$, $V_{Lh}(V_{hL})$, $V_{Ch}(V_{Ch})$ are the covariances between metric lightness and chroma, and lightness and hue angle, and chroma and hue angle, respectively. This technique is similar to the technique used in Brown-MacAdam ellipsoids[8]. This perceptual distance can be used to evaluate gamut-mapping techniques. The gamut-mapping technique that provides the shortest perceptual Mahalanobis distance is considered as the best technique.

Psychophysical experiments

Psychophysical experiments were performed to find a covariance matrix to define the Mahalanobis distance for four endoscope images. For this purpose, the lightness of endoscope image was changed by -4, -2, 0, 2, 4 units, the chroma was changed by -6, -3, 0, 3, 6 units, and the hue angle was changed by -2, -1, 0, 1, 2 degrees depart from the original images. Every possible combination of these three color attributes was prepared as 125 images for each endoscope image. Each image was displayed randomly with the original image. Ten observers who are students in our laboratory were asked to watch each pair on CRT and asked to answer if two images have noticeable difference or not. The resultant inverse covariance matrices are shown in Fig. 3 with the images. We can see the characteristics of the electronic endoscope images from these matrices. First, the element W_{hh} is larger than any other elements in the matrices. This indicates that hue angle should be maintained unchanged in the electronic endoscope images to keep the color appearance of the images. Second, the elements $W_{LC}(W_{CL})$ and $W_{Lh}(W_{Ch})$ are negative. This indicates that the lightness and chroma, lightness and hue angle should be increased or decreased simultaneously in direction of the same sign. Third, the element $W_{Ch}(W_{hC})$ is positive. This indicates that the lightness and hue angle should be increased or decreased in direction of the opposite sign.

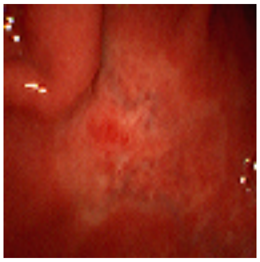
Comparison with the results by specialists

Hara and coworkers carried out psychophysical experiment[13] with collaboration of five specialists for diagnosis. They changed the metric lightness, chroma and hue angle in order to reproduce a preferred endoscope image on CRT. In this experiment, they only examined variance of metric lightness, chroma, hue angle and covariance between metric chroma and hue angle. Unfortunately, it is not possible to calculate the perceptual Mahalanobis distance using the result of Hara's experiment. However, they found that the variance of metric chroma was greater than that of lightness, the variance of lightness was greater than that of hue angle, and covariance between chroma and hue angle have a negative value like the results of our experiments. We assume that our experimental results by students can be appropriate in comparison with the results by specialists.

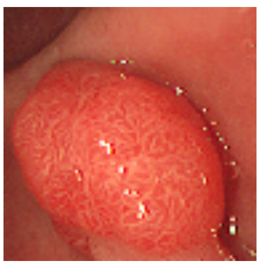
Comparison with the results for natural scenes

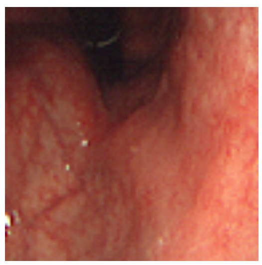
We also performed the psychophysical experiments to find an inverse covariance matrix for two natural scenes. The resultant inverse covariance matrices are shown in Fig. 4 with the images. The matrices for natural scenes were fairly different from those for the electronic endoscope images. Particularly, the sign of non-diagonal elements is different between natural scenes and electronic endoscope images. We can conclude that the color difference was customized for the electronic endoscope images well.

Evaluation of gamut-mapping techniques for endoscope images in our system



$$\begin{bmatrix} 0.42 & -0.15 & -0.32 \\ -0.15 & 0.21 & 0.54 \\ -0.32 & 0.54 & 2.32 \end{bmatrix} \quad \begin{bmatrix} 0.20 & -0.06 & -0.11 \\ -0.06 & 0.12 & 0.16 \\ -0.11 & 0.16 & 0.95 \end{bmatrix}$$





$$\begin{bmatrix} 0.40 & -0.16 & -0.36 \\ -0.16 & 0.25 & 0.66 \\ -0.36 & 0.66 & 2.81 \end{bmatrix} \quad \begin{bmatrix} 0.25 & -0.15 & -0.11 \\ -0.15 & 0.29 & 0.40 \\ -0.11 & 0.40 & 1.45 \end{bmatrix}$$

Figure 3. Sample electronic endoscope images and their inverse covariance matrces

$$\begin{bmatrix} 0.51 & 0.06 & 0.18 \\ 0.06 & 0.31 & 0.02 \\ 0.18 & 0.02 & 0.53 \end{bmatrix} \quad \begin{bmatrix} 0.31 & -0.06 & 0.01 \\ -0.06 & 0.18 & -0.13 \\ 0.01 & -0.13 & 0.93 \end{bmatrix}$$

Figure 4. Sample natural scenes and their inverse covariance matrces

As a preliminary research, simple gamut-mapping techniques were evaluated in our system using the obtained covariance matrix for electronic endoscope images. The scaling and translation of metric lightness chroma and hue angle are considered as follows;

$$L^{*\prime} = aL^* + b$$
$$C^{*\prime} = cC^* + d$$
$$h' = eh + f$$

where L^*, C^*, h are the lightness, chroma and hue angle before the mapping respectively, the $L^{*\prime}$, $C^{*\prime}$, h' are the mapped lightness, chroma and hue angle respectively, and a, b, c, d, e and f are coefficients for translation or scaling. The clipping techniques were not applied in this paper. Each coefficient was varied independently and reproduced images were evaluated based on the color difference defined in the previous section.

Our system is constructed from a CRT 1 (Nanao FlexScan 56T) in a dark environment and CRT 2(AppleColor High-Resolution RGB Model MO401) under illuminant “A” The color gamut of CRT 2 is different from that of CRT 1. The perceptual Mahalanobis distance produced by each mapping were calculated when 99% of the pixels are reproduced inside color gamut of the CRT for all the combinations of coefficients. The minimum averaged perceptual Mahalanobis distance was 1.357 when color mapping is as follows.

$$L^{*\prime} = 0.95L^* + 5$$
$$C^{*\prime} = C^* + 3$$
$$h' = h$$

This result shows that it is better to adjust metric lightness and chroma simultaneously and maintain the hue angle unchanged to minimize changes of color appearance in our system.

Discussion

The color difference has been discussed in the context of a specific application of electronic endoscope. The new concept for designing the color difference based on the covariance matrix is extremely general in the applications where the processed images have characteristic of covariance matrix.

The color difference is the only one aspect of many differences between original image and processed image. The contrast of the images is one of the important aspects to evaluate the images. We should consider the spatial information[14,15] to improve the evaluation techniques furthermore.

Conclusion

A Mahalanobis distance for color difference was defined to evaluate various gamut-mapping techniques for electronic endoscope images. This perceptual distance was calculated by using covariance matrix for the differences of metric lightness, chroma and hue angle, and indicated how the color appearance of reproduced endoscope image was affected by gamut-mapping. By using this color difference, we could evaluate the gamut-mapping techniques in our reproduction system for electronic endoscope images on CRT under the illuminant.

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