Color Image Processing—Present and Future

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Abstract

The researches of color image processing include many kinds of topics such as pattern recognition, color reproduction, robot vision, remote sensing, medical imaging etc. In this paper, we present a some what personal overview of color image processing—present and future. Namely, improved color reproduction is mainly introduced.

Introduction

The studies of color reproduction have been done independently in printings, photography and television for past several decades. in recent years, however, many kinds of imaging systems have been developed and it became increasingly important the image transformations between in each imaging system. Color transformation in each imaging device is particularly important problems, therefore the studies of device independent color reproduction, color portability, color management have been widely done at the universities and industries.

Our goal of research is to improve the image quality, particularly color reproduction of images. To achieve our goal, many studies[2-16] have been done since 1974 in our laboratory. These researches include principal component analysis of spectral reflectance, estimation of spectral reflectance, eye movement analysis, facial pattern detection, and its applications to improve color reproduction for digital hardcopies and electronic endoscopes.

Dr. Hunt[1] classified the purpose of color reproduction into 6 categories; spectral color reproduction, colorimetric color reproduction, exact color reproduction, equivalent color reproduction, corresponding color reproduction and preferred color reproduction. In device independent color reproduction, colorimetric color reproduction is usually considered. Figure 1 shows the color reproduction systems of the image. The value $E(\lambda)$ is the spectral radiance distribution of the light source, $o(\lambda)$ is the spectral reflectance of the object, $Si(\lambda)i$ = R,G,B is spectral sensitivity of the CCD area sensor or color film, $L(\lambda)$ is the spectral transmittance of the imaging lens, respectively. The R, G, and B values of the imaging systems are calculated by Eq.(1)

$$V_R = \int f_R(i)E(\lambda)L(\lambda)S(\lambda)o(\lambda)d\lambda$$
$$V_G = \int f_G(i)E(\lambda)L(\lambda)S(\lambda)o(\lambda)d\lambda \qquad (1)$$
$$V_B = \int f_B(i)E(\lambda)L(\lambda)S(\lambda)o(\lambda)d\lambda$$

The amount of cyan, magenta, and yellow dyes in the color film can be related to the VR, VG, VB, then the spectral reflectance of the image $Oi(\lambda)$ is determined by subtractive mixture of c, m, y dyes. On the other hand, the spectral luminance of the CRT image $Oc(\lambda)$ is also determined by the spectral characteristics of phosphor.

Then the tristimulus values of the object (Xo, Yo, Zo), image on the CRT monitor (Xc,Yc, Zc), and color film (hardcopy) (Xh, Yh, Zh) are calculated by using color matching function. Colorimetric color reproduction is defined as reproduction in which the colors have chromaticities equal to those of original, namely (Xo = Xc = Xh, Yo = Yc = Yh, Zo = Zc = Zh) .

Therefore, in color transformation from CRT to hardcopy, the RGB and CMY can be expressed as polynomial equation:

$$(C,M,Y)^t = M(R,G,B,RG,GB,RB,R,G,B,RGB,1)^t \qquad (2)$$

where, $[\bullet]^t$ is transposition, and M represents the color transformation matrix with 3×11 elements. The coefficient of the matrix was determined to minimize the summation of color difference ΔE^* in the color space of L*u*v* or L*a*b* which is calculated by tristimulus values XYZ between CRT and hardcopy for many kinds of color chart by using least square method. Neural network and Look Up Table methods for color transformation are also used for color transformation. In this color imaging system, we may consider that it can be done easily the computer simulation if we know the spectral characteristics of each imaging component.

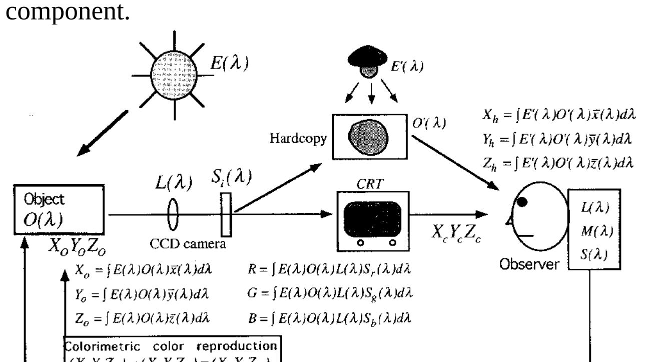


Figure 1. Color reproduction system

Principal Component Analysis of Spectral Reflectance of the Object

We measured about thousand reflectance spectra of gastric mucous membrane by developed endoscopic spectrophotometer. We also measured about 4000 reflectance spectra of color chart includes 146 oil paint and 104 skin color of Japanese women. These measured reflectance spectra have been analyzed by the principal component analysis. Because the orthonormal vectors with ndimensional space were obtained by the principal component analysis, the reflectance spectra of the object o can be calculated by

$$\mathbf{o} = \sum_{i=1}^{n} \alpha_i \mathbf{u}_i + \mathbf{m} \tag{3}$$

where α_i is an expansion coefficient and $\mathbf{m}$ is the mean vector of measured reflectance spectra. From the result of principal component analysis, $\mathbf{o}$ can be approximated by the linear combination of the three eigenvectors $\mathbf{u}_1$, $\mathbf{u}_2$ and $\mathbf{u}_3$ with the mean vector $\mathbf{m}$. The result showed that the contribution ratio from first to third components is about 99%; in other words, the reflectance spectra of skin color can be represented approximately 99% of the time using a linear combination of three principal components $\mathbf{u}_1$, $\mathbf{u}_2$ and $\mathbf{u}_3$. It was also found that the reflectance spectra of gastric mucous membrane which were measured by developed endoscopic spectrophotometer can be also represented approximately 99% by three principal components. However, in color chart and oil painting, five components were necessary to reproduce the spectra. These experimental results show that it is possible to calculate the reflectance spectra of all pixels $O(x,y,\lambda)$ from the R, G, B output signals obtained by a general imaging system or multiband imaging systems.

Simulation of Color Reproduction in Electronic Endoscopes

The method was applied to improve color reproduction of endoscopic image. Gastric membranes with (a) cancer, (b) early stage of chronic gastritis, (c) chronic gastritis IIb, (d) advanced stage of chronic gastritis, (e) gastric ulcer, (f) normal membrane, (g) polyp and (h) xanthoma were used for computer simulation. In the simulation, first the spectral reflectance of gastric mucous membrane of 270×270 pixels was calculated from R, G, B signals, then the color reproduction of electronic endoscopes under twelve illuminants was estimated by computer simulation. To estimate the optimum illuminant, those obtained images were displayed on a CRT and evaluated by two physicians who are specialist of endoscopic diagnosis. Images by xenon lamp was selected as most preferred. Because the xenon lamp has been used as light source in conventional electronic endoscopes, we consider that the color memory of doctors may be fixed to the color reproduction by xenon lamp illumination. However, the doctors said that in the diagnosis of the membrane, particularly in the vascular pattern of polyp, image by a kind of fluorescent lamp is more significant than the image with other illuminants. The method was also applied to improve color reproduction of arts and skin color images.

Facial Pattern Detection and Local Color Correction

In color reproduction of a picture, familiar colors such as the skin of the face, sky and grass are significant, particularly the color of the facial pattern. We first developed a new method to detect skin color region from negative color film. To detect skin color from negative color film, it is important to discriminate the taking illuminant light to negative color film. The CDF (Cumulative Distribution Function) calculated from R,G,B density histograms of negative color film, average chromaticity of the image, and the chromaticity of maximum visual density were used to the discrimination of light source. Then the many kinds of skin colors were measured for many illuminant conditions. From these experimental results, region of skin color for negative color film were determined as the probability ellipse.

Facial patterns were extracted by using both bi-level image processing and the geometrical properties of shape. Figure 2 is an example of facial pattern detection from negative color film. The method was also applied to detect facial pattern from television picture and reversal color film. Therefore color of facial region can be changed to preferred color easily.

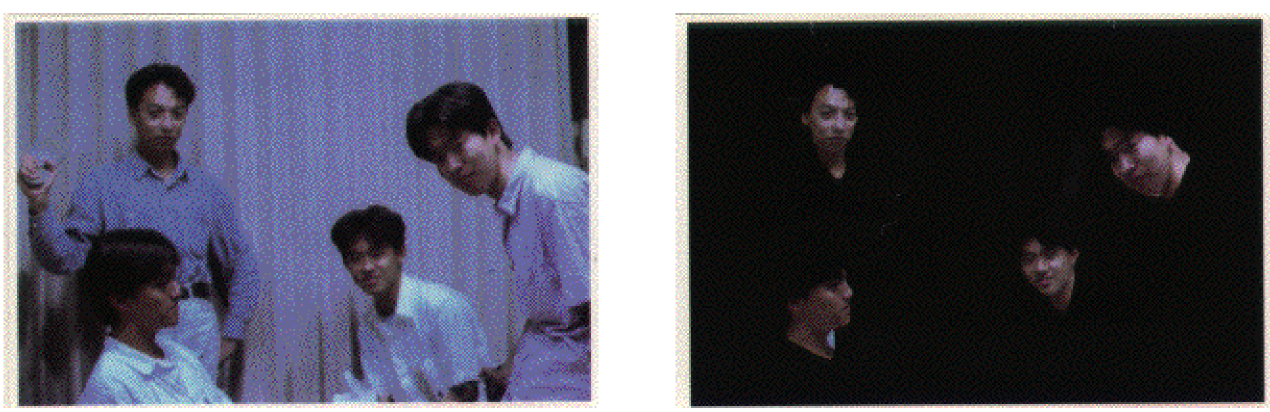


Figure 2. An example of facial pattern detection from negative color film

Furthermore, the method was modified and applied to color transformation from CRT image to hardcopy. For example, the picture was classified into five categories by using its chromaticity. In the color transformation from RGB to CMY, five transformation matrices were determined in each category. Namely, after the five regions were transformed by each matrix, then five regions were synthesized. We also developed the method to suppress the false contour in boundary area between each category.

Eye Movement Analysis and its Application for Color Reproduction

For the classification of the image, we considered to use the gazing area of the image which is measured by eye movement analysis, because the gazing area is most important region of the image. From the experiment, we found that images have a particular gazing area. Figure 3 (b) shows an example of a gazing area distribution of the image shown in Figure 3(a).

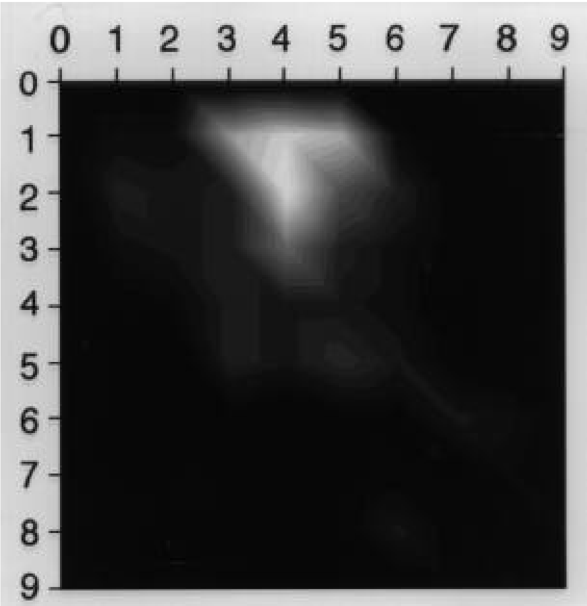
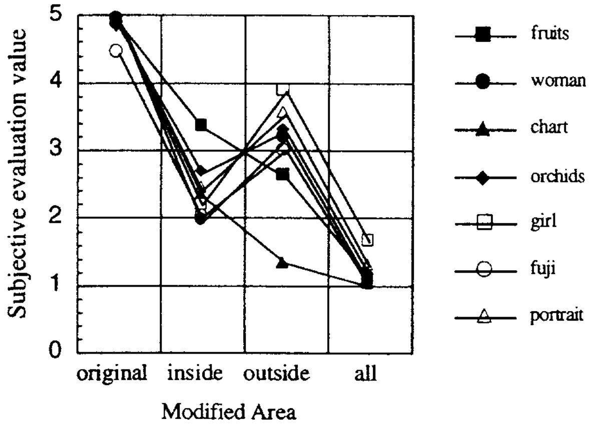


Figure 3 Gazing area of image

We rated image quality of three types degradation images; blurred and compressed inside of gazing area, outside gazing area and entire of the image. Figure 4 shows the observer rating experiment result for seven kinds of image. It is apparent that the images blurred (a) and compressed (b) inside of gazing area are rated as poor quality compared to the images blurred (compressed) outside of gazing area. We consider that the practice can be applied to local color correction and data compression



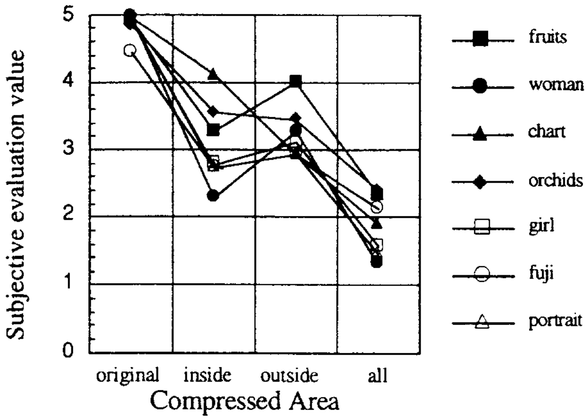


Figure 4. Subjective evaluation of blurred (a) and compressed (b) inside of gazing area, outside gazing area and entire of the image for seven kinds of images.

Color Reproduction Based on Color Appearance Models

In the above discussions, we only considered the improvement of color reproduction based on colorimetric color reproduction. The perceived colors, however, are different in practice from the colorimetric color reproduction, that are caused by the chromatic adaptation of human vision. The color appearance can be predicted using chromatic adaptation models such as the von Kries, Fairchild, RLAB, Hunt, etc. These adaptation models are defined based on the color matching of color charts. We found that those proposed models are not always significant to predict the facial skin color. Therefore we modified the Fairchild model to predict the facial skin color.

Experimental results showed that the facial skin color under different illuminants can be predicted more precisely by proposed adaptation model. However, further research considering color appearance models for the optimum color reproduction should be performed for each of the various viewing condition.

Conclusion

In this paper, various method to improve color reproduction of imaging were described which we have developed. First, colorimetric color reproduction is introduced, then we showed that the spectral reflectance of gastric mucous membranes and skin color can be estimated with high accuracy using only three principal components. On the basis of the analysis, computer simulation of color reproduction was introduced.

One of the goals of color reproduction studies is to reproduce preferred color, for the purpose we introduced eye movement analysis, scene classification, facial pattern detection and local color correction methods. Furthermore, color adaption models were also applied to improve color reproduction. In the future, we consider that it will become more important to introduce the human perception for improvement of color reproduction.

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