Improved Color Reproduction of Electronic Endoscopes

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Abstract

Image quality of the electronic endoscopes are poor compared to the conventional optical endoscopes which use color film. It is our goal to improve the image quality, particularly color reproduction of electronic endoscopes.

To achieve our goal, we have developed the endoscopic spectrophotometer to measure the spectral reflectance of gastric mucous membrane. The instrument consists of a light source with xenon lamp; a conventional spectrophotometer; an optical multichannel analyzer with 1024 silicon photodiodes; and personal computer. Three hundred and ten spectra have been analyzed by the principal component analysis. The results indicate that the reflectance spectra can be adequately described less than the average color difference $\Delta E = 2.66$ in the L*u*v* color space using only three principal components.

Based on the above experimental result, it is shown that the spectral reflectance of all pixels in gastric mucous membrane can be calculated from the R, G, B signals of the conventional electronic endoscopes. Computer simulations of the color reproduction of electronic endoscopes were performed, and the resulting spectral characteristics under different illuminants are described and analyzed.

Introduction

Electronic endoscopes with CCD area sensor have been developed and widely used instead of the conventional optical endoscopes which use color film. It is considered that the images by electronic endoscopes can be easily applied to the remote-diagnosis, image filing, image processing and PACS. However, image quality, particularly, color reproduction of the images by electronic endoscopes is poor since the present electronic endoscopes uses the NTSC system.To improve the color reproduction of electronic endoscopes, we have developed the endoscopic spectrophotometer to measure the spectral reflectance of gastric mucous membrane.[1] We measured about three hundred spectral reflectance using this spectrophotometer and reported the capabilities of automatic diagnosis using spectral data and chromaticitiy.[2,3] We also reported a color correction method in the electronic endoscope's input system using a simple 3*3 matrix to reproduce a colorimetrically correct color based on the analysis of the spectral reflectance.[4]

In this paper, we analyze those measured spectral reflectance by principal component analysis and it is shown that those measured spectral reflectance can be adequately described using only three principal compo-

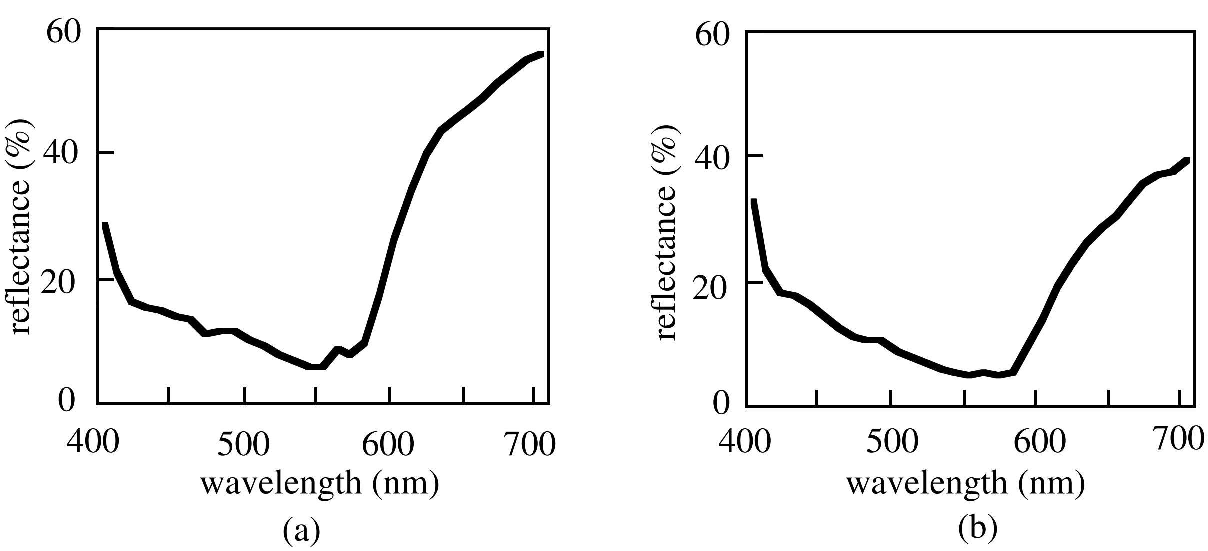

Figure 1. Examples of spectral reflectance of gastric mucous membrane

nents. It is also shown that the spectral reflectance of all pixels in gastric mucous membrane can be estimated by R, G, B signals taken by electronic endoscopes. On the basis of the experimental results, the computer simulation of the color reproduction of electronic endoscopes was performed.

Principal Component Analysis of the Spectral Reflectance of the Gastric Mucous Membrane

Figure 1 (a) and (b) show the examples of spectral reflectance of gastric mucous membrane measured by the developed spectrophotometer.

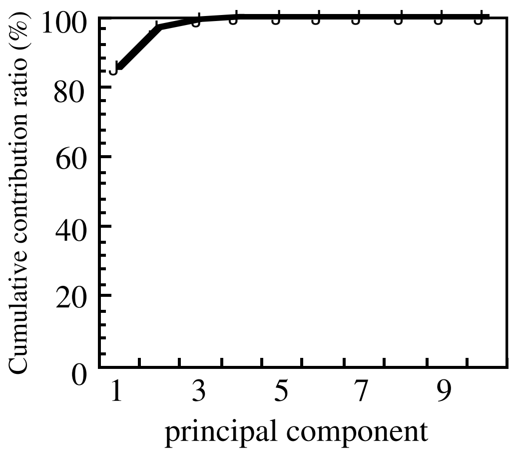

Figure 2. Cumulative contribution ratio of principal components

In a previous paper, we have reported that the spectral reflectance of human skin color can be estimated by only three principal components.[5] Same method was applied to analyze three hundred and ten spectral reflectance of gastric mucous membrane. Figure 2 shows that the cumulative contribution ratio of principal components of them. The result shows that the contribution ratio from first to third components is about 99%, in other words the spectral reflectance of gastric mucous membranes can be represented approximately 99% by using linear combination of three principal components $\mathbf{u}_1$, $\mathbf{u}_2$ and $\mathbf{u}_3$. Figure 3 shows the eigenvectors $\mathbf{u}_1$, $\mathbf{u}_2$ and $\mathbf{u}_3$.

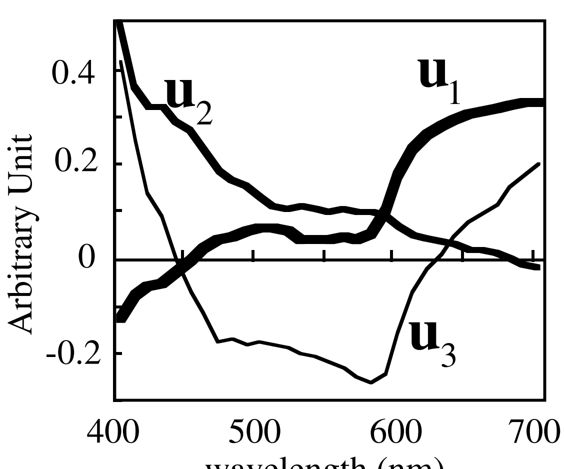

Figure 3. Eigen vectors of principal component

Estimation of Spectral Reflectance

Figure 4 shows the model of electronic endoscopes which utilizes RGB sequencing, incorporating a rotating color wheel comprised of R, G, B filters used in the simulation.

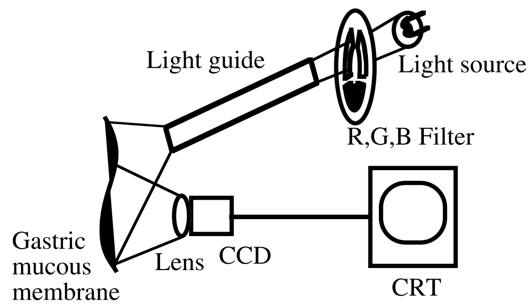

Figure 4. Model of electronic endoscopes

In this system, R, G and B values of electronic endoscopes, v_i(R, G, B) are given by using vector notation as follows,

$$\begin{aligned} v_i &= \mathbf{f}_i^t \mathbf{ELSo} \\ &= \mathbf{F}_i^t \mathbf{o} \\ &(i = R, G, B) \end{aligned} \qquad (1)$$

where F_i^t (i=R, G, B) are the overall spectral sensitivities of an electronic endoscope, and $[\bullet]^t$ represents the transpose of [•]. Namely, **E:**E(λ) is spectral radiant distribution of light source, **f:**$f_R(\lambda)$, $f_G(\lambda)$, $f_B(\lambda)$, is spectral transmittance of R, G, B filters, **S:**S(λ) is spectral sensitivity of CCD area sensor, **L:**L(λ) is combined spectral transmittance of the light guide fiber and the imaging lens, and **o:**o(λ) is the spectral reflectance of gastric mucous membrane.

As the orthonormal vectors with n-dimensional space was obtained by the principal component analysis, then the spectral reflectance of gastric mucous membrane **o** can be calculated by

$$\mathbf{o} = \sum_{i=1}^{n} \alpha_i \mathbf{u}_i \qquad (2)$$

where α is constant. From the result of principal component analysis, **o** can be approximated by the linear combination of eigenvectors $\mathbf{u}_1$, $\mathbf{u}_2$ and $\mathbf{u}_3$.

$$\mathbf{o} \cong \sum_{i=1}^{3} \alpha_i \mathbf{u}_i = \begin{bmatrix} \mathbf{u}_1 & \mathbf{u}_2 & \mathbf{u}_3 \end{bmatrix} \begin{bmatrix} \alpha_1 \\ \alpha_2 \\ \alpha_3 \end{bmatrix} \qquad (3)$$

From Equations (1) and (3)

$$\begin{bmatrix} v_R \\ v_G \\ v_B \end{bmatrix} = \begin{bmatrix} \mathbf{F}_R^t \\ \mathbf{F}_G^t \\ \mathbf{F}_B^t \end{bmatrix} \begin{bmatrix} \mathbf{u}_1 & \mathbf{u}_2 & \mathbf{u}_3 \end{bmatrix} \begin{bmatrix} \alpha_1 \\ \alpha_2 \\ \alpha_3 \end{bmatrix} \quad (4)$$

Then, the constant value α_1, α_2 and α_3 is given by

$$\begin{bmatrix} \alpha_1 \\ \alpha_2 \\ \alpha_3 \end{bmatrix} = \begin{bmatrix} \mathbf{F}_R^t\mathbf{u}_1 & \mathbf{F}_R^t\mathbf{u}_2 & \mathbf{F}_R^t\mathbf{u}_3 \\ \mathbf{F}_G^t\mathbf{u}_1 & \mathbf{F}_G^t\mathbf{u}_2 & \mathbf{F}_G^t\mathbf{u}_3 \\ \mathbf{F}_B^t\mathbf{u}_1 & \mathbf{F}_B^t\mathbf{u}_2 & \mathbf{F}_B^t\mathbf{u}_3 \end{bmatrix}^{-1} \begin{bmatrix} v_R \\ v_G \\ v_B \end{bmatrix} \quad (5)$$

Since F_i^t (i=R, G, B), $\mathbf{u}_i$(i=1, 2, 3) and v_i(i=1, 2, 3) are obtained, the constant value α_1, α_2 and α_3 can be calculated.

Namely the spectral reflectance of gastric mucous membrane can be estimated by the Equation (4), therefore it becomes possible to calculate the spectral reflectance of all pixels from the R, G, B signals of the NTSC camera image.

We estimated three hundred and ten spectral reflectance of gastric mucous membrane based on the above mentioned method. Examples of estimated spectral reflectance are shown in Figure 5 (a) and (b). Estimated spectral reflectance are approximately equal to the measured spectral reflectance.

On the other hand, color differences of CIE L*u*v* (illuminant D65) between measured and estimated are shown in Figure 6. Average color difference ΔE^*_{uv} of three hundred and ten samples was 2.66, minimum color difference ΔE^*_{uv} was 0.64 and maximum color difference ΔE^*_{uv} was 9.14, respectively. This result indicates that the proposed method has sufficient accuracy to estimate the spectral reflectance of the gastric mucous membrane.

Simulation of Color Reproduction in Electronic Endoscopes

The method was applied to the practical endoscopic image with 160*160 pixels, and the color reproduction of electronic endoscopes under four different illuminants shown in Figure 7, CIE standard illuminants A, D65 and typical fluorescent lamp F1 and F2 were estimated by computer simulation.

We analyzed the obtained images and the results indicated that it was difficult to recognize the details of the mucous membrane both under the CIE standard illuminant A and F1, however, in the images calculated by illuminants D65 and F2, it was easy to discriminate the details of the vascular pattern in the images.

Figure 8 shows the chromaticities of the simulated images with four illuminants shown in Figure 7. It is clear that the color gamut of the images under the illuminant D65 and F2 is expanded in comparison to the images under the illuminant A and F1.

Conclusion

In this paper, it was shown that the spectral reflectance of gastric mucous membrane can be estimated with high accuracy using the three principal components. On the basis of the analysis, computer simulation model of the color reproduction of electronic endocopes was developed, and the color reproduction by four kinds of taking illuminants was estimated and analyzed.

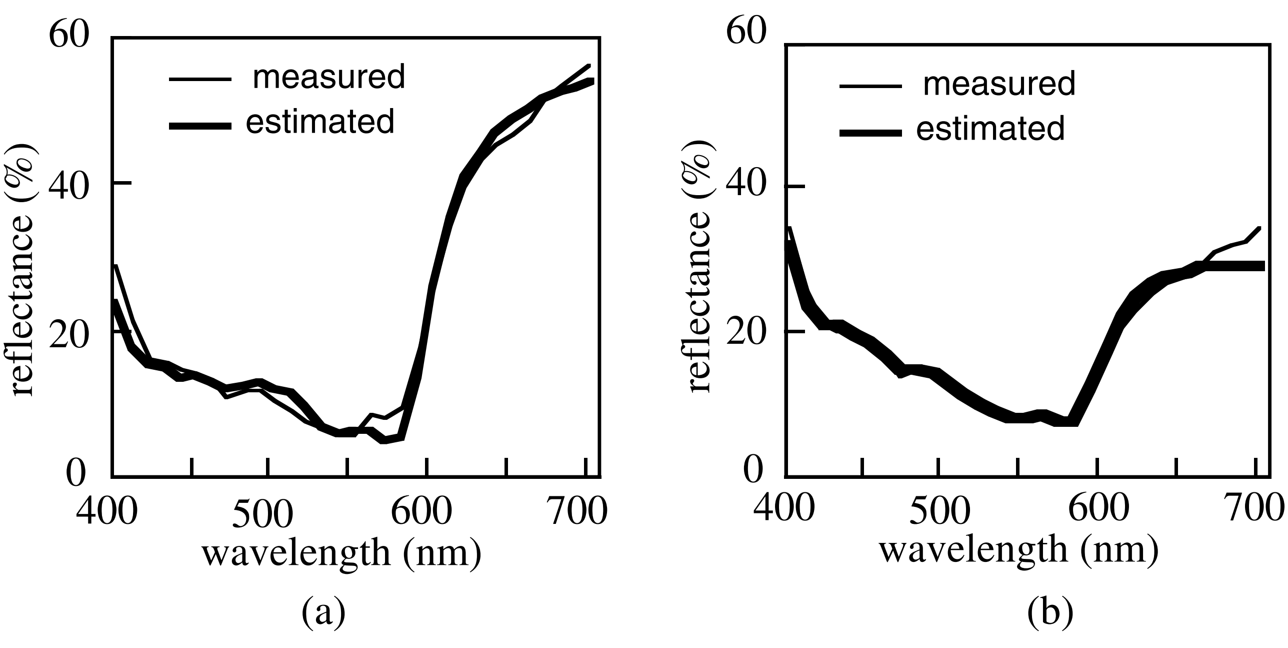

Figure 5. Examples of estimaged spectral reflectance

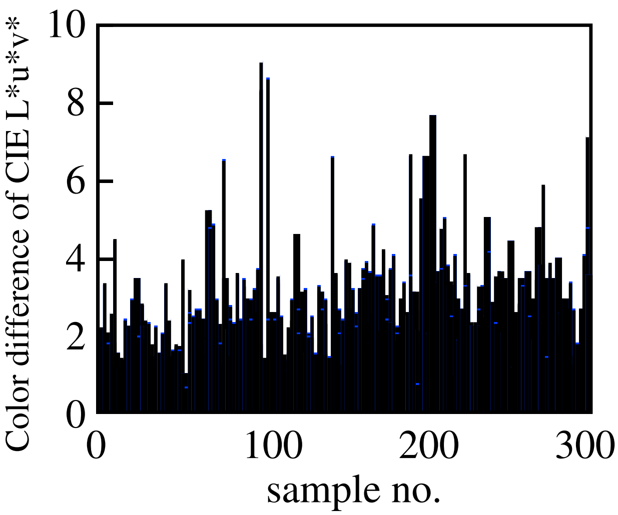

*Figure 6. Color differeences of CIE L*u*v* between measured and estimated spectrral reflectance*

We consider to design the optimum spectral characteristics of illuminant, RGB filters, CCD sensor and imaging lens for electronic endoscopes by using the developed simulation systems.

Acknowledgment

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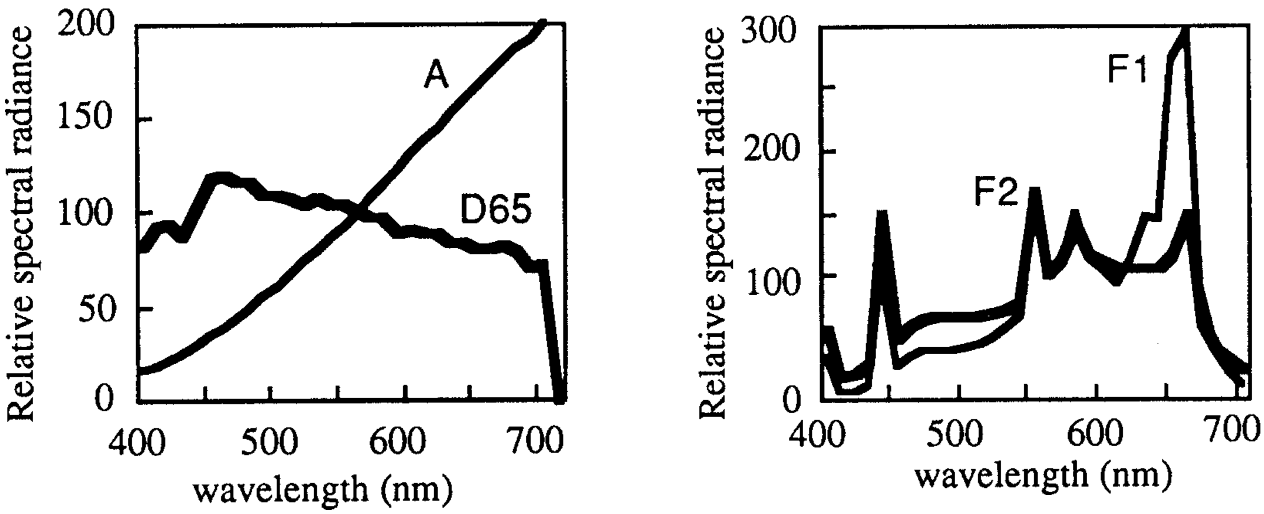

(a) (b)

Figure 7. Spectral radiant distribution of four illuminants used in the stimulation

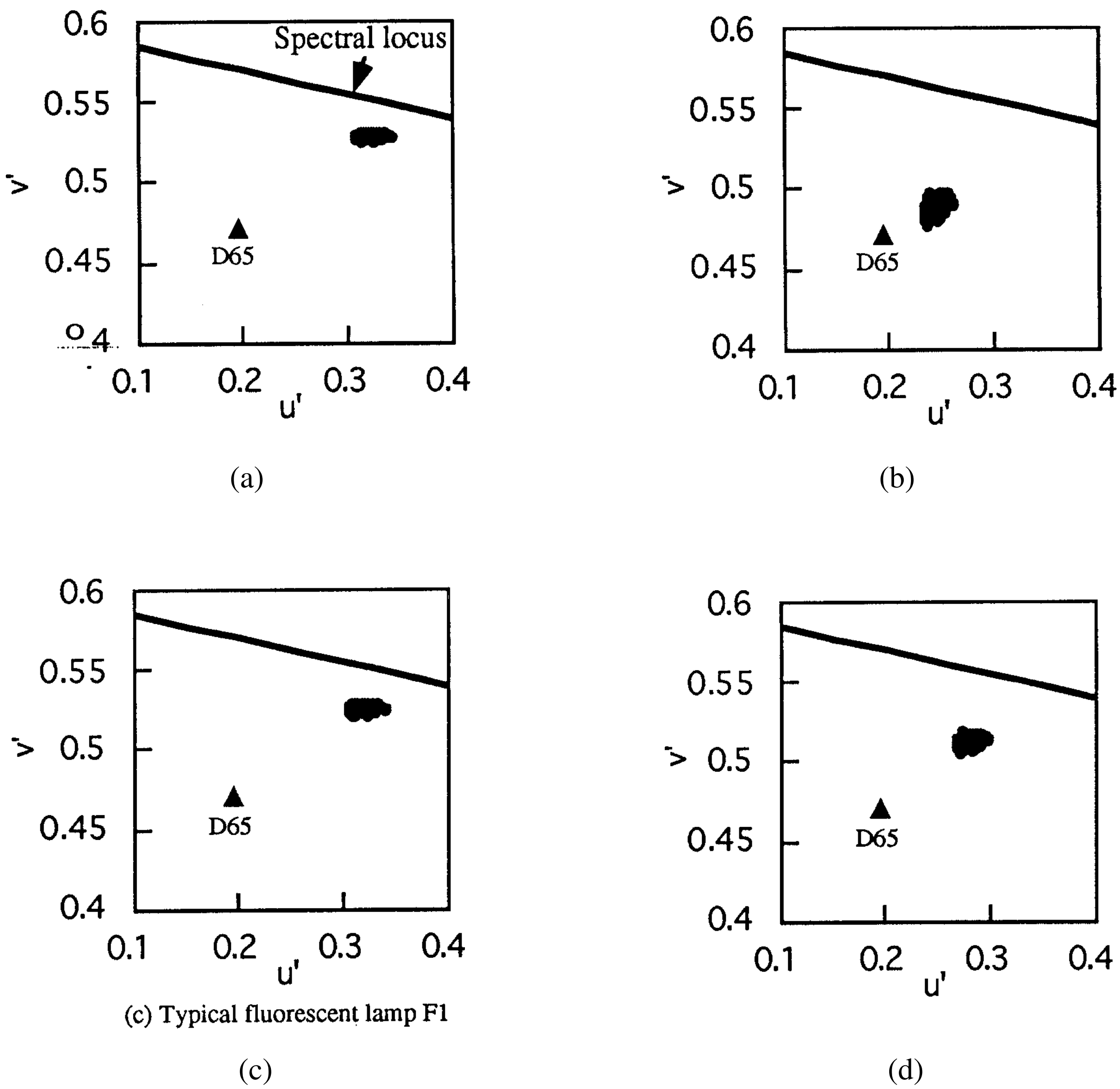

Figure 8. Simulated u',v' chromaticity distributions of gastric mucous membrane under four kinds of illuminant