JOURNAL OF BIOMEDICAL OPTICS 3(3), 373–378 (JULY 1998)

COLOR CORRECTION OF THE VIDEO IMAGE OBTAINED BY ANGIOSCOPE

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(Paper JBO-153 received Sep. 22, 1997; revised manuscript received Feb. 6, 1998; accepted for publication Feb. 10, 1998.)

ABSTRACT

In this article, a simple color correction method for the color reproduction of image obtained by angioscope is reported. We present the method to obtain the matrices theoretically and experimentally, respectively. For the angioscope system, we suggest two matrices: an average color correction matrix A and a blood vessel color correction matrix A'. Using the two matrices, the images of several color samples captured by an angioscope are processed, and their reproduced colors are evaluated. With this method, the discrimination ability of the angioscope will be improved dramatically. [S1083-3668(98)00603-0]

Keywords angioscope; color correction matrix; image process.

1 INTRODUCTION

The angioscope is a novel type of medical apparatus. It has been used in clinical areas and indicates wide application prospects for the medical field. The angioscope is composed of an illumination system, image-guiding system, displaying system, and other ancillary systems such as a flushing system, etc. In the illumination system, a light source such as a xeon lamp, which has a spectrum similar to that of sunlight, is generally used, and the light is focused onto the tip of illumination fibers, and then illuminates the field of view. The objects in this field image on the tip of the image-guide fiber by the gradient index (GRIN) lens. The image which is transported by the fiber can be observed by the eyepiece or projected to the target of a charge coupled device (CCD) camera by the lens, then displayed on the monitor. With the development of the technique of image grab adapter and computer, the image taken by the CCD camera can be captured by the image grab adapter and displayed on the monitor and stored in the memory of the computer to be processed and analyzed, thereby making computer-aided diagnosis possible. The colors of the different pathology tissues in the blood vessel are different[1]: the normal tissues usually are white, while the colors of the pathology tissues usually are red, yellow, or brown. Therefore the real color image displayed on the computer is necessary. The distortions between the reproduction colors of image on the computer and the real colors of the object are attributed to the structure of the angioscope. It can be summed up as three main origins:

1. The spectrum of the source light is different from the standard white light spectrum,
2. The transitivity of the illuminating fiber and the image-guide fiber are different at a different wavelengths,
3. There are distortions in the color reproduction system such as the CCD camera and cathode ray tube (CRT) system.

It is very important to find a way to correct the colors of the image to improve the diagnosis accurately for the pathology of the blood vessel. Because of the complexity of the human visual system, is difficult to process the real color image, and most scientists agree that image processing should take place in three dimensions, reflecting the visual attributes.[2] A few papers about this research have been written, and usually a 3×3 matrix masking or 3×9 nonlinear matrix masking[3,4] is used to process the color image. Haneishi reported a color correction method for an electronic endoscope[5] and hardcopy from the CRT image.[6] And Ohyama[7] suggested a 3×3 matrix to enhance the color image of the endoscope.

In this article, a simple color correction method for color reproduction of the angioscope system is reported. The light source used is a WBr lamp. Its spectrum is much different from the standard white light D65. The light intensity in the long wavelength is strong and therefore the objects illuminated by it appear more orange, while the CCD camera and the CRT system will also distort the image color. First we neglect the color distortions produced by the CCD system and consider the color to be real. The color distortion produced by the illuminating and transport system of the angio-

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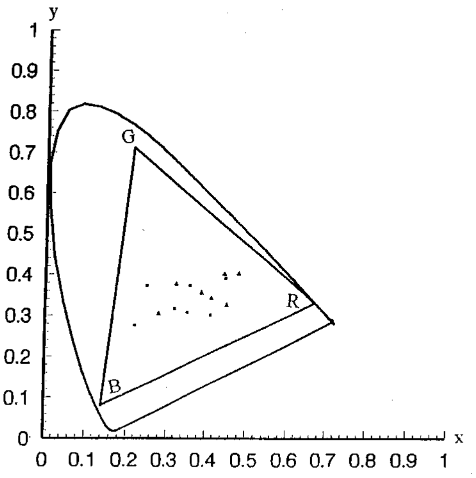

Fig. 1 The C.I.E. chromaticity chart showing the location of tristimulus colors RGB that satisfy the NTSC standard system: (■) represents the reproduced colors obtained without angioscope system, (▲) represent the reproduced color obtained with the angioscope C.I.E.

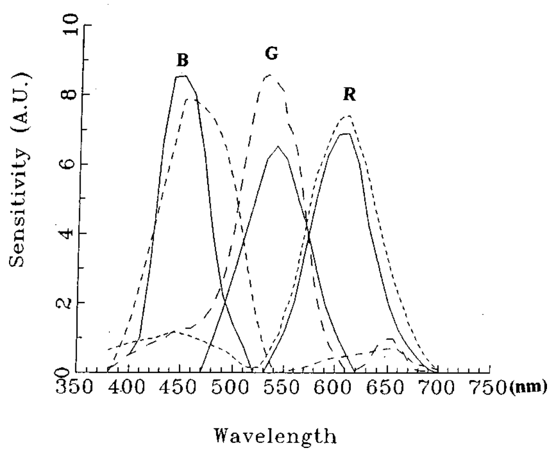

Fig. 2 Spectral sensitivity response curves. Solid line: for NTSC phosphor primaries, dotted line: for the CCD camera.

scope was considered in the first order approach. We suggest two matrices: a 3×3 average color correction matrix A and a 3×3 blood vessel color correction matrix A' to correct this color distortion. The images are processed with the two matrices and the results are analyzed. Considering that the CCD system does not satisfy the NTSC standard very well, this will induce certain color distortion also, as Sproson suggested.[8] We also use a 3×3 matrix B to compensate this color distortion further.

2 THEORY

In our work, the angioscope system includes an illuminating system, a light guide system, and an image guide system as shown in Fig. 4(b). According to the chromaticity theory, a color can be matched by a suitable mixture of three selected radiation colors. In the CRT system, a color displayed on it is produced by the different intensity cathode rays that stimulate the red, green, and blue phosphor dots. Choosing the three colors differently makes the display standard different. In the National Television Systems Committee (NTSC) standard system, the locations of the tristimulus colors of the CRT system in the C.I.E. 1931 chromaticity chart are shown in Figure 1.

R, G, B represent the tristimulus colors of the NTSC standard system, and the colors in triangle RGB can be reproduced on the CRT. It includes most of colors in nature, especially the colors we see commonly. If adding the matrix circuit in that CRT system to compensate, the distribution coefficients will all be positive. A comparison of the ideal NTSC and CCD systems spectral distribution curves for the equal-energy spectrum is shown in Figure 2.

If one color reproduced by CRT and its spectral composition $\varphi(\lambda)$ is known, the tristimulus values of R, G, B can be given by[9,10]

$$\mathrm{R}=\sum_n (\varphi_\lambda \cdot \bar{r}_\lambda),$$

$$\mathrm{G}=\sum_n (\varphi_\lambda \cdot \bar{g}_\lambda), \tag{1}$$

$$\mathrm{B}=\sum_n (\varphi_\lambda \cdot \bar{b}_\lambda).$$

Here φ_λ is related to the light source and the reflectance of the object. For convenience, we express all the continuous values by n discrete values. The spectral luminance factors matrix of the standard white light source is

$$S=\begin{bmatrix} s_1 & & 0 \\ & \ddots & \\ 0 & & s_n \end{bmatrix},$$

where s_i represents the corresponding energy at wavelength λ_i. [The spectral distribution of the reflectance of an object is $\rho=(\rho_1 \cdots \rho_n)^t$] ($\rho_i$ represents the reflectance at wavelength λ_i).

The R, G, B are the tristimulus values of an object with standard illumination, and can be expressed as follows:

$$C=\begin{pmatrix} \mathrm{R} \\ \mathrm{G} \\ \mathrm{B} \end{pmatrix}=\begin{pmatrix} r_1 & \cdots & r_n \\ g_1 & \cdots & g_n \\ b_1 & \cdots & b_n \end{pmatrix}\begin{pmatrix} s_1 & & 0 \\ & \ddots & \\ 0 & & s_n \end{pmatrix}\begin{pmatrix} \rho_1 \\ \vdots \\ \rho_n \end{pmatrix}$$
$$=\mathrm{M} \cdot \mathrm{S} \cdot \rho = G\rho, \tag{2}$$

where M stands for the matrix

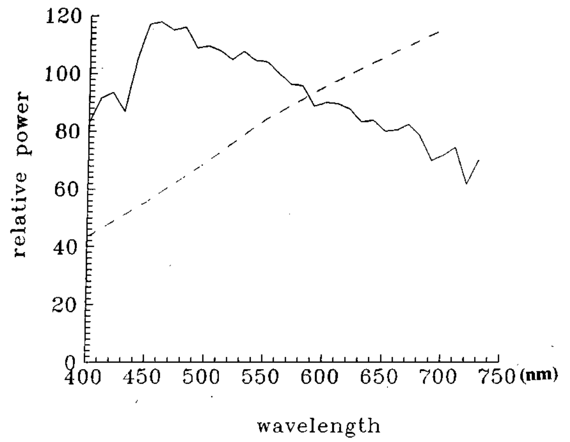

Fig. 3 Spectral power distributions of illuminates D65 and the WBr lamp. The solid line is the D65 spectrum; the dotted line is the WBr lamp.

$$\begin{pmatrix} r_1 & \cdots & r_n \\ g_1 & \cdots & g_n \\ b_1 & \cdots & b_n \end{pmatrix}$$

and S stands for the matrix

$$\begin{pmatrix} s_1 & \cdots & 0 \\ & \cdots & \\ 0 & \cdots & s_n \end{pmatrix},$$

and r_i, g_i, b_i are the distribution coefficients at wavelength λ_i, respectively. The values have been shown in Figure 2.

The spectral luminance factor matrix of the WBr lamp light source is

$$S'=\begin{bmatrix} s'_1 & & 0 \\ & \ddots & \\ 0 & & s'_n \end{bmatrix}.$$

The spectral power distributions of illuminate D65 and the WBr lamp are shown in Figure 3.

The transmissivity of the fiber against the wavelength is:

$$\eta=\begin{bmatrix} \eta_1 & & 0 \\ & \ddots & \\ 0 & & \eta_n \end{bmatrix},$$

where η_i represents the transmissivity at wavelength λ_1.

Illuminating with the WBr lamp, the reproduced color values R′, G′, B′ of the image putout by the CCD camera are

$$C'=\begin{pmatrix} R' \\ G' \\ B' \end{pmatrix}=\begin{pmatrix} r'_1 & \cdots & r'_n \\ g'_1 & \cdots & g'_n \\ b'_1 & \cdots & b'_n \end{pmatrix}\begin{pmatrix} s'_1 & & 0 \\ & \ddots & \\ 0 & & s'_n \end{pmatrix}$$

$$\times\begin{pmatrix} \eta_1 & & 0 \\ & \ddots & \\ 0 & & \eta_n \end{pmatrix}\begin{pmatrix} \rho_1 \\ \vdots \\ \rho_n \end{pmatrix}$$

$$=\mathrm{MS}'\,\eta\rho=G'\rho, \tag{3}$$

where r'_i, g'_i, b'_i are the spectral response of the CCD system at wavelength λ_i respectively, the values of which have been shown in Figure 2. The values of R′, G′, B′ are different from the values R, G, B. A color correction method is necessary in order to reproduce the real color image using the angioscope and CCD camera. We use a matrix A to correct the color distortion produced by the source light and transport system of the angioscope. From Figure 2, it is shown that the spectral sensitivity response curves for the CCD camera are similar to the NTSC primaries. First, we assume the colors reproduced by the CCD camera system alone are the real colors. The elements of color correction matrix A should be determined so that the color difference between the real colors and the processed colors is minimum. We can get matrix A by setting the minimum value (equal to 0) of the color difference between the processed colors of the angioscope and the reproduced colors of the CCD camera system. That is,

$$AC'=C, \tag{4}$$

where the values of C and C' colors must be adjusted to the equal brightness.

From Eqs. (2) and (3), Eq. (4) can be expressed as

$$\begin{gathered} AG'\rho=G\rho, \\ AG'\rho\cdot\rho^tG'^t=G\rho\cdot\rho^tG'^t. \end{gathered} \tag{5}$$

Then the correction matrix A is obtained by

$$A=GR(\rho)G'^t[G'R(\rho)G'^t]^{-1}. \tag{6}$$

Here $R(\rho)=\rho\cdot\rho^t$. From the above equation, we see that A can be expressed as a 3×3 matrix, and it is related to $R(\rho)$. That is, A is related to the original color values, and there is no matrix A that can make $AC'\equiv C$ for the different color C, so the optimal values of matrix A are obtained by making the sum of different colors differences minimum. That is,

$$\sum \Delta E(C,AC')\rightarrow\mathrm{min}. \tag{7}$$

Here, ΔE of the two colors, color C(R,G,B) and color C'(R′,G′,B′), is defined as follows:

$$\Delta E_{\mathrm{RGB}}(C,C')=\|C-C'\|$$

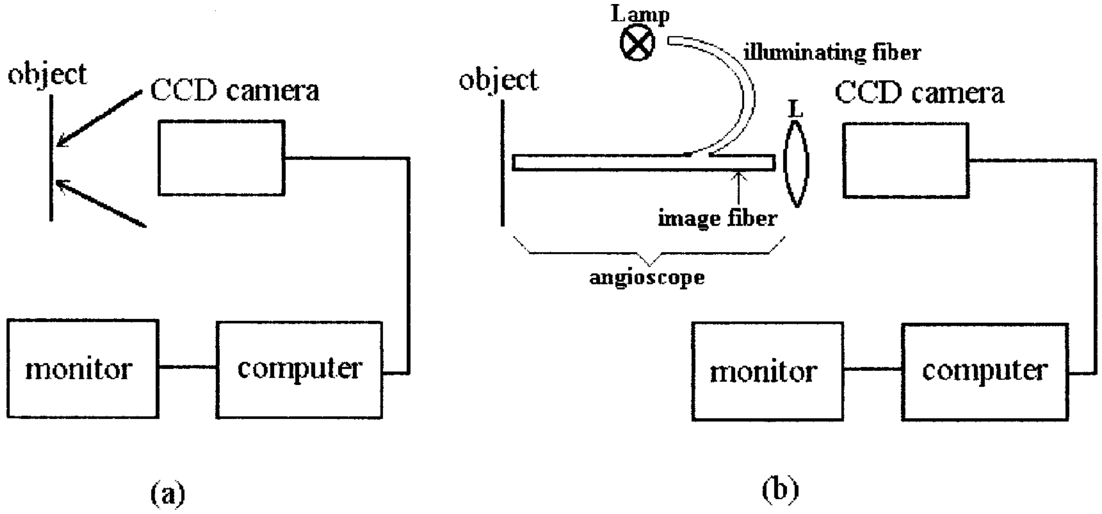

Fig. 4 Experimental apparatus for getting a color image in the CCD system: (a) without angioscope system; (b) with angioscope system.

$$=\sqrt{(R-R')^2+(G-G')^2+(B-B')^2} \tag{8}$$

where $\|\cdot\|$ represents a matrix's norm.

We chose 14 typical colors. The coordinates of these colors in the Munsell color system are 7.5R6/4, 5Y6/4, 5GY6/8, 2.5G6/6, 10BG6/4, 5PB6/8, 2.5P6/8, 10P6/8, 4.5R4/13, 5Y8/10, 4.5G5/8, 3PB3/11, 5YR8/4, and 5GY4/4, respectively.

We can get 14 color values from R, G, B and R′, G′, B′, so the color correction matrix of these 14 colors A_t can be obtained with the above method:

$$A_t=\begin{bmatrix} 1.17 & 0 & 0.07 \\ -0.19 & 1.19 & 0.02 \\ 0.06 & -0.28 & 0.97 \end{bmatrix}.$$

Considering that the CCD camera system can also produce a color difference, we can use the same method to obtain a correction matrix B. The matrix B is obtained by setting the color difference between the reproduced colors of the NTSC system and processed colors of the CCD camera system to minimum:

$$B=\begin{bmatrix} 1.14 & 0.02 & -0.15 \\ -0.07 & 1.22 & -0.18 \\ -0.09 & -0.21 & 1.33 \end{bmatrix}.$$

At the same time, we can get the color correction matrix A for the angioscope system by experiment.

3 COLOR CORRECTION MATRIX A OBTAINED BY EXPERIMENT

The color correction matrix can be obtained experimentally. The experimental apparatus is shown in Figure 4. In Figure 4(a), the color image is collected directly by a CCD camera system, and in Figure 4(b) through the angioscope system and then collected by the CCD camera.

The CCD camera used is the model TP-8001A color CCD camera made in Taiwan. The image grab adapter used is the CA6300 color video grab card. It has 2 Mbyte video random access memory (VRAM) and can capture the image with 8, 16, 24, or 32 bits. With 24 or 32 bit image capture, 16 777 216 kinds of colors can be reproduced, so the real color of an object can be mainly reproduced. The image can be overlaid with the video grasp adaptor (VGA) signals of the computer and displayed on the monitor. The computer used is a PC 486 computer.

The software package is written by the authors and designed for the Windows operating system. The image is saved as a 24-bit color bitmap (BMP) file. A file of this type has three segments: a device independent bitmap (DIB) header (14 bytes), a Bitmapinforheader region (40 bytes), and an image data region. In the former 54 bytes store the image structure data such as image width, image length, color depth, etc. From that every 3 bytes represent a pixel's value of brightness: blue, green, red, respectively, so we can get the color tristimulus values (R,G,B) from the file directly.

As mentioned above, the reproduced colors of the CCD camera system alone are assumed to be real colors. We select the objects of the red, pink, orange, yellow, white, blue, and green colors. As shown in Figure 4(a), the objects are illuminated by sunlight, and the CCD camera is used to capture the image and the image data is sent to the computer for the color values R, G, B. The values of RGB can be transferred to the coordinate of the CIE1931 x-y graph as follows:

$$\begin{cases} X=0.5876\mathrm{R}+0.1792G+0.1832\mathrm{B}, \\ Y=0.2894\mathrm{R}+0.6059G+0.1047\mathrm{B}, \\ Z=0.0683G+1.0206\mathrm{B}, \end{cases} \tag{9}$$

Table 1 Quantitative evaluation of color correction method with the average matrix and the blood vessel matrix for the samples.

	Without correction	Average color correction	Blood vessel color correction
Orange	0.0667	0.0477	0.0368
Pink	0.1471	0.0284	0.0019
Yellow	0.1930	0.0657	0.0456
Green	0.1960	0.0298	0.1442
Blue	0.1708	0.0308	0.1566
White	0.1726	0.0400	0.0199
Red	0.0935	0.0160	0.0131
Mean value	0.1485	0.0301	0.0597

and the unit coordinates x, y, and z will be given by

$$\begin{cases} x=\dfrac{X}{X+Y+Z}, \\ y=\dfrac{Y}{X+Y+Z}, \\ z=\dfrac{Z}{X+Y+Z}. \end{cases} \tag{10}$$

The locations of the reproduced colors by the CCD system without the angioscope system in the CIE1931 x-y graph (shown in Figure 1) are represented by ■. This kind of color is regarded as the standard color for comparison. In Figure 4(b), the objects are illuminated by a WBr lamp; then its image is captured with a CCD camera through the angioscope system. The reproduced color tristimulus values are R′, G′, B′. The locations of these colors in the CIE1931 x-y graph represented as ▲ are also shown in Figure 1. As shown in Figure 1, the locations of points ■ and points ▲ do not coincide, demonstrating that the color difference is produced by the angioscope system.

With the method presented in Sec. 2, first we perform correction of the color difference produced by the angioscope. Assuming $AC'=C$, the values of color C need to be adjusted so that their brightness is equal to the values of color C'. A series of equations are obtained. We get the optimal average color correction matrix A by calculating the sum of seven color differences minimum, $\Sigma_{n=7}\|AC'-C\| \rightarrow \min$:

$$A=\begin{bmatrix} 1.27 & 0.10 & -0.01 \\ -0.12 & 1.29 & -0.08 \\ -0.05 & -0.39 & 1.03 \end{bmatrix}.$$

Compare the results of the experimental values A with the theoretical values A_t.

In the blood vessels, the locations of tissue colors are in the bottom right part of the triangle RGB in Figure 1, short of the blue and green colors, so we can also get the blood vessel color correction matrix A' by setting to minimum the sum of the five colors (red, pink, orange, yellow, white) that are more common in the blood vessel as the difference between the correction color and the real color:

$$A'=\begin{bmatrix} 1.37 & 0.37 & -0.13 \\ -0.14 & 1.17 & -0.02 \\ -0.22 & -0.52 & 1.14 \end{bmatrix}.$$

4 RESULTS AND DISCUSSION

The sample colors obtained are corrected using the two experimental matrices A and A'; the color differences are calculated with Eq. (8). The results are shown in Table 1. The color difference values in the table are obtained by comparing the reproduced colors by the CCD camera system without the angioscope. The values in the first column of the table are the color differences by the angioscope; the values in the second column are the color differences processed by the average correction matrix A, and the values in the third column are the color differences processed by the blood vessel correction matrix A'.

From the table, it can be concluded that the mean value of the color difference without correction is 0.1485, and the mean value corrected with average color correction matrix A is 0.0301, while the mean value corrected with the blood vessel correction matrix is 0.0597. With the two color correction matrices, the color difference is deduced. For an object that includes many colors, the reproduced colors corrected with the average color correction matrix A are better than that with the blood vessel color correction matrix A'. But considering the blood vessel condition, the mean color difference of the five colors (red, pink, orange, yellow, white) corrected with the matrix A' is 0.02346, and the mean value of the five colors corrected with the matrix A is 0.0375. Thus, the matrix A' is better for the blood vessel image. The average value of 0.1346 without correction of these five color differences is much higher than the mean color differences of the five colors corrected with the matrix A'. We also processed the blood vessel images obtained by the angioscope with the average correction matrix A and the blood vessel correction matrix A'. The images improved much and the results corrected with matrix A' are also better than those corrected with matrix A. Considering the color distortion produced by the CCD camera, the result should be multiplied by matrix B. That is, the final R′, G′, B′ are obtained by

$$\begin{bmatrix} R \\ G \\ B \end{bmatrix} = \begin{bmatrix} 1.59 & 0.52 & -0.32 \\ -0.22 & 1.49 & -0.22 \\ -0.39 & -1.08 & 1.53 \end{bmatrix} \begin{bmatrix} R' \\ G' \\ B' \end{bmatrix}.$$

5 CONCLUSION

Usually the colors of the image obtained by the angioscope are distorted. According to the chromatometry theory, there should be a 3×3 color correct matrix that can minimize color difference between the real colors of the object and the reproduced colors of the image obtained by an angioscope. Therefore the images displayed on the CRT of the computer are improved. In this study, we present methods to obtain the color correction matrix by both theory and experiment, and compare the results. Using seven color objects and five color objects (for blood vessels), we get the optimal average color correction matrix A and the optimal blood vessel color correction matrix A', respectively. The color images captured by angioscope are processed by these two matrixes, and the results are compared. The images of the blood vessel corrected with the blood vessel color correction matrix A' are better than that with the average correction matrix A. Thus the quantity of output image and the discrimination ability of the angioscope will be improved dramatically. The normal tissues and the pathology tissues can be identified more accurately.

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