Color Management in Ophthalmic Photography

Joel A. Witwer, Mark D. Fairchild, Christie X. Sisson

Munsell Color Science Laboratory, RIT, Rochester, NY, USA, 14623-5604

1. PROCEDURE

The experimental procedure involved developing a ophthalmic version of a color checker which could be used with the fundus cameras. The color checker was then captured with each of the four fundus cameras studied and the individual sRGB output values were recorded. These sRGB values along with the CIEXYZ values of the color checker were used to develop a camera specific 3x3 transformation matrix to transform the camera colors to the color checker colors. Finally, this matrix was used to alter the captured image color back to a baseline color that is similar between all the studied cameras.

1.1 Cameras

Four digital fundus cameras were selected. The first was a Canon CF-60UVi, the second a Topcon TRC-50X. A slightly newer version of this camera, the Topcon TRC-50DX was the third camera selected. And the final camera was the Zeiss FF450plus. All of the cameras selected are variable angle, mydriatic fundus cameras. All cameras were set to as close to a 30 degree angle of view as possible. The Zeiss FF450 - Plus was taken at a 30 degree angle of view, while the two topcons and the Canon were taken at a 35 degree angle of view. Another difference was that a different power flash was used on each camera as each sensor has different sensitivities. In each case, the power flash that obtained the best exposed image was used. Other than the varying angle of view and differing flash powers, each camera was set identically as if taking a picture of an emmetropic eye; there was no power correction, no astigmatism correction and no filters were used.

1.2 Ophthalmic Color Checker

Fundus cameras are specifically designed to take pictures of the retina meaning that the is incorporated as the second half of the imaging system. Along with this, the fundus camera is meant to capture images of the retina which is a curved surface. Taking these two considerations into account, an ophthalmic color checker was specifically designed for this project. A model eye called a Reti Eye, manufactured by Gulden Ophthalmics, was acquired as it roughly models both the refraction and curvature of an emmetropic eye.

From here, twelve color patches were chosen and fit inside of the model eye. A three point grayscale was chosen, then the standard RGB patches were included. Finally, six colors were chosen that commonly appear in human retinas. These colors were a purple, a brown, two more shades of red and two shades of orange.

1.3 Image Capture

The color patches were inserted into the model eye one at a time. The camera was operated in the same way an ophthalmologist would use one; the eye was mounted, the camera brought into proper working distance from the cornea, the back of the eye brought into focus and an image captured. This was done three times for each color as to reduce the possibility of an operator induced artifact in the image. In total, 36 images were capture on each of the four camera.

Once the images were captured, they were exported out of the camera specific, FDA approved ophthalmic software as TIFF files and saved to an external hard drive for transportation and further use.

1.4 Image Processing

The individual images were then open in the image manipulation freeware GIMP and cropped to 500x500 pixel sections. These sections were always towards the center of the image and chosen as to which area had the most uniform distribution of color. From here, the 500x500 regions were averaged in order to achieve one triad of sRGB values for the image. This triad was then averaged with the other two triads from that particular color patch and camera combination in order to achieve just one sRGB triad per color. To finalize the image processing, the triads for each image were normalized by dividing each value by 255.

1.5 Target XYZ Values

On the other end of the spectrum, the target colors needed to be classified. To do this, the spectral reflectances of each of the color patches were measured using a Macbeth Color Eye 7000. The spectral reflectances were then converted in CIEXYZ triads using two degree observer and D65 data. The resulting values were then normalized and recorded.

1.6 Transformation Matrix Development

Before the matrix to transform the camers sRGB values to the target XYZ values can be developed, the sRGB triplets must be linearized. This is done using the three grayscale values. Their R values are plotted against their Y values. Next a simple exponential model was created to find a γ value that fit the curve of the data. Once a satisfying curve had been found, linearized R values, R', were found using equation **??**. This was done for each of the three colour channels, R, G and B.

$$R' = R^{\frac{1}{\gamma}} \tag{1}$$

Once the sRGB values were linearized they were put into a 3x12 matrix. The CIE XYZ target values were put into another 3x12 matrix with the goal of finding a 3x3 transformation that could transform one to the other. This can be seen in Figure **??**.

$$|M| \begin{vmatrix} X_1 & ... & X_{12} \\ Y_1 & ... & Y_{12} \\ Z_1 & ... & Z_{12} \end{vmatrix} = \begin{vmatrix} R'_1 & ... & R'_{12} \\ G'_1 & ... & G'_{12} \\ B'_1 & ... & B'_{12} \end{vmatrix} \tag{2}$$

To find M, the Moore-Pembrose Pseudo Inverse was found and applied to each side. The resultant 3x3 matrix is the desired transformation matrix.

Canon CF - 60UVi

$$\begin{vmatrix} X \\ Y \\ Z \end{vmatrix} = \begin{vmatrix} 0.586 & -0.235 & 0.522 \\ 0.426 & -0.023 & 0.523 \\ 0.223 & -0.252 & 1.070 \end{vmatrix} \begin{vmatrix} R' \\ G' \\ B' \end{vmatrix} \tag{3}$$

Topcon TRC - 50X

$$\begin{vmatrix} X \\ Y \\ Z \end{vmatrix} = \begin{vmatrix} 0.0.465 & 0.150 & -0.035 \\ 0.303 & 0.205 & 0.095 \\ 0.130 & 0.048 & 0.511 \end{vmatrix} \begin{vmatrix} R' \\ G' \\ B' \end{vmatrix} \tag{4}$$

Topcon TRC - 50DX

$$\begin{vmatrix} X \\ Y \\ Z \end{vmatrix} = \begin{vmatrix} 0.475 & -0.088 & 0.711 \\ 0.280 & 0.132 & 0.751 \\ 0.017 & -0.055 & 1.495 \end{vmatrix} \begin{vmatrix} R' \\ G' \\ B' \end{vmatrix} \tag{5}$$

Zeiss FF450 - Plus

$$\begin{vmatrix} X \\ Y \\ Z \end{vmatrix} = \begin{vmatrix} 0.933 & 0.703 & -0.140 \\ 0.318 & 1.006 & 0.097 \\ -0.352 & 0.109 & 1.686 \end{vmatrix} \begin{vmatrix} R' \\ G' \\ B' \end{vmatrix} \tag{6}$$

1.7 Transforming the Image

To transform the image, it is first linearized once again using equation **??** and the respective γ values for each of the channels. Then the triplet at each x,y location was run through transformation matrix in order to turn the colours from the cameras sRGBs to the target XYZs. Next the target XYZ values were turned into target RGB values for display purposes. This matrix was a standard XYZ to sRGB matrix made using D65 lighting. This was taken from brucelindbloom.com. To be safe, all digital counts were clipped at both 0 and 255 to prevent out of gamut colours. Finally, the colours were exponentially scaled back up by the monitor gamma for proper display.