Scanner Color Characterization for Multi-Function Systems

Huanzhao Zeng and Ouyang Julie, Digital Printing Technologies, Hewlett-Packard Company, 18311 SE 34th Street, Vancouver, WA 98683, USA

Abstract

In a multi-function copy system, a scanner is used for scanning photos as well as documents that may contain text only or mix text and photo contents. The scanner color characterization is therefore the tradeoff of many factors, such as content types (photo, text/graphics, or mixed contents), media types, and printing technologies. The color characterization of the scanner pipeline in a copier or a multi-function system is different from that of stand-alone scanners. This paper covers methods for scanner color characterization for general office copies. Color characterization for the copy path will also be brief described.

Keywords: scanner, printer, copy, color characterization, device color calibration, gamut mapping

1. Introduction

Scanner color characterization [1-4] is a sub-set of the copier system color characterization. Mostly for copying documents, scanner color characterization for general office copiers is different from that of stand-alone scanners. Fig. 1 shows the basic block diagram of a copier system.
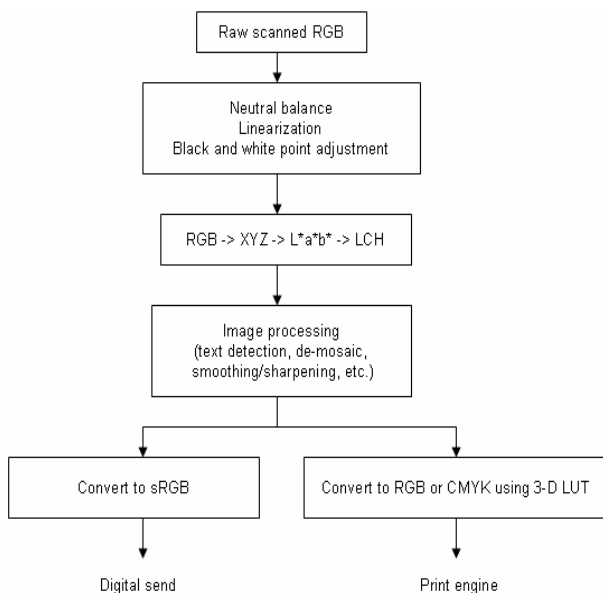

Figure 1. Block diagram of a copier color flow

The neutral balance and white and black points must be properly determined for copying office documents. The relationship between scanner RGB and a device-independent color space may be obtained by neutral calibration followed by polynomial regression or 3-D interpolation. Because the type of a target for polynomial regression or 3-D interpolation is often different from that of a target for neutral balance calibration, the polynomial regression or 3-D interpolation may change the neutral balance calibration using a neutral balance target. This paper will focus on how to perform scanner characterization preserving the neutral balance for copier color characterization.

2. Neutral Balance

The neutral balance is determined by setting R=G=B for the scanned neutral patches of a neutral balance target. The RGB tone curves may be generated by linearizing one of the channels to CIE Y or L*, and determining the other two channels by the condition of neutral balance. Different neutral targets may result in significantly different neutral balanced curves.

The scanner used for our copier was provided by a third vendor. It outputs 8-bit/channel RGB signal approximately linearized to CIE L*. The sensor to sensor calibration of the CCD array and the line scanning gain adjustment are performed inside the scanner and is beyond our control. The neutral balance calibration will be described in following sub-sections.

2.1 Neutral balance aimed at Q13 neutral

A Kodak Q13 black and white AgX neutral target has twenty neutral patches from white to black. The spectral reflectance of each patch measured using a Gretag SpectroScan is shown in Fig. 2. Except for the media white patch, all other patches are very flat (or non-selective) in absorption, which is more reliable for scanner neutral balance calibration, for a scanner has different spectral sensitivity from human eyes.
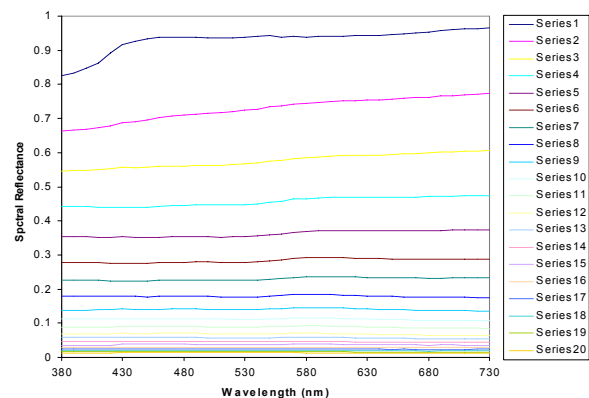

Figure 2. The spectral reflectance of a Q13 target

Fig. 3 shows the CIE a*b* values of the Q13 target under a hybrid illuminant, D65F, which is the weighted combination of D65 illuminant and office fluorescent light. Since the neutral balance of the target is not stable, especially the light patches, the scanner neutral balance calibrated using Q13 may require manual

adjustment. Another problem for using a Q13 target is that the maximum density of the target is only about 1.9, which may be insufficient for calibrating the lower end of a scanner that is able to sense higher density.
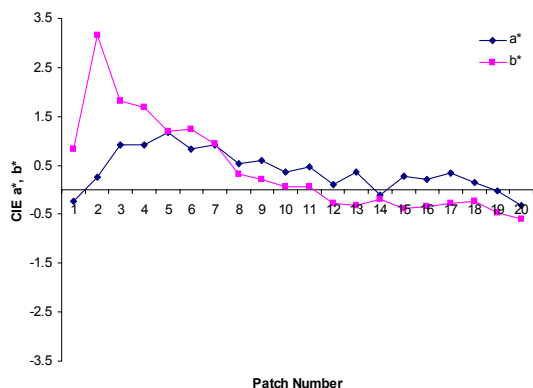

Figure 3. Neutral balance of a Q13 target under D65F

The scanner neutral balance characterized using the Q13 target is shown in Fig. 4. The RGB tone curves are linearized to CIE Y component. This set of curves are used to generate RGB 1-D lookup tables (LUT) to be used in a copier ASIC. Passing through the 1-D LUTs, the scanner RGB values are converted to balanced RGB signal, in which R=G=B colors are the aimed neutral.
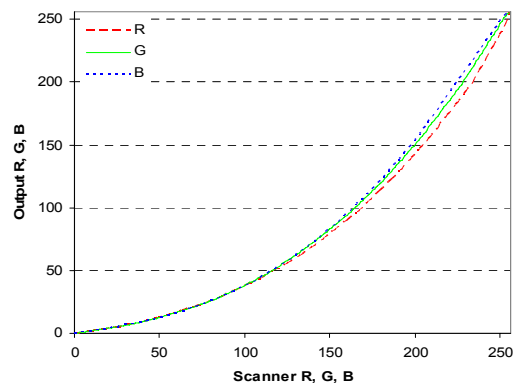

Figure 4. Neutral balance characterized using a Q13 target

2.2 Neutral balance aimed at Munsell neutral

Munsell glossy neutral patches were used for the characterization, for it has higher maximum density than that of the Munsell matte book. The neutral ramp (N9/ to N1/) was used to characterize neutral balance curves. The darker patches (N.75/ and N.5/) were only used to determine a proper black point for the scanner. Fig. 5 shows the spectral reflectance of N9/ to N1/ measured using an EyeOne spectrophotometer. Different from Q13, Munsell neutral patches have high absorption on the short-wavelength end. Except for that, the absorption is very flat on the entire visual spectrum.
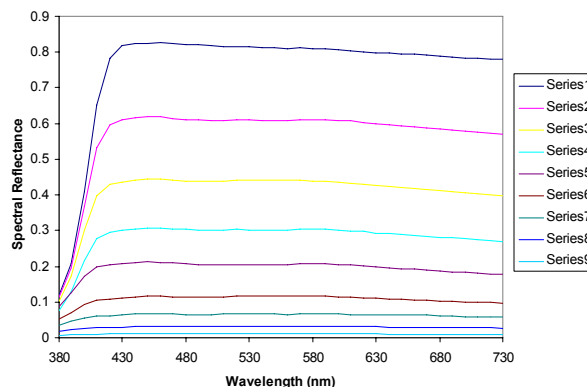

Figure 5. The spectral reflectance of Munsell neutral patches

Fig. 6 shows the perturbation of CIE a*b* values of these nine Munsell neutral patches. The neutral balance is more consistent than that of Q13. The scanner neutral balance characterized using this target is shown in Fig. 7, which is different from the neutral balance curves derived using a Q13 target.
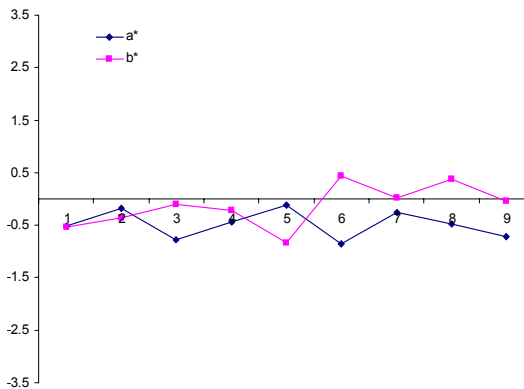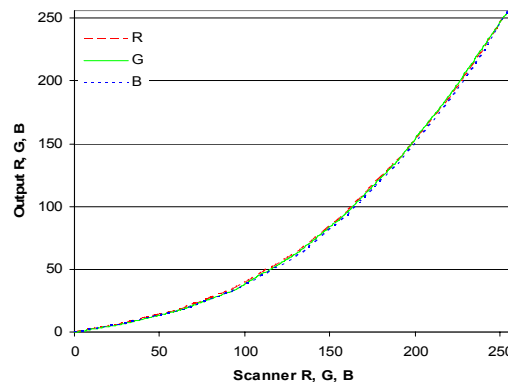

Figure 6. Neutral balance of Munsell neutral under D65F

Figure 7. Neutral balance characterized using Munsell neutral

2.3 Neutral balance aimed at Q60 neutral

The neutral ramp on the bottom of a Q60 target was used for the scanner neutral balance characterization. The spectral reflectance curves of these twenty-four patches are shown in Fig. 8. Because Q60 neutral are produced by color dyes, the absorbance is quite selective, which may not be a good choice for neutral calibration. However, since scanning and copying AgX photographic hardcopies are very common, it is important to study the neutral balance using this target.
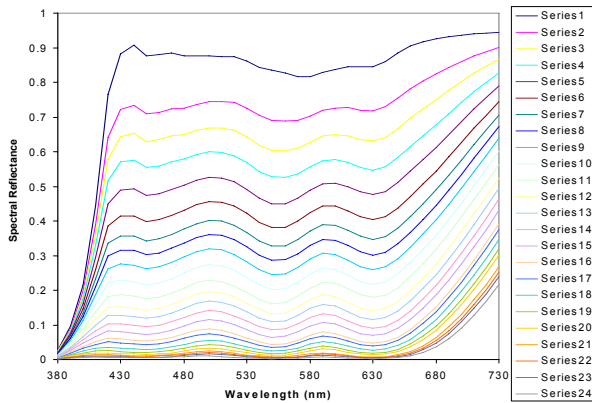

Figure 8. The spectral reflectance of Q60 neutral patches

Fig. 9 shows CIE a*b* perturbation of these twenty-four Q60 neutral patches. Comparing to the Q13 target and the Munsell neutral patches, Q60 neutral has the worst neutral balance. The maximum density of the Q60 target is about 2.3, which is high enough for determining the scanner black point.

The scanner neutral balance characterized using Q60 neutral patches is shown in Fig. 10. This set of curves is very different from those derived using a Q13 target or the Munsell neutral patches. It shows that the red signal needs to be substantially reduced for neutral balance.
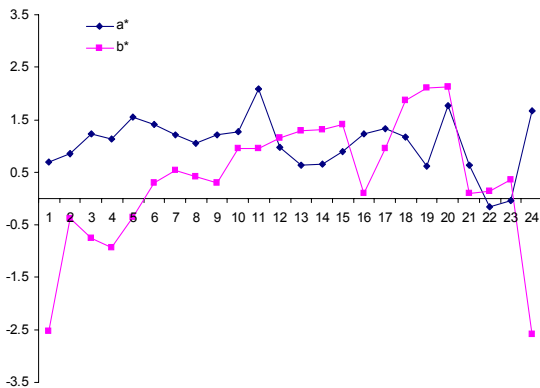

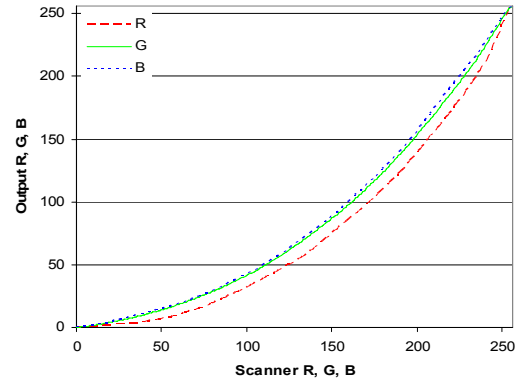Figure 9. Neutral balance of Q60 neutral patches under D65F

Figure 10. Neutral balance characterized using Q60 neutral

2.4 Compromised neutral balance

In order to compromise the neutral balance for different media sources, a final set of neutral balance curves were obtained from the weighted combination of different curve sets. For general scanning and copy, neutral ramps printed using laser toner black and inkjet black may also be used for neutral calibration. In our copy system, we used different neutral balance curves for different scanning modes.

3 Scanned Black and White Points

To characterize the scanner of a copier, the range of RGB code values (scanned black and white points) must be determined. The RGB values of the white point and the black point are the raw RGB scanned values to be mapped to the media white and black point of the printer hardcopy, respectively. The raw scanned RGB values of the black and the white points are usually mapped to (0, 0, 0) and (255, 255, 255) in 8-bit/channel, respectively. For different scanning or copy modes, different black and white points may be used.

The raw RGB values of the black point are used to adjust the neutral balance curves so that the raw scanned RGB values of the black point are mapped to (0, 0, 0). Similarly, the raw RGB values of the white point are used to adjust the neutral balance curves so that the raw scanned RGB values of the white point are mapped to (255, 255, 255).

4 Scanner Color Characterization

After determining the scanner neutral balance curve, the next step is to determine the transformation from the neutral balanced RGB to a device-independent color space, such as CIE XYZ or L*a*b*.

4.1 Traditional polynomial regression

The curves (or 1-D LUTs) generated in the previous sections is used to convert scanner RGB to neutral balanced and linearized R'G'B', as shown in Eq. (1).

$$R' = TRC_r(R)$$
$$G' = TRC_g(G) \qquad\qquad (1)$$
$$B' = TRC_b(B)$$

Followed this step may be a 3x3 matrix operation as shown in Eq. (2).

$$\begin{pmatrix} X \\ Y \\ Z \end{pmatrix} = Matrix_{3x3} \begin{pmatrix} R' \\ G' \\ B' \end{pmatrix} \qquad (2)$$

Depending on the nature of a scanner, using above 3x3 matrix may result in poor colorimetric color accuracy. A higher order polynomial regression may be used to improve the accuracy. A second-order polynomial example is shown in Eq. (3).

$$\begin{pmatrix} X \\ Y \\ Z \end{pmatrix} = Matrix_{10x3} \cdot$$

$$\begin{pmatrix} 1 & R & G & B & R^2 & G^2 & B^2 & RG & RB & GB \end{pmatrix}^T \qquad (3)$$

A target that over-determines the parameters is used for the regression that minimizes an error metric. Different targets (e.g. targets from different inkjet prints, laser printer prints, magazines, AgX photos, etc.) result in different coefficients. A typical characterization method is to use a weighted combination of different targets.

We used a Q60 target to study the color accuracy. All of the 264 color patches on the target are used for regression. Constraints on all nine elements of the 3x3 matrix in Eq. (1) are: the value of every element must not be negative. Aiming at minimizing ΔE_{a*b*}, we obtained an average ΔE_{a*b*} of 11, and maximum ΔE_{a*b*} of 64.

A general linear regression that minimizes total error in XYZ space is applied to obtain coefficients of Eq. (3). After a regression matrix is generated, the color difference in CIELAB space is computed. An average ΔE_{a*b*} of 3.4 and a maximum ΔE_{a*b*} of 21.9 are obtained.

The problem in using a 3x3 matrix is the inaccuracy. A 3x3 matrix is not able to model the RGB to XYZ relationship accurately. Using higher order polynomial fitting instead improves the color accuracy, but the neutral balance is altered, i.e., an equal RGB color is no longer an aimed neutral color.

4.2 Polynomial regression preserving neutral balance

Since an RGB color space does not have a chrominance (or chroma) coordinate, it impossible for us to use a standard regression algorithm to generate a set of matrix that preserves the neutral axis (i.e. if chroma in RGB color space is zero, the LAB or XYZ computed using the matrix should result in zero chroma.). If we convert the RGB color space on Eq. (3) to another color space that has chrominance coordinates, the right side of Eq. (3) will have chrominance axes. Similarly, we may change the left side of XYZ color space to a color space that associates with chrominance coordinates (e.g. CIE LAB or CAM02 JAB). Then, we set a regression condition that if the chroma on the right side is zero, the

chroma on the left side should be zero. The neutral balance is therefore preserved.

To preserve the neutral balance, the XYZ color space is replaced by L*a*b* color space. We convert RGB into YCC (or YIQ) using a 3x3 matrix, such as the matrix for the conversion from sRGB to sYCC. If the scanner RGB color space in this step is linearized to CIE Y component, tone transformation is applied to the RGB data so that the RGB tone transformation is similar to L* before the conversion from RGB to YCC. sRGB tone curve can be used for this purpose. The regression becomes YCC to LAB. An n-order polynomial regression model becomes:

$$\begin{pmatrix} L* \\ a* \\ b* \end{pmatrix} = \begin{pmatrix} t_0 & t_1 & ... & t_{1n} \\ u_0 & u_1 & ... & u_{1n} \\ v_0 & v_1 & ... & v_{1n} \end{pmatrix} \cdot$$

$$\begin{pmatrix} 1 & Y & C_b & C_r & ... & Y^n & C_b^n & C_r^n \end{pmatrix}^T \qquad (4)$$

The chroma of the YCC space is $C_{in} = \sqrt{C_r^2 + C_b^2}$, and the chroma of L*a*b* space is $C_{out} = \sqrt{a*^2 + b*^2}$. To preserve the neutral balance, i.e. Cin = 0 results in Cout = 0, we simply set coefficients that are not related to chrominance to zero.

Again, the same Kodak Q60 target is used for 2nd order polynomial regression with neutral preservation. The average and maximum ΔE_{a*b*} are 2.6 and 15.7, respectively. The regression accuracy is improved. The reasons may be: 1) it minimizes color difference in L*a*b* color space instead of in XYZ space; 2) these two color spaces are both luminance-chrominance color spaces, in which the lower-order terms may be more significant and higher-order terms may be less significant.

5 Color Transformation for e-Send

For digital send, or e-send, scanning RGB are usually transformed into sRGB. The L*a*b* values obtained from the previous step are converted into sRGB. White point adaptation and black point adjustment are included in the transformation. For different objects types, different tone curves and different black/white points may be used. These transformations may be implemented using 1-D LUTs and a 3-D LUT.

6 Color Transformation for Copy

A color separation LUT may be generated for the transformation from printer RGB into printer device color space (e.g. CMYK, CMYKcm, etc.) to lower the printer modeling to a 3-dimensional space [5, 6]. Printer characterization for the transformation from printer device color space to a device-independent color space is constructed for gamut mapping and interpolation.

With both the scanner and the printer transformations, the scanner RGB are converted to a device-independent color space,

followed by white point and black point adjustments, gamut mapping from the source gamut to the printer gamut, and finally transformed to CMYK. In order to guarantee the source white and black points are mapped to the destination white and black points, the white and black points of the scanner 1-D LUTs must be set properly (see Section 3). Reference 7 provides more details for the copier color characterization.

7 Conclusion

The color characterization of the scanner pipeline for multi-function systems was presented. A set of background removal tables was used to set a normalized white point and to set the scanner RGB neutral balance. A method for scanner color characterization preserving the neutral balance was developed for the scanner color characterization. The method also improves the color transformation accuracy.

References

1   H. Kang, Color Scanner Calibration, J. Imaging Sci. Technol., 36: 162-170 (1992).
2   P. Hung, "Colorimetric Calibration for Scanners and Media", Proc. SPIE 1448, 164-174 (1991).
3   J. DiCarlo, G. Montgomery and S. Trovinger, "Emissive chart for imager calibration", IS&T/SID 12th Color Imaging Conference, 295-301(2004).
4   H. Shen and J Xin, "Colorimetric and Spectral Characterization of a Color Scanner Using Local Statistics", J. Imaging Sci. Technol. 48, 342-346 (2004).
5   H. Zeng, "3-D Color Separation Maximizing the Printer Gamut", Proc. SPIE 5008, 260-267 (2003).
6   H. Zeng, "Special Interpolation to Minimize Grain in Printer Color Separation", SPIE 5667, 424-433 (2005).
7   H. Zeng, "Color characterization for inkjet copiers", Color Imaging XIII: Processing, Hardcopy, and Applications, IS&T/SPIE Electronic Imaging Conference, San Jose, January 2008.