Colorimetric Precision in Scanner Calibration Using Matrices

Hideaki Haneishi, Tsutomu Hirao, Akihiro Shimazu and Yoichi Miyake
Department of Information & Computer Sciences, Chiba University, Chiba, Japan

Abstract

Colorimetric precision in a scanner calibration based on matrix transformation is investigated in case that the number of color patches used for calibration is reduced. The precision when the media or colorant used in the calibration is different from that of the target color image is also investigated through the experiment using four kinds of colorants.

Introduction

In a color management system, a scanner calibration is very important for obtaining colorimetric values such as XYZ or LAB. If the scanner's channel sensitivities are linear combinations of the color matching functions, exact tristimulus values, XYZ can be derived from the scanner data values (RGB) by a linear transformation (3x3 matrix operation)[1]. This condition is known as the Luther condition. The matrix for the linear transformation can be determined as follows: Several color patches are prepared, the exact tristimulus values, XYZ are measured and the scanner responses, RGB are recorded. Then using the XYZ-RGB paired data obtained, a transformation matrix with 3×3 entries is calculated regressively.

Practical, general purpose scanners, however, do not satisfy this condition and therefore one has to calibrate the scanner in a more complicated manner. For example, a technique using polynomials or higher order matrices and a technique using look up table and interpolation have been proposed.[2,3] In any case, for high end user such as designer working in graphic arts, it is necessary to prepare many color patches and to measure its colorimetric values with high precision for the calibration.

On the other hand, desk top publishing does not require such high precision in calibration, consequently, the number of color patches could be potentially reduced. One of the purposes in this paper is to clarify how we can reduce the number of patches for calibration in such a case as keeping good precision. Unless the Luther condition is satisfied, precision in calibration depends on the media or colorant used in the calibration and those of the target color image, as well as the number of patches. This point is also addressed in the paper.

Calibration Technique

In this paper, we assume that the scanner is calibrated in a simple manner based on a matrix transformation rather than look up table. Let the goal of calibration be to obtain the values of the uniform color space, CIE-LAB from the scanner responses, RGB. A first or second order matrix with a constant term is used for transforming RGB to XYZ. After that, the XYZ values are transformed to LAB values according to the definition.

A concrete procedure to determine a transformation matrix is described below:

Prepare a proper number (N) of color patches and measure the exact colorimetric values by means of spectrophotometer.

$$[L^*_{0i}, a^*_{0i}, b^*_{0i}]^t, \qquad \text{for } i = 1,...,N$$

Record the RGB values of the patches by the scanner in question.

$$[R_i, G_i, B_i]^t, \qquad \text{for } i = 1,...,N$$

Determine the transformation matrix.

Initialize the matrix.

For each color patch, convert from RGB to XYZ by the followings ($\mathbf{M}_{ixj}$ means a transformation matrix with i rows and j columns):

First order case:

$$[X_i, Y_i, Z_i]^t = \mathbf{M}_{3\times4}[R_i, G_i, B_i, 1]^t$$

Second order case:

$$[X_i, Y_i, Z_i]^t = \mathbf{M}_{3\times10}[R_i, G_i, B_i, R_i^2, G_i^2, B_i^2, R_iG_i, G_iB_i, B_iR_i, 1]^t$$

Transform XYZ to LAB.

$$[X_i, Y_i, Z_i]^t \to [L^*_i, a^*_i, b^*_i]^t$$

Define an objective function to be minimized by the equation below and update the matrix entries so as to decrease the value of the objective function.

$$\Delta E^*_{ab} = \sum_{i=1}^{N} \Delta E^*_{ab,i}$$

where

$$\Delta E^*_{ab,i} = \left\| [L^*_{0i}, a^*_{0i}, b^*_{0i}]^t - [L^*_i, a^*_i, b^*_i]^t \right\|^2$$

If the objective function becomes small enough, terminate the procedure. Else return to b) and repeat the update of matrix.

Reduction of the Number of Color Patch

Colorimetric precision when calibration was carried out with reduced number of color patches was investigated. A color sublimation printer was used in the experiment, which can produce 256 density levels for each ink of Y, M, C to yield full color for each pixel. In the experiment, first, nine output levels were evenly selected from 256 levels for each ink and all those combinations or 729 color patches were printed. The colorimetric values of these color patches were measured by a spectrophotometer (SF500, ICS Texicon) exactly. The RGB responses of these patches by the scanner (CLC500, Canon) were also recorded.

Several patches were selected from the 729 patches in a manner described below and a first and second order matrix were determined using their exact colorimetric values and RGB responses. After that, using the transformation matrix obtained, the colorimetric values of 729 patches were estimated from their RGB responses and the error from the exact values was evaluated.

As shown later, even if the number of patches for calibration increases over about twenty, the remarkable improvement in colorimetric precision cannot be achieved. Thus, we mainly investigated the precision in the cases that the number of patches is under twenty. It is considered that the color patches should be selected from the YMC color space evenly. In this experiment, therefore, we divided the YMC color space into 3×3×3=27 subblock regions, determined one color patch for each block, and selected the required number of patches from the 27 regions in a manner that the patches were selected as evenly as possible.

Evaluation results are shown in Table 1 and 2. The color differences become extremely large when the number of patches is nine for the second order case, three for the first order case. This is because the number of patches is less than the number of unknowns for each tristimulus value and therefore the problem is ill-conditioned. From the tables, in the second order case, the average color difference is ranging from 2 to 3 for $N \geq 13$, where the calibration is successfully performed. On the other hand, in the first order case, the color difference is ranging 4 to 5 for $N \geq 9$, which can be applied only to the case that low precision calibration is allowed.

In any case of first and second order, even if the number of patches is increased up to 125, remarkable improvement cannot be achieved. Thus, as long as the matrix transformation method is used, using such an excess number of patches for calibration may be meaningless.

Table 1. Color Differences, ΔE^*_{ab} for Each Number of Color Patches when the Second Order Transformation Matrix was Used.

# of patch	9	10	11	12	13	14	125
average	109.1	3.8	5.0	3.2	2.9	2.6	2.0
maximum	300.4	16.4	36.9	14.5	14.9	14.9	14.0

Table 2. Color Differences, ΔE^*_{ab} for Each Number of Color Patches when the First Order Transformation Matrix was Used.

# of patch	3	4	5	9	10	11	125
average	119.0	21.4	8.6	4.8	4.7	5.0	4.9
maximum	270.0	88.0	56.4	16.1	16.3	21.9	16.6

Applying the Transformation Matrix to the Other Colorant

We next investigated the applicability of the transformation matrix obtained with a certain colorant to the target image data with other colorant. The colorant or media used in the experiment are listed below. These are what we are routinely using in the laboratory.

A. sublimation printer
B. toner type printer
C. sliver halide type digital printer
D. silver halide photographic print (direct print of output negative from film recorder)

For each colorant, 5×5×5=125 color patches were generated and the first and second order matrix were determined using their own patches. As a result, four matrices were generated for each of the first and second case. Then the colorimetric values for each color patch were estimated from the scanner output using four transformation matrices. The resulting average color differences are shown in Table 3 and 4. As expected, in the case that the colorant for calibration is same as that of target (the diagonal components in the tables), the precision is good and ranging from 1.6 to 3.0, whereas in the other cases (off-diagonal components in the tables), the precision is inferior. In the latter case, the color difference is ranging from about 5 to 13, and thus the usage is not recommended for critical use.

Comparing the first and second order case, there are distinct differences with respect to the diagonal components, whereas the off-diagonal components are comparable. This fact shows that when a calibration parameters obtained with a certain colorant are applied to the other colorant, the higher (second) order matrix has no advantage against the first order matrix.

Table 3. Color Differences ΔE^*_{ab} when Using the Second Order Transformation Matrix. Each Row Means the Average Color Differences when the Color Patches with each Colorant were Calibrated by a Matrix Obtained with the Left End Colorant.

		target colorant			
		A	B	C	D
matrix determined with	A	■	8.7	9.5	12.9
	B	8.5	■	6.6	6.5
	C	7.4	6.3	■	7.0
	D	9.4	5.6	6.2	■

Colorimetric precision when the colorant for calibration is different from that of target seems strongly related to the similarity of the spectral characteristics of each colorant. Namely, if the two kinds of colorants are similar with respect to the spectral characteristics, then the colorimetric precision may be high even if the different transformation matrix is used. So we measured the spectral reflectance of the solid color of each colorant itself and calculated the correlation coefficients between these colorants. The spectral reflectance measured and the correlation coefficients calculated are shown in Figure 1 and Table 5, respectively.

From the comparison between this result and table 3 and 4, it was found that the more similar the spectral reflectance are, the better colorimetric precision becomes. For example, in the second order case, A and D are not similar in spectral reflectance (0.918), and the precision is low (12.9 and 9.4). On the contrary, A and B are similar in spectral reflectance (0.986), and the precision is high (6.5 and 5.6). From these facts, if the spectral reflectance of the colorant to be used is known in advance, the effect of calibration could be estimated in some degree.

Table 4. Color Differences ΔE^*_{ab} when Using the First Order Transformation Matrix.

		target colorant			
		A	B	C	D
matrix determined with	A	■	8.2	8.6	11.1
	B	9.6	■	10.2	4.7
	C	7.5	7.1	■	7.2
	D	9.4	6.7	7.0	■

Table 5. Correlation Coefficients between Four Kinds of Colorants with Respect to Spectral Reflectance.

	A	B	C	D
A	1.000	0.952	0.977	0.918
B	-	1.000	0.970	0.986
C	-	-	1.000	0.957
D	-	-	-	1.000

Conclusions

We assumed to calibrate a scanner to yield the colorimetric values by means of transformation matrix and discussed on the relationship between the number of color patches used in calibration and the resulting precision. According to the results obtained, when the second order matrix is used, the performance with the error ranging from 2 to 3 in average can be achieved by using over 12 patches. When the first order matrix is used, the precision is about 5 at maximum.

In the case that the colorant for calibration and that in the target are different each other, however, the above precision are not accomplished. Even if sufficiently many color patches were used, color difference was ranging from 5 to 13. It was also verified that there exists some correlation between the similarity of the spectral characteristics of colorant and the precision in colorimetry.

References

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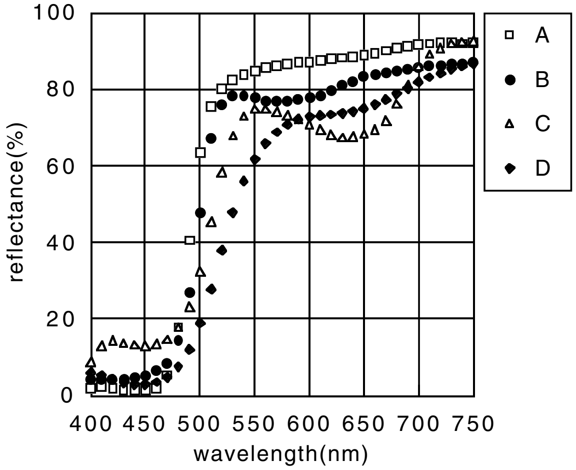

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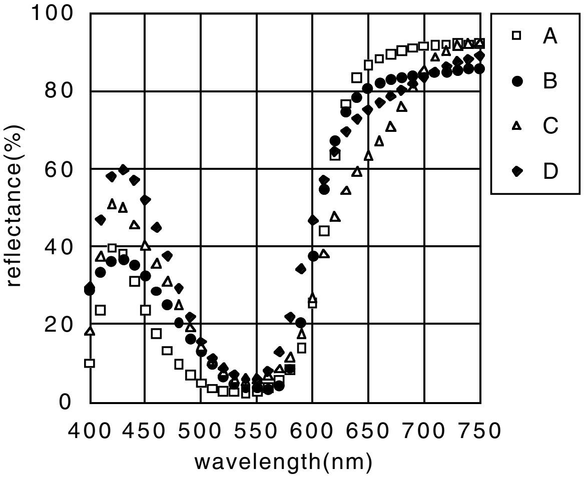

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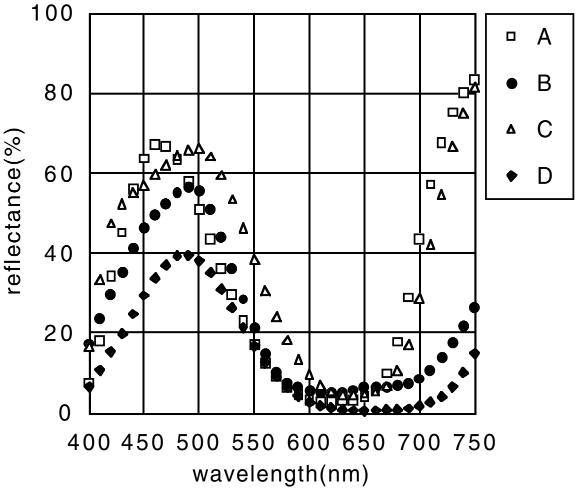

cyan

Figure 1. The spectral reflectance measured