Implementation of Digital Still Camera ICC Profile Generator

Yi-Ching Liao, Jyh-Jiun Lee, Chih-Yuan Yang, and Chao-hua Wen
Industrial Technology Research Institute, Opto-Electronics & Systems Laboratory,
Hsinchu, Taiwan, R.O.C.

Abstract

The paper describes an implementation of Digital Still Camera (DSC) ICC profile generator. Both the three components matrix model and N components look-up-table model are implemented in the DSC ICC profile generator. The generator mainly consists of a reference-file-parser, a lightness-equalizer, a target-image-analyzer, and a profile-parameter-evaluator. The reference-file-parser retrieves the XYZ and Lab values of color patches from the ANSI CGATS.5 compliance file that records the measured values of IT8.7/2 target. The lightness-equalizer is used to remove the shading effect of lens and non-uniformity of light source from captured IT8.7/2 target image. Then, the RGB values of color patches of IT8.7/2 target image are extracted automatically by the target-image-analyzer. Once the RGB, XYZ, and Lab values of color patches obtained, the parameters required for constructing the DSC ICC profile can be evaluated by profile-parameter-evaluator. Experimental results show, based on the test of 2 types of DSCs, the average ΔE*abs less than 4 are achieved by using the three-dimensional look-up-table based model with the size of 9 x 9 x 9.

Introduction

As the popularity of color peripheral devices grows, the problem of color inconsistency among color devices becomes more and more important. The ICC profile,[1,2] which is specified by the ICC (International Color Consortium), is a reasonable solution to achieve color consistency. Under the color management framework of ICC, each color device has its ICC profile. An ICC Profile characterizes a color device and provides the transformation information between color device's color space and PCS (Profile Connection Space). The PCS is the intermediate color space for convincing color space transformation among color devices. The CIE XYZ and CIE Lab are used as PCS in ICC specification. There are two color space transformation models defined by ICC can be used to describe the transformation between the DSC's color space and PCS. One is called three components matrix based (3C-Matrix) model and another is called N components Look-Up-Table based (NC-LUT) model. The two models are described as follows.

3C-Matrix model: The model primarily consists of a red Tone-Reproduction-Curve (*rTRC*), a green Tone-Reproduction-Curve (*gTRC*), a blue Tone-Reproduction-Curve (*bTRC*), a red colorant, a green colorant, and a blue colorant. The red, green, and blue TRCs are used to linearize the red, green, and blue tone curves with PCS, respectively. Where the TRC can be a single value that represents the gamma of tone curve or an array that sketches the tone curve. The red, green, and blue colorants organize a matrix, which is used to transform the linearized RGB to XYZ. Each colorant consists of an X, an Y, and a Z. That is, the red colorant consists of its X ($rColorant_x$), Y ($rColorant_y$), and Z ($rColorant_z$). The green colorant consists of its X ($gColorant_x$), Y ($gColorant_y$), and Z ($gColorant_z$). The blue colorant consists of its X ($bColorant_x$), Y ($bColorant_y$), and Z ($bColorant_z$). To transform the RGB, which is captured by the DSC, to XYZ using the model, the RGB must be linearized using RGB TRCs (formulas (1) $-$ (3)) first. Then, the linearized RGB can be transformed to XYZ using the RGB to XYZ matrix (formula (4)).

$$linear_r = rTRC[Device_r] \qquad (1)$$

$$linear_g = gTRC[Device_g] \qquad (2)$$

$$linear_b = bTRC[Device_b] \qquad (3)$$

$$\begin{bmatrix} PCS_X \\ PCS_Y \\ PCS_Z \end{bmatrix} = \begin{bmatrix} rColorant_X & gColorant_X & bColorant_X \\ rColorant_Y & gColorant_Y & bColorant_Y \\ rColorant_Z & gColorant_Z & bColorant_Z \end{bmatrix} \begin{bmatrix} linear_r \\ linear_g \\ linear_b \end{bmatrix} \qquad (4)$$

Where the $Device_r$, $Device_g$, $Device_b$ are the RGB captured by DSC, the $linear_r$, $linear_g$, $linear_b$ are the linearized RGB, and the PCS_x, PCS_y, PCS_z are the resulted XYZ.

NC-LUT model: The model mainly consists of three input linearization curves, a three-dimensional look-up-table, and three output linearization curves. Where the input linearization curves are used to linearize the input tone curves with PCS, the three-dimensional look-up-table is used to transform the DSC's color space to CIE Lab, and the output linearization curves are used to linearize the output tone curves. The flowchart of color space transformation from RGB to Lab using the NC-LUT model is depicted in figure 1.
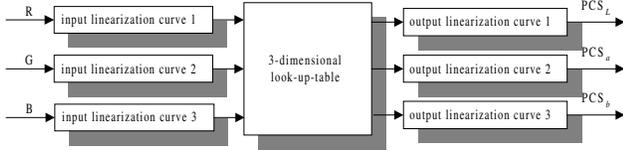
Figure 1. The NC-LUT model

In the paper, both models described above are implemented in the DSC ICC profile generator.

The rest of this paper is organized as follows. The system architecture of DSC ICC profile generator is given in section 2. The implementation details of reference-file-parser, lightness-equalizer, target-image-analyzer, and profile-parameters-evaluator are described in section 3. The experimental results are listed in section 4. Finally, the conclusions are given in section 5.

System Architecture

To generate the DSC ICC profile, the color characteristics of DSC must be determined. The IT8.7/2,[3] which is a standard color target defined by ANSI, contains variety color patches that can be used to analyze the color characteristics of input device. To determine the color characteristics of DSC using IT8.7/2, an IT8.7/2 target image must be captured by DSC first. Next, the lightness non-uniformity of DSC results in lens and light source should be removed from the captured IT8.7/2 target image. After that, the color characteristics of DSC required for constructing an ICC profile can be evaluated using the captured RGB values and measured XYZ/Lab values of color patches of IT8.7/2 target. The system architecture of DSC ICC Profile generator is depicted in figure 2.
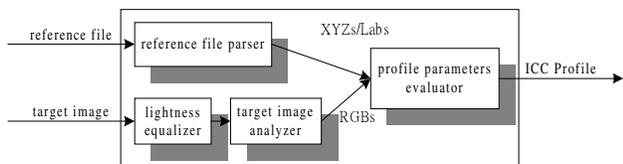
Figure 2. System architecture of DSC ICC profile generator

Where the target image is the image of IT8.7/2 target captured by DSC and the reference file is the ANSI CGATS.5[4] compliance file that stores the measured XYZ and Lab values of IT8.7/2 target.

In figure 2, we can see the DSC ICC profile generator includes four functional blocks: the reference-file-parser, the target-image-analyzer, the lightness-equalizer, and the profile-parameters-evaluator. First, the reference-file-parser retrieves the XYZ and Lab values of IT8.7/2 target from the ANSI CGATS.5 compliance file. Next, the lightness-equalizer removes the shading effect of lens and non-uniformity of light-source from captured IT8.7/2 target image. Then, the RGB values of lightness equalized IT8.7/2

target image are extracted by target-image-analyzer. Finally, the parameters required for constructing the DSC ICC profile can be evaluated by profile-parameters-evaluator.

Implementation

In this section, we will present the implementation details of DSC ICC profile generator. The reference-file-parser, lightness-equalizer, target-image-analyzer, and profile-parameters-evaluator are described in the following.

Reference-File-Parser

The reference-file-parser is used to retrieve the XYZ and Lab values of IT8.7/2 target from the ANSI CGATS5 compliance file. The ANSI CGATS5 standard specifies a methodology for taking spectral measurements and making colorimetric computations as well as defines a data exchange format for storing the measured color data. Figure 3 shows an example of ANSI CGATS5 compliance file.

Figure 3. An example of ANSI CGATS5 compliance file

To retrieve the XYZ and Lab values from the ANSI CGATS5 compliance file, a simple algorithm is given as follows:

The Algorithm of Reference-File-Parser
(a) File validity checking: The first 7 characters in the file must be "IT8.7/2".
(b) Data format retrieving: Before retrieving the measured data of color patches, the information about how the measured data stored in the file must be known. Such information are stored in the file and can be found between the "BEGIN_DATA_FORMAT" and "END_DATA_FORMAT" keywords.
(c) Measured data retrieving: The XYZ and Lab values are stored between the "BEGIN_DATA" and "END_DATA" keywords and can be retrieved using the information obtained in step (b).
(d) Data validity checking: To ensure the correctness of retrieved XYZ and Lab values, the number of retrieved values and retrieved values are checked. That is, the number of retrieved values of color patches must equal to 288 and the differences between the retrieved values and default values (such as the IT8.7/2's standard values) should less than an allowence value.

Lightness-Equalizer

To remove the shading effect of lens and non-uniformity of light-source from captured IT8.7/2 target image, a uniform gray card with 20% reflectance is captured under the same capturing environment and the same settings of DSC that are used to capture the target image. Next, a median filter is applied for removing the noise from the gray card image. Finally, the noise removed gray card image is used to remove the lightness non-uniform from captured IT8.7/2 image by multiplying each pixel of the target image with its intensity ratio. For a pixel in the target image, we can get an intensity value from the noise-removed gray-card image of the same position. The intensity ratio of a pixel can be obtained by dividing the max intensity of the noise-removed gray-card image by the intensity value of the pixel.

Target-Image-Analyzer

The target-image-analyzer is used to extract the RGB values from the captured IT8.7/2 target image. A target-positioning algorithm is proposed to determine the positions of four-corners of outer frame in the target image. After the positions of four-corners determined. The positions of color patches can be derived and the RGB values of color patches can be retrieved. The target-positioning algorithm is presented as follows.

Target-Positioning Algorithm

(a) Determine the positions of left and right edges of outer frame: First, the middle row of the target image is picked. Then, the left edge in the middle row can be found by checking pixels of the middle row from left to right until the edge pixel is found. In the same way, we can find the right edge in the middle row. Here, an approach provided in[10] is used to check a pixel is an edge pixel or not.

(b) Determine the positions of upper-left and upper-right corners of outer frame: After the left and right edges of middle row found, we can find the edge pixels of the upper row by checking only the pixels which are of the same or nearly horizontal position as of the edge pixels of middle row. By using the same procedure, all the left and right edge pixels up to the middle row can be found. As a result, the upper-left and upper-right corners of the outer frame can be found.

(c) Determine the positions of lower-left and lower-right corners of outer frame: As described in the step (b), we can find the edge pixels of the lower row by checking pixels which are of the same or nearly horizontal position as of the edge pixels of middle row. And then, the lower-left and lower-right corners of the outer frame can be found.

Profile-Parameters-Evaluator

In this paper, both the 3C-Matrix model and NC-LUT model are implemented. Hence, the parameters required by both models must be generated. That is, the RGB TRCs, the RGB to XYZ transformation matrix, the input linearization curves, the RGB to Lab LUT, and the output linearization curves must be evaluated. Since the output color space of the NC-LUT model for DSC ICC profile is Lab, the output linearization curves required for the NC-LUT model are set as with the gamma value of 1. The generation process of the RGB TRCs and input linearization curves, the RGB to XYZ transformation matrix, and the RGB to Lab LUT are described as follows.

The generation process of RGB TRCs: The RGB TRCs are used to linearize the red, green, and blue tone curves with the XYZ, since the linearized RGB will be transformed to XYZ. The RGB values of 22 gray patches from captured IT8.7/2 target image and the Y value of the same patches from reference file are used to generate the RGB TRCs.

The generation process of the RGB to XYZ transformation matrix: In the paper, the regression model[5-9] is used to create the RGB to XYZ transformation matrix. All the available IT8.7/2 color patches are used as the input of regression model. Where the color patches located in column 20 to 22 are not used. That is, for a set of linearized RGB and XYZ data $\{R(l), G(l), B(l), X(l), Y(l), Z(l): l=1$ to $252\}$. The RGB to XYZ transformation matrix M can be derived by the following equations.

$$C(l) = \{c_0(l), c_1(l), c_2(l)\}$$
$$= \{R(l), G(l), B(l)\};$$
(6)

$$A_{3 \times 3} = \{a(i, j): i = 0 \sim 2, j = 0 \sim 2\},$$
$$a(i, j) = \sum_{l=1}^{252} c_i(l) \cdot c_j(l);$$
(7)

$$B_{3 \times 3} = \{b(i, j): i = 0 \sim 2, j = 0 \sim 2\},$$
$$b(i,0) = \sum_{l=1}^{252} X(l) \cdot c_i(l),$$
$$b(i,1) = \sum_{l=1}^{252} Y(l) \cdot c_i(l),$$
$$b(i,2) = \sum_{l=1}^{252} Z(l) \cdot c_i(l);$$
(8)

$$M_{3 \times 3}^{T} = A_{3 \times 3}^{-1} \cdot B_{3 \times 3}$$
(9)

The generation process of input linearization curves: The input linearization curves are used to linearize the red, green, and blue tone curves with the Lab, since the linearized RGB will be transformed to Lab. The RGB values of 22 gray patches from captured IT8.7/2 target image and the L value of the same patches from reference file are used to generate the input linearization curves.

The generation process of the RGB to Lab LUT: The generation process of RGB to Lab LUT is shown in figure 4. In figure 4, the 9×9×9 RGBs are firstly linearized by the input linearization curves. Then, a 3×14 matrix, which is evaluated using regression model, is used to transform the linearized RGBs to Labs.
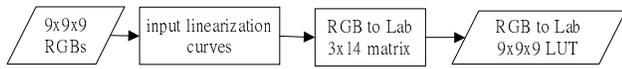
Figure 4. The generation process of the RGB to Lab LUT

The RGB to Lab 3x14 matrix used here is generated using the regression model. The generation process of the matrix is similar to the generation process of the RGB to XYZ transformation matrix. But sets the $C(l) = \{c_0(l), c_1(l), c_2(l), c_3(l), c_4(l), c_5(l), c_6(l), c_7(l), c_8(l), c_9(l), c_{10}(l), c_{11}(l), c_{12}(l), c_{13}(l)\}=\{1, R(l), G(l), B(l), R(l)^2, G(l)^2, B(l)^2, R(l){\times}G(l), G(l){\times}B(l), R(l){\times}B(l), R(l)^3, G(l)^3, B(l)^3, R(l){\times}G(l){\times}B(l)\}$, the size of matrix A = 14 x 14, and the size of matrix B = 14 × 3.

Experimental Results

To evaluate the performance of the DSC ICC Profile generator, the DSC ICC Profile evaluator is developed. The flowchart of the DSC ICC Profile evaluator is shown in figure 5.
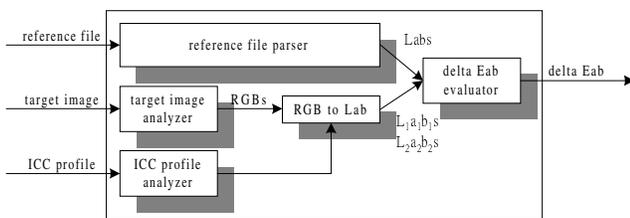
Figure 5. Flowchart of DSC ICC profile evaluator

Where the reference-file-parser and the target image-analyzer are the same as of the DSC ICC profile generator. The ICC-profile-analyzer is used to retrieve the parameters of 3C-Matrix model and of NC-LUT model from the ICC profile. The RGB to Lab function translates the RGB values extracted from target-image to two sets of Lab values using the 3C-Matrix model and NC-LUT model, respectively. In NC-LUT model, a trilinear interpolation scheme[9] is applied for transforming RGB to Lab. After the two sets of Lab values obtained, the ΔE^*abs of both models can be evaluated by equation (10).

$$\Delta E * ab = \sqrt{(L - L_1)^2 + (a - a_1)^2 + (b - b_1)^2} \qquad (10)$$

In the experiments, a Kodak IT8.7/2 target produced in July 1998, a gray card with 20% reflectance, and two kinds of DSC - Sony DSC-F505 and Olympus C2000Z - are used for evaluating the performance of DSC ICC profile. In the experiments, the ICC profiles of testing DSCs are generated using the DSC ICC profile generator with the Kodak IT8.7/2 target and the gray card. Then, the same reference file and IT8.7/2 target images used to generate the ICC

profiles are also used to evaluate the performance of the generated DSC ICC profile. The average ΔE^*abs of tested DSCs using the 3C-Matrix model and NC-LUT model are given in Table 1.

Table 1. The average ΔE*abs of using 3C-Matrix model and NC-LUT model

DSC	3C-Matrix model ΔE^*abs	NC-LUT model ΔE^*ab
Sony DSC-F505	3.69	2.69
Olympus C2000Z	7.03	3.67

From the above table, we can see the average ΔE^*abs of both tested DSCs in 3C-Matrix model are large than of the NC-LUT model. That is, the NC-LUT model is a better choice for the DSC's ICC profile.

Conclusions

The paper describes an implementation of DSC ICC profile generator. Both the 3C-Matrix model and NC-LUT model are implemented in the DSC ICC profile generator. A gray card and an IT8.7/2 target are captured in generating DSC ICC profile. After that, the DSC ICC profile is generated easily and automatically. The experimental results show the NC-LUT model is more suitable to be used in the DSC ICC profile than 3C-Matrix model and the average ΔE^*abs less than 4 can be achieved by using NC-LUT model with the size of 9 x 9 x 9.

References

1. International Color Consortium, "ICC.1," Sep., 1998.
2. International Color Consortium, "ICC.1A," Apr., 1999.
3. ANSI IT8.7/2, "Graphic Technology – Color reflection target for input scanner calibration," 1993.
4. ANSI CGATS5, "Graphic technology – Spectral measurement and colorimetric computation for graphic arts images," 1993.
5. Henry R. Kang, "Color scanner calibration," J. Imaging Technol., Vol. 36, No. 2, pp. 162-170, March 1992.
6. Shoji Suzuki, Tadakazu Kusunoki, and Masahiro Mori, "Color characteristic design for color scanners," Applied Optics, Vol. 29, No. 34, pp. 5187-5192, Dec. 1990.
7. Po-Chieh Hung, "Colorimetric calibration for scanners and media," Proc. SPIE, vol 1448, pp. 164-174, 1991.
8. A. A. Afifi and S. P. Azen, Statistical Analysis, Academic Press, NY, 1972.
9. J. M. Kasson, "Performing color space conversions with three-dimension linear interpolation," J. Electronic Imaging, 4(3), pp. 226-250, 1995.
10. Yi-Ching Liaw and Chun-Yen Chen, "Implementation of scanner ICC profile generator," Proceedings of SPIE Vol. 4080, pp.159-166, July, 2000.

Biography

Yi-Ching Liao received the M.S. degree in information engineering and computer science from Feng-Chia University of Taichung, Taiwan, in 1994. Since July 1998, he has been employed as a member of the Color Technology Section of OES/ITRI, Taiwan. His current research interests include image processing and color calibration.