Customized ICC Scanner Profile Construction and Concerns

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Abstract

The main concept of using scanners is to convert an analog hard copy image into digital form and then exchange its data across different media, such as displays or printers. As each color device can reproduce a different amount of color, which can be defined as its color gamut, it is essential to have a reliable color reproduction across these devices. This can be controlled by constructing an ICC profile for each device based on ICC (International Color Consortium) standards that assist the Color Management Systems' (CMS) ambition of achieving consistence color transformation and appearance across color media.

Accurate color transformation from a device-dependent color space (RGB or CMYK) to a standard color space or device-independent color space (LAB or XYZ), as defined by the CIE (Commission Internationale de L'Éclairage), starts with efficient colorimetric color characterization of each device and thus an efficient ICC profile. The focus of this paper will be on characterizing scanner devices.

First this paper studies and evaluates existing scanner characterization methods. A new and enhanced colorimetric characterization model is proposed. The method was assembled based on the previous evaluation results. The goal is to estimate a smooth transformation function whose derivatives are continuous, which reflects a smooth scanner device gamut. A transformation LUT (look-up table) was then built using these resulting values from the new characterization method. The built LUT was then stored inside a newly constructed scanner profile, which was achieved by using a customized C++ program code as our profile editor. The new method was applied on different scanners and the ΔE error was computed to evaluate the accuracy of the characterization.

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Introduction

In addition to their lower prices and their greatly benefit of converting an image into a digital form, color scanners have become an important part in many digital imaging environments. These environments also include monitors and printers, where digital image data are exchanged across them. Therefore, for an accurate and consistence color appearance of this image across different media, the use of a *Color Management System* (CMS) becomes a must.

Basically a CMS is implemented by four main procedures: *consistency, calibration*, *characterization* and *conversion*. The first three procedures involve each color medium that is part of any digital imaging system. Consistency of process insures the device optimization and the device calibration process insures resetting the device response to a starting condition (Wallner, 2002). Actual measuring of the device color behavior and quantifying of the device gamut are achieved in the characterization procedure. Consequently a transformation function will be generated to convert from a device-dependent color space to a standard device-independent color space (PCS or Profile Connection Space). This procedure is equivalent to the ICC profile constructing procedure (Bala, 2003). Finally, the CMM (Color Management Model) is used with the assist of ICC profiles to perform the conversion process between different devices color spaces (Sharma, *et al.*, 2008).

In the case of a scanner device the characterization process involves generating a mapping or transformation function between its RGB colorant space and CIE LAB or CIE XYZ space. The overall characterization process is performed by scanning a target test chart that contains a set of color patches and mapped its RGB values with its equivalent LAB or XYZ values that were generated by measuring the same test chart using a color measurement device (Lee *et al.*, 2007)(Figure 1). This map or transformation is nonlinear due to non-colorimetric characterization of scanners (Sharma, 2000).

Generally, scanner characterization methods can be implemented either by an empirical approach such as polynomial regression method or by mathematical approach by using a 3D Look Up Table (LUT) along with some interpolation method such as trilinear or tetrahedral (Green, 2002). The color characterization data will then be saved inside an ICC (International Color Consortium) input profile.

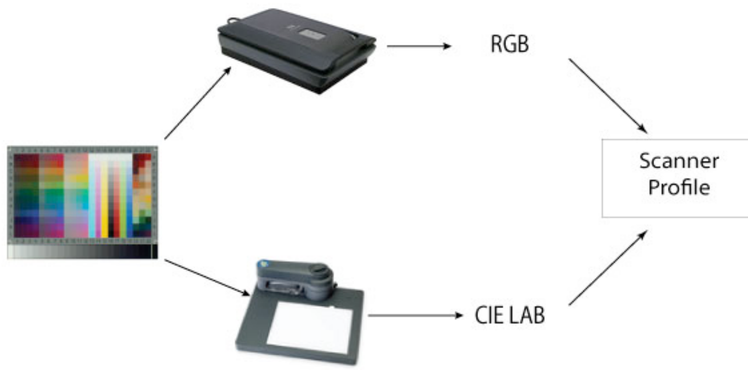
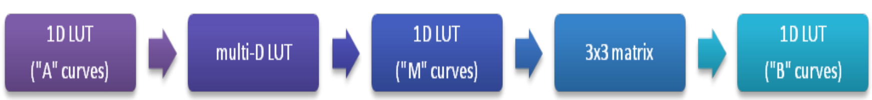


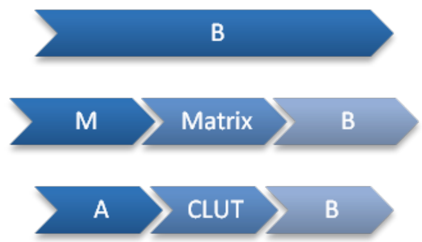
Figure 1. *Scanner characterization general schema.*

Based on the algorithmic models of converting from a device color space to a PCS, an ICC profile is divided into two main types: Matrix-base and LUT-base profiles.(Reinhard *et al*., 2008).For matrix-based profiles, the linear transformation model employs a 3x3 matrix and a set of 1D LUTs. The matrix parameters represents the XYZ values of the RGB primaries and the ID LUT data are stored in the Tone Reproduction curves (TRC) tags for each RGB channel (Sharma, 2004).

For the LUT-based profile the non-linear transformation model employs up to five elements which are a set of 1D LUT (or "A" curves), a 3x3 matrix, another set of 1D LUT (or "M" curves) a multidimensional LUT and a final set of 1D LUT (or "B" curves). All these elements are stored inside the AToBTag tag. The general schema of performing the color transformation is demonstrated as follow (ICC, 2004):



The using of all transformation elements is not required. Other possible combinations of the LUT-model's elements are demonstrated as follows (ICC, 2004):



The color transformation that is employed by a LUT-base profile is more accurate than using a Matrix-base profile, since more information is used to perform that transformation. As previously mentioned scanner devices are non-colorimetric and therefore they are accurately profiled using LUT-base profiles (Wallner, 2002).

Consistent color appearance of any image across media starts from consistent device characterization model. This study provides better understanding of the fundamentals behind the process of constructing scanner ICC profile. In addition, we propose an enmeshed scanner characterization model, which minimizes the noise from measuring processes and produces a smooth transformation.

Experimental Design

For a scanner characterization process, a Kodak Q60 IT8.7/2-1933 test chart target is scanned by HP ScanJet G4050 at 300 dpi. All automatic color correction features were disabled. The RGB values of the IT8 color patches where collected from Adobe Photoshop CS5. The same IT8 target was also measured using X-Rite i1iOand MeasureTool software to generate the XYZ values. Using both the RGB values and the measured XYZ values a mapping function between them was driven using Minitab 15.Based on the open source library "Little CMS" (lcms) that designed by Marti Maria (Little CMS, 2010),a customized C++ code (designed using Microsoft Visual Studio 2008 VC++ 9.0) was built to construct the 3D LUT with a 25 grid points using the coefficients of the mapping functions and save it inside the AToBx tag as part of generating a scanner profile. The selected combination of A2B tag's elements is:

Another ICC profile was built using GretagMacbeth ProfileMaker 4.8 software using the scanned test target image and the measure XYZ values as a reference file. Chromix ColorThink 3.0Pro software was used to visualize the gamut volume of the resulted ICC profiles.

Results and Discussions

By definition all the values that are included in A2B tag which represent the transformation model between RGB and XYZ should be in the space of visible colors. In addition, a typical mapping function should not include an intercept values, which mean that at RGB equal to 0 XYZ should also equal to 0 which is related to the physical behavior of the tested device. Moreover, a well behave scanner transformation matrix should have a positive Jacobin determinant which reflect a sensible scanner response.

The following is the generated mapping function between the RGB values and XYZ values of IT8 target using Minitab:

$$X = 0.121R + 0.115G + 0.00269B$$

$$Y = 0.0510R + 0.211G - 0.0195B$$

$$Z = -0.0214R + 0.0191G + 0.200B$$

These fit functions follow both the no intercept and the positive Jacobin determinant constraints.

Generally, for any mapping function the resulting XYZ values should be positive, because negative XYZ values will produce corresponding negative chromaticity values (Yxy) values and thus they will be invisible if we try to plot them in Yxy color space or in other words, they will be out-of-gamut. Therefore, to control this issue, a constraint was set before building the LUT to set the negative X, Y or Z to 0.001.

Another important concern to look at while we build our profile is that the generated mapping functions were constructed using 8-bit input and output values. The LUT in lcms was encoded as 16-bit precision. Therefore, and to insure consistency the 16-bit input values need to be set to 8-bit values and the resulted 8-bit XYZ values will be converted back to 16-bit precision to be suitable to be stored in the LUT.

(A) (B)

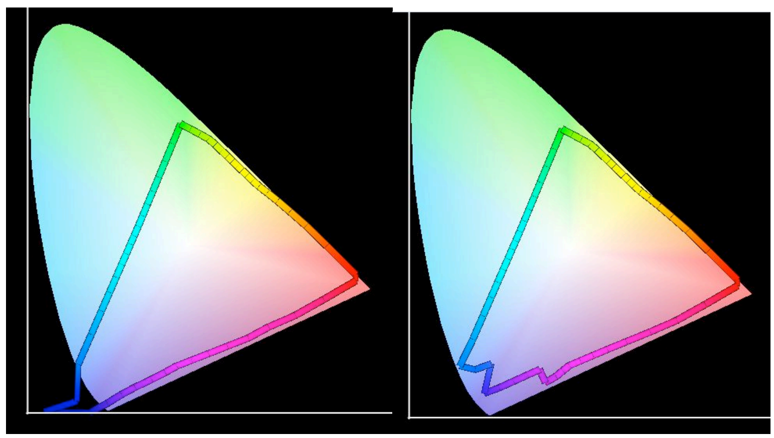


Figure 2. *Generated Scanner profile before clipping constraints (A) and after clipping (B).*

Figure 2 (a) demonstrates the visualized gamut volume of the generated Scanner profile as plotting in Yxy space. It's clearly show the out-of-gamut values which are deposit outside the chromaticity diagram's boundary. Therefore another constraint was set to control this situation. The idea was to calculate the equivalent chromaticity values (Yxy) from the generated XYZ values that were results from the mapping function and then clip any out of gamut xy values to be inside the boundaries of the chromaticity diagram. The Yxy values were calculated using the following formulas:

$$x = \frac{X}{X+Y+Z} \quad y = \frac{X}{X+Y+Z}$$

The resulting gamut plots after these constraints are demonstrated in Figure 2 (b).

In Addition, The fit values of the mapping functions were used to construct a reference file to be used in the ProfileMaker software to build a Scanner Profile. Figure 3 demonstrates the gamut plot in Yxy color space of that profile as compared to our generated scanner profile.

(A) **(B)**

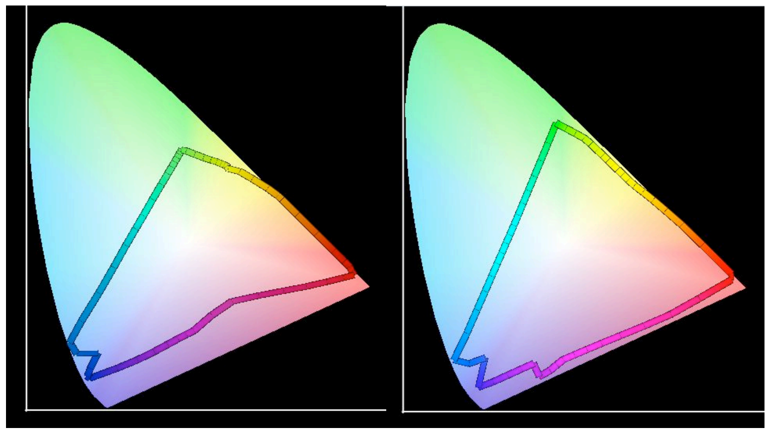


Figure 3. *ProfileMaker Scanner profile (A)*
Generated lcms profile (B).

The overall shapes of both profiles are the same. However, the gamut volume of the ProfileMaker profile is less than our profile. A possible explanation for this could be because ProfileMaker built their A2B tag using a relative colorimetry rendering intents, where our profile was build using an absolute colorimetry rendering Intents. The "ragged" behavior in the blue corner indicates additional difficulties in keeping the gamut plot inside the chromaticity "horseshoe."

Future Work

This paper demonstrates some constraints that could improve the accuracy of a scanner ICC profile. However, more investigation needs to be conducted to find a better way to control the accuracy of the ICC profile and to smooth its gamut volume as well.

Even with an accurate mapping function, the scanner gamma needs to be put into consideration which could also affect the accuracy of the scanner profile. Therefore, it's important to determine the optimum gamma value that would be suitable for accurate scanner profile.

This study was focused on a simple linear transformation function. An accurate scanner profile should be built using a nonlinear transformation function.

Conclusions

This study provides us with a better understanding of how difficult is to control the accuracy of a constructed ICC profile. Generally, an accurate ICC profile reflects an accurate device characterization method. However, constructing the ICC profile should not rely only on the characterization method, as there are other elements that could affect the accuracy. Therefore, different constraints need to be set to achieve the accuracy goal of a consistent color transformation.

References

Bala, R.

2003 "Device characterization," In *Digital Color Imaging Handbook*, edited by G. Sharma, Chapter 5, CRC Press, pp. 273–331.

Lee, B-S., Bala, R. and Sharma, G.

2007 "Scanner characterization for color measurement and diagnostics," J. Electronic Imaging 16(4), 043009.

Little CMS.

2010 see http://www.littlecms.com.

Green, P.

2002 "Overview of characterization methods," in *Colour Engineering: Achieving Device Independent Colour*, edited by P. Green and L. MacDonald, Chapter 6, John Wiley & Sons, pp. 127–138.

ICC.

2004 "Specification ICC.1:2004-10 (Profile Version 4.2.0.0)," pp. 15 see http://www.color.org.

Reinhard, E., Khan, E.A., Akyuz, A.O., and Johnson, G.M.

2008 *Color Imaging: Fundamentals and Applications*, A K Peters, pp. 851-863.

Sharma, A.

2004 *Understanding Color Management*, Delmar Thomson Publishing, Ed. pp. 137–146.

Sharma, A., Suffoletto, J.J., and Adams II, R.M.

2008 *Color Management Handbook*, PIAGATFPress.

Sharma, G.

2000 "Targetless Scanner Color Calibration,*" J. Imaging Science and Technology* 44(4), pp. 301–307.

Wallner, D.

2002 "Color Management and transformation through ICC profiles," In *Colour Engineering: Achieving Device Independent Colour*, edited by P. Green and L. MacDonald, Chapter 11, John Wiley & Sons, Ed. pp. 248–257.