Customized ICC Output Profile Construction and Concerns

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Abstract

Today Color Management Systems (CMS) are used in almost every digital imaging environment, where controlling color transformation between different devices is essential. For printing devices, the accuracy of achieving the CMS goal depends on the accuracy of interpreting a color printer behavior in a standardized format that is saved in a ICC profile, which therefore becomes crucial for many imaging industries. The process of constructing ICC profiles depends on many factors. Understanding and controlling these factors will influence the construction of ICC profiles.

The aim of this study is to control all the elements that affect producing an accurate output ICC profile. Starting from having an accurate printer characterization model to fundamentally creating an ICC profile with the assistance of a customized C++ program code provides us a framework to also edit and probe other ICC profiles.

Introduction

ICC stands for *International Color Consortium,* which is responsible for developing standards to interpret any device color behavior in a common device-independent color space based on a human vision model and save the information in a special file known as an *ICC profile.* [1]

Device Profiles are one of the seven ICC profile types. These include input (for scanners and digital cameras), display (for monitors) and output (for printers and presses) profiles. Each of these profiles has a different set of required tags that includes the required data to perform a color transformation [2]. This paper will focus on the output profile for an RGB Printer.

Basically ICC profiles are also divided into two types based on the color conversion model between color spaces; Matrix/TRC-based profiles and Look-up table (LUT) based profiles. Output profiles necessarily employ the latter converting model. [3]

The elements of the LUT converting model are stored inside AToB tags and they include 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).[2]

While AToB tag indicate a forward color transformation from device color space (in this case RGB) to device-independent color space (or Profile Color Connection -PCS), another required tag in the output profile indicate the inverse transformation from PCS to a device color space. This tag refers to BToA tag. Both AToB and BToA tags have the same set of elements, however to perform a transformation it's not required to use all five transformation elements for either. [4]

In addition, the title of AToB or BToA tag is combined with a number from 0 to 2 that indicates the equivalent rendering indents as described in Table 1. Rendering indents are used by the Color Matching Module (CMM) to handle replacing the out-of-gamut colors or to form a gamut mapping. Specifying rendering intent will help setting a corresponding GMA to achieve an accurate color reproduction across media [5]

Table 1: ICC profile tags and their corresponding rendering intents

Tag Name	General Description	Rendering Indents
AToB0	Device-to-PCS LUT	Perceptual
AToB1	Device-to-PCS LUT	Media-Relative colorimetric
AToB2	Device-to-PCS LUT	Saturation

The process of finding a relation between a device-dependent color space and PCS and interpret it in terms of a LUT inside AToB or BToA tag is identified as the *Device Characterization* process. Output devices (printer or presses) usually employ an empirical approach for the characterization. This approach involves using a color test chart, as training data, along with some type of regression method (such as polynomial regression) to construct the forward characterization function. However, this approach is still subjected to some measuring errors and may have poor performance on the gamut boundaries. [6]

The accuracy of ICC profile doesn't only rely on the accuracy of the characterization model; other factors could also affect this accuracy. The goal of this research is to find an improved characterization model for RGB printer devices and to provide a better understanding of the fundamentals of constructing an output ICC profile.

Experimental Design

Using a previous output RGB ICC profile that was constructed using ProfileMaker 5.0.9 software for a dye sublimation printer (Mitsubishi CP3020DA – **Figure 1**), the measurement data that were stored inside the private GretagMacbeth measurements tag (CIED tag) was read using SampleICC open source library code [7]. The ambition is to use the same measurement data to construct a new characterization model and a new profile using our customized profile editor. This editor consists of a customized C++ program that was built on Microsoft Visual Studio 2008 VC++ 9.0 based on LittleCMS "Lcms" open source library [8].

Figure 1*- Mitsubishi CP 3020DA* [9]

The measurement file reflects the measured RGB and the equivalent XYZ values of the 936 color patches of TC9.18 test chart that was measured using an X-Rite Eye One iO Spectrophotometer and used to construct the ProfileMaker's ICC profile for the dye sublimation printer.

The new characterization mathematical model was generated using Minitab 15 and both RGB and XYZ values from the measurement file, but any regression routine can be used. This model represents the forward transformation from RGB to CIE XYZ color space. In addition, a set of constraints were also employed to control the behavior of the transformation. These constraints were performed on the characterization model and on the resulted XYZ values as well.

A Forward 3D LUT with 33x33x33 gird points that cover the printer RGB color space was constructed based on the characterization model and its equivalent constraints and was stored inside AToB Tag as a part of generating a printer profile.

In Addition, the inverse transformation model was also generated using Minitab software to transform from CIE XYZ to RGB color space and the generated LUT was stored inside the BToA Tag.

Chromix ColorThink 3.0 Pro software was used for evaluation purpose between different ICC profiles.

Results and Discussions

Let f be a device characterization model that relates between different color spaces, the following conditions must be satisfied to assure well behaves transformation performance:

- The function should be continuous and have continuous derivatives.
- The Jacobin determinant of the transformation matrix, based on the 3x3 matrix of first partial derivatives, and the calculated eigenvalues, must be positive to assure both invertability and diagonal dominant properties of the matrix.
- By definition, the transformation matrix must be positive definite.

The following functions demonstrate the forward regression polynomial model for our RGB printer to transfer from RGB to XYZ color spaces as resulted from Minitab software

$$X = 1.72 + 0.0310R + 0.00257G - 0.0133B + 0.000790RG + 0.000051RB + 0.000113GB + 0.000245R^2 - 0.000013G^2 + 0.000109B^2 \quad (1)$$

$$Y = 2.29 + 0.0236R - 0.00689G - 0.0085B + 0.000990RG + 0.000026RB + 0.000110GB - 0.000021R^2 + 0.000237G^2 + 0.000040B^2 \quad (2)$$

$$Z = 3.91 - 0.0026R + 0.02010G - 0.0337B + 0.000185RG + 0.000217RB + 0.000740GB - 0.000123R^2 - 0.000154G^2 + 0.000340B^2 \quad (3)$$

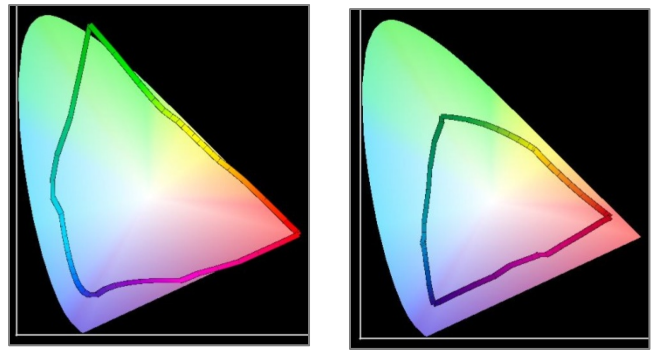

Figure2-the gamut volume of the Dye sublimation's RGB output profile built using customized profile editor (left) and the original profile built using ProfileMaker software (right)

Figure 2-left demonstrates the gamut volume of RGB output profile for the dye sublimation printer which was constructed using polynomial regression fitting model **(equations 1-3)** and before setting any constraints. The same training data were used to build another profile by ProfileMaker software **(Figure2-right)**. The gamut volume of ICC profile actually reflects the populated LUT entries that are stored inside the AToB tag.

As seen in **Figure 2**, beside the huge gamut volume of our profile, some points are located outside the chromaticity diagram which reflects invisible and out-of-gamut points.

Looking back at the liner terms of the X, Y and Z functions **(equations 1-3)**, it's clearly shown the existent of some negative coefficients and the generated matrix that will hold these coefficients will not be diagonal dominant. The calculated determinant of the transformation matrix was positive; however the eigenvalues were a set of negative and positive real numbers which reflects unstable system behavior near the origin. Moreover, the first derivatives at 255 along the primaries are negative which indicate a changing in the slop of the fitting curve or in another word generating unsmooth fitting.

To overcome all of these problems, we have set constraints on the fitting function to force having a positive definite matrix and positive derivatives along the primaries and at the whitepoint as well.

For G=B=0 the general form of X function with no intercept will be

$$X = aR + bR^2 \quad (4)$$

Finding the derivative of **equation (4)**

$$dX/dR = a + 2bR^2 \quad (5)$$

Based on the assumption that the derivative should be positive throughout the physical range of r (0-255) and that X should saturate at R=255, we can use **equation (5)** to find the value of b at R=255 corresponding to a maximum, we obtain the general constrained form of the X function

$$X = a\left(R - \frac{R^2}{510}\right) \quad (6)$$

A regression process on the training data for all X values at G=B=0 was conducted to find the coefficient of a_R. Similarily, we obtain the same steps to find the new G and B equations with the new a_G and a_B.

The new training data for X values were conducted using the following equation:

$$X = X - \left(K + a_R\left(R - \frac{R^2}{510}\right) + a_G\left(G - \frac{G^2}{510}\right) + a_B\left(B - \frac{B^2}{510}\right)\right) \quad (7)$$

K value represents the X value of the black point from the measurement data. The aim of including the black point in the subtraction function is to correct for the black point mapping, which was due to imperfect absorption in the black and measurement noise.

The ambition behind using this constraint is to conduct a new regression process with the new training data of X values to find the coefficient of the remaining cross terms (RG,RB and GB). Then we combine the new fitting function with the new functions of the R,G and B and the general form of the new fitting function for X will be:

$$X = a_R\left(R - \frac{R^2}{510}\right) + a_G\left(G - \frac{G^2}{510}\right) + a_B\left(B - \frac{B^2}{510}\right) + a_{RG}\,RG + a_{RB}\,RB + a_{GB}\,GB \quad (8)$$

Finally, we perform the same steps to find the new fitting functions for both Y and Z values to have the same form of **equation (8).**

These constraints will state a positive linear term of the fitting function, which will assure having positive derivatives along the primaries or zero at the end point of the primaries and having positive real parts of eigenvalues as well.

The deducted values from **equation (7)** from each X, Y and Z were re-added again to the resulted XYZ value from the new fit function during the building of the LUT process. **Figure 3** demonstrate the resulted RGB primaries ramps inside the constructed profile before and after applying the constraints.

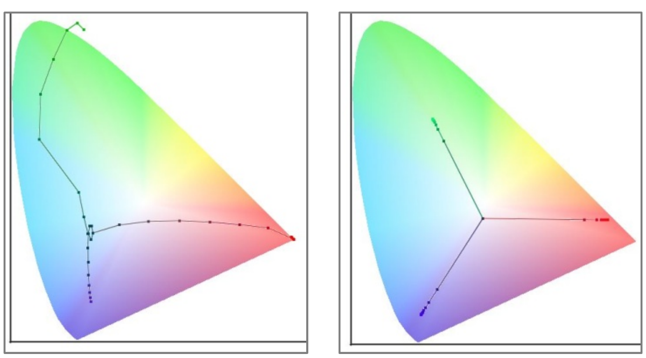

Figure 3- RGB primaries ramps in the output profile before constraints (left) and after constraints (right)

Figure 4 shows the projected gamut volume of the constructed profile before and after the constraints. Despite that the new profile after applying constrains has a smaller gamut volume, the overall shape is not smooth especially at the gamut boundaries. This indicates that we still didn't reach the optimum characterization model and more investigations need to be employed to overcome this drawback.

Moreover, looking at **Figure 5** that demonstrates the gray ramp of the profile before and after applying constrains we see a big flat end toward the white point.

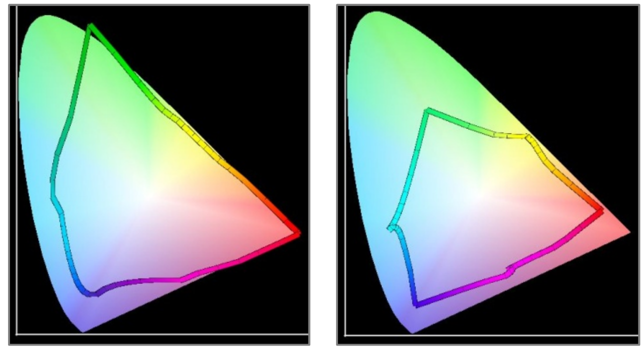

Figure 4- The gamut volume of the constructed output profile before constraints (left) and after (right)

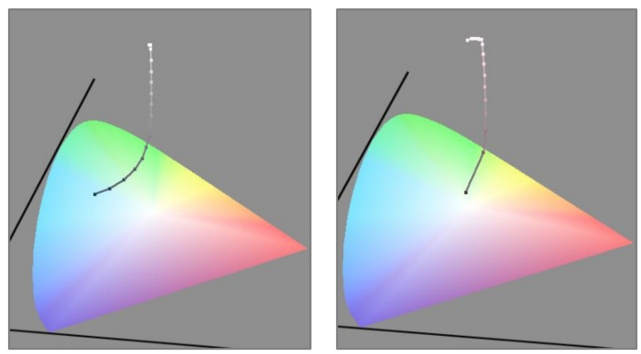

Figure 5- the gray ramp of the constructed profile before constraints (left) and after (right)

We could possibly have expected the gray ramp behavior if we had either negative determinant value, negative real part eigenvalues or negative derivative which is not the case with our fitting function. Therefore, there should be another investigation to understand the behavior of the gray ramp. The aim is that if the gray ramp is well behaved, everything else should be well behaved too.

Further- work

More investigation needs to be conducted to overcome the unsmooth edges of the gamut boundaries.

Fixing the gray ramp could result in improving the performance of the fitting function as well and therefore, more investigations need to be conducted to find good constraints that would control the behavior of the gray ramp.

Conclusions

An accurate ICC profile reflects accurate interpretation of the current device color behavior. However, this interpretation does not include only the equivalent mathematical model, but also another set of constraints to achieve accurate mapping between device-dependent color space and PCS.

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