White Paper #55

Level: Introductory

Date: October 2020

Profiling using colorimetry for D65 and 10° observer

1. Introduction

In traditional ICC color management the Profile Connection Space (PCS) is CIE colorimetry based on the D50 illuminant and the CIE 1931 2-degree observer (hereafter D50/2). However, many industries employ colorimetry based on the D65 illuminant and the CIE 1964 10-degree observer (hereafter D65/10). There are use cases where it is desirable to use D65/10 colorimetry in conjunction with ICC color management. These include:

- High volume digital textile printing
- Certain applications of industrial inkjet printing

The purpose of this document is to recommend an approach that can be used with ICC version 4 color management to enable D65/10 color reproduction while retaining interoperability with other v4 profiles. It also outlines additional possibilities available with ICC version 5 (iccMAX) color management.

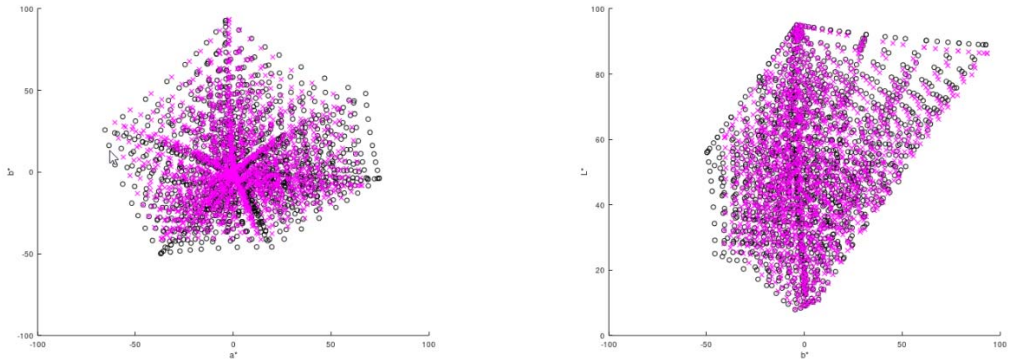

FIGURE 1 – COMPARISON OF D50/2 LAB VALUES AND D65/10 LAB VALUES FOR SAME RPC6 SPECTRAL REFLECTANCES

As can be seen in Figure 1 there are significant differences between D65/10 Lab values (magenta x) and D50/2 Lab values (black circles) for the same reflectances. Adjustments are needed to convert from one to another. However, it is important to note that any linear transformation of D65/10 colorimetry to D50/2 colorimetry will only be an estimate, and differences are inevitable. For example, two unique spectral reflectances can have the same D65/10 colorimetry (i.e. they are a metameric match for a given observer in the D65/10 condition) but have different colorimetry for D50/2 (and hence will not match in the D50/2 condition). In this case, a linear transform of

the D65/10 colorimetry to predict D50/2 colorimetry produces just a single approximate XYZ value.

It is important to distinguish the above transform, which seeks to predict the colorimetry which would have been obtained if the XYZ values had been computed from reflectance using a different illuminant, from a transform which seeks to predict the corresponding colour appearance when the observer is chromatically adapted to a different illuminant. The first type of transform is known as a material equivalence, or material adjustment (MAT) transform, while the second is known as a chromatic adaptation transform (CAT) [6] .MATs and CATs may produce similar results but are not expected to produce identical results.

2. Recommended V4 approach

Version 4 ICC profiles use the D50/2 PCS to ensure unambiguous connection, but the original colorimetry of the profiles does not need to be D50/2. V4 supports the use of non-D50/2 data, but it must be adapted or adjusted to D50/2 for PCS connection.

One example of this is display profiles where the measurements are usuallyD65/2 colorimetry, but the colorimetry in the profile is adapted to D50/2 colorimetry for PCS connection. The same can be done for V4 printer profiles that utilize D65/10 colorimetry. The workflow for doing this is outlined in the following figure:

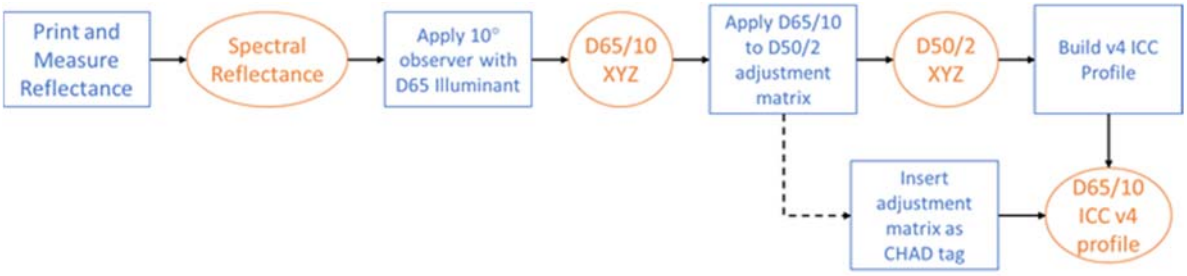

FIGURE 2 – RECOMMENDED WORKFLOW FOR CREATING V4 PROFILES HAVING D65/10 COLORIMETRY

The top line of the figure represents the building of color transforms in the ICC profile. The difference between this and the hack described in Section 4 is that an adjustment is made to convert D65/10 XYZ colorimetry to D50/2 colorimetry using a linear transform matrix. Additionally, the transform matrix used to perform the adjustment is placed in the chromaticAdaptationTag (hereafter CHAD tag) of the profile. This provides metadata that can be used to identify the actual colorimetry that was used to build the profile.

This results in a Version 4 profile that provides color management that is correct for D65/10. When two profiles built like this are connected the adjustments cancel out and you are performing D65/10 color management. You just need to have profiles that have D65/10 colorimetry internally adjusted to D50/2 for PCS connection. (Note: this works because applying a 3x3 linear matrix to colorimetry does not change the color matching of the colorimetry).

D65/10 colorimetry cannot be accessed directly from applying the profile.. The CHAD tag is informative data that is not applied as part of profile applications, but would enable an application to convert PCS data to D65/10 if it supported this functionality, for example for process control purposes.

Following the v4 specification, the adjustment matrix “is required to be stored in the chromaticAdaptationTag, 'chad' (63686164h), when the chromaticity of the actual adopted white is not equal to the chromaticity of the PCS adopted white” [2].

It is also recommended that the profile description field include text to clarify the colorimetric conditions where there is potential for confusion. For example, “for D65/10 colorimetry” could be added after the profile description text. This recommendation does not apply to profiles where the illuminant is expected to be different from D50, such as for display profiles.

3. Recommended Adjustment Matrix

For the purposes of establishing D65/10 color reproduction workflows the following matrix transform is recommended for both conversion of D65/10 colorimetry to D50/2 colorimetry and population of the CHAD tag when V4 ICC profiles are created.

TABLE 1 – RECOMMENDED D65/10 TO D50/2 ADJUSTMENT MATRIX

1.2584	-0.1616	-0.0626
0.1537	0.9438	-0.0834
-0.0906	0.1071	0.7486

This represents a Wpt-based Material Adjustment Transform [1] that has been optimized for converting D65/10 colorimetry to D50/2 colorimetry derived from spectral reflectances in the range from 380nm to 730nm. A Material Adjustment Transform (rather than a chromatic adaptation transform) is recommended for two reasons: firstly because the adjustment is for a change in both the illuminant and observer (rather than just the illuminant), and secondly because the goal is to predict the colorimetry under a different condition rather than the corresponding color appearance.

The purpose of recommending and using a single adjustment matrix is to avoid the situation when input and output profile where the Lab values have been adjusted with different D65/10 to D50/2 matrices which results in the matrix transforms not canceling out.

The inverse of the recommended matrix in Table 1 can be used to estimate D65/10 colorimetry from D50/2 colorimetry.

Matrix evaluation

For comparison purposes, colorimetry for reflectances corresponding to RPC6 were converted to D65/10 and D50/2. Then four different methods were used to adjust D65/10 colorimetry to approximate D50/2 colorimetry: XYZ white point scaling as used in ICC media-relative transforms [2], CAT02 chromatic adaptation [3], the linearized Bradford CAT [4] recommended by ICC, and the recommended adjustment matrix in Table 1. The adjusted and actual D50/2 colorimetry were then compared. Plots of resulting D50/2 lab values are found in Figure 3, and mean and 95th percentile color differences of the four adjustment methods are shown in Table 2.

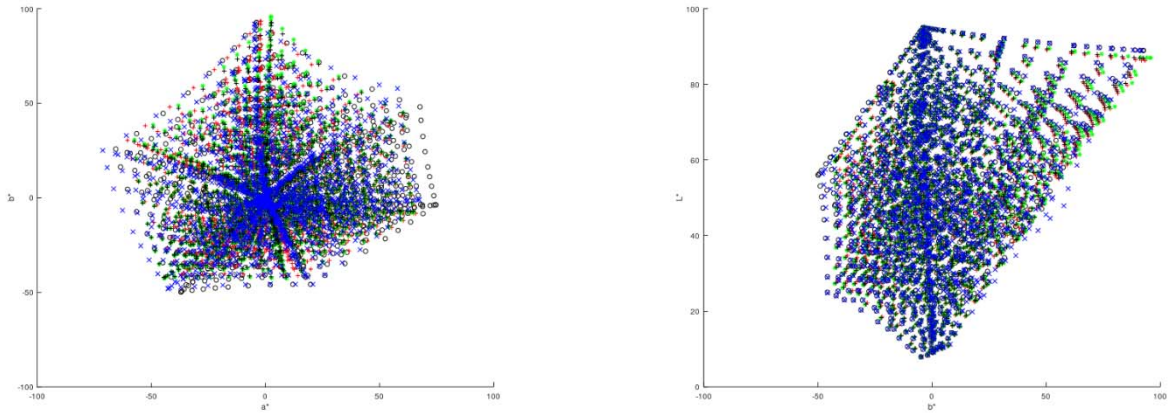

FIGURE 3 – COMPARISON OF ADJUSTMENT METHODS – WITH ACTUAL LAB VALUES FOR D50/2 DEPICTED BY BLACK O, XYZ WHITE POINT SCALING ADJUSTED LAB VALUES DEPICTED BY GREEN *, CAT02 ADJUSTED LAB VALUES DEPICTED BY RED +'S, BRADFORD ADJUSTED LAB VALUES DEPICTED BY BLACK +, AND THE LAB VALUES USING THE RECOMMENDED MATRIX DEPICTED BY BLUE X

TABLE 2 – ΔE*AB COLOR DIFFERENCES BETWEEN ACTUAL D50/2 COLORIMETRY AND ADJUSTED D65/10 COLORIMETRY

Adjustment Method	Mean	95th Percentile
XYZ White Balancing	3.92	8.28
CAT02	4.26	8.95
Bradford	4.29	9.14
Recommended	3.05	7.10

As can be seen from these results the recommended matrix results in closer approximations of the actual D50/2 colorimetry for the RPC6 reflectances evaluated. Similar results have been obtained for spectral reflectance datasets from other sources.

The matrix in Table 1 is optimized for D65/10. In other cases where it is desired to use colorimetry that is not D50/2, it is possible to use the same approach and compute a linear transform matrix using the methods described in [1].

4. Non-recommended approach

One alternative strategy that has been employed by users is to print samples, measure their D65/10 XYZ colorimetry and CIELAB values, and present them to a profiling system as if they were D50/2 in order to build an ICC version 4 output profile. Input profiles are created in similar fashion and the pair of profiles are used to perform color management.

This approach works well as long as only D65/10 pretending to be D50/2 profiles are used in the color management workflow. However, when profiles built for D50/2 are mixed into the workflow unexpected outcomes are likely because needed adjustments to convert between D65/10 colorimetry and D50/2 colorimetry are not being made.

Pretending that non-D50/2 colorimetry is actually D50/2 in the profile should be considered non-conformant, since the ICC version 4 specification requires the colorimetry of the PCS to be D50/2. Therefore, ICC strongly recommends that this approach is not used.

5. Using V5 profiles

ICC version 5 profiles (such as those following the Extended Output ICS – Part 1 [5]) allow for profiles to utilize a PCS with an arbitrary illuminant and observer. This makes it possible to directly store D65/10 colorimetry in the transform tags (with no additional adjustments needed). The recommended adjustment transform can be stored as part of a Matrix processing element in the customToStandardPccTag and its inverse in the standardToCustomPccTag.

No conversion or adjustment is made when connecting such V5 profiles with the same D65/10 based PCS. This avoids problems when the PCC adjustment tags are different, since the PCC adjustment tags are only applied when the CMM needs to convert to or from D50/2 colorimetry.

References

[1] https://www.rit.edu/cos/colorscience/re_WptNormalization.php

[2] ICC.1:2010 Image technology colour management — Architecture, profile format, and data structure, Annex D

[3] Fairchild, Mark D.; Luo, M. R.; Hunt, R. W. G. (2000) A Revision of CIECAM97s for Practical Applications, Color Research & Application 25 (4): 260–266

[4] ICC.1:2010 Image technology colour management — Architecture, profile format, and data structure, Annex E

[5] Interoperability Conformance Specification: colorimetricEncoding – Part 1: basic colorimetric encoding, (202x), International Color Consortium

[6] Green, P. and Habib, T. Chromatic adaptation in colour management, Proc. CCIW 2019