https://doi.org/10.2352/EI.2022.34.15.COLOR-140

Non-standard colorimetry in ICC colour management

Peter Nussbaum, Milan Kresović and Phil Green, Norwegian University of Science and Technology, Gjøvik, Norway

Abstract

In ICC v4 colour management, data is exchanged between different colour encodings via a fixed Profile Connection Space (PCS), in which colorimetry is based on the D50 illuminant, and the CIE 1931 standard observer. According to the ICC specification, colorimetry that is based on a different illuminant, or observer should be transformed into the fixed PCS; however, while a chromatic adaptation method is specified for when illuminants are different, there is no method specified for differences in observer. The Waypoint method has been proposed as a means of transforming between different colorimetric data encodings. In this study a Waypoint-based method recommended by ICC was evaluated as a mechanism for transforming into the ICC PCS, as applied to a use case in digital textile printing in which source colorimetry is based on the D65 illuminant and the CIE 1964 observer. It was compared with an alternative approach in which a non-ICC PCS was used within a conventional ICC colour management framework. The results show that when both source and destination colorimetry are based on D65/10-degrees, both methods perform equally well. However, when the source and destination colorimetry do not match, the ICC approach of transforming via the standard PCS yields better results.

Introduction

Colour management is based on the communication of the associated data needed for unambiguous interpretation of colour content data, and application of colour data conversion, in order to produce an intended reproduction. Colour management considers the characteristics of input and output devices in determining colour data conversion for these devices [1]. An important element in the transform from source device colour data into the destination device colour data is the Profile Connection Space (PCS). In ICC.1 colour management, the PCS is CIE colorimetry based on the D50 illuminant and the CIE 1931 2-degree observer (abbreviated for convenience to D50/2).

For the PCS to be an unambiguous colour exchange space it is important that the observer and illuminant are standardised. However, practices vary between industries; the D50/2deg PCS corresponds to usage in graphic technology but other industries have different standards. As ICC colour management becomes more widely adopted in industries outside the graphic arts, there is an increasing demand to process colorimetry that is based on different standard observers, illuminants and measurement geometries. Such data is in principle supported in ICC.1, and where such data is used, the ICC.1 specification [1] requires that it is transformed into the D50/2 PCS. Annexes D and E of the specification describe the logic of this approach in more detail.

Where the illuminant of the source or destination data encoding differs from the PCS illuminant, PCS values are determined by applying a chromatic adaptation transform. The linear Bradford CAT is recommended by ICC [1], and has been shown to give a good performance [2]. By assuming full adaptation to the PCS white point this CAT can be simplified to a 3x3 matrix. The transform workflow in creating profiles is therefore as shown in Eqn 1.

$$\begin{bmatrix} X_{PCS} \\ Y_{PCS} \\ Z_{PCS} \end{bmatrix} = M_{CHAD} \begin{bmatrix} X_{CIE} \\ Y_{CIE} \\ Z_{CIE} \end{bmatrix} \tag{1}$$

To obtain the CIE colorimetry from chromatically adapted PCS values, the inverse matrix is applied:

$$\begin{bmatrix} X_{CIE} \\ Y_{CIE} \\ Z_{CIE} \end{bmatrix} = M_{CHAD}^{-1} \begin{bmatrix} X_{PCS} \\ Y_{PCS} \\ Z_{PCS} \end{bmatrix} \tag{2}$$

The 3x3 matrix M_{CHAD} is informatively stored in the profile in the chromaticAdaptationTag. This makes it possible to determine the original illuminant used in calculating tristimulus values, although the matrix is not used in the normal colour management transform workflow since it has already been applied to the data to obtain the PCS colorimetry in the profile. Where the source colorimetry uses the same illuminant as the destination, M_{CHAD}^{-1} is the inverse of M_{CHAD} and transform has no effect on the final output. Therefore, if the same observer and illuminant are used for both source and destination data encoding, the resulting data is unaffected by intermediate conversion to the ICC PCS, while if the observer or illuminant are different between source and destination, the workflow will convert the data accordingly.

While chromatic adaptation for different illuminants is well defined, adjustment for differences in observers or measurement geometries is less well understood. The use of a chromatic adaption transformation for changes in observer is problematic since linear CAT transforms involve using a singular definition of cone fundamentals for white point balancing, and associated corresponding colour experiments only involve evaluations of individual observers with no established relationship of appearance between observers [3].

In many industries colorimetry is based on the D65 illuminant and the CIE 1964 10-degree observer (D65/10). In some use cases such as high volume digital textile printing and certain applications of industrial inkjet printing, D65/10 colorimetry is used and there is a need to use this data in a colour managed workflow [4].

One approach of providing an observer to observer transform is to use a Waypoint colour equivalency transform [3] to provide PCS estimates from other colorimetry. Since D65/10 colorimetry is widely used in the colorant industries, a procedure using a Wpt matrix to convert between D65/10 and D50/2 has been recommended by ICC [5]. This allows for integration into a fully colour managed workflow with potentially different source and destination data encodings. The Wpt matrix is shown in Table 1 below.

Table 1: D65/10 to D50/2 adjustment matrix [6].

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

In this paper we evaluate an implementation of this approach. We compare it with an alternative workflow of simply encoding D65/10 source colorimetric data in the profile (i.e. without conversion to the PCS). This latter approach has the advantage of not requiring the transform in Eqn 1 when creating the profile, but also has the potential for interoperability problems and undefined output.

Evaluation

The evaluation tests a number of different workflows in which D65/10 data is used. These use either the procedure described above (ICC White Paper 55) to convert to the ICC PCS or the alternate, non-ICC PCS in which V4 ICC profiles are used but all data is D65/10, i.e. not converted to the ICC PCS. Testing of transform accuracy was carried out following the recommendations of ISO 23564 [7]. Tests of three different workflows were performed (Figure 1). They include a workflow in which D65/10 colorimetry is at both source and destination, and hybrid workflows in which D65/10 and D50/2 colorimetry is at source and destination respectively.

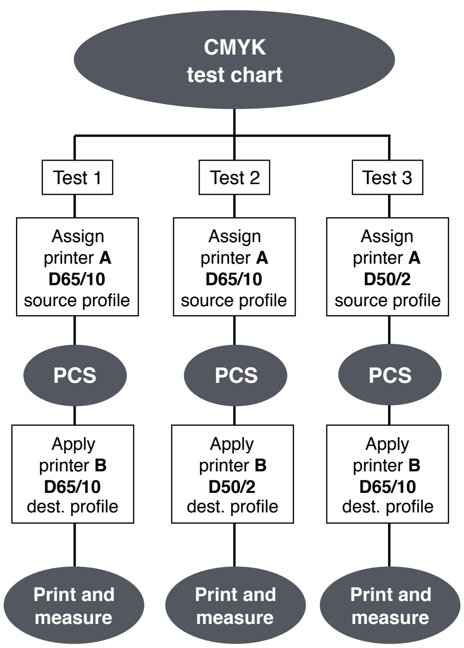

Figure 1: Test print procedure; Printer A is always used as the source profile in the conversion, printer B is the destination profile.

All profile conversions used the ICC-absolute colorimetric rendering intent, in which the CMM scales the media-relative values encoded in the AToB1 or BToA1 tables in the profile to produce a colorimetric match on the destination. All the profile conversions were performed using the Adobe ACE CMM.

Profile generation

Profiles were made for the two different printers in the study. To obtain the printer characterization data, the target test chart ECI2002 which is a superset of the ISO 12642 [8], was printed and measured. From this training data, different colour profiles were created for each printer:

(a) CMYK colour profile based on D50/2colorimetry

(b) CMYK colour profile based on D65/10 colorimetry – created using the non-ICC PCS method

(c) CMYK colour profile based on D65/10 colorimetry – created using the WP55 method

For the WP55 method the D65/10 to D50/2 adjustment matrix shown in Table 1 was applied to the D65/10 data set to obtain PCS values for the profile.

For the non-ICC PCS, D65/10 colorimetry were calculated from the measured spectral reflectance, and V4 printer profiles were generated without converting the data to the PCS. All profiles were made using commercial profiling software.

Test prints

For each of the three tests shown in Figure 1 the Ugra/Fogra Media Wedge CMYK v3.0 (72 colour patches) was reproduced. To provide a D65/10 or D50/2 data source, each of the Printer A profiles was assigned as the source profile in the conversion, and the data were converted using the appropriate printer B profile as the destination profile, using the ICC-absolute colorimetric rendering intent. The test chart was then printed using Printer B and measured, with the D65/10 colorimetric difference between original and reproduction used as a basis for comparison. The three tests shown in Figure 1 are described in more detail below.

Test 1:

The first test evaluates how well results match those obtained by going direct, rather than via the ICC PCS. The printer A profile and the printer B profile are both created using D65/10 data, using both non-ICC PCS and WP55 methods. The printer A source profile was assigned to the CMYK test chart and converted to the printer B profile. The output of this test is a CMYK image that was then printed and measured, and compared with the characterisation data used for creating the colour profiles. Since D65/10 is the intended destination, CIELAB colour differences are found using the D65 illuminant.

Test 2:

In the second test the D65/10 data is connected to a destination profile that uses D50/2 colorimetry. The goal of the test is to determine how well the output matches the source when converting between profiles with a different colorimetry via the ICC PCS. Printer A profiles made using the non-ICC PCS and WP55 methods for D65/10 colorimetry were assigned to the test chart, which was then converted to output CMYK using the Printer B D50/2 profile. As with test 1, the test image was printed and the measurements compared with the starting D65/10 values.

Test 3:

The third test is the inverse of test 2. The goal is to demonstrate how well the output matches the source using colour profiles with different type of colorimetry such as D65/10 data for printer B destination profile. As for the source, printer A uses colour profiles obtained from D50/2 data. Same procedure as previous, the printer A profile is assigned to the test chart converting to PCS using the AToB1Tag of the profile. And Profile B defines the transform from PCS to output CMYK.

2 different sub cases were tested for the B profile:

(a) Printer B profile is made using the non-ICC PCS method

(b) Printer B profile is made using the WP55 method

In order to preserve the appropriate colorimetry by calculating the colour difference between the print measurement and the characterisation data, the CIELAB values based on D50/2 has been calculated (Source profile is based on D50/2).

Profile accuracy

To evaluate the accuracy of the profiles used in this study, both forward transform and round trip tests were performed [7]. For the forward transform, the chart Ugra/Fogra Media Wedge CMYK v3.0 including 72 colour patches has been assigned with the generated profile to transform from CMYK to PCS. The colour difference has been calculated between the obtained CIELAB values and the characterisation values used to generate the profile.

For the roundtrip (which evaluates the invertibility of the transforms), device values were converted to the PCS (using the AToB1 tag), back to device (using the BToA1 tag), and back again to PCS (using AToB1). The first and second set of PCS values were compared.

The results for profile accuracy (forward transform and roundtrip) are shown in Table 2, and it can be seen that the accuracy is similar for all three methods of creating the profiles and for the two printers.

Table 2: Forward transform (AToB1) and Roundtrip test (using ICC-absolute rendering intent only) for each profile. Colour differences are reported in ΔE_{00}.

	Printer A			Printer B		
	D50/2	WP55	non-ICC PCS	D50/2	WP55	non-ICC PCS
Forward Trans-form (AToB1)						
Median	0.67	0.63	0.67	0.56	0.57	0.60
Max.	2.08	1.57	2.31	1.43	1.39	1.49
95th percentile	1.31	1.12	1.30	1.10	1.11	1.07
Round trip						
Median	0.73	0.72	0.72	0.85	0.88	0.96
Max.	2.06	1.65	2.87	1.81	2.34	1.91
95th percentile	1.43	1.38	1.77	1.69	1.57	1.72

Results

The final printed test image measurements are compared with the data source which was used for printer A, and the colorimetric differences (ΔE_{00}) are calculated. It should be noted that this method of evaluating the forward transform includes an additional source of uncertainty from the test prints and measurements, so it is expected that the errors are larger than those for the forward transform which include only the uncertainties present in the first set of prints and measurements [9].

The results of test 1 are shown in Table 2, where as expected the performance of the non-ICC PCS method (a) and WP55 method (b) are very similar. Since two D65/10 profiles are connected in Test 1 (a) the adjustment matrix cancels out and a D65/10 colour management is performed.

Table 3: Test 1, ΔE_{00} between the colour measurement data from the final printed test wedge and the characterisation data for printer A.

	Median	Max.	95th percentile	
Test 1 (a)	1.38	5.82	3.70	Non-ICC PCS
Test 1 (b)	1.36	5.99	3.96	WP55 Method

The results in Table 4 show that for the Test 2 workflow the WP55 method performs significantly better than the non-ICC PCS method.

Table 4: Test 2 (a and b), results of ΔE_{00} between the obtained colour measurement data from the wedge and the characterisation data for printer A.

	Median	Max.	95th percentile	
Test 2 (a)	7.93	14.90	13.63	Non-ICC PCS
Test 2 (b)	2.86	8.38	6.21	WP55 Method

Similarly, Table 5 shows that the WP55 method performs significantly better than the non-ICC PCS method in Test 3.

Table 5: Test 3 (a and b), results of ΔE_{00} between the obtained colour measurement data from the wedge and the characterisation data for printer A.

	Median	Max.	95th percentile	
Test 3 (a)	7.05	12.19	11.12	Non-ICC PCS
Test 3 (b)	2.41	6.51	5.02	WP55 Method

Conclusions

While colorimetric data for one observing condition (i.e. particular combination of illuminant and observer) cannot be exactly transformed to data for a different observing condition, it has been shown that ICC profiles derived using the Waypoint equivalency method give acceptable results for practical applications.

This evaluation has only tested a single instance of non-standard colorimetry, and the degree to which other observing conditions can be converted to PCS colorimetry depends on the performance equivalency transform used. However, the general approach of using a linear conversion to the virtual intermediate colour space of the PCS is shown to be valid. Although it is necessary to derive and apply the equivalency transform to colorimetry when making the profile, there is no computational cost at run time when applying the profile to images.

We also note that while the equivalency transform is a requirement when using the fixed ICC.1 PCS, another solution is to use a custom PCS in an ICC.2 (iccMAX) profile [10].

Acknowledgements

The authors wish to thank BARBIERI electronic SNC, Italy, for printing and measuring the test charts.

Author biographies

Peter Nussbaum completed his PhD degree in imaging science in 2011 from the University of Oslo, Norway. In 2002, he obtained his MSc in imaging science from the Colour & Imaging Institute, University of Derby, UK. Currently, he is an associate professor at the Colour and Visual Computing Laboratory, NTNU, Norway.

Milan Kresović is a master's student in the Computational Color and Spectral imaging program at NTNU, Norway. He obtained his BSc in Computer Science & Control Systems in 2020 from the Faculty of technical sciences, University of Novi Sad, Serbia.

Phil Green is Professor of Colour Imaging at the Colour and Visual Computing Laboratory, NTNU, Norway. He is also Technical Secretary of the International Color Consortium. Phil received an MSc from the University of Surrey in 1995, and a PhD from the former Colour & Imaging Institute, University of Derby, UK in 2003.

References

[1] ISO 15076-1, Image technology colour management -- Architecture, profile format and data structure -- Part 1: Based on ICC. 2010, International Organization for Standardization: Geneva.

[2] Green, P. and T. Habib. Chromatic adaptation in colour management. in International Workshop on Computational Color Imaging. 2019. Springer.

[3] Derhak, M.W., L. Luo, and R.S. Berns, Wpt (waypoint) shift manifold difference metrics for evaluation of varying observing-condition (observer+ illuminant) metamerism and color inconstancy. Color Research & Application, 2020. 45(6): p. 1005-1022.

[4] Kraushaar, A., Improving textile communication, in ICC GASIC Meeting, FOGRA, Editor. 2020.

[5] Profiling using colorimetry for d65 and 10° observer, in White Paper 55. 2020, International Color Consortium.

[6] Wpt (Waypoint) Normalization. Available from: https://www.rit.edu/cos/colorscience/re_WptNormalization.php.

[7] ISO/TS 23564, Image technology colour management — Evaluating colour transform accuracy in ICC profiles. 2020, International Organization for Standardization: Geneva.

[8] ISO 12642-2, Graphic technology -- Input data for characterization of 4-colour process printing -- Part 2: Expanded data set. 2006, International Organization for Standardization: Geneva.

[9] Green, P. Accuracy of colour transforms. 2006. Proc. SPIE 6058.

[10] ISO 20677, Image technology colour management — Extensions to architecture, profile format and data structure, International Organization for Standardization. 2019: Geneva.