Spectral versus trichromatic color management – application and benefits

Radovan Slavuj, Elie Khoury

Abstract

In this work we aim to identify in which manner spectral encoding and spectral processing can optimize color management and print process. In comparison with conventional color management, spectral data processing is superior in terms of reducing metamerism, has significantly higher prediction power with the same amount of training data. To prove these claims, we utilize state-of-the-art spectral and color prediction models, and we apply them on all major printing technologies in CMYK and multi-color mode. Our evaluation confirms far superior prediction power of spectral models. We also show that spectral prediction can effectively enable automation of the color management without a need for the dedicated printing session. This is only possible if print condition change is captured and modelized with the fraction of the time and measurements usually needed by conventional color management.

Introduction

Colour management is the communication of data for unambiguous interpretation of color information and the application of color data conversions required for the intended reproductions [1]. Traditionally, colour management systems (CMS) have been based on tristimulus colorimetry through which all imaging devices can communicate color data. In ICC color management paradigm, characterization of an imaging device is encoded in ICC profile that serves as the bridge between device dependent and device independent space (e.g. Profile Connection Space). Through the device independent PCS, imaging devices can communicate color data even though their native device spaces are quite different (Figure 1).

Alwan Color Expertise

Figure 1. ICC colorimetric reproduction workflow. Devices communicate via common color space (PCS), under the fix illumination conditions and the standard observer

All imaging devices benefit from calibration before characterization. In essence, the calibration process brings the device into a known state. Various types of calibration exist in printing; from aimed calibration (e.g. ISO or G7) that is present in conventional printing to the linearization that is commonly used in digital printing. In any case, individual primary ink channels are modelized with interpolated curves that are computed from the measurements of the single ink ramps.

Characterization on the other hand aims to modelize ink mixing on the substrate, given specific device settings. In the same manner as the calibration process, a set of primary inks mixes are printed and measured. The intermediate values can be predicted through interpolation between measured points. Once characterization model is established, and the device behavior can be predicted, one can proceed to the color reproduction. Input color can be encoded in a device specific space or as a physical signal. Spectrophotometers are measuring instruments widely used to obtain physical property of a material to reflect, transmit and absorb incoming light. In the past, spectral measurements of characterization data were converted to CIELab or CIEXYZ values [2] and then processed. With the increased computing power and data storage capacity in the last two decades, more and more spectral processing is taking place [3]. Also, with the development of multicolor printing machines, there is a high chance to have spectrally matched original [4]. One such spectral printing system is depicted on Figure 2.

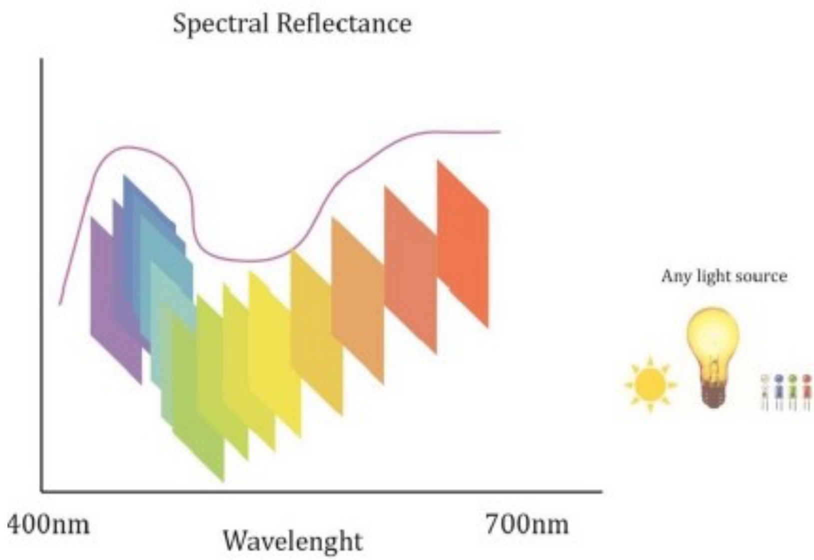

Figure 2. Spectral reproduction workflow. The spectral reflectance is measured with instrument or estimated with a camera. Spectral printer models can be used to search for the best spectral match of the input signal. Once a solution is found a separation file is sent to the printer.

Spectrally matched original is becoming a desirable outcome in modern high-quality printing. In packaging and textile industry spectral matching is much more important than in book or magazine printing. Quite often, packaging design and coloration include spot colors while production printing uses process inks. As the pigments used to make the spot color are different from the ones in the printing system, some level of spectral mismatch can be expected. Spectral mismatch might not be visible under the reference light conditions present in the print shop (e.g. CIE D50 illuminant) but can be quite prominent under the new light conditions where packaging is placed (e.g. F11 illuminant). The situation just described is called metamerism, or metameric match. For CMYK printing system that uses conventional color management, metameric matches are usual. With additional primary inks added to the printer, such are OGV inks, metamerism problems can be significantly reduced [5]. However, metamerism can only be addressed if the original spot color is a spectral measurement (e.g. encoded in CxF-x4 standard). Unfortunately, majority of spot colors are defined as CIELab or even as RGB data. In this paper we show that any hope of spectral matching is gone once an input spot color is defined this way. Still, we evaluate if the match is possible under multiple illuminants.

Spectral processing through the spectral prediction models have been applied in printing [6,7,8], but in practice we have not been able to compete with conventional characterization methods. Due to its simplicity, characterization of the printing condition has been dominated by the ICC profiles that are usually built using large number of measurements (known as IT8 target). However, such characterization is valid only until print conditions change. When this occurs, one must re-start the characterization process which is time and material consuming. As a result, most of the printers rarely do the re-profiling process, which leads to sub-optimal color accuracy. Solution therefore can only be sought in the prediction power of spectral models and ability to adapt to different printing technology characteristics. By combining single constant Kubelka – Munk [9] and YN [10] - Neugebauer model [11], authors [12] reported promising results of characterization from only single ink ramps. In this paper we extend the idea described in [12] to the predictions of Neugebauer Primaries (NP) with Offset and Flexo printing characteristics. After each NP is predicted, we collect the data into spectral engine (Alwan Hydra) to get spectral prediction for any device values. This spectral modelling strategy is compared to the CIEXYZ based model (SCOP) described in [13,14].

When color is not matching one would benefit from the analysis of the problem and a possibility to correct for the reproduction error. There are many sources of color reproduction error. Day-to-day machine oscillations (e.g. manifested in print repeatability error) are common examples while other sources of the error can come from substrate variations, quality settings, or ink density variation. Ideally, any change of print conditions should be addressed with the new calibration and characterization. As this is time consuming, in busy printing environments these issues are often overlooked. A simpler method is needed that can significantly reduce setup time and which can potentially be automated.

The key to such automation is the one-line chart that can be used with in-line instruments or with some of commercially available rail-guided instruments such as xRite Intellitrax, xRite eXact or Techkon SpectroDrive. The process of analysis and correction should not take more than 5 minutes.

Method

In this paper, we first evaluate the benefit of having spectral data for the input color to reduce the metamerism (Section 3.1). We then evaluate prediction power of spectral models that process spectral data and have the possibility to optimize print production (Section 3.2). Finally, we evaluate if spectral predictions and analysis could lead us to an automated color management and decision – making system (Section 3.3).

To evaluate Metamerism reduction, ink – mixing performance and automation potential, we use selected spectrally measured Spot colors that are used in reproduction of a packaging material (Figure 3). The test Spot colors are selected to cover both spectral and color gamut uniformly. All Spots are first gamut - mapped to the target profile and then in-gamut color accuracy is reported. From the spectral measurements D50 ICC profiles have been built with Alwan Hydra spectral processing framework. Separations are done with B2A table of the profile.

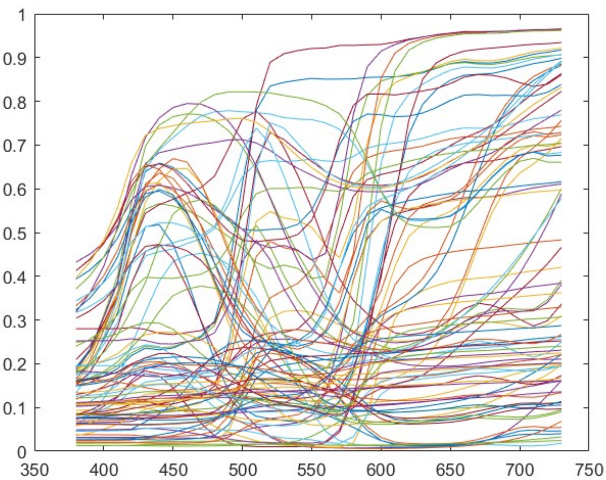

Figure 3. Spectral reflectance measurements of spot colors printed on various packaging material.

Metamerism reduction (Section 3.1) is evaluated as an ability to have good color accuracy under multiple illuminants for two cases of inputs: when input spot is defined as CIELab (in which case is illuminant dependent definition and needs to be adapted to another illuminant) and when spot is defined as spectral data. As the D50 illuminant is a standard in print industry, we evaluate color and spectral encoding of Spot inks and its separation under D65 and F11 illuminants (Figure 4). To transform Spot ink in CIELab encoding from the D50 to D65 and F11, we use Bradford chromatic adaptation. Spot color in spectral encoding is directly convertible to CIELab values under D65 and F11 illuminants. After input Spots are transformed under D65 and F11, we apply separation on the new values through the B2A table for each printing technology used in evaluation. The error of colorimetric approach is expressed as the DE 2000 between original Spots CIELab values and the reproduced CIELab values. At this stage, we do not print the separation but just report prediction error of the chromatic adaptation – separation.

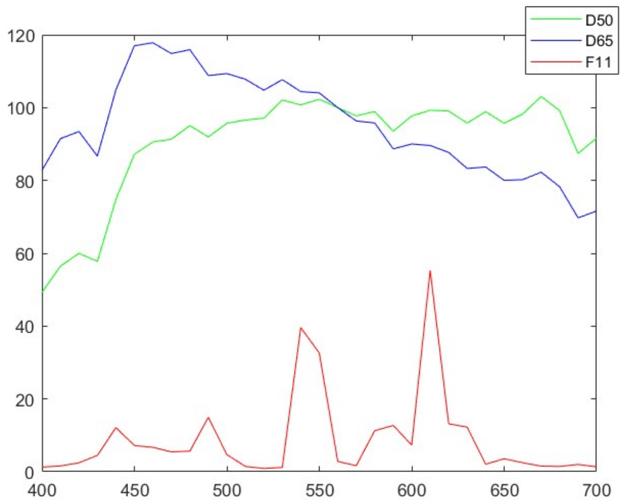

Figure 4. Spectral Power distribution of the D50(green), D65(blue) and F11(red) illuminants.

Evaluation of ink mixing prediction accuracy (Section 3.2), is done in two manners: we first aim to predict two and four spot color overprints and then we test how good the ICC profile that is created by adding ramps of primary ink channels (OGV) to the CMYK characterization chart (Figure 5). In this section we compare trichromatic CIEXYZ (SCOP) and spectral overprint models. SCOP model needs prints of spot color on substrate, neutral grey and process black while spectral model needs only prints on substrate. This is three times less patches needed to train spectral model than SCOP model.

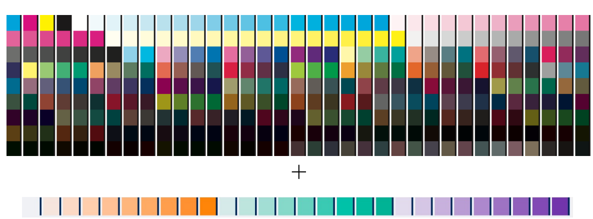

Figure 5. Example of the CMYK profiling chart and single ink ramps of orange, green and violet process inks used in Ink Mixing test

To demonstrate prediction potential of the spectral technology and its applicability to the automation of the color management (Section 3.3), we use small charts from Alwan Profiling chart package for Hydra profiling technology (Figure 6). As a reference, the spectral IT8 dataset is used to build ICC profile that is used as a reference for comparison.

Figure 6. Example of small profiling chart (Offset profiling Chart 40 patches)

Results and discussion

Metamerism

From Table 1. one can instantly observe how much additional error is added with unnecessary color transformation of the input Spot (D50 to D65 – Table 1, and D50 to F11 – Table 2) . In fact, if we assume that spectral matches are only possible when colorimetric match under each illuminant is < 1 DE, we can observe that Spor CIELab encoding is not suitable for spectral matching. In all cases, whether printing process is with four or seven inks, reproducing of in-gamut Spots under D65 illuminant with colorimetric approach yields on average 70% of Spots reproduced under 1 DE00. The same average for spectral approach is 94%.

Printing Machine – Spot Definition	Mean – 95%	% < 1	% < 2
Konica Minolta KM-1 - CIELab	0.77 – 1.6	77	99
Konica Minolta KM-1 - Spectral	0.4 – 0.8	97	99.7
Epson SC P5000 CMYK - CIELab	0.9 – 1.7	66	98
Epson SC P5000 CMYK - Spectral	0.4 – 1.1	94	99.5
Flexo Coated Adhesive - CIELab	0.9 - 1.8	68	96
Flexo Coated Adhesive - Spectral	0.4 – 1.2	93	99
Offset Coated – CIELab	0.8 – 1.6	78	99
Offset Coated – Spectral	0.1 – 0.7	97	100
HP Indigo CMYKOGV - CIELab	1 – 1.9	65	96
HP Indigo CMYKOGV - Spectral	0.5 – 1.5	90	97
Epson SC P5000 CMYKOGV - CIELab	0.9 – 1.8	64	98
Epson SC P5000 CMYKOGV - Spectral	0.4 – 1.2	92	99

Table 1. Reproduction of spot colors encoded as Spectral and D50 CIELab. From Spectral data D65 CIELab is directly computed while D50 CIELab is first chromatically adapted to D65 CIELab.

The results are significantly worse once we switch to target illuminant F11 (Table 2). The F11 is selected as a much better representation of real, indoor illumination sources. The average percentage of the Spots reproduced with < 1 DE2000 in this case is only 21% for CIELab Spot encoding while it remains 94% for spectral encoding.

Printing Machine – Spot Definition	Mean – 95%	% < 1	% < 2
Konica Minolta KM-1 - CIELab	1.8 – 4.4	22	72
Konica Minolta KM-1 - Spectral	0.4 – 0.9	97	99.7
Epson SC P5000 CMYK - CIELab	2 – 5	19	67
Epson SC P5000 CMYK - Spectral	0.4 – 1	96	99.8
Flexo Coated Adhesive - CIELab	1.7 - 4	20	73
Flexo Coated Adhesive - Spectral	0.4 – 1.2	93	99
Offset Coated – CIELab	1.7 – 4	25	74
Offset Coated – Spectral	0.1 – 0.8	96	99.9
HP Indigo CMYKOGV - CIELab	2 – 4.5	20	69
HP Indigo CMYKOGV - Spectral	0.5 – 1.4	90	97
Epson SC P5000 CMYKOGV - CIELab	2 – 5.6	17	64
Epson SC P5000 CMYKOGV - Spectral	0.4 – 1.2	92	99

Table 2. Reproduction of Spot colors under F11 illuminant encoded as D50 CIELab and spectral data using various printing technologies.

Ink Mixing Predictions

In this section, we compare the results of the SCOP model with our spectral overprint prediction models for Offset and Flexo printing processes (Table 3 - 6). Charts of two- and four-color overprints are printed - measured and compared with predictions. The prediction error is reported as the mean, 95% and Max DE2000. It is instantly clear that the spectral model is superior to the CIEXYZ model, even though it requires significantly less calibration patches (only prints on substrate).

Spot Color Overprint – 2 Colors - Offset	Avg DE	95%	Max
SCOP model	3.4	10.8	13.6
Spectral Model	0.9	2.8	3.8

Table 3. Two color Spot Color Overprint models comparison – Offset

Spot Color Overprint – 2 Colors - Flexo	Avg DE	95%	Max
SCOP model	3.1	7.2	11.6
Spectral Model	1.2	2.6	4.3

Table 4. Two color Spot Color Overprint models comparison - Flexo

Spot Color Overprint 4 Color - Offset	Avg DE	95%	Max
SCOP model	3.8	7.7	12.2
Spectral Model	1.5	3.9	6.8

Table 5. Four color Spot Color Overprint models comparison - Offset

Spot Color Overprint 4 Color - Flexo	Avg DE	95%	Max
SCOP model	4.4	9.4	15.1
Spectral Model	1.4	3.4	4.9

Table 6. Four color Spot Color Overprint models comparison – Flexo

In Table 7, we demonstrate how ICC profiles made with spectral overprint predictions compares to ICC profile created with 875 patches Alwan Hydra 7 color chart. We also add CMYK ICC profile analysis to proof that it is better to use ICC profile CMYK + OGV ramps in reproduction of spots then to gamut map many of them in the CMYK profile.

	Mean – 95%	% < 1	% < 2
Offset – Alwan Hydra CMYKOGV (875p)	0.3 – 0.7	99	100
Offset – Alwan Hydra CMYK (377p) + OGV ramps (30p)	0.8 – 1.6	88`	96
Offset – Alwan Hydra CMYK (377p)	1.2 – 4.1	66	82
Flexo – Alwan Hydra CMYKOGV (875p)	0.3 – 0.8	98	99
Flexo – Alwan Hydra CMYK (377p) + OGV ramps (30p)	0.7 – 1.5	91	97
Flexo – Alwan Hydra CMYK (377p)	1.1 – 3.3	71	86

Table 7. Reproduction of spots with ICC profiles created with: Alwan Hydra CMYKOGV (875p), Alwan Hydra CMYK (377p) + OGV (30p) ramps and Alwan Hydra CMYK (377p) data.

Automatic Process Control and Color Management

To evaluate this possibility, we perform reproduction of selected Spot colors from Figure 3. with the profiles created from small number of patches (e.g. Figure 5). From single line chart we first predict IT8 chart and then build the ICC profile. We continue with CIELab vs Spectral workflow comparison and their ability to create accurate profile for the separation of the spots from Figure 3. The results are reported as the average, 95 % and maximal DE 2000 of the in-gamut spots (Table 8).

Spot Color Reproduction	Avg DE	DE 95%	DE Max
IT8 Digital	0.5	0.9	2.2
80 Patches Digital CIELab	4.5	8.4	16.8
80 Patches Digital Spectral	1.1	2.6	4.8
IT8 Flexo	0.4	0.9	2
80 Patches Flexo CIELab	4.2	8.8	18.9
80 Patches Flexo Spectral	0.8	1.4	2.8
IT8 Offset	0.3	0.8	1.8
40 Patches Offset CIELab	3.6	8.2	14.8
40 Patches Offset Spectral	0.7	1.2	2.6

Table 8. Reproduction accuracy of Spot colors on CMYK printing machines with small number of patches.

It is clear from Table 8. that only Spectral data processing can be accurate enough to create ICC profile from 80 patches digital and flexo and from 40 patches for Offset CMYK printing. This means that only Spectral profiling can essentially provide the conditions for automation of process control and color management. One-line chart measurements are essentially sufficient for good accuracy of the CMYK profile but only if the spectral prediction technology is used.

Conclusions

In this paper we demonstrated that usage of spectral data can be effectively utilized to reduce metamerism problem in printing, especially when multi-color printing is employed. Also, we demonstrate that with state-of-the-art spectral prediction models that consider specifics of the printing technology, one can have effective simulations of multi-color printing without the need for expensive print and measure process. Finally, we show that prediction power of spectral models could serve as the key component in the automation of color management and decision making in the busy printing environment.

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