A simplified method of predicting the colorimetry of spot color overprints

Kiran Deshpande and Phil Green; London College of Communication; London, United Kingdom

Abstract

Although methods exist for predicting the color of a spot color ink when it overprints another ink, there is a need for a simplified model for the purpose of previewing that can be used during document creations.

The proposed model characterizes each spot color individually and predicts the color of overprinting solids and halftones by linearly combining the reflectances of two colors. Each ink is defined separately in terms of its opacity, and relatively few measurements are required to predict the resulting color of the overprint.

The model was evaluated for three different substrates. A 6-color test chart, containing a total of 4550 patches of different combinations of C, M, Y, K and two spot colors, was printed using the offset printing process.

The overprint model was applied to predict the resulting colors. Model predictions were compared to the measured data in terms of ΔL, Δa*, Δb* and CIEDE2000. Average CIEDE2000 values between the measured and predicted colors were found to be below 3, for both the spot colors on all papers.*

Introduction

Printing uses four process inks, *CMYK*. In some industries, additional inks are used, for example to print critical brand colors. These are known as spot colors or special inks.

Colors printed by a combination of process inks and spot colored inks can be characterized by means of an ICC profile. However, it is not practical to print a profile target and generate an ICC profile for all inks in combination. This makes it difficult to predict the effect of overprinting spot colors onto process inks or other spot colors, whereas in a color reproduction workflow it is important to have a preview or proof of the anticipated color.

Spectral printer models are available for characterizing the four-color printing system. These models try to depict the complex interaction between light, paper and ink. Some of these models include: Kubelka-Munk model, Yule-Nielsen modified Neugebauer model [1], Van De Capelle and Meireson model patented by EskoArtwork [2][3], Enhanced Yule-Nielsen modified Neugebauer (EYNSN) model to account for ink spreading in different ink superposition conditions [4][5]. Although these models were not developed for spot colors, they can be used to predict the color of ink combinations of spot colors.

Some of these models require extensive number of inputs and optimization process. Furthermore, these are relatively complex models and they cannot be easily integrated into the existing standards like ICC profiles and PDF/X.

YNSN model requires to print all combinations of primary inks. For a 6-ink printing system, it needs 64 color patches. The packaging industry uses a large number of spot colors. For example, one sample library contains 1114 spot colors, and it is not practical to print and measure all possible combinations of these inks.

Here a simple numerical method for estimating the colorimetry of spot color overprints is described. This method does not necessarily generate a more accurate prediction than existing methods, but simply provides a simplified method that can be easily implemented and that is free of existing intellectual property.

Method

A 6-color test chart (Fig.1) was designed to evaluate the model, which is described in the next section. The Basic set of the IT8.7/3 *CMYK* chart,, consisting of 182 color patches, was selected to represent the background objects. Two spot colors, Pantone 157C and Pantone 330C, were printed in addition to Cyan, Magenta, Yellow and Black inks.

On each of the 182 patches of *CMYK*, different combinations of spot colored inks (0%, 25%, 50%, 75% and 100%) were printed. Thus, for each *CMYK* basic color, there were 25 combinations resulting in a total of 4550 patches.

Figure 1. *Fraction of the 6-color test chart*

To define each spot colored ink individually, an ink characterization chart was used. This consists of ramps of inks from 0% to 100% printed over the substrate, over the grey backing (50% black ink) and over the black backing (solid black ink).

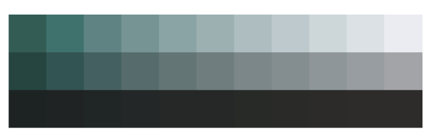

Figure 2. *Ink characterization chart for Spot Colour2 (Pantone 330C)*

Thus there were three similar ramps consisting of 11 steps, printed over white (i.e. Substrate), grey and black backings. This is similar to Van De Capelle's method [2]. Spectral measurements of the ink characterization chart provide ink reflectance characteristics transparency.

Printing process used in this study was the Offset printing process on three different substrates: Mitsubishi Paper MYU Coat NEOS, Hokuetsu Paper Pearl Coat N and Nihon Paper Be-7. Toppan standard inks were used with the following sequence: *K – C – M – Y – Spot Colour1 (PMS 157C) – Spot Colour2 (PMS 330C)*. The test charts and ink characterization charts were measured according to ISO 13655:2010 measurement condition M0 using an X-Rite SpectraScan. The ink characterization chart is used to calculate the coefficients of the model. Model predictions were compared to the measured tristimulus values of color patches.

The proposed model is compared to following existing models: Kubelka-Munk with Saunderson correction, YNSN model, Van De Capelle model. These models were applied for the above mentioned 6-ink printing system.

Proposed Overprint Model

The overprint model is used to predict colors resulting from combinations of special inks, which includes solid overprints as well as halftone overprints. The assumption made in this method is that at each wavelength the reflectance factor of an overprint approximates the product of the reflectance factors of the two inks measured independently. When this reflectance product is modified by a scaling constant, the approximation is often a good prediction of the actual reflectance.

Since XYZ is a linear transform of reflectance, the same approach can be adopted for XYZ tristimulus values.

In the overprint model, each ink is characterized separately. This is done by printing a solid ink and its tints on three backings – plane substrate (white), grey and solid black. Spectral measurements of these patches are used to derive the coefficients of the model (scaling factors and constants) for each spot colored ink by linear regression.

Where a spot color is printed over another color, the first-printed underlying color is considered as a background object and the overprinted spot color as a foreground object. The overprint model assumes that a resulting color (Xr, Yr, Zr) is correlated to the product of the background color (Xb, Yb, Zb) and foreground color (Xf, Yf, Zf). The resulting color (Xr, Yr, Zr) is predicted as follows:

$$X_r = j_x \times (X_b \times X_f) + k_x$$

$$Y_r = j_y \times (Y_b \times Y_f) + k_y$$

$$Z_r = j_z \times (Z_b \times Z_f) + k_z \quad (1)$$

where
$[X_b\ Y_b\ Z_b]$: tristimulus values of background color
$[X_f\ Y_f\ Z_f]$: tristimulus values of foreground color
$[j_x\ j_y\ j_z]$: Scaling factors
$[k_x\ k_y\ k_z]$: Constants

As seen in Eq. (1), linear regression is used to model the relationship between the resulting color (X_r, Y_r, Z_r) and the products of the background and foreground colors.

Scaling factors and constants are calculated from the ink characterization chart using Equation (1). Color patches on all three backings (white, grey and black) are measured and used as the resulting color (X_r, Y_r, Z_r) in Equation (1). The foreground color for each patch is obtained from the tints of ink on white backing. Background color for each patch is extracted from the black ink characterization chart. A least squares method was sufficient to derive the scaling factors (j_x, j_y, j_z) and constants (k_x, k_y, k_z).

In case of 2-inks overprint (say 40% Spot1 and 30% Spot2), the background color is the first color printed on the substrate (40% Spot1) and the foreground color is the second color (30% Spot2) printed after the first color. These are obtained from the ink characterization charts (tints printed on the white backing). The missing dot percentages are derived by interpolating the existing measurements.

For a printing system of multiple spot inks printed on top of each other, Eq. 1 can be applied recursively to predict the resulting color of any given combinations of inks. There is no need to measure overprints of different combinations of inks; we only have to characterize each ink individually.

In a color managed workflow, the tristimulus values of background color (made of C, M, Y, K ink-combinations) can be calculated using the A2B tag of the output intent ICC profile. Tristimulus values of the foreground color (i.e. Spot colored ink) can be derived from the measurements of the ink characterization chart (colors on the white backing). Tristimulus values of the resulting color (Xr, Yr, Zr) are predicted by applying Eq. 1. Finally the B2A tag of ICC profile can be used to estimate the colorant percentages.

Results

Figure 3 shows the relationship between the measured colors (X, Y, Z) and the variable terms in Eq. 1. Variable term products, for example (Xb * Xf) are plotted against the measured values of X, Y and Z. This is for Nihon Paper Be-7 and combinations of CMYK (background color) + Spot Color1(foreground color).

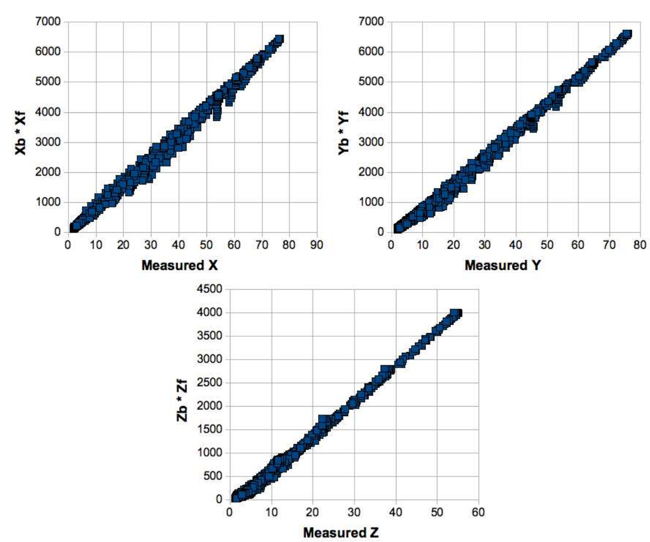

***Figure 3**. Linear regression between the measured X, Y, Z and the variable terms in Equation (1)*

There is clearly a strong linear relationship. It means that the resulting color can be derived by a simple linear regression method.

Table 1 shows the color difference values between the predicted and the measured colors for CMYK + Spot Color1 combinations on Nihon paper Be-7. All CIEDE2000 values are below 3. It can be seen that Δa* values have contributed the most to color difference values.

Paper	Average			
	CIEDE2000	Delta L*	Delta a*	Delta b*
Be-7	**2.89**	1.30	2.40	2.07
MYU Coat NEOS	**2.90**	1.50	2.40	2.35
Pearl Coat N	**2.92**	1.51	2.42	2.35

Table 1. *Overall accuracy of the overprint model for Spot Color1*

Color difference results for CMYK + Spot Color2 combinations on the same substrate are given in Table 2. Accuracy achieved is similar to that for Spot Color1.

Paper	Average			
	CIEDE2000	Delta L*	Delta a*	Delta b*
Be-7	**2.49**	1.28	2.22	1.35
MYU Coat NEOS	**2.51**	1.41	2.44	1.42
Pearl Coat N	**2.48**	1.39	2.43	1.48

Table 2. *Overall accuracy of the overprint model for Spot Color2*

A histogram of CIEDE2000 values is shown in Figure 4. This is for MYU Coat Paper and combinations of CMYK and Spot Color1. Most of the values are below 5. Despite being a simple linear model, it gives relatively good accuracy.

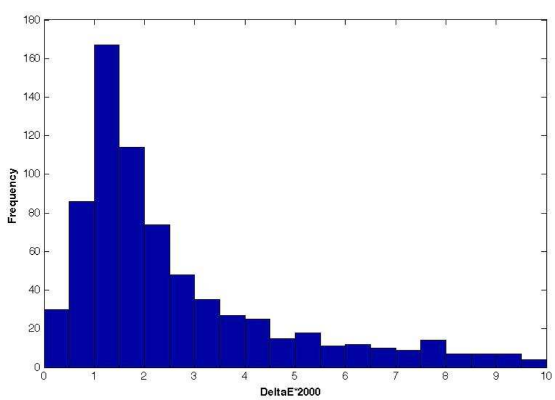

Figure 4. *Histogram of CIEDE2000 for CMYK + Spot1 on Nihon Paper Be-7*

Table 3 shows the scaling factors (jx, jy, jz) and constants (kx, ky, kz) for the Nihon Paper Be-7 are shown for each spot colored ink. For the given paper, scaling factors remain the same, but constants are changing.

Ink	Coefficients					
	jx	kx	jy	ky	jz	kz
SPOT1	0.012	0.741	0.011	1.172	0.013	1.250
SPOT2	0.012	1.061	0.011	1.095	0.013	0.983

Table 3. *Scaling factors and constants for Spot1 and Spot2 inks: Paper Be-7*

To further investigate the robustness of scaling factors and constants, the overprint model was applied separately to different dot percentages of spot color, for example, 25%, 50%, 75% and 100%. Table 4 shows the accuracy for these dot percentages for the paper MYU coat NEOS and Spot Color1.

	Average			
	CIEDE2000	Delta L*	Delta a*	Delta b*
CMYK + 25% Spot1	1.22	0.51	1.02	0.89
CMYK + 50% Spot1	2.07	1.27	4.89	1.68
CMYK + 75% Spot1	2.84	1.44	2.45	2.30
CMYK + 100% Spot1	3.68	1.73	4.38	3.11

Table 4. *Accuracy of the overprint model for different dot percentages of Spot Color1*

Color differences increase with the dot percentages of the spot colors, indicating that the model works better for highlights and mid-tones than for shadows.

The following table compares accuracy of different models for a combination of Nihon Paper Be-7 and 6-inks (K, C, M, Y, Spot1, Spot2). Kubelka-Munk theory showed the worst performance, whereas YNSN model gave the least values of mean color differences. The proposed simplified model shows moderate accuracy (mean CIEDE2000 4.01). Considering the simplicity of this model, these results are acceptable for displaying a preview of spot color overprints.

Models for 6-ink system (Spot1 and Spot2)	Mean	
	ΔEab	ΔE2000
Kubelka-Munk with Saunderson's correction	18.6	14.74
YNSN	3.32	2.72
Van De Cappelle Model	6.91	5.35
Simplified overprint model	5.43	4.01

Table 5. *Comparison of models for a 6-inks printing system (overprint of Spot1 and Spot2)*

Figure 5 shows histograms of CIEDE2000 values for all models. It is clear that YNSN model shows the best results.

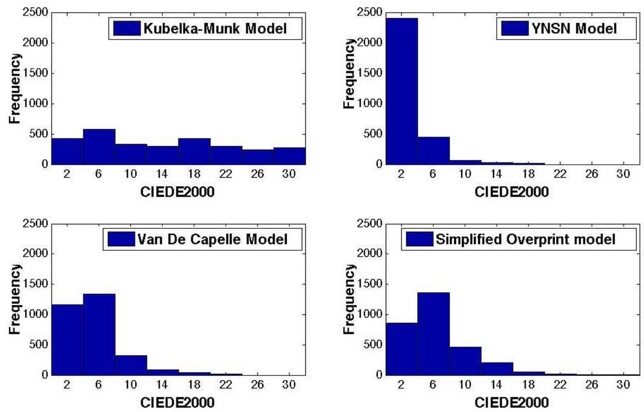

***Figure 5**. Histograms of CIEDE2000 values for different models*

These results show that the proposed simple method provides the first approximation to predict the resulting color without having to deal with complex mathematical framework. Accuracy of the predicted colors is reasonably good. Furthermore, the model can be used recursively to predict colors printed by multiple spot inks.

Although YNSN is the most accurate model, it is impractical to use this for a database of a large number of special inks. Because the inputs required for this model are all possible combinations of primary inks. The proposed model needs the ink characterization charts only to predict the resulting color.

Conclusion

A simple overprint model is proposed to predict the color resulting from different combinations of spot colors.

This model is relatively simple to use, computationally inexpensive and requiring a minimum number of measurements. It calculates the resulting color in XYZ color space rather than spectral domain. This makes it applicable to be incorporated in workflows based on ICC profiles and PDF/X documents. It characterizes each ink separately by calculating ink opacity. Both solid and halftone overprints can be predicted with this model. It requires small number of inputs as compared to other models.

The model was evaluated using a 6-color test chart and ink characterization charts. Prediction accuracy of the model is reasonably good, and further work is being undertaken to improve the accuracy of the prediction.

References

[1] J.A.S. Viggiano, Modeling the color of multi-colored halftones, Proc. TAGA, pg. 44-62 (1990)

[2] J.P. Van De Capelle and B. Meireson, A new method for characterizing output devices and its fit into ICC and HIFI color workflows, Proc. 5th IS&T/SID Col. Imag. Conf., pg. 66-69 (1997).

[3] J.P. Van De Capelle, E. Sundermann, B. Meireson and W. Geurts, Method and device for determining the color appearance of color overprints, United States Patent 10/143,543 (December 19, 2002).

[4] R.D. Hersch, F. Collaud, F. Crete and P. Emmel, Spectral prediction and dot surface estimation models for halftone prints, IS&T/SPIE Electronic Imaging Symposium, Conf. Imaging IX: Processing, Hardcopy and Applications, SPIE Vol. 5293, pg. 356-369 (2004).

[5] R.D. Hersch and F. Crete, Improving the Yule-Nielsen modified spectral Neugebauer model by dot surface coverages depending on the ink superposition conditions, IS&T/SPIE Electronic Imaging Symposium, Color Imaging X: Processing, Hardcopy and Applications, SPIE Vol. 5667, pg. 434-445 (2005).

Acknowledgement

We would like to thank Toppan Printing, UK for printing the test charts and providing substrates for this study.

Author Biography

Kiran Deshpande is a PhD student at London College of Communication, where he received his MSc in digital color imaging. He has an extensive working experience of color management and quality control in the Graphic Arts industry. He is currently working as a color specialist in Burgopak, London. His research interests include: N-color printing, spot color overprints and spectral printer models