Predicting Spot-Color Overprints
A Quantitative Approach

Khalid Akhter Husain
kah2227@rit.edu

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spot colors, lookup table (LUT), trapping, spectral models, predictability, overprint, portability, color management

Abstract

This paper investigates two methods to predict the spot-color overprints for a given set of colorants: 1) using ICC based lookup tables and 2) a mathematical model based on spectral data.

Two spot-color test targets for two ink sets were printed, by lithography and by a digital printing process, and the spectrum of the colorants was measured. The measured reflectances were then utilized to create an n-channel ICC profile using X-Rite GregtagMacbeth's ProfileMaker. The spectral reflectance measurements of the solids were then also used to explore a spectral based model which also uses the following parameters: ink trap, a way to estimate the transparency of the second ink, and a measure of mechanical and optical dot gain.

The mathematical model shows an acceptable level of accuracy in predicting spot-color overprints. The color difference between the predicted and measured spot-color overprint was found to be less than 4 ΔEab.

1.0 Introduction

Spot colors are special colors and not part of process set CMYK. The spot colors, for instance, are defined by the Pantone system as swatch books or color library plug-ins found in Adobe Creative Suite and they are available as printing inks. Some advantages of spot colors for printing application are: (1) to obtain more colors that are outside the gamut of process colors; (2) for brand identification in packaging applications; and (3) since a single color is required it is easier to maintain the color consistency on the press rather than maintaining the color balance between four process colors.

Today, spot colors find their place in many packaging and wall covering applications. For process colors, the ICC color management system works because it is based on actually printed targets that sample the whole color gamut. When using spot-color overprinting, obtaining color profiles is complicated as there are more than 1,000 spot colors available. For a graphic designer to predict the appearance of a two spot-color overprint, he or she would first have to print a profiling target, which is impractical.

Today's PostScript-based premedia software does not understand or support the use of multi-channel separation and transparency and flattens or knockouts the overprint when the image is processed (Prakhya & Chung, 2008). The graphical software applications do not provide an accurate representation of spot-color interaction, from design to display and to print. In technical words, the spot-color system lacks color management infrastructure.

There are mathematical models that can predict the appearance of spot-color overprints. For these equations to work they have to know some printing variables such as trap, ink sequence, transparency, dot gain and spectral information of each ink used. Having the correct inputs to the mathematical model reduces errors in predicting the color of the overprints. In this report, preliminary results obtained by both the ICC-based method and mathematical model for predicting the spot color overprints are explored.

Companies such as Sun Chemicals have introduced their own proprietary digital color library via a SmartColour plug-in in Adobe Photoshop. This software uses spectral data, which can predict the tints and the solid overprints of two or more colorants. This proprietary profiling software uses a complex mathematical model to generate and simulate the print process with the specified inks on the given substrate to the printed production (Sharma, 2008). However this software was not used for this report.

2.0 Objectives

The objective of this paper is to evaluate two methods available for predicting overprints colors. The study is intended to assess the accuracy of the ICC-based LUT (Lookup Table) method, and to evaluate a spectral-based model to predict reproduction of spot color and their overprints.

3.0 Literature Review

Research done by Prakhya and Chung (2008) on predicting the spot-color overprints points out the failure of today's available premedia software in communicating the true color of spot-color overprints. Their article deals with soft proofing, and conducts an evaluation of display-to-print match of the spot-color solids and their overprints with a change in ink sequence. The study shows that there is a void in the color management workflow for spot colors because of the missing link between the device-to-PCS (A-to-B).

Viggiano (1990) examined a mathematical model to predict the combination of colored halftone patterns. His paper discusses the Neugebauer color mixing model and the Yule-Neilson model to predict the tints from its solid. The paper pointed to the importance of the effect of ink trapping when two ink dots are partially overlapped on top of one another.

Viggiano and Prakhya (2008) discuss how the different trapping models can estimate the overprint. The paper also discusses the importance of subadditivity failure that needs to be taken into account when studying the ink trap. Subadditivity is related to transparency of an ink. It is caused by scattering of light in an ink layer

4.0 Methodology

Two sets of Pantone spot colors 1788C (red)-7466C (turquoise) and 599C (green)-493C (pink) were used for this research. The rationale behind using these colors was to investigate the overprint prediction for both high and low chroma colors. These same colors were used by for the research done by Viggiano & Prakhya (2008) and Prakhya & Chung (2008).

The red and turquoise inks were printed on a Heidelberg Speedmaster 74 for both ink sequence. The test charts printed used nominal dot area percentages of 0, 25, 50, 75, and 100% for each primary color, resulting in a 25-patch chart. Because the printing was performed wet-on-wet, only one sequence was expected to trap well, because of the tack sequence. The tack value of the inks used was provided by the ink manufacturer and shown in Table 1. The other set represents 100 patches of two-color overprint with nominal dot area percentages of 0, 20, 30, 40, 50, 60, 70, 80, 90, and 100% for each primary color . These sets of patches were printed on an HP Indigo 5500 (dry-on-dry). The same procedure was repeated for offset for the pink and green inks.

Table 1. Tack value of the inks specified by the manufacturer

Pantone spot-color # (coated)	Tack Value
1788 (Red)	13
7466 (Turquoise)	12
493 (Pink)	12
577 (Green)	11.5

The 25 patches target was generated and measured using X-Rite/GretagMacbeth's Measure Tool, which allows the user to set the amount of colorants and the ink sequence used. The printed target was measured with a GretagMacbeth Spectrolino Spectroscan spectrophotometer using 0/45 geometry measuring the spectrum from 380nm to 730nm at 10nm intervals, without a UV-cut filter. The spectrum of the colorants measured is in terms of absolute (non-zeroed-on-paper) reflectances. Once the target is measured, the reflectance spectrum of the different solids and overprints and the unprinted substrate, are collected in an Excel spreadsheet where all analysis is done.

The spectral reflectances will be converted to colorimetric values to create an ICC profile using ProfileMaker's Multichannel option that can create n-color profiles. The profile created is inspected using Profile Editor.

Using the Yule-Neilson model and Hamilton's trapping model, both the tint values and the 100% overprints can be predicted from the solid spectral curves.

To determine how the two inks interact when overprinted, the following paramters were measured: percent trap, tack and transparency for offset inks, and densitometric and colorimetric parameters. For offset inks, the saturation density of the second-down ink was measured using an Eye-One Pro spectrophotometer for the ink film thickness of approximately 2 mm. After the measurements and computations, the data were analyzed and evaluated by means of graphical analysis. The printed hardcopies were used as the reference to evaluate the accuracy of the mathematical model.

4.1 Lookup Table Approach

This section describes the ICC-based workflow using the LUT approach. Most ICC printer profiles work in the CMYK colorspace, but in this case, profiles that would deal with more than just CMYK are needed. Such profiles are identified as "n-channel" or "multi-channel." Each special color combination requires its own new target to create the profile.

The ICC workflow uses three profiles: the input source profile, the display or monitor profile, and the output profile (Sharma, 2003). The ICC workflow converts the input device dependent color space to corresponding points in device independent color space, called the profile connection space (PCS). The CIELAB color space is used as the standard color space for the PCS. The LUT uses a complex interpolation method that maps the input color to the nearest PCS color value available in its database. The ICC profiles do not contain any spectral data or colorant parameters, but contain CIELAB values to predict the color rendition of CMYK printing devices (Sharma, 2003). The monitor is just like an output device. Monitor profile is obtained through its calibration, which contains a lookup table connecting the PCS (CIELAB) color space to the monitor color space (RGB).

To use profiles with spot colors, a plug-in by GretagMacbeth is required for PhotoShop to convert an RGB or CMYK original to spot-color separations. The flow chart shown in Figure 1 displays the processes and resources involved in the LUT-based approach.

4.2 Spectral-based Model

This section describes how to determine the spectrum of an overprint of halftone colorants using the parameters of colorants and substrate. Besides the spectral curves of the solids and substrate, there are four other parameters that need to be considered: trap, transparency, n-factor and mechanical dot gain.

The spectral-based method uses the Neugebauer equation modified by Yule-Neilson and Hamilton's trapping model to predict the color of halftones and the 100% overprint respectively. The spectrum of the printed overprint is not used in the model, but is needed to verify the accuracy of the model.

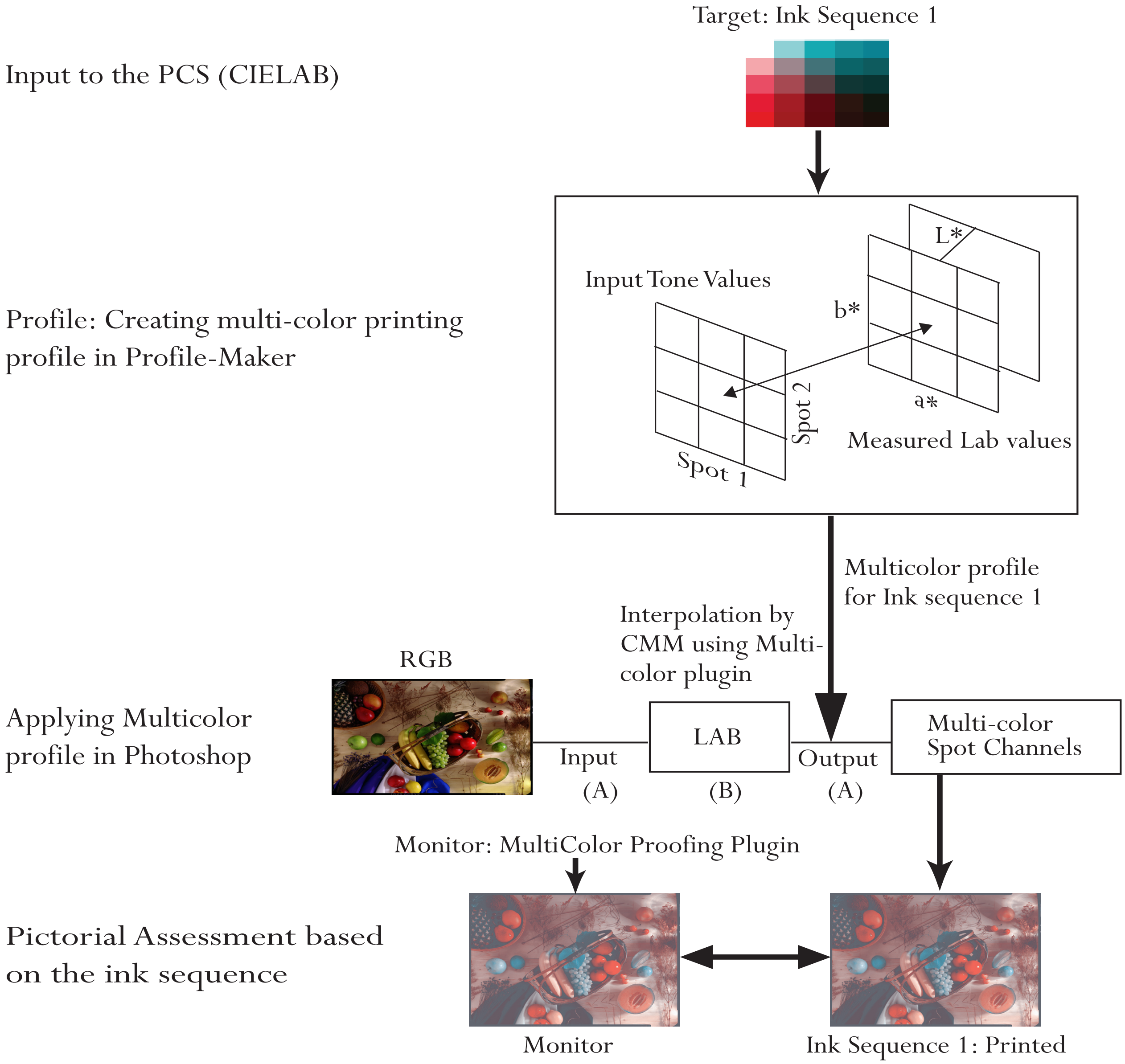

Figure 1. The flowchart representing the process for ICC-based approach

The model for predicting appearance of colors for a halftones printing process was first introduced by Neugebauer in 1937. The model is based on additive color mixing of the partial areas that result when overprinting the dots of the printing inks as shown in Figure 2.

Figure 3 represents the density spectrum of two inks and the substrate. Interestingly, the overprint density is less than the second ink down density in the red region between 590 nm-700 nm. This is probably caused by trapping.

4.2.1 Neugebauer Model and Yule-Neilson Model for Colored Halftones

The spectral Neugebauer model predicts the reflection spectrum of a color halftone patch as the sum of the reflection spectra of its individual colorants (Neugebauer primaries) weighted by their fractional coverage area and the substrate (Viggiano, 1990). Figure 3 shows the Neugebauer primaries of a two spot color tint that relate to the Demichel's halftone dot areas on the paper. The equation is expressed symbolically as:

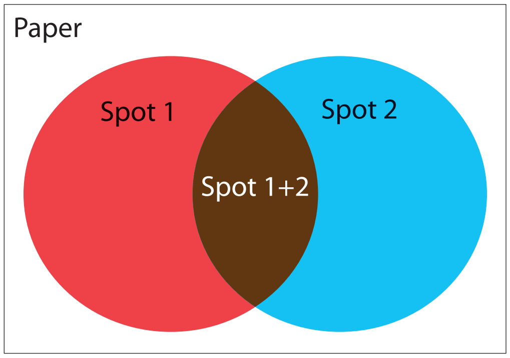

Figure 2. Neugebauer primaries for two color overprint

$$R(\lambda) = \sum_{i=1}^{2^N} w_i R_i(\lambda) \qquad \text{(Eq.1)}$$

wi = relative area for each primary as calculated by Demichel equation

Ri = reflectance of the primary at each wave length

Therefore for two-color overprint, there will be 2^2 = four Neugebauer primaries, which are assumed to be mixed additively: one containing paper only; two which contain one ink; and one which contains both inks.

The Neugebauer color-mixing model fails to account for optical dot gain that is caused by internal reflection at the paper surface. Yule-Neilson, in 1951 proposed a correction factor for the Murray Davis equation for this effect by using an n-factor to improve the model accuracy. In 1985 and 1990, Viggiano applied the Yule-Neilson relationship to the spectral Neugebauer equation, yielding the Yule-Neilson modified Spectral Neugebauer model. The model can be referred to as Viggiano-Yule-Neilson-Neugabauer model and is defined as:

$$R(\lambda) = \sum_{i=1}^{2^N} \{w_i R_i(\lambda)^u\}^n \qquad \text{(Eq.2)}$$

n = Yule-Neilson factor

u = 1/n

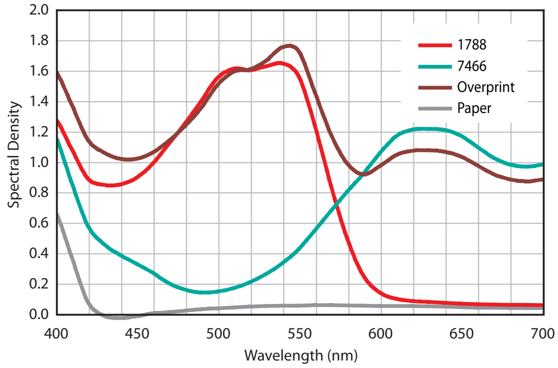

Figure 3. Density spectrum of an overprint: first-down ink (1788), second-down ink (7466)

For a two spot-color overprint, Equation 2 can only predict the spectrum of the overprint tints if the spectrum of the overprint solid is known. Therefore (in the absence of a printed profiling target), another equation is needed to predict the spectrum of the two spot-color solid overprint. There are two variables that affect the color of an overprint: trapping and transparency.

Trap indicates how much of a colorant sticks to an underlying colorant that is previously printed (Viggiano & Prakhya, 2008). In 2008 Viggiano and Prakhya examined various trapping models for predicting the overprint. They re-cast Hamilton's trapping model to predict overprint spectra, and found, for the cases they considered, that it did so accurately. Their re-arrangement of Hamilton's trapping model to predict overprint spectra is expressed as:

$$D_{12}(\lambda) = D_{2\infty},\lambda - (D_{2\infty},\lambda - D_1,\lambda)\left[\frac{D_{2\infty},\lambda - D_2,\lambda}{D_{2\infty},\lambda - D_p,\lambda}\right]^{T_h} \qquad \text{(Eq.3)}$$

D_{12} = spectral density of the overprint

D_1 = spectral densiy of first ink down

D_2 = spectral densiy of second ink down

T_h = Hamilton's trap

$D_{2\infty}$ = saturation density of the second-ink down

D_p = density of the unprinted substrate

While developing and verifying the model, the spectral reflectances of the solids, tints, and the overprint are readily available from a print.

The saturation density is needed to determine the transparency of the second ink down. According to Davidson (1969), the saturation density is a point at which the optical density no longer increases as the ink film thickness is increased. A simple way to understand the concept of transparency is by simply looking at the color of the ink in the ink can. If one can see the actual color of that ink, then the ink is considered to be opaque and hence the saturation density will be same as the density of that ink when printed at normal ink film thickness. If the color of the ink in the can is darker or black from the printed color, then the ink is considered to be transparent as all the light incident on the ink gets absorbed by the pigment. In this case the saturation density is very high compared to the density of the printed ink. Transparency is not just a constant, but varies with wavelength.

Therefore it is possible to evaluate the transparency on the basis of practical measurements. This is not the case for trapping, because to actually measure trapping for the two color overprints we would require an actually printed two color overprint. There are two solutions to this dilemma: 1) making an educated guess of the trap value (based on the tack of the individual inks) and hope that this is good enough for a first approximation; 2) try to find the correlation between the trap and the tack on the basis of experiments. Option 2 is beyond the scope of this report. All that is attempted at this time is to show that if we had the correct input value for the trap, then the equation gives an accurate prediction of the spectral curves of an overprint. So the question is how do we find the correct input value for the trap. Since, for the development of the equation, we have the printed target and therefore know the spectral curve of the overprint color, we can use an iterative approach to find which trap value would give the best agreement between the measured and the calculated spectral curve of the overprint.

The flowchart shown in Figure 4, displays the process and the input parameters involved in the prediction of the spot-color overprint spectrum for the spectral-based model.

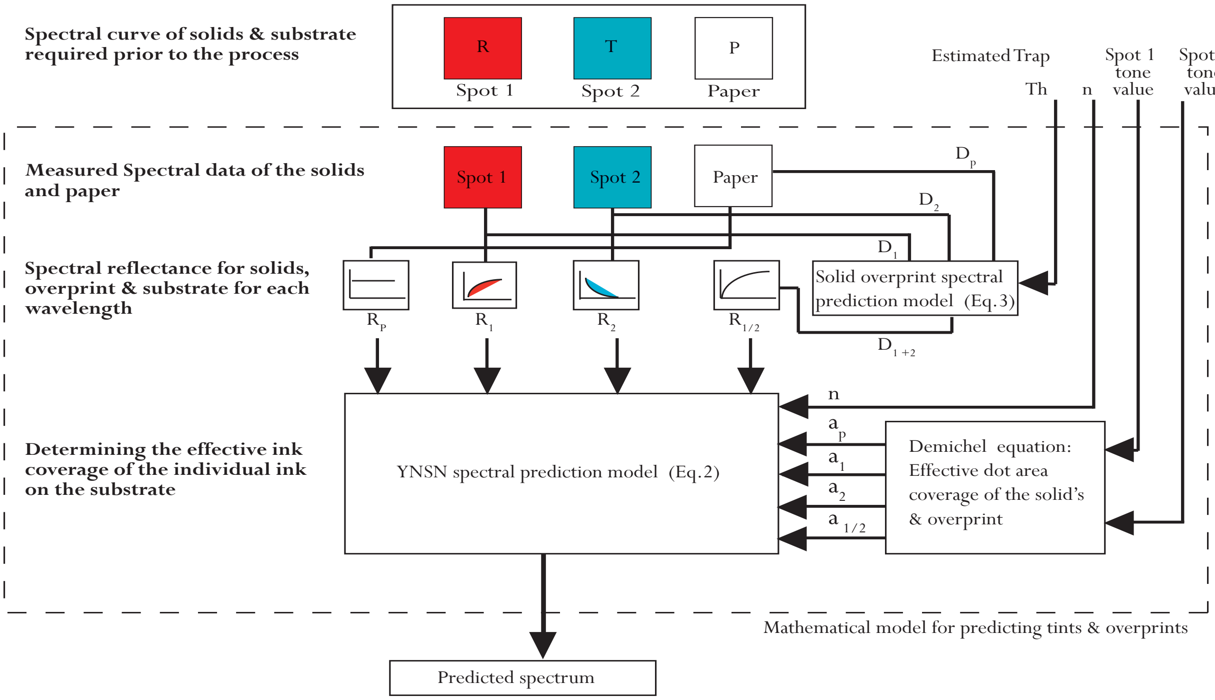

Figure 4. The flowchart representing the method for predicting spot-color overprints using spectral-based model

5.0 Result

5.1 Measurements of Printed Spot-Colors and Their Overprints, for Different Printing Processes and Ink Sequences

Profiling targets were printed on both Heidelberg SM74 and HP Indigo 5500 using both ink sequences for both ink sets (Pantone1788 (red) – 7466 (turquoise) & Pantone 493 (pink) – 577 (green)). The spectral reflectance of the two ink sets was measured with a GretagMacBeth SpectroScan spectrophotometer. Figure 5 shows the differences in the color when the ink sequence is changed. The 3-D gamut plot displays the color differences between the two ink sequences, the color of the arrow is a function of magnitude in terms of ΔEab. The green arrows indicate ΔE of less then 2, yellow arrows indicate ΔE of less than 4, and the red arrows indicate large color differences with ΔE of more than 4. Further investigation shows that the change in the ink sequence does not affect the paper white and the single solids reproduced, but does affect the two color tints and solid overprints. It can be observed from the printed results that the color produced with 1788 as the first-ink down has more chroma compared to the color produced when 7466 is the first-ink down. Similar test forms are included in this Test Target book on pages 66-67 and pages 70-71.

Figure 6 shows a comparison between the two-color overprint measurements when printed dot-on-dot, i.e., on HP Indigo 5500. It can be seen from the 3-D gamut plot that the color difference between the two sequences is minimal compared to the wet-on-wet process, since there is a minimal effect due to trapping in digital printing, as the colorant printed is dried before the next colorant is applied on top.

Figure 7 displays a 3-D gamut plot for the other set of inks used, i.e., 577C-493C. Compared to Figure 5, the overall colors reproduced are less than a ΔEab of 4. Also the change in the ink sequence does not have much effect on the solid overprints. As noted, the color gamut with the 1788-7466 ink set is larger compared to the color gamut of 577-493 ink set.

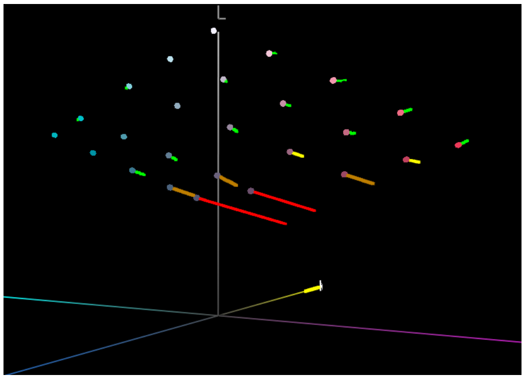

Figure 5. 3-D gamut plot of two spot-color overprint sequences printed wet-on-wet. The vector tail represents the first ink sequence (Red as first ink down) and the vector head represents the second ink sequence (Turquoise as first ink down)

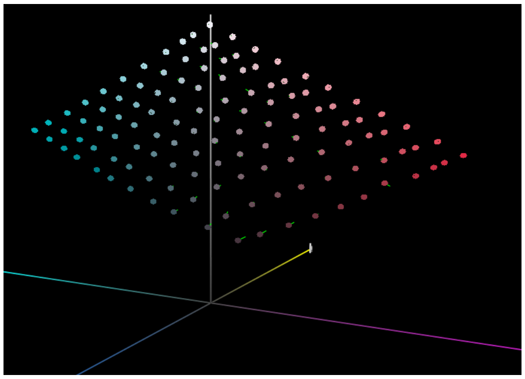

Figure 6. 3-D gamut plot of two spot-color overprint sequences printed dry-on-dry. The vector tail represents the first ink sequence (Turquoise as first ink down) and the vector head represents the second ink sequence (Red as first ink down)

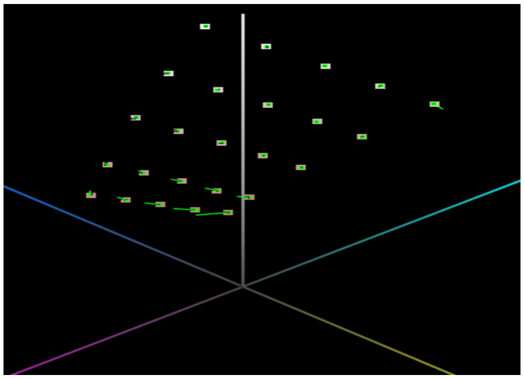

Figure 7. 3-D gamut plot of two spot-color overprint sequences printed wet-on-wet. The vector tail represents the first ink sequence (Pink as first ink down) and the vector head represents the second ink sequence (Green as first ink down)

Table 2 lists the ΔEab color differences for the change in the ink sequence for both ink sets.

Table 2. Color differences of Offset inks between the ink sequence.

	Inks	Tone Value	ΔEab
Offset	*1788-7466*	*50*	*2.42*
		100	*25.80*
	577-493	*50*	*0.79*
		100	*4.88*
HP Indigo	*1788-7466*	*50*	*0.73*
		100	*3.7*

5.2 Testing GretagMacbeth MultiColour Plug-In

The color separations for pages 66-67 and pages 70-71 were done using the MultiColor Separation Plug-In. The soft proofing preview did not appear to match the printed colors very well, but this could be because we have not yet applied the MultiColor Proofing Plug-In correctly.

5.3 Spot-Color Reproduction Using Spectral-Based Model

Figures 8 and 9 show the spectral density curves of the solid overprints for both sequences and both ink sets, comparing the measured and calculated response.

It can be seen from both graphs that the differences are small. The saturation densities used in the equations come from real measurements of the inks. The n-value was arbitrarily fixed at 2 and mechanical dot-gain was assumed to be zero, the digi-

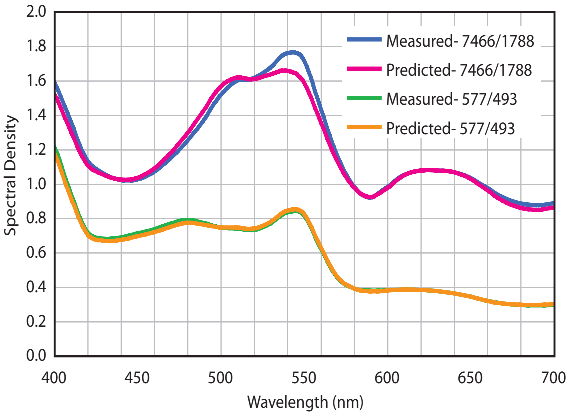

Figure 8. Measured and Predicted overprint spectra: Turquoise over Red & Green over Pink

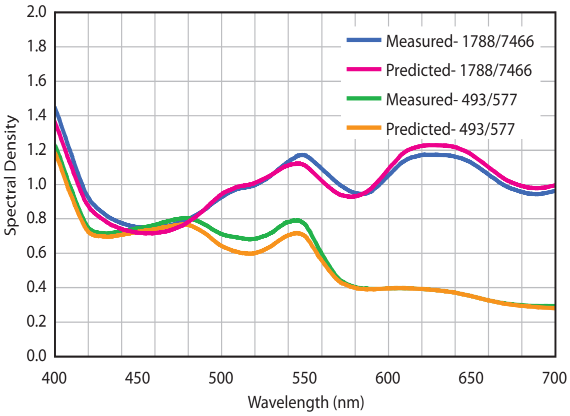

Figure 9. Measured and Predicted overprint spectra: Red over Turquoise & Pink over Green

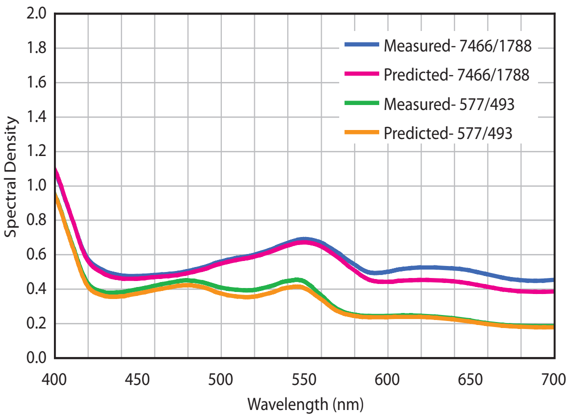

Figure 10. Measured and the Predicted specra for 50% tints: Turquoise over Red & Green over Pink

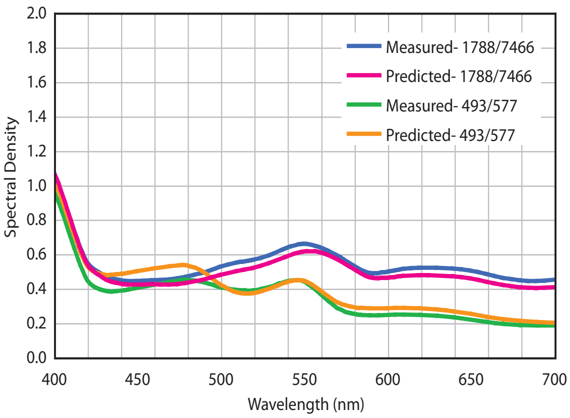

Figure 11. Measured and the Predicted spectra for 50% tints: Red over Turquoise & Pink over Green

tal or PostScript dot size was used. The trapping values were obtained through iteration for each ink set and sequence. Theoretically the trap values are lower with incorrect tack sequence (Viggiano, 2008). It is seen that the trap difference for high chroma ink sets (Red and Turquoise) is larger compared to the low chroma inks (Pink and Green).

Figures 10 and 11 display the predicted and measured spectra using the Yule-Neilson colored halftone model when overprinting 50% halftone tints. Table 3 displays the trap based on the ink sequence.

T*able 3. This table shows the trapping values, for each oveprint combination. The overprint with reverse tack sequence are indicated by* *

R over T*	T over R	P over G	G over P*
0.43	*0.81*	*0.66*	*0.58*

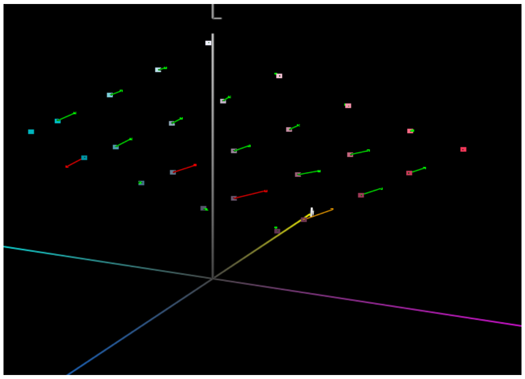

Figure 12. 3-D gamut plot of t25 predicted samples using spectral-based model. the vector tail represents the predicted colors and the vector head represents the measured colors

Table 4. CIELAB total color difference ΔEab between the measured and the predicted spectral response

Ink Sets	Sequence	Tone Value	ΔEab
Set 1	*T over R*	*50*	*4.7*
		100	*2.27*
	R over T	*50*	*1.36*
		100	*1.39*
Set 2	*P over G*	*50*	*1.7*
		100	*1.39*
	G over P	*50*	*1.83*
		100	*3.07*

5.4 Plot of Measured and Predicted Overprint Gamut

The 3-D gamut plot shown in Figure 12 represents the predicted colors relative to the measured colors. The prediction errors are probably mainly due to the under estimating of meachanical dot gain, thereby overestimating the spectral reflectance factors. Table 4 shows that the iterated Δ Eab color differences between the measured and the predicted value for both ink sets using the spectral-based model are less than 4.

6.0 Summary & Conclusion

For the Lookup Table method the following is required: 1) A profiling target is generated using the GretagMacbeth Measure Tool: 2) This target is printed and the measurements are used by Profile Maker to create the multi-color profile. In order to apply this profile to an image the MultiColor Plugin from GretagMacbeth is required in Photoshop to convert the image to multi-channel. To display this multi-channel file in true colors on the monitor, or to optimize it for a proofing system, it is necessary to use the MultiColor Proofing plug-in from GretagMacbeth.(See Appendix on pg.17.)

The advantage of an ICC-based multi-channel profile is that the Lab values come from a printed target, which accounts for parameters such as substrate, ink transparency, trapping and dot-gain. Changes in the process, such as a change in ink sequence, require printing of a new profiling target. Each combination of spot colors requires printing of a new profiling target. Therefore, this workflow is not suitable for spot colors in a situation where a graphic designer has to choose between many possible spot colors for a new product, because the number of spot-color permutations is high.

The advantage of mathematical model is that it can be easily adapted to different printing conditions by simply changing parameters in the equations. No printing of test targets is required, except a one time production of a swatch book, and a one time measurement of ink properties such as tack, trap, and ink saturation density. A preliminary test of the accuracy indicates that a good agreement can be achieved for practical purposes. The needed parameters for the spectral model all come from single color prints, no overprinted colors are required. This is because the spectral-based model uses data from actual colorants characterization and physics which involves only a few input parameters and just the spectral curves of the solid and substrate, no overprints and tints.

The mathematical model discussed in this paper on the basis of preliminary results seems to have the potential to predict the spot color overprints and tints accurately enough (less than 4 ΔEab) for practical applications.

7.0 Suggestions for Future Research

This paper investigated the available method to predict spot-color overprints. It is now required to take a step ahead and use more than two-color overprints to test the accuracy of the model. Instead of using the iterative method of optimizing the trap values to find the least ΔE color difference, one can find the correlation between the trap value and tack of the ink. It would be also important to investigate the effect of absorption and scattering in the ink layers as proposed by the Kubelka-Munk model.

8.0 Acknowledgments

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Appendix: Using X-Rite's MultiColor Plug-In for Adobe Photoshop1.2 To Create and Proof Multi-channel Files

About MultiColor Plug-In 1.2

MultiColor Separation Plug-In creates separations for multi-channel processes. Using this plug-in, one can create up to 10 multi-channel files based on the ink sequence. This MultiColor plug-in gives the user full control to convert Lab, RGB, and CMYK files into multi-channels based on selectable intent and ICC profiles. This plug-in is necessary because Photoshop does not display multichannel files colors in true colors. To display such files in true colors on the screen, MultiColor Proofing Plug-In is required. The proofing plug-in can be used for displaying the preview of the printed result for the press and proofer.

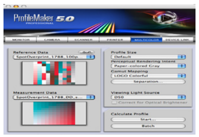
Profiles in MultiColor Plug-In

MultiColor Separation Plug-In use three inputs: the source profile, the press or the output profile, and the rendering intent. The source profile describes the origin of the file and is used to ensure correct color transformation. If the multi-channel files not have profiles embedded, then one can choose it from the available source profiles. The rendering intent is used to determine the method by which the source gamut is transformed to the press gamut. Relative rendering intent is usually used to achieve highest accuracy in the reproduction and is used for logos. The press profile is used to describe the destination of the printing process for which the data is being optimized.

Workflow

Creating the multicolor files starts with creating a profiling target using ProfileMaker's MeasureTool. The multi-channel profile is generated using ProfileMaker 5.8. In ProfileMaker there is a option for multicolor, where the user can set the desired rendering intent, profile size, and the light source. The multicolor profile takes into account the ink sequence based on the reference file. Once the profile is created, save it in the ColorSync folder.

Use any RGB, CMYK, or Lab image and apply multi-channel separation using the MultiColor Plug-In in Photoshop. Choose the multichannel profile created in Profile Maker with the desired rendering intent. The plug-in will generate individual separations for each individual ink used. To display the multi-channel file in true colors on the screen, MultiColor Proofing Plug-In is required. Activate the proofing plug-in and choose the required press profile, proofer profile and the rendering intent. Use Preview Press to see the multi-channel files on the screen as they would be outputted in the multicolor process. Preview Proofer is used to simulate the press. The flow diagram below describes the documented process for creating and proofing multi-channel files.



Profile Maker: Multi-channel profile for two spot colors (1788 & 7466)

Pictorial RBG image

MultiColor Separation Plug-In

MultiColor Separation (kvandenbosch@xrite.com0)

Source Profile: sRGB IEC61966-2.1

Rendering Intent: Absolute Colorimetric

Press Profile: SpotOverprint_1788

Two-color output file generated by the plug-in

MultiColor Proofing Plug-In

MultiColor Proofing (kvandenbosch@xrite.com0)

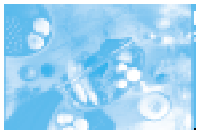
Press Profile: Overprint_1788_WW

Rendering Intent: Absolute Colorimetric

Proofer Profile: SpotOverprint_1788

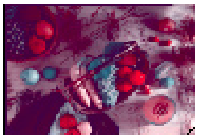
72 DPI

72 DPI



Separation: Spot channel 1

Separation: Spot channel 2



Preview on screen

Profiling Target created in MeasureTool