Predicting Color of Overprint Solid

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Keyword: color, overprint, spectrophotometry, ink trapping

Abstract:

Process color printing has three chromatic inks (C, M, and Y). Colorimetric properties of the two-color overprint solids (R, G, and B) are measured to determine the color gamut of the process ink set. Non-process colors, as defined by the Pantone Color Library, have more than a thousand ink formulations. There are too many possible two-color overprint solids to be measured. Colors of non-process color overprints are unknown until they are printed. While ‘Overprint Fill’ is available in Adobe Creative Suites that allows one spot color overprinting to the other, there is no color management solution to ensure that the overprint solids, as displayed, correctly matched that as printed. This paper describes a spectral-based solution based on paper, 1st ink, 2nd ink, and a generalized ink trapping factor, t, using uni-tack inks, to predict color of overprint solid. Color differences between predicted and printed two-color overprint solids, resulted from wet-on-wet (offset) ink transfer are discussed.

1. Introduction

In traditional process color printing, only four primaries, CMYK inks, are used. Colorimetric properties of two-color overprints are measured as a part of the color characterization task. These colorimetric measurements provide look-up tables for color display and color conversion in a color-managed workflow. There was no need to predict two-color overprints.

In spot color printing, the Pantone Color Library defines more than a thousand unique ink formulations. Today, “Overprint Fill” of any two spot colors is permitted in Adobe Creative Suites software. While spot color solid by itself is displayed accurately with the use of Pantone supplied look-up tables, display of spot color overprint is incorrect (Chung, Riordan & Prakhya, 2008). No one knows what the color of the two-color overprint would look like until printed. In other words, the spot color management infrastructure is lacking in the current version of the Adobe Creative Suites software.

The key questions in this research are, “What is the color difference of overprint due to ink sequence change in wet-on-wet printing?” and "Can the color of the two-color overprint be predicted accurately with a spectral-based model?" By answering the first question, we identify a critical gap in current color management infrastructure. If we are able to devise a solution, it will enhance color communication of spot color applications between designers and printers.
2. Literature Review

The term, overprint, means “image elements that are either solids or tints applied over a previously applied colorant or colorants” (CGATS.4, 2006). In this research, the scope of overprint is limited to overprint solids only.

The relationship between color of the overprint, the first ink, and the second ink had been studied in the past. CGATS.4 documents a number of ink trap formulas, i.e., Brunner, Hamilton, and Preucil. These formulas are density-based and intended to express ink trapping (t) as a function of overprint (D_{op}), paper (D_0), first ink (D_1), and second ink (D_2). In other words, ink trapping (t) is calculated when all four of the quantities (D_0, D_1, D_2, and D_{op}) are known. Equation (1) depicts the Preucil trap formula (CGATS.4, 2006).

\[
t = \frac{D_{2op} - D_1}{D_2 - D_0} \quad \text{(Eq. 1)}
\]

To predict overprint color, Viggiano and Prakhya (2008) explored the use of a spectral-based model by adopting various ink trapping formulas (pp. 112-133). A fundamental obstacle in this pursuit is that there are two unknowns (t and D_{op}) in a single equation. The best they could do was to iterate ink trapping (t) until a minimum \(\Delta E\) is calculated for a given ink-paper-printing condition.

Holub, Pearson, and Kearsley (1986) reported the use of a reflectance-based spectral model to predict overprint colors (pp. 166-196). As shown in Eq. (2), spectral reflectance of the overprint at a given wavelength \(R_{op(\lambda)}\) is equal to the product of the reflectance of the first ink \(R_{1(\lambda)}\) and the second ink \(R_{2(\lambda)}\) at that wavelength. Upon testing and analyses, they concluded that the model did not perform well.

\[
R_{op(\lambda)} = R_{1(\lambda)} \times R_{2(\lambda)} \quad \text{(Eq. 2)}
\]

In an earlier study, we found that ink trapping is a function of ink tack difference between the two inks, and gravimetric ink trapping, t, of uni-tack inks is 0.7 in wet-on-wet printing, and 1.0 in wet-on-dry printing (Chung, Hsu, Clark and Husain, 2009). In other words, it may be possible to predict two-color overprint with a modification of Eq. (2) if we constrain the two overprinting inks with the same ink tack. If and when ink trapping of uni-tack inks converges to a constant, we will be able to predict overprint color because there is only one unknown, i.e., overprint, left in Eq. (1).

3. Methodology

This research has the following objectives: (1) conduct press runs using two inks in two sequences to find out the color difference of overprint due to ink sequence change in wet-on-wet printing; (2) develop the spectral-based overprint model by modifying the Holub equation with all variables in the Preucil equation; (3) test the performance of the spectral-based model by conducting offset press runs to simulate wet-on-wet ink transfer using inks with the same tack and in different ink sequences; and (4) test the performance of the spectral-based model by conducting digital printing to simulate dry-on-dry ink transfer.

3.1 Developing spectral-based overprint model

To begin with, we can re-write Eq. (2) by substituting \(R_{2(\lambda)}\) in density term and including the ink trapping value (t) as a multiplier or factor to account for ink trapping of the second ink, as
shown in Eq. (3). In order to solve for the reflectance of the overprint, all quantities, including the ink trapping (t), to the right of the equal sign, must be known.

\[ R_{op(\lambda)} = R_{t(\lambda)} \times 10^{-\left(D_{2(\lambda)} - D_{0(\lambda)}\right)} t \]  \hspace{1cm} (Eq. 3)

The influence of paper in the spectral measurement of Ink \(2, D_{2(\lambda)}\), should be subtracted because the paper factor is already accounted for by the spectral measurement of Ink 1. Thus, Eq. (4) represents the spectral model that accounts for the influence of both trapping and paper substrate.

\[ R_{op(\lambda)} = R_{t(\lambda)} \times 10^{\left(D_{2(\lambda)} - D_{0(\lambda)}\right) t} \]  \hspace{1cm} (Eq. 4)

We can re-write all density variables in Eq. (4) in terms of reflectance, as shown in Eq. (5). Expressing overprint in spectral reflectance is necessary for CIELAB computation by means of tristimulus integration. Note that Eq. (5) is the same as Eq. (2) when both \(R_0\) and \(t\) are equal to 1.

\[ R_{op(\lambda)} = R_{t(\lambda)} \times 10^{-\log \left(\frac{R_{0(\lambda)}}{R_{t(\lambda)}}\right) t} \]  \hspace{1cm} (Eq. 5)

A Microsoft Excel spread sheet was devised to perform the following computational tasks: (a) accept spectral reflectance data for paper, ink 1, ink 2, and overprint solid; (b) compute the overprint spectra for a number of ink trapping values using Eq. (5); (c) perform tristimulus integration of these overprint spectra; and (d) compute \(\Delta E_{ab}\) between predicted overprint color and the printed overprint.

3.2 Testing spectral-based overprint model

To test the performance of the spectral-model in predicting overprint color, a step-by-step procedure is shown below:

a. Collect overprint samples from spot color press runs. The Heidelberg Speedmaster sheet-fed offset press run represents wet-on-wet ink transfer using uni-tack inks.

b. Measure spectral reflectance values of paper, first- ink solid, second- ink solid, and their overprint. The measured overprint color is the reference.

c. Predict the spectral reflectance curve of the overprint by means of Eq. (5) and compute its CIELAB value (D50, 2° observer). The predicted overprint color is the sample.

d. Compare the color difference between the sample and the reference.

e. The HP Indigo 5500 digital press run represents dry-on-dry ink transfer.

4. Results and Discussion

The prediction of the color of overprint solid requires that spectral characteristics of the paper, the two inks, ink sequence, and ink trapping be known. In wet-on-wet ink transfer, ink trapping can be approximated if uni-tack inks are used (Chung, Hsu, Clark and Husain, 2009). In dry-on-dry ink transfer, ink trapping approaches unity. This section describes specific findings from the experiment.
4.1 Color difference of overprint due to ink sequence change

By changing the ink sequence of the two spot color inks in the Heidelberg Speedmaster 74 (SM74) sheet-fed offset press run, the color difference between the two spot color overprints, as shown in Table 1, is very different (22.8 ΔE). This points out the influence of ink sequence on the overprint color in wet-on-wet ink transfer. This finding also confirms the fact that pre-media display of overprint color is incorrect due to the lack of an overprint prediction model.

Table 1. Color difference due to ink sequence change in offset printing

<table>
<thead>
<tr>
<th>Uni-tack 11</th>
<th>SM74_1788 (1st)</th>
<th>SM74_7466 (1st)</th>
<th>ΔE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Paper</td>
<td>95.5 ± 1.9</td>
<td>95.7 ± 1.8</td>
<td>0.2</td>
</tr>
<tr>
<td>PMS 1788</td>
<td>54.4 ± 71.8</td>
<td>54.7 ± 70.5</td>
<td>3.1</td>
</tr>
<tr>
<td>PMS 7466</td>
<td>64.1 ± -51.7</td>
<td>64.8 ± -51.0</td>
<td>0.9</td>
</tr>
<tr>
<td>Overprint</td>
<td>27.0 ± 28.8</td>
<td>32.2 ± 10.5</td>
<td>22.8</td>
</tr>
</tbody>
</table>

4.2 Overprint solid prediction in wet-on-wet ink transfer

This section summarizes results of overprint prediction based on wet-on-wet ink transfer using the Heidelberg Speedmaster 74 (SM74) sheet-fed offset press. Two inks of the same tack (Tack 11) were printed in two ink sequences. Figure 1 shows the spectral reflectance curves (SRCs) of the paper (in gray), first-down ink (Pantone 1788), and second-down ink (Pantone 7466) and the overprint color (in black).

Figure 1. SRCs of paper, Pantone 1788 (1st), Pantone 7466 (2nd), and overprint color

Figure 2 shows SRCs of the predicted spot color overprints with a range of ink trapping, t, from 0.7 to 1 with an increment of 0.1. Color differences (ΔE) between predicted overprint colors and the actual overprint color are also shown. As the ink trapping (t) assumes a larger value, i.e., more transfer of the second-down ink on top of the first-down ink, the overall reflectance of SRCs decreases (indicated by the dash arrow).
Figure 2. Spectral prediction and color difference of SM_1788 (1\textsuperscript{st} ink) overprint

Figure 3 compares predicted overprint colors with the reference print in a*b* diagram. We can see that as ink trapping assumes a larger value, the hue of predicted overprint shifts toward the chromaticity of the second-down ink (indicated by the dash arrow). It is also true that by decreasing the ink trapping (t), the L\* increases and the hue of the overprint shifts toward the chromaticity of the first-down ink. While the color difference between the actual and predicted color with ink trapping value of 1.0 is 9.1, the best color match between the predicted and the actual overprint color is 4.7 \( \Delta E \) at the ink trapping (t) of 0.8.

Figure 4 shows SRCs of the predicted spot color overprints with a range of ink trapping, t, from 0.6 to 1 with an increment of 0.1. Color differences (\( \Delta E \)) between predicted overprint colors and the reference are also shown. In this case, as ink trapping (t) assumes a smaller value, overall reflectance of the SRC increases; so is the higher reflectance value of the overprint in the spectral region where the second-down ink absorbs.
Figure 4. Spectral prediction and color difference of SM_7466 (1st ink) overprint

As shown in Figure 5, the hue of the overprint is quite off when ink trapping is 1. As ink trapping assumes a smaller value, differences in hue, chroma, and lightness are all decreased. While the color difference between the actual and predicted color with ink trapping value of 1.0 is 19.9, the best color match between the predicted and the actual overprint color is 3 ΔE at the ink trapping (t) of 0.6.

Figure 5. Predicted vs. the actual spot color overprint by offset (7466 as 1st ink)

Regarding two-color overprints in two ink sequences using uni-tack inks by offset printing, we conclude that colorimetric aim point of the overprint depends on the ink sequence. The ink trapping (t) in the spectral model alters lightness, hue, and chroma of the overprint color. As the ink trapping decreases, the hue of the overprint solid bears more influence of the hue of the first-down ink with lighter tonality.

Table 2 summarizes how the spectral model predicts the overprint color in wet-on-wet printing using uni-tack inks. The color difference is minimized, i.e., about 6 ΔE, when the ink tack is between 0.6 and 0.8.
Table 2. Effect of ink trapping on color difference in wet-on-wet printing

<table>
<thead>
<tr>
<th></th>
<th>SM74 t</th>
<th>ΔE</th>
<th>SM74 t</th>
<th>ΔE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ink</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PMS 1/88 (1st)</td>
<td>0.9</td>
<td>4.7</td>
<td>PMS 1/466 (1st)</td>
<td>0.9</td>
</tr>
<tr>
<td>Tack 11</td>
<td>0.7</td>
<td>8.5</td>
<td>Tack 11</td>
<td>0.6</td>
</tr>
</tbody>
</table>

The same was concluded when we replicated the printing experiment using tack 14 inks. This finding is in reasonable agreement with the gravimetric ink trapping average of 0.7, as reported in a previous study (Chung, Hsu, Clark and Husain, 2009). In other words, by providing two input conditions, i.e., wet-on-wet printing and ink sequence, the spectral-model with an ink trap constant of 0.7 serves as a first-order approximation of overprint color in pre-media software.

4.3 Overprint solid prediction in dry-on-dry ink transfer

This section summarizes results of the overprint prediction based on dry-on-dry ink transfer using the HP Indigo 5500 digital press. Two Pantone colors were printed in two ink sequences. As shown in Table 3, the color difference (5.5 ∆E) due to ink sequence is quite small in comparison to wet-on-wet printing (22.8 ∆E).

Table 3. Effect of ink sequence on overprint color difference in dry-on-dry printing

<table>
<thead>
<tr>
<th>Dry-on-Dry</th>
<th>HP_1788 (1st) L*</th>
<th>a*</th>
<th>b*</th>
<th>HP_7466 (1st) L*</th>
<th>a*</th>
<th>b*</th>
<th>ΔE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Paper</td>
<td>94.1</td>
<td>2.2</td>
<td>-7.7</td>
<td>94.3</td>
<td>2.4</td>
<td>-7.6</td>
<td>0.3</td>
</tr>
<tr>
<td>PMS 1788</td>
<td>50.7</td>
<td>70.5</td>
<td>43.2</td>
<td>62.6</td>
<td>-50.3</td>
<td>-26.3</td>
<td>3.3</td>
</tr>
<tr>
<td>PMS 7466</td>
<td>62.5</td>
<td>-50.3</td>
<td>-26.3</td>
<td>50.6</td>
<td>71.4</td>
<td>46.3</td>
<td>0.1</td>
</tr>
<tr>
<td>Overprint</td>
<td>20.5</td>
<td>16.2</td>
<td>-6.5</td>
<td>22.2</td>
<td>17.0</td>
<td>4.6</td>
<td>5.5</td>
</tr>
</tbody>
</table>

By definition, the gravimetric ink trapping of dry-on-dry ink transfer is one. By specifying dry-on-dry printing, the spectral-model with an ink trap constant of one will do a good job to approximate the overprint color in either ink sequence with a color difference, as shown in Table 4, of less than 6 ∆E.

Table 4. Effect of ink trapping on color difference in dry-on-dry print

<table>
<thead>
<tr>
<th>HP</th>
<th>t</th>
<th>ΔE</th>
<th>HP</th>
<th>t</th>
<th>ΔE</th>
</tr>
</thead>
<tbody>
<tr>
<td>PMS 1788 (1st)</td>
<td>1.0</td>
<td>3.4</td>
<td>PMS 7466 (1st)</td>
<td>1.0</td>
<td>5.4</td>
</tr>
<tr>
<td>0.9</td>
<td>6.5</td>
<td></td>
<td>0.9</td>
<td>5.4</td>
<td></td>
</tr>
<tr>
<td>0.8</td>
<td>11.3</td>
<td></td>
<td>0.8</td>
<td>9.2</td>
<td></td>
</tr>
<tr>
<td>0.7</td>
<td>16.9</td>
<td></td>
<td>0.7</td>
<td>14.9</td>
<td></td>
</tr>
<tr>
<td>0.6</td>
<td>23.2</td>
<td></td>
<td>0.6</td>
<td>21.6</td>
<td></td>
</tr>
</tbody>
</table>

5. Conclusions and Further Research

A technology gap of current pre-media software is its inability to predict spot color overprint. While current pre-media software has no solution in predicting spot color overprint solid, this research shows that it is feasible to predict the color of the overprint solid by means of a spectral model and ink sequence to account for color characteristics of the ink, paper, and how the two inks interact during printing.

To implement the overprint prediction feature, consumable suppliers should standardize spectral characteristics of paper and inks. Inks of the same tack should be used to increase the prediction accuracy. Pre-media software needs to include the printing process and ink sequence as part of the ‘advanced’ output preview preferences. Ink sequence is required in wet-on-wet printing, e.g., offset printing, and a trap value of 0.7 is used to compute the overprint color. If dry-on-dry (electro-photographic) or wet-on-dry (conventional printing using inter-drying station) printing
applies, ink sequence is not required and a trap value of 1.0 is used to compute the overprint color.

The spot color overprint solution, discussed in the paper, should be considered as a first approximation. To further improve the prediction of overprint color, additional spectral-based corrections may include first-surface reflection and ink transparency. Once two-color overprint solids can be predicted with higher accuracy, the next step is to predict the color of any tint combination of two spot colors.

**Acknowledgments**

This has been a journey of discovery and problem solving with regard to the prediction of overprint color in wet-on-wet printing. While the solution is still in the making, the authors wish to recognize their colleagues (Michael Riordan and Daniel Clark) as well as their students (Sri Prakhya and Khalid Husain) who had collaborated with them on the subject in previous publications.

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