Advantages of Spectral Data for Subtractive Color Models

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Abstract

The paper will discuss the spectral data of additive and subtractive color models, the need and use of spectral data for color optimization in the printing industry. The experimental data was conducted to demonstrate the effectiveness of spectral data in color models using the following data sets: cyan + magenta (from a proprietary data set), CMYK - textile, CMYK - digital, CMYK - flexo, and CMYK - offset.

The results of the experimental data indicate that additional data such as spectral gradients and overprints causes the most accurate color models. Therefore, the use of spectral data should be required for color modeling.

Introduction

In the printing industry, the goal of color reproduction is to reproduce an image as close as possible to the original. There are many different types of output systems that all have different specifications. To accurately reproduce colors from the original image, would be painstaking without some form of standardization. In 1993, the International Color Consortium (ICC) was formed by eight industry leaders. The establishment of the ICC was to create, promote and standardize an open, vendor-neutral, cross-platform color management system architecture and components (www.color.org/abouticc.xalter). The creation of the ICC device profile format (.icc file) was born.

To achieve the optimal production output, color profiles of the source and destination systems are common standards in print production. The color management system interprets and converts the data of test charts or patch sets, which represent the characteristic of the production device. Depending on the color model used, the quality of profiles may be better than using simple mathematical interpolations.

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Furthermore, converting spot colors into the target system will be required to simulate overprints with other elements. To do this accurately, this simulation must use a precise color model. To achieve a precise color model the intermediate colors between patch sets must be interpolated. To improve this, the interpolation of a color model can be implemented. The color model can then be used to predict the output of the printer when changing process colors and works more accurately than generic interpolation methods.

Additive vs. Subtractive Color Models

Additive color models or systems are the results of light emission and various intensities of red, green, and blue primaries, which produces the wide-ranging colors on digital medias such as monitors, digital billboards, smartphones, and tablets. The additive spectral distributions can be expressed as well as in a colorimetric color system. The mathematical formulas (Equations 1-5) for additive color models can be seen in Appendix I.

While additive color models begin with black and involve the "addition" of the primary colors, subtractive color models are the opposite. A subtractive color system may be understood as a system with multiple energy absorbing layers (filters, inks, or substrates) in the spectral power distribution. However, it is a physical model describing how absorption of multiple colors reacts upon spectral power distribution. This process cannot be translated into a colorimetric formula (see Appendix 1, Equation 6).

Evaluation of Subtractive Color Models

Based on these considerations, we will compare the accuracy of different subtractive color models with measurement data of different output systems. We used four color models to compare against the experimental data.

The 'L*a*b Full Tones Model' was based on the idealized subtractive color model, using the values of the L*a*b full tones only. As the model requires spectral data, a spectral distribution for each L*a*b value was calculated.

The 'Spectral Full Tones Model' was based on the same subtractive color model as well, but using the spectral data from the full tones. The intermediate values of the gradients were predicted based on the 'Yule- Nielsen' approach.

The 'Spectral Gradients Model' was based on the same subtractive color model. In addition, the spectral data of the gradients were used and the rest of the data were disregarded.

The ‘Full Model’ used an enhanced subtractive color model with two additional parameters to respect opacity and color acceptance. Intermediate values for each channel were interpolated along the gradients. The gradients were then assigned to the model and the parameters for each channel were optimized based on the overprints.

Obtaining the Experimental Data

One data set was based on Cyan and Magenta colors only. Four IT8.7 data sets were used as a reference for the experimental data of the following output systems: CMYK - Textile, CMYK - Digital, CMYK - Flexo, and CMYK Offset. These data sets are characteristics of the different output processes.

In the first experimental data set, the colors cyan and magenta (CM) were chosen to provide a simple visual comparison of data of the full tones, gradients, and overprints. This data set consisted of 81 patches (see Figure 1).

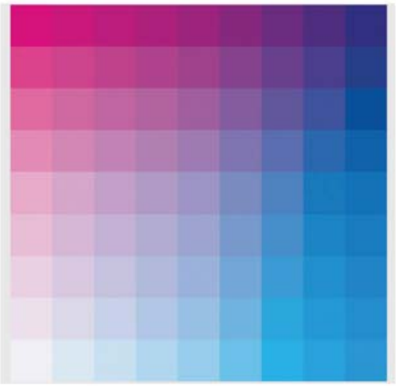

Figure 1 *- Cyan and Magenta patch set*

Procedure

From the original data, the gradients of cyan and magenta were extracted. The reference data was opened and converted using the color model based on the cyan and magenta gradients. This was the predicted data of our cyan-magenta model.

In the next step, only the paper substrate and the full tones of cyan and magenta were used. Following the same process as before, the model of the spectral full tones of cyan and magenta were applied to the reference dataset. This was the predicted data of our simplified cyan-magenta model.

A visual of the process is depicted in Figure 2.

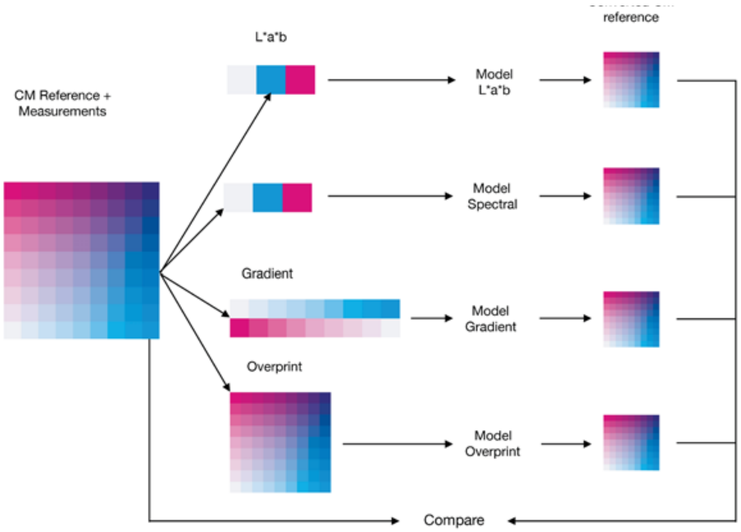

***Figure 2 –** Visualization of Experimental Procedure*

The first visualization of the spectral overprints vs. L*a*b full tones shows original data compared to the predicted values of the L*a*b model. It shows that the L*a*b data itself was not sufficient for an accurate output. There was a significant visual difference between the predicted data of the L*a*b full tones model and the measurement data in the gradients and overprints (see Figure 3). The blocks with color differences above 3 Delta E are marked with a red frame. The block of color outlined in light blue indicated the largest discrepancy of data. The comparison in Delta E was at a maximum of 17.71 and an average of 8.28, which means the deviation of the predicted model is significantly above industry standards.

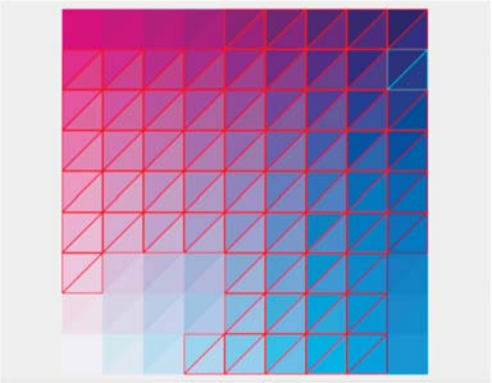

***Figure 3 -** L*a*b Full Tones*

As seen in the sample data, the spectral data of full tones provided more information than the L*a*b data. The Delta E maximum decreased down to 8.10 from 17.71 and the average was decreased to 2.50 from 8.28. The difference between the L*a*b full tones and spectral full tones were significant not only visually (see Figure 4), but the measurement as well between the two datasets. The color accuracy was improved when the spectral data of full tones were added. The prediction of the gradients was significantly better, but still slightly off the measurement data.

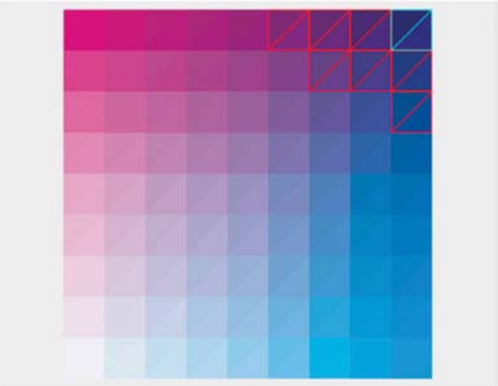

Figure 4 *- Spectral Full Tones*

The spectral data for gradients is obtained, again using the same process. As shown in Figure 5, the data of the spectral gradients improved the color optimization slightly. The maximum remained the same at 8.10 because adding information about the gradients does not affect the full tones. The average decreased to 1.59 from 2.50, which indicated that it was possible to obtain a high-level of color optimization by adding the spectral data of color gradients.

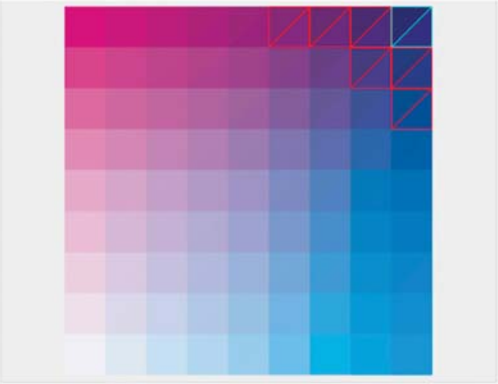

Figure 5 *- Spectral Gradients*

The model respecting the spectral overprints shows the best color accuracy and the output will be extremely close to the original (see Figure 5). The maximum decreased down to 6.32 and the averagedecreased to 1.16. Comparing the results indicate that providing additional data generates more accurate models.

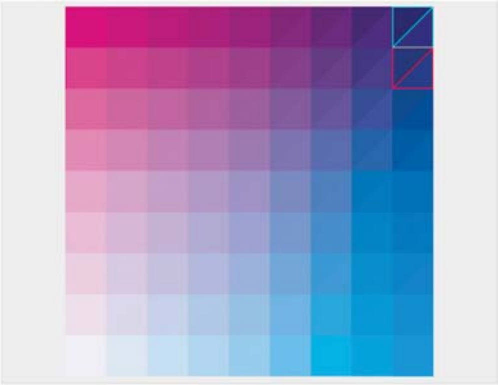

Figure 5 *- Spectral Overprints*

Results & Discussion

The same process was used to obtain the L*a*b full tones, spectral full tones, spectral gradients and spectral overprints of the following four CMYK output processes: textile, digital, flexo and offset. All the data sets demonstrate that the use of only full tone data is not sufficient for color optimization nor for output accuracy. This is especially true when printing on different materials. The data and visual results from each of the different output processes demonstrate that the more data we obtain, the better the results will be for color output and production (see Table 1).

Models	LAB Full-Tones		Spectral Full-Tones		Spectral Gradients		Spectral Overprints	
Data Sets	Max	Avg.	Max	Avg.	Max	Avg.	Max	Avg.
CM	17.71	8.28	8.10	2.50	8.10	1.59	6.23	1.16
CMYK – Textile	18.15	7.12	17.99	6.90	14.64	6.21	6.61	2.47
CMYK – Digital	32.37	15.96	27.55	12.28	15.33	2.27	8.83	1.73
CMYK – Flexo	25.26	8.11	18.81	4.79	18.89	2.80	9.72	2.74
CMYK – Offset	17.71	6.29	12.50	2.58	12.14	1.99	6.52	1.63
Averages	22.28	9.15	16.92	5.81	13.82	2.97	7.6	1.95

Table 1

The bar graphs (Figure 6) illustrates that additional data results in a smaller discrepancy.

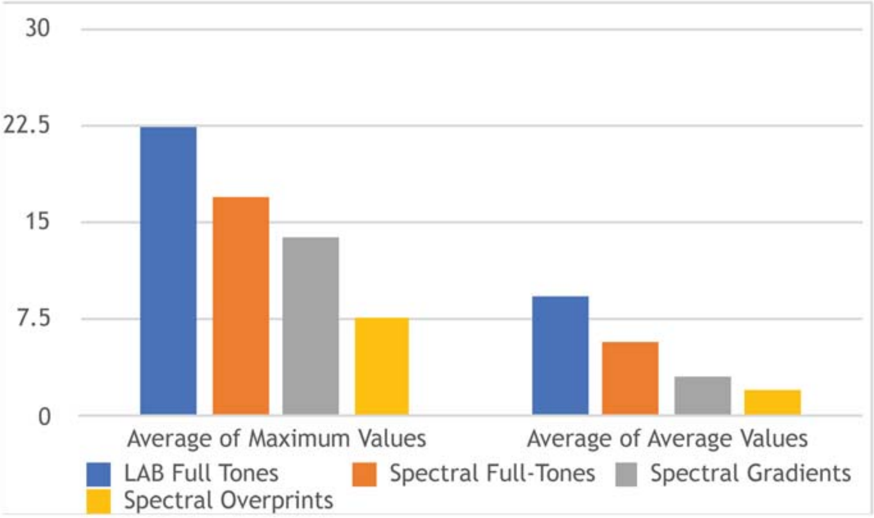

Figure 6 *- The averages of maximum and average values from the four color models.*

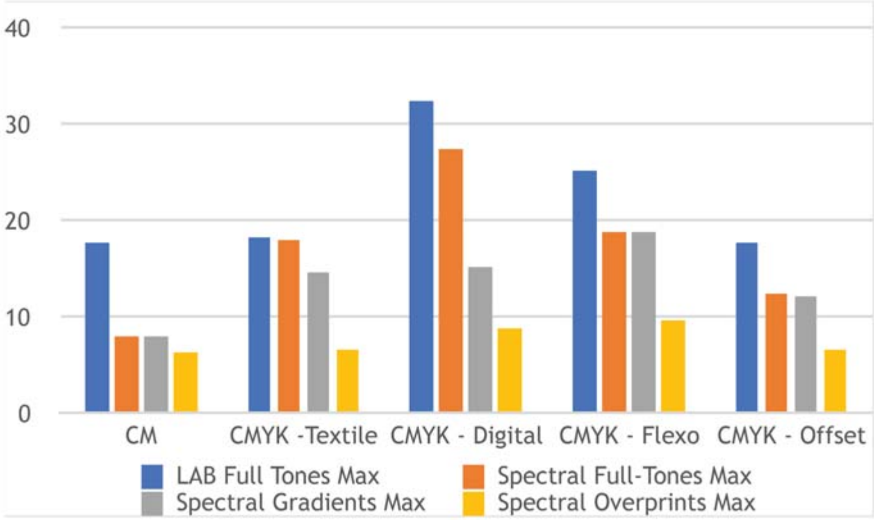

Figure 7 *- Results from the output systems showing maximum values only.*

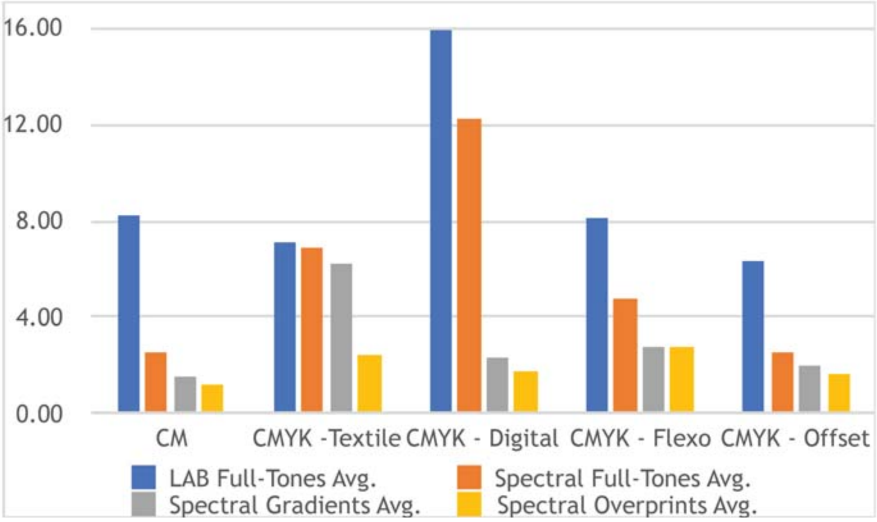

Figure 8 *- Results from the output systems showing average values only.*

Conclusion

As evidenced by the results of the experimental data, spectral data should be required to model subtractive color systems to obtain the best prediction and should be implemented in production workflows to improve proofing systems and output quality. It is essential to include color gradients because the linearity of a system is not predictable.

The (basic) subtractive color model must be extended to get more accurate predictions (e.g. by opacity and color acceptance parameters). As explained, the enhanced color model only uses two additional parameters to improve the spectral gradients model. This means that only a few overprints are required for the optimization of these parameters. This allows the reduction of the number of color patches significantly to still achieve a good color model.

Glossary

Additive Colors – Red, green, and blue primaries

Colorimetry – The science of predicting color matches as the human eyes see or perceive it.

Color Model – A model that describes how colors appear on either a digital screen (e.g. tablet, TV, monitor, smartphone) or on paper.

Color Patch – Color values of an output system, e.g. CMYK values.

Data Set – A complete set of patches and their measurements.

Delta E – Unit of measure that calculates and quantifies the difference between two colors: one is a reference color and the other, is a sample color that attempts to match it. This is based on the L*a*b coordinates. The higher the Delta E, the greater the difference between the two samples being compared.
(http://www.colorwiki.com/wiki/Delta_E)

Full Tones – 100% of a singular additive or subtractive color (ex. 100% cyan or 100% magenta).

L*a*b Full Tones – L*a*b values of a 100% singular additive or subtractive color.

Overprint – Combination of at least two different colors.

Spectral Data – Additional data or measurements obtained by spectrophotometers.

Spectral Full Tones – Spectral data obtained from a singular additive or subtractive color.

Spectral Gradients – Spectral data from intermediate colors of an additive or subtractive color.

Spectral Overprints – The inclusion of spectral full tones, spectral gradients, and combinations of (an) additive color(s) and/or subtractive color(s).

Spot Color – A special premixed ink that is used instead of, or in addition to, process inks. The special premixed ink requires its own printing plate on a printing press.
(https://helpx.adobe.com/indesign/using/spot-process-colors.html)

Subtractive Colors – Cyan, magenta, and yellow; These colors “subtract” or absorb light to produce various colors.

Test Chart – Color patches in a form (e.g. TIFF file) which can be printed and measured.

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Appendix I

The energy of light denoted by E.
A wavelength of light denoted by lambda.
Colorimetric data characterized by X = R, Y = G, and Z = B.

Equation 1
$E = E_1 + E_2$

Equation 2
$E(\lambda) = E_1(\lambda) + E_2(\lambda)$

Equation 3

$$\begin{aligned}
\begin{bmatrix} X \\ Y \\ Z \end{bmatrix}(E_1 + E_2) &= \int_\lambda \begin{bmatrix} \overline{x} \\ \overline{y} \\ \overline{z} \end{bmatrix}(\lambda)(E_1 + E_2)(\lambda)\, d\lambda \\
&= \int_\lambda \begin{bmatrix} \overline{x} \\ \overline{y} \\ \overline{z} \end{bmatrix}(\lambda)E_1(\lambda) + \overline{x}(\lambda)E_2(\lambda)\, d\lambda \\
&= \int_\lambda \begin{bmatrix} \overline{x} \\ \overline{y} \\ \overline{z} \end{bmatrix}(\lambda)E_1(\lambda)\, d\lambda + \int_\lambda \begin{bmatrix} \overline{x} \\ \overline{y} \\ \overline{z} \end{bmatrix}(\lambda)E_2(\lambda)\, d\lambda \\
&= \begin{bmatrix} X_1 \\ Y_1 \\ Z_1 \end{bmatrix} + \begin{bmatrix} X_2 \\ Y_2 \\ Z_2 \end{bmatrix}
\end{aligned}$$

Equation 4

Resulting in the following equation:

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix} = \begin{bmatrix} X_1 \\ Y_1 \\ Z_1 \end{bmatrix} + \begin{bmatrix} X_2 \\ Y_2 \\ Z_2 \end{bmatrix}$$

Instead of adding spectral distribution we may use XYZ data to predict the colorimetric result. The additive XYZ color system can then be used for calculation.

Equation 5
Example:

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix} = \begin{bmatrix} X_R & X_G & X_B \\ Y_R & Y_G & Y_B \\ Z_R & Z_G & Z_B \end{bmatrix} \begin{bmatrix} R^\gamma \\ G^\gamma \\ B^\gamma \end{bmatrix}$$

The integral of the product cannot be simplified nor resolved into a colorimetric formula. Therefore, a colorimetric equivalent cannot be found and an accurate model for subtractive color mixing must be based on spectral data.

This would be the idealized model, but may not reflect practical applications. To respect special print properties such as opacity and color acceptance this model must be enhanced.