Research on Spectral Reflection Characteristics of Overprinted Color Inks and the Numeric Compensation to the Theoretical Model

Ji Qi, Yang Jin, Xinggen Qian and Yusheng Lian

Abstract The trapping of several color inks on substrate is a general phenomenon in multicolor printing. As fundament of color reproduction, the spectral characteristics of mono-color ink and of overprinted color inks are close related with the color reproduction. Theoretically, the spectral reflectance of overprinted color inks can be obtained from spectral reflectance of inks and of substrate. But the error appears, because some influences from ink, paper and other external conditions exist. Based on the measured spectral reflectance of Cyan/Magenta/Yellow/Black ink, of paper and of the overprinted inks, the spectral difference between measured and the theoretical data is compared and analyzed. The spectral difference data is transformed to DCT coefficients and filtered. Applying the compensation data from inverse DCT curve, the corresponding color errors (ΔE) are very small.

Keywords Spectrum characteristics · Ink trapping · Color reproduction · Numerical compensation

1 Introduction

In color reproduction of printing, a color can be reproduced and apperceived rely on its light spectrum, which comes from the printed paper or other substrates. The spectrum of the light from the paper is related closely to the spectrums of light source, of the reflection/transmission/absorption rates of inks and of the paper. As showed in Fig. 1, the spectral reflectance of a ink film on paper, $r_1(\lambda)$ depends on spectral reflectance of paper $r_P(\lambda)$ and spectral transmission rate of ink film $\tau_{Ink}(\lambda)$:

$$r_1(\lambda) = \frac{\Phi_0(\lambda) \times \tau_{Ink}(\lambda) \times r_P(\lambda) \times \tau_{Ink}(\lambda)}{\Phi_0(\lambda)} = \tau_{Ink}(\lambda)^2 \times r_P(\lambda) \quad (1)$$

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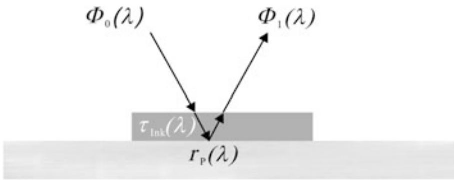

Fig. 1 Light transmission path of a single ink film on paper

If the spectral reflectance of a single ink film on paper $r_1(\lambda)$ and the spectral reflectance of the paper $r_P(\lambda)$ are measured, the transmission ratio of the ink $\tau_{Ink}(\lambda)$ can be obtained:

$$\tau_{Ink}(\lambda) = \sqrt{\frac{r_1(\lambda)}{r_P(\lambda)}} \tag{2}$$

Formula 3 describes the relationship among spectral reflectance ratio of n layers of ink films on paper and the spectral transmission ratios of every ink layers and the spectral reflectance of paper, the transmission ratios can be computed out from the ratios of single layer of inks and of paper:

$$r_n(\lambda) = \tau_{Ink1}(\lambda)^{2\times n} \times \tau_{Ink2}(\lambda)^{2\times n} \times \cdots \times \tau_{Inkn}(\lambda)^{2\times n} \times r_P(\lambda) \tag{3}$$

But the influences from ink, paper and others lead to errors in the predicted spectral reflectance of trapped inks. Researchers have made efforts to construction models for more accurate results [1–3].

2 The Measured and Theoretical Spectral Data of Single- and Multi-layers of Ink

On a printability tester (IGT AIC2-2000), applying process color inks of CMYK ("New Caps"/DIC), samples are printed on coated paper (128 g/m^2). The thickness of the ink films are 1.2 μm. The samples are printed with only one ink on paper (K/C/M/Y), or more layers of ink on paper (M + Y/C + Y/C + M/K + C/K + M/K + Y, K + M + Y/K + C + Y/K + C + M/C + M + Y, K + C + M + Y). The sequence of the printed color ink is K → C → M → Y. The spectral reflectance of every 15 samples and of paper is measured with an X-Rite 530 spectral photometer. Every sample is measured at 5 positions and the average values are applied. The measured spectral curves are showed as Fig. 2.

Based on the measured spectral reflectance of single-layer of CMYK inks and of paper, the spectral transmission rates of the inks $\tau_{Ink,\ i}$ (λ) can be obtained, wherein i = 1/2/3/4 correspond separately to C/M/Y/K. According to Formula 3,

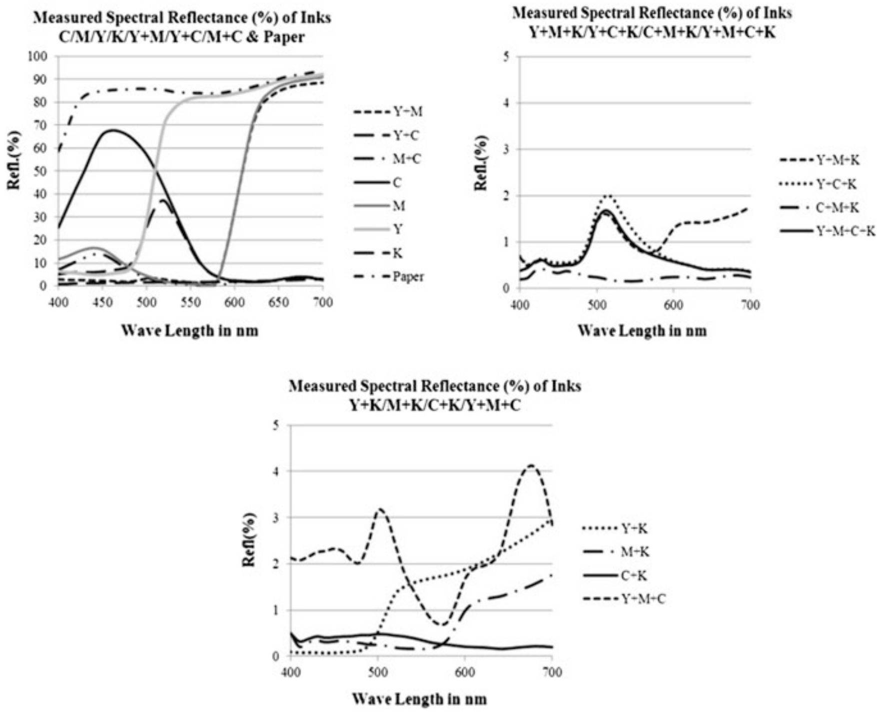

Fig. 2 Measured spectral reflectance of paper and of single or multi-layers of CMYK inks

the spectral reflectance of trapped ink *r* (λ) can be computed out. These theoretical spectral data are showed in Fig. 3.

3 The Error of Spectral Data and Its Numeric Compensation

According to the measured and theoretical data of spectral reflectance, error data can be obtained, which comes from the subtraction of the theoretical from the measured reflectance data. The curves of error (Difference) data are showed in Fig. 4.

As we have analyzed, the wrong spectral reflection and absorption of inks, i.e. the insufficiency or excess of spectral reflection (or absorption) ratio of the ink in relevant spectral ranges, the spectral influence of the first ink layer, the spectral reflectance of paper, all of these factors lead to the spectral differences. The color error ΔE under CIE 1976 L*a*b* system of theoretical and measured spectral data are listed in Table 1. The average color error is 10.11, while the maximal value reaches 17.47 and the minimal one is 1.74.

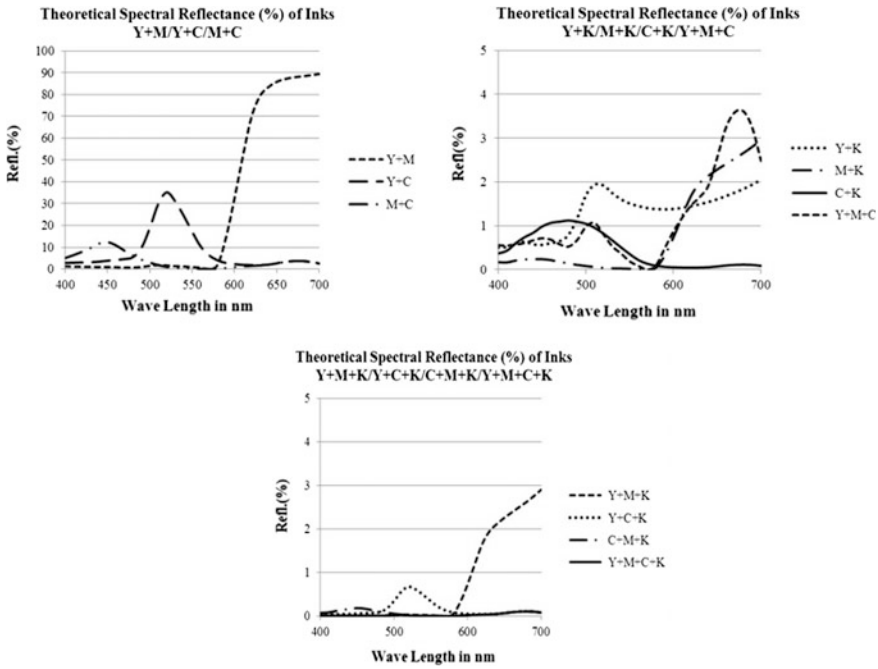

Fig. 3 Theoretical spectral reflectance of multi-layers of CMYK inks

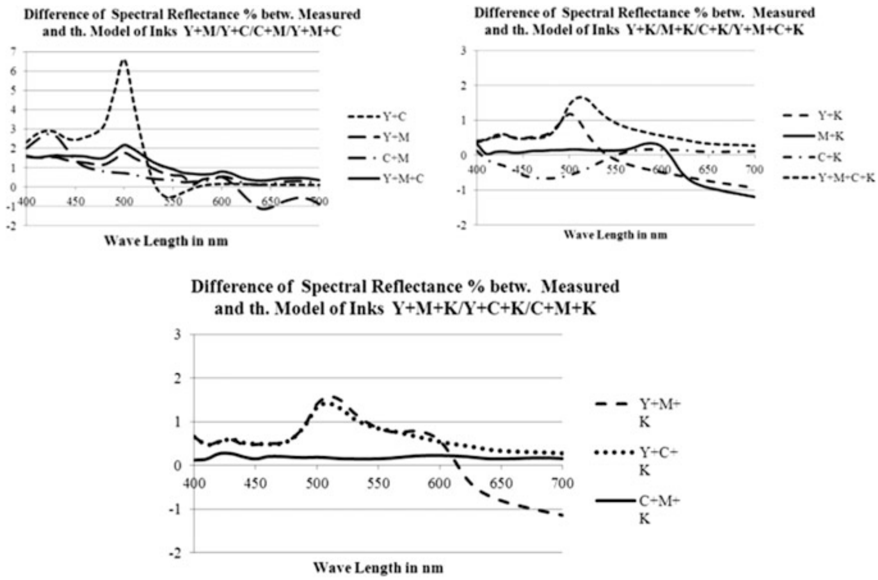

Fig. 4 Difference of the measured and theoretical data of spectral reflectance

Table 1 Color error of theoretical and measured spectral data

Color	Y + M	Y + C	M + C	Y + K	M + K	C + K
Δ*E*	13.40	9.86	4.22	11.69	5.38	8.01
Color	Y + M + K	Y + C + K	C + M + K	C + M + Y	C + M + Y + K	ΔE_{Av}
Δ*E*	17.47	11.51	1.74	13.51	14.46	10.11

In application of Neugebauer Equation for the prediction of printing color, the predictive precision depends on the color accuracy of the "color elements", i.e. the solid printed color. If the colors of elements are with errors as listed in Table 1, the computing of reproduced color is also incorrect. For the precise computing of colors, either the curves of spectral error serve as compensation curves or the measured spectral curves are directly applied in color computing. The spectral error curves or the measured spectral curves can be fitted as mathematical functions.

Because the interval of the wave length (λ as argument) is constant, the spectral reflectance or spectral error (difference) data can be transformed in frequency domain. The spatial data can be described as a series of coefficients in frequency. The original data can be complete restored through the inverse transform. The usage of frequency data have their advantages, such as can be filtered, smoothed etc. To avoid complex data (like in FFT), 1 dimensional Discrete Cosine Transformation (DCT) is applied. After DCT, every spectral error curve has 31 coefficients; they are showed in Fig. 5. It can be seen, that most of the coefficients in the high frequency range are very small, so they can be filtered and set to zero. Through the inverse DCT, the unfiltered coefficients are transformed back to the original data. If unfiltered DCT coefficients are applied, the absolute error values of the restored data are smaller than 5×10^{-10}; if the DCT coefficients whose absolute values less than 0.05 are filtered, the maximal errors of absolute values are less than 0.071, the curves can be high precisely recovered.

Applying the data which from filtered coefficients and inverse DCT, add them with the spectral data from model, the model-based spectral data are corrected. The color error (Δ*E*) based on corrected spectral data and the original measured data are less than 1.89 and are listed in Table 2.

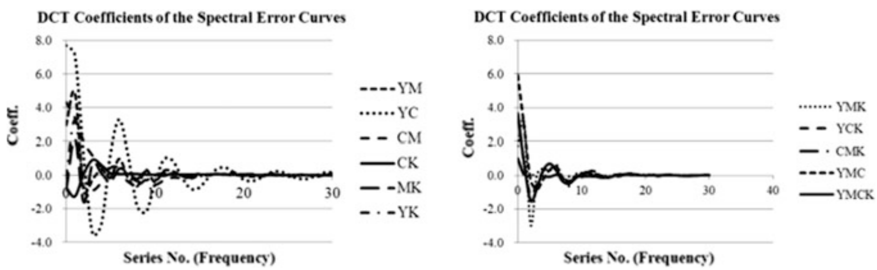

Fig. 5 DCT coefficients of the spectral error curves

Table 2 Color error based on corrected and measured spectral data

Color	Y + M	Y + C	M + C	Y + K	M + K	C + K
ΔE	0.00047	0.00043	0.00059	0.02916	0.0156	1.8939
Color	Y + M + K	Y + C + K	C + M + K	C + M + Y	C + M + Y + K	ΔE_{Av}
ΔE	0.2027	0.6342	0.0606	1.1897	1.2252	0.4775

4 Conclusions

Under the influences of some factors, the spectral reflectance of solid printed ink and overprinted inks has more or less difference with the ideal theoretical value. Based on the measured and theoretical spectral data, the spectral characteristics of trapped printing color are analyzed. According to the difference between measured and theoretical data (spectral error data), compensation-curves are fitted in frequency domain. The curves can be applied to improve the accuracy of prediction of color.

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