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A novel spectral trapping model for color halftones

Sasan Gooran[1] *and Shahram Hauck*[2]

[1] Dept. of Science and Technology, Linköping University,
Campus Norrköping, 601 74 Norrköping, Sweden sasan.gooran@liu.se

[2] Dept. of Informatics and Media, Beuth University of Applied Sciences Berlin,
Luxemburger Straße 10, 13353 Berlin, Germany shauck@beuth-hochschule.de

Abstract

The amount of trapping has a great impact on the gray balance and color reproduction of printed products. The conventional trapping models are print density based and give percentage values to estimate the effect of trapping. In an earlier research, a spectral trapping model was proposed, that defines the trapping effect as the ΔE^*_{ab} colorimetric differences between the real ink overlap (measurements) and the ideal ink overlap. All the trapping models proposed so far, however, only calculate the trapping value for full-tone (solid) ink overlap. As the trapping value for full-tone ink overlap could be overestimating the actual ink trapping effect for halftones, it is important to be able to also approximate the trapping value of color halftones. Furthermore, for a detailed gray balance shift analysis, there is a need to estimate the trapping effect for specific color halftones. In the present paper, we propose a novel spectral trapping model that delivers the trapping value as ΔE^*_{ab} color difference for color halftones taking into account secondary and tertiary ink overlap. The results of the experiments show that the trapping values for color halftones are much smaller than the corresponding trapping value at full tone. The trapping value of halftones, besides other common quality parameters, should still be considered if some quality inaccuracy, such as gray balance shift, occurs in a print production.

Keywords: ink trapping, halftoning, gray balance, color difference (ΔE^*_{ab}), printing quality

1. Introduction

In a multicolor offset printing machine, the process inks (KCMY) are printed consecutively on the substrate in one printing unit after the other. The dots in different ink units are printed either isolated or partly or completely overprinted and the overprinted inks are printed wet on wet. The thickness or the amount of the second printed ink on the first one is not the same as when the second ink is printed on the paper, which makes the ink overlap not be ideal. This phenomenon is called trapping. Trapping varies due to different parameters such as ink temperature, dampening, printing speed, etc. Trapping affects the gray balance and the color appearance (secondary and tertiary colors) of the printed products. Therefore, it is very important to have an explicit value for measuring trapping.

There are different conventional trapping models, such as Preucil (1953), Brunner (Du Pont, 1979), Ritz (1996), Hamilton (1986) and Viggiano and Prakhya (2008), which are named after their inventors, and give a trapping value based on the amount of the second printed ink on top of the first one in percent. There is also a spectral trapping model proposed in literature that presents the trapping value as ΔE^*_{ab} color difference (Hauck and Gooran, 2011; 2013). Hence, the latter model delivers more useful and meaningful trapping value for the press machine operators than the conventional trapping models. As also been shown in Hauck and Gooran (2011), the dynamic range of this model is larger than the conventional trapping models. However, all trapping models proposed so far, including the aforementioned spectral trapping model, only calculate the trapping value for full-tone (solid) ink overlap. However, the trapping value for full-tone ink overlap could be overestimating the actual ink trapping that might occur for halftones. Furthermore, for a detailed gray balance shift analysis, there is a need to estimate the trapping effect for specific color halftones.

In the present paper, we propose a novel spectral trapping model that delivers the trapping value as ΔE^*_{ab} color difference for color halftones and takes into account secondary and tertiary ink overlap. We start with a short introduction to the previously published spectral trapping model for full-tone ink overlap, following with a description of the proposed spectral trapping model for color halftones. The results of the model are presented and discussed and finally, summary and conclusion of the paper are given.

2. The spectral trapping model for full-tone ink overlap

The spectral trapping model for full-tone ink overlap is based on the reflectance spectra and presents the trapping value as the ΔE^*_{ab} color difference (Hauck and Gooran, 2011). The color difference is computed between the CIELAB values of the ideal ink overlap and the measured (real) ink overlap. For a single printed ink, for example cyan or magenta in Figure 1, the reflectance spectra $R_c(\lambda)$ and $R_m(\lambda)$ can be calculated by Equations [1] and [2], respectively.

$$R_c(\lambda) = T_c^2(\lambda) \cdot R_p(\lambda) \quad [1]$$

$$R_m(\lambda) = T_m^2(\lambda) \cdot R_p(\lambda) \quad [2]$$

Here $R_p(\lambda)$, $T_c(\lambda)$ and $T_m(\lambda)$ denote the reflectance of the paper, the transmittance of full-tone cyan and the transmittance of full-tone magenta, respectively. Note that the incoming light passes through the ink layer twice before being reflected back, and that is why the transmittances are squared in Equation [1] and [2]. The reflectance of the overlapped inks, $R_b^{ideal}(\lambda)$, assuming ideal ink overlap, in this case magenta printed on cyan (giving blue) as shown to the right in Figure 1, is calculated by Equation [3].

$$R_b^{ideal}(\lambda) = T_c^2(\lambda) \cdot T_m^2(\lambda) \cdot R_p(\lambda) \quad [3]$$

Here $R_b^{ideal}(\lambda)$ represents the spectral reflectance of full-tone blue (cyan + magenta), assuming ideal ink overlap.

Inserting Equations [1] and [2] into Equation [3] gives Equation [4], which is the calculated overlapped spectral reflectance based on the reflectance of the single inks printed on paper and the reflectance of the paper, assuming ideal ink overlap has occurred.

$$R_b^{ideal}(\lambda) = \frac{R_c(\lambda) \cdot R_m(\lambda)}{R_p(\lambda)} \quad [4]$$

For the calculation of trapping, both the measured, i.e. $R_b^{measured}(\lambda)$, and the ideal overlapped spectral reflectance, i.e. $R_b^{ideal}(\lambda)$ from Equation [4], are needed. These two reflectance spectra are therefore converted to CIELAB values. The trapping value in this trapping model is defined as the ΔE^*_{ab} color difference between these two CIELAB values. In this paper, ΔE^*_{ab} according to the CIE 1976 color difference formula (Equation [5]) is used. However, other color difference formulas, such as ΔE^*_{94} or ΔE^*_{00}, can also be used.

$$\Delta E^*_{ab} = \sqrt{(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2} \quad [5]$$

The trapping value for red and green can be calculated correspondingly.

For tertiary ink overlap, i.e. CMY, the proposed model needs to include three inks. Since the yellow ink is usually and according to ISO 12647-2:2013 (International Organization for Standardization, 2013) printed on top of cyan and magenta inks (giving blue), the tertiary ink overlap can be considered as full-tone blue and full-tone yellow ink overlap. Therefore, Equation [6] shows the ideal spectral reflectance for full-tone CMY.

$$R_{cmy}^{measured}(\lambda) = \frac{R_b(\lambda) \cdot R_y(\lambda)}{R_p(\lambda)} \quad [6]$$

The trapping value is calculated, as before, by Equation [5] between the CIELAB values of the ideal full-tone CMY ink overlap and the real (measured) full-tone CMY ink overlap.

It has been shown in Hauck and Gooran (2011) that the correlation factors between the trapping value according to ΔE^*_{ab} and the Ritz (1996) and Preucil (1953) models, being the most known and important conventional trapping models, are 93 % and 96 %, respectively. Furthermore, it has also been shown that the dynamic range of the proposed spectral trapping model for full-tone ink overlap is larger than that of both the Preucil and the Ritz model, which makes the spectral model even more useful for the press operators.

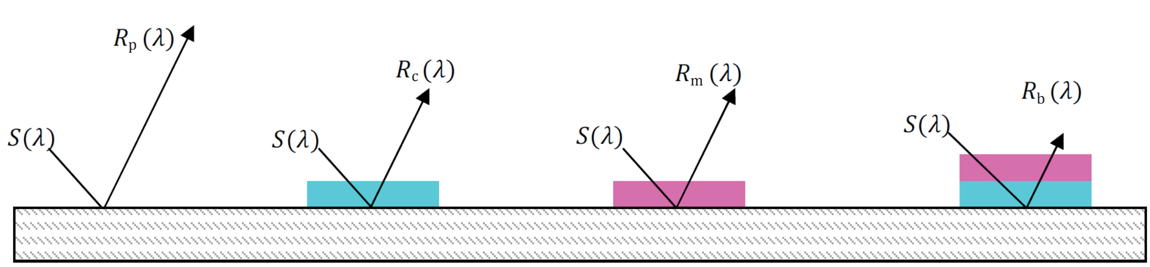

Figure 1: A schematic of a full-tone ink print, from left: paper, cyan, magenta and ideal ink overlap

3. The novel spectral trapping model for color halftones

As discussed in Section 2, all trapping models proposed so far, calculate the trapping value only for full-tone ink overlap. As will be shown later in Section 4, the trapping values calculated for full-tone ink overlap overestimate the actual trapping occurring in color halftones. Furthermore, for a better analysis of printing quality, a thorough understanding of trapping value for halftones can be very useful. For example, the gray balance shift, which is one of the most important quality criterion in color printing, can be better analyzed if the trapping value for halftones are also known in addition to dot gain and other basic parameters.

Like in the spectral trapping model for full-tone ink overlap, in the proposed model the trapping value is defined as the color difference ΔE^*_{ab} between the ideal and the real ink overlap. Since the proposed model is supposed to be used for color halftones having different primary ink combinations, there is a need for a color prediction model to approximate the reflectance spectra of a color halftone. The used color prediction model is described in the following subsection.

3.1 The used color prediction model

Neugebauer equation (Neugebauer, 1937), Equation [7], is commonly used to approximate the average reflectance spectra of a color halftone.

$$R_{\text{average}}(\lambda) = \sum_i a_i R_i(\lambda) \qquad [7]$$

where i denotes the so-called Neugebauer primaries (NPs): the substrate with no ink, single ink and multi-ink overlap combinations, summing up to a total of 2^m primaries, m being the total ink number; $R_i(\lambda)$ is the spectral reflectance of each NP at full-tone, a_i is the corresponding fractional ink area coverage of the NPs and $R_{\text{average}}(\lambda)$ is the calculated/approximated spectral reflectance of the color halftone. Assuming a semi-stochastic ink overlap behavior between primary inks, Demichel equations (Demichel, 1924) can be used to calculate a_i. However, Neugebauer equation presented in Equation [7] does not take into account the effect of dot gain if a_i coefficients are calculated using the reference (commanded) ink coverage of the primary inks in the digital bitmap. Therefore, the model we propose to use as the color prediction model starts by first calculating the effective dot coverage using Murray-Davies formula (Murray, 1936), Equation [8].

$$R_{\text{MD}}(\lambda) = aR_i(\lambda) + (1-a)R_{\text{p}}(\lambda) \qquad [8]$$

where R_{p}, R_i and a denote the reflectance spectrum of the paper, the reflectance spectrum of the full-tone ink, and the coverage of the ink, respectively. If $R_{\text{MD}}(\lambda)$ is replaced by the real (measured) reflectance spectra of a halftone in Equation [8], the effective ink coverage of the ink can be calculated by Equation [9].

$$a_{\text{eff}}(\lambda) = \frac{R_{\text{measured}}(\lambda) - R_{\text{p}}(\lambda)}{R_i(\lambda) - R_{\text{p}}(\lambda)} \qquad [9]$$

Therefore, in the proposed model, Equation [9] is used to find the effective coverage for the primary inks, i.e. cyan, magenta and yellow. Notice that, in our proposed model, as seen in Equation [9], the effective coverages are wavelength dependent and all multiplications and divisions are performed element-wise. Assuming the reflectance spectra being measured from 400 nm to 700 nm with a step of 10 nm, all spectra and thereby the effective coverages are 1 × 31 vectors. This is something that differs this used color prediction model from many of the other color prediction models.

After the effective coverages of the primary inks have been calculated, Demichel equations can be used to find the coverage of the Neugebauer primaries (NPs), see Equation [10].

$$\begin{cases} a_{\text{p}}(\lambda) = (1 - a^{\text{c}}_{\text{eff}}(\lambda)) \cdot (1 - a^{\text{m}}_{\text{eff}}(\lambda)) \cdot (1 - a^{\text{y}}_{\text{eff}}(\lambda)) \\ a_{\text{c}}(\lambda) = (a^{\text{c}}_{\text{eff}}(\lambda)) \cdot (1 - a^{\text{m}}_{\text{eff}}(\lambda)) \cdot (1 - a^{\text{y}}_{\text{eff}}(\lambda)) \\ a_{\text{m}}(\lambda) = (1 - a^{\text{c}}_{\text{eff}}(\lambda)) \cdot (a^{\text{m}}_{\text{eff}}(\lambda)) \cdot (1 - a^{\text{y}}_{\text{eff}}(\lambda)) \\ a_{\text{y}}(\lambda) = (1 - a^{\text{c}}_{\text{eff}}(\lambda)) \cdot (1 - a^{\text{m}}_{\text{eff}}(\lambda)) \cdot (a^{\text{y}}_{\text{eff}}(\lambda)) \\ a_{\text{r}}(\lambda) = (1 - a^{\text{c}}_{\text{eff}}(\lambda)) \cdot (a^{\text{m}}_{\text{eff}}(\lambda)) \cdot (a^{\text{y}}_{\text{eff}}(\lambda)) \\ a_{\text{g}}(\lambda) = (a^{\text{c}}_{\text{eff}}(\lambda)) \cdot (1 - a^{\text{m}}_{\text{eff}}(\lambda)) \cdot (a^{\text{y}}_{\text{eff}}(\lambda)) \\ a_{\text{b}}(\lambda) = (a^{\text{c}}_{\text{eff}}(\lambda)) \cdot (a^{\text{m}}_{\text{eff}}(\lambda)) \cdot (1 - a^{\text{y}}_{\text{eff}}(\lambda)) \\ a_{\text{k}}(\lambda) = (a^{\text{c}}_{\text{eff}}(\lambda)) \cdot (a^{\text{m}}_{\text{eff}}(\lambda)) \cdot (a^{\text{y}}_{\text{eff}}(\lambda)) \end{cases} \qquad [10]$$

where, indices p, c, m, y, r, g, b and k denote the following eight NPs, paper, cyan, magenta, yellow, red (magenta + yellow), green (cyan + yellow), blue (cyan + magenta) and black (cyan + magenta + yellow), respectively. The effective coverages $a^{\text{c}}_{\text{eff}}(\lambda)$, $a^{\text{m}}_{\text{eff}}(\lambda)$ and $a^{\text{y}}_{\text{eff}}(\lambda)$ are calculated using Equation [9].

Notice that Equation [10] is written for three primary inks, giving $2^3 = 8$ NPs. If two primary inks were involved, only the coverages of 4 NPs were needed to be calculated by Demichel equations. Notice also that, as discussed above, even in Equation [10], the multiplications are performed element-by-element and therefore the coverage of NPs are also wavelength dependent and represented by vectors. The coverage of NPs calculated in Equation [10] can now be used in Neugebauer equation (Equation [7]) to approximate the reflectance spectrum of a color halftone, see Equation [11].

$$\begin{aligned} R^{\text{model}}_{\text{halftone}}(\lambda) = {} & a_{\text{p}}(\lambda)R_{\text{p}}(\lambda) + a_{\text{c}}(\lambda)R_{\text{c}}(\lambda) + a_{\text{m}}(\lambda)R_{\text{m}}(\lambda) \\ & + a_{\text{y}}(\lambda)R_{\text{y}}(\lambda) + a_{\text{r}}(\lambda)R_{\text{r}}(\lambda) + a_{\text{g}}(\lambda)R_{\text{g}}(\lambda) \\ & + a_{\text{b}}(\lambda)R_{\text{b}}(\lambda) + a_{\text{k}}(\lambda)R_{\text{cmy}}(\lambda) \end{aligned} \qquad [11]$$

where $a_i(\lambda)$ is the effective coverage of NPs calculated using Equation [10], and $R_i(\lambda)$ is the reflectance spectrum of the NPs at full tone. Notice again that the multiplications in Equation [11] are also performed element-by-element.

Before we use this model to approximate the trapping value described in Section 3.2, the accuracy of the proposed model needs to be examined. Since the proposed trapping model is supposed to be practically useful, it is important that the number of patches (i.e. training samples) to be measured is limited. Therefore, as will be discussed in more detail in Section 4.2, to examine the model we have chosen three color halftones using different CMY ink coverage combinations, namely (a_c = 25 %, a_m = 18.4 %, a_y = 18.6 %), (a_c = 50 %, a_m = 40.9 %, a_y = 40.1 %) and (a_c = 75 %, a_m = 68.9 %, a_y = 69.9 %). For each halftone, we firstly used Equation [9] to calculate the effective ink coverage for each primary ink. Then, Equation [10] was used to find the ink coverage for all eight NPs and thereafter Equation [11] was used to approximate/calculate the spectral reflectance of the halftone. The ΔE^*_{ab} color differences between the CIELAB values of this calculated and the measured reflectance spectrum of the color halftones were calculated, being 0.52, 0.94 and 2.72 for these three color halftones, respectively, giving the well acceptable average of 1.39 ΔE^*_{ab}. As expected, the color prediction model is less accurate for darker halftones, giving the higher value of 2.72 ΔE^*_{ab}. This color difference is still acceptable, especially when considering the fact that only 17 patches were needed to be measured to predict the colors. For these calculations, we needed to measure eight patches to be used in Equation [11]. These eight patches are paper (1 patch), the primary inks at full tone (3 patches), the secondary inks at full tone (3 patches), and the tertiary ink (CMY) at full tone (1 patch). We also needed to measure nine patches to find the effective coverage for primary inks by Equation [9]. These nine patches are halftones of cyan at 25 %, 50 % and 75 % (3 patches), halftones of magenta at 18.4 %, 40.9 % and 68.9 % (3 patches), and halftones of yellow at 18.6 %, 40.1 % and 69.9 % (3 patches).

Due to the fact that not many patches are needed to be measured and also the simplicity of the proposed color prediction model, this model is used in this paper to predict the color of halftones and thereby approximating the trapping value, which is described in the following subsection.

3.2 Approximating trapping value of color halftones

In order to approximate the trapping value of color halftones, like in the spectral trapping model for full-tone inks described in Section 2, two different ink overlaps have to be taken into account, namely ideal ink overlap and real ink overlap. Therefore, for red, green, blue and black (cyan + magenta + yellow) halftones, the model presented in Section 3.1 is used to calculate the spectral reflectance of the halftones. By setting the measured reflectance spectra of the paper, primary ($R_c(\lambda)$, $R_m(\lambda)$, $R_y(\lambda)$), secondary ($R_r(\lambda)$, $R_g(\lambda)$, $R_b(\lambda)$), and tertiary ($R_{cmy}(\lambda)$) inks at full tone in the right-hand side of Equation [11], the real reflectance spectrum of a halftone is approximated, which is denoted by $R_{\text{halftone}}^{\text{real}}(\lambda)$.

Then, by setting

$$R_r(\lambda) = R_r^{\text{ideal}}(\lambda) = \frac{R_m(\lambda) \cdot R_y(\lambda)}{R_p(\lambda)} \text{ (similar to Equation [4])},$$

$$R_g(\lambda) = R_g^{\text{ideal}}(\lambda) = \frac{R_c(\lambda) \cdot R_y(\lambda)}{R_p(\lambda)} \text{ (similar to Equation [4])},$$

$$R_b(\lambda) = R_b^{\text{ideal}}(\lambda) = \frac{R_c(\lambda) \cdot R_m(\lambda)}{R_p(\lambda)} \text{ (Equation [4]), and}$$

$$R_{cmy}(\lambda) = R_{cmy}^{\text{ideal}}(\lambda) = \frac{R_b(\lambda) \cdot R_y(\lambda)}{R_p(\lambda)} \text{ (Equation [6])}$$

in the right-hand side of Equation [11], the ideal reflectance spectrum, called $R_{\text{halftone}}^{\text{ideal}}(\lambda)$ is also calculated for the same halftone. The ΔE^*_{ab} color difference between the CIELAB values of $R_{\text{halftone}}^{\text{real}}(\lambda)$ and $R_{\text{halftone}}^{\text{ideal}}(\lambda)$ is now calculated and used as an approximation of the trapping value of the color halftone.

4. Results and discussion

In order to study the trapping effect on color halftones, a number of experiments were carried out. The experiments were done using a sheet-fed offset printing machine (Speedmaster 74) and high glossy coated papers on both sides; AM halftoning at lpi = 150 and dpi = 2 400 was used. The color channels were halftoned at different angles, ensuring a semi-stochastic ink overlap behavior between primary inks, for which Demichel equations can be used.

In this section the results of the approximation of the trapping values for full-tone ink overlap, and also color halftones, as well as an analysis of the results are given.

4.1 Full-tone ink trapping value

Table 1: The trapping value for full-tone R, G, B and CMY ink overlap

Trapping value	R	G	B	CMY
ΔE^*_{ab}	14.7	7.2	13.9	17.4

For full-tone red (R), green (G) and blue (B) trapping values, Equation [4] (or its correspondence for R and G), was used to calculate the ideal spectral reflectance.

By calculating ΔE^*_{ab} color difference between the ideal and the measured reflectance spectra, the trapping values for full-tone R, G and B were calculated, see Table 1.

For black full tone (cyan + magenta + yellow, CMY), Equation [6] was used to calculate the ideal spectral reflectance, which was compared to the measured full-tone CMY, as discussed above.

As expected, the ink trapping value for full-tone CMY (tertiary) is higher than those for full-tone secondary ink overlap. Furthermore, it can be noticed that the trapping value for green (yellow on cyan) is lower than the rest, which was also expected. The reason is that the print processing time between the cyan (printing unit 2) and yellow (printing unit 4) printing units, is longer than the other two combinations which are printed in consecutive printing units. Therefore, in the full-tone green, the cyan ink has more time to be dried before the second ink (yellow) is printed on top of it, which causes a smaller trapping effect.

4.2 Trapping value of color halftones

By using the spectral trapping model for halftones presented in Section 3, we calculated the trapping value for four different color halftones of R (MY), G (CY), B (CM) and CMY, respectively. The tonal value of each ink coverage combination making the halftones was taken from the proposed tonal values for gray balance and gray reproduction presented in Table A.1 in Annex A to ISO 12647-2:2013 (International Organization for Standardization, 2013), which is also shown in Table 2.

Table 2: The used tonal values for R, G, B and CMY halftones

Color	Quarter tone (%)	Mid tone (%)	Three quarter tone (%)	Full tone (solid) (%)
C	0.250	0.500	0.750	1.000
M	0.184	0.409	0.689	1.000
Y	0.186	0.401	0.699	1.000

For example, a quarter tone B (CM) halftone in our experiments means a halftone consisting of 25.0 % C and 18.4 % M. A mid-tone CMY halftone, for example, means a halftone consisting of 50 % C, 40.9 % M and 40.1 % Y. The ink coverage combinations of other halftones were chosen accordingly.

As observed in Table 3, the trapping value for halftones are much less than their counterparts for full tones. This means that the trapping values for full-tone prints overestimate the actual trapping effect on halftone prints. Another observation is that the trapping value increases with increasing tonal value. The reason is that with increasing tonal value, the ink overlapping areas also increase, resulting in increased trapping effect. As also mentioned in Section 4.1 and as also expected, the trapping values for all CMY halftones are larger than the trapping values of their corresponding two-ink overlaps (R, G and B halftones). The trapping values for G halftones are smaller than the trapping values for other halftones, meaning that they are following the same trend as those for full-tone, discussed in Section 4.1.

Table 3 shows the ΔE^*_{ab} trapping value for halftone R, G, B and CMY at four different tone ranges specified above.

Table 3: The ΔE^*_{ab} trapping value for halftone and full-tone R, G, B and CMY

Color	Quarter tone	Mid tone	Three quarter tone	Full tone (solid)
R	0.1	0.7	2.8	14.7
G	0.1	0.5	2.0	7.2
B	0.2	1.1	3.4	13.9
CMY	0.3	1.9	6.6	17.4

Recall from Section 3.1 that only 17 patches were needed to be measured to estimate the trapping values of these color halftones.

4.3 Analysis of ink trapping effect on printed color halftones

For evaluation and analysis of gray balance at different tonal values, normally the dot gain for C, M and Y halftones and the CIELAB values of the CMY halftones and full-tone CMY print are used. Besides these quality criteria, the trapping values for halftones, can also be used for a better understanding and analysis of halftone color prints and specifically gray balance. Therefore, we propose that during the print process calibration (CtP calibration) according to ISO 12647-2:2013 (International Organization for Standardization, 2013) or PSO-calibration (Belz, 2012; 2016) the trapping value is also noted along with other parameters such as dot gain, etc. If in a print production some quality inaccuracy, such as gray balance shift, occurs, besides other common quality parameters, the trapping value should also be considered. If other parameters are inside the acceptance range but trapping value has increased compared to the value noted at the print process calibration, then the parameters affecting trapping should be checked. The most important parameters affecting trapping are ink temperature, dampening, printing speed, and rheology of the inks (Hauck, 2015).

In the fourth row of Table 3, the ΔE^*_{ab} trapping value of four different CMY halftones were shown. In order to

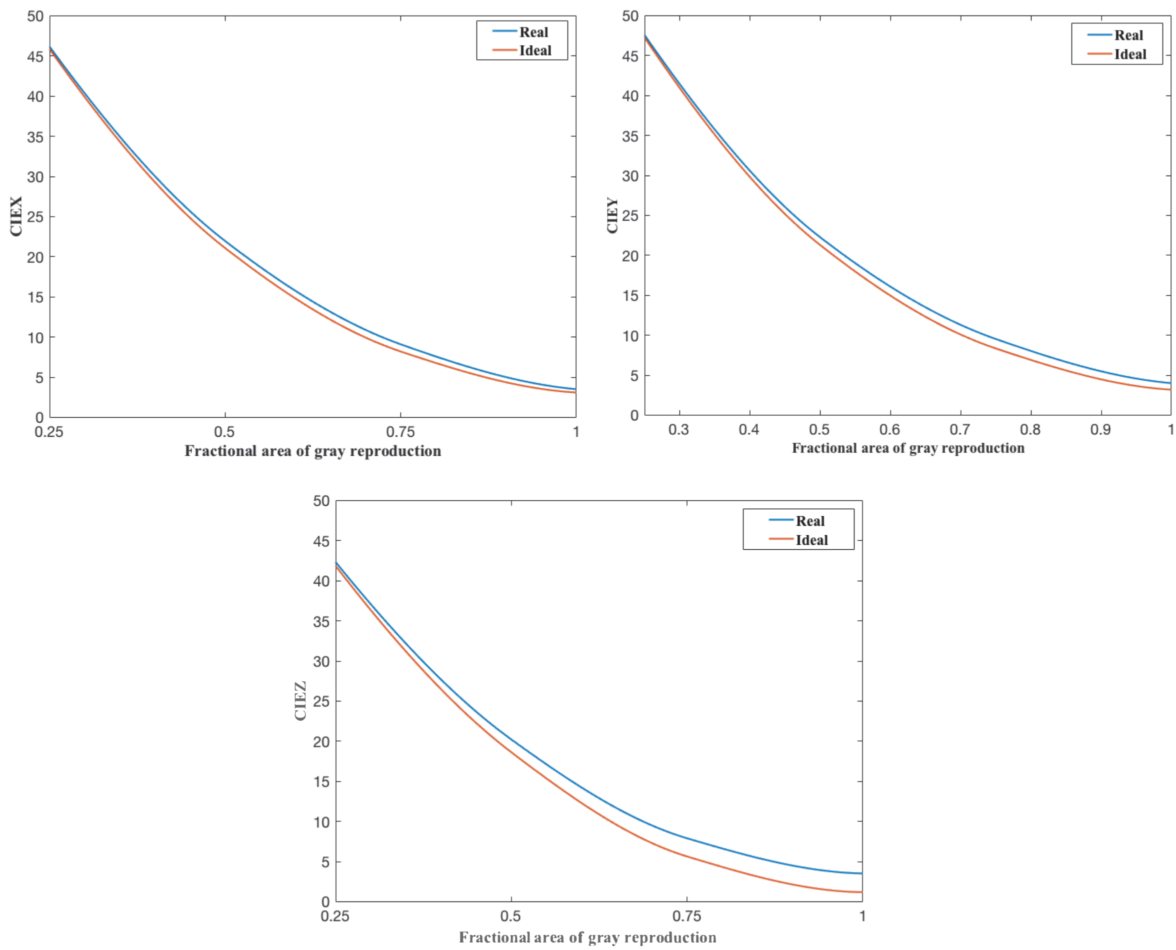

Figure 2: Interpolated CIE X, Y and Z values of CMY halftones for real and ideal ink overlap at tonal values according to Table 2

conduct a better analysis of trapping effect, the CIEXYZ values for real (measured data which include ink trapping) and ideal CMY ink overlap at the four tonal values shown in Table 2 were calculated. They were then interpolated and shown in Figure 2. The first observation by noticing these curves is that the CIE X, Y and Z values for the ideal ink overlap are all smaller than those of the real ink overlap. This means that, trapping effect makes the halftones brighter, which was expected. Another observation is that, the difference in the CIE Z values between real and ideal ink overlap is more than the difference in the CIE X and CIE Y values. This means that trapping causes the halftones to be more blueish. The reason is that, trapping mainly causes the overprinted ink (in this case yellow) to be thinner than in ideal case, which makes the print less yellowish (and thereby more blueish) and also brighter.

By using these curves, it is also possible to find an approximation of the trapping value at any tonal value for gray reproduction. This can be done, by firstly collecting the CIE *X*, *Y*, *Z* color values from the real and ideal curves in Figure 2 at that specific tonal value, and then by converting them to CIELAB values it is possible to calculate the ΔE^*_{ab} trapping value for that specific halftone.

5. Summary and conclusion

All trapping models proposed in literature so far have delivered the trapping value considering full-tone (solid) ink overlap. In this paper, a novel spectral trapping model for color halftones has been proposed. The model delivers the trapping value as the ΔE^*_{ab} color difference taking into account both the ideal ink overlap (full ink trapping) and the real ink overlap (measurement). The results of our experiments show that the trapping values of color halftones are much smaller than those of their counterparts at full-tone, but still not negligible for some halftones. The proposed model is practically useful because it is simple to implement and it doesn't need many training samples to be measured. Despite the simplicity, the model is still general and can be used to approximate the trapping value of any color halftone having arbitrary ink coverage combinations.

We believe that for a better analysis of printing quality, a thorough understanding of trapping effect on halftones can be very useful. Therefore, besides other parameters such as dot gain, the effect of the trapping on print quality has to be studied. The proposed model helps the print machine manufacturers and print machine operators to gain a better understanding of trapping effect on different color halftones.

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