Color Shift of Printing with Hybrid Halftone Images for Overlay Misalignment

Xu Guoliang, Tan Qingping

Abstract—Color printing proceeds with multiple halftone separations overlay. Because of separation overlay misalignment in printing, the percentage of different primary color combination may vary and it will result in color shift. In traditional printing procedure with AM halftone, every separation has different screening angle to make the superposition pattern in a random style, which will reduce the color shift. To evaluate the color shift of printing with hybrid halftoning, we simulate printing procedure with halftone images overlay and calculate the color difference between expected color and color in different overlay misalignment configurations. The color difference for hybrid halftone and AM halftone is very close. So the color shift for hybrid halftone is acceptable with current color printing procedure.

Keywords—color printing, AM halftone, Hybrid halftone, misalignment, color shift, Neugebauer Color Equation

I. INTRODUCTION

COLOR offset printing is made by printing on the paper several times with inks of 3 or 4 primary color inks. Any position on the paper is either printed with solid ink or left blank. This means the image transferred to paper is bi-level. The gray level between blank and solid color block is expressed by percentage of solid ink in a certain area. The color of the inks used is called primary color. The combination of primary colors with different percentage represents different color.

First step of printing procedure is to separate the continue tone color image into separations. Each separation is a grey mode image. Then the grey images are halftoned. When the supposition of the halftoned separated images is observed in normal viewing distance, it looks like a continue tone color image. Color offset printing employs a complicated mechanical procedure, so there is a misalignment problem of registration for separated images. If the ink is absolutely transparent in color, there will be no color shift problem for misalignment of separations. Unfortunately the ink is only partially and not absolutely transparent in color in practical situation. When two color separations are overlaid, the color resulted by dot over dot supposition is quite different from that of dot off dot supposition. In traditional offset printing with AM halftone,

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screening angle is optimized with the criterion that the difference of screen angles for any two separations is up to 30 degree. When CMY halftone images are overlaid, the dot pattern varies randomly. Even if there is misalignment of separations overlay, the percentage of the primary color changes little. This is a proved approach to reduce the color shift in traditional printing procedure.

To evaluate the color shift of printing with hybrid halftone, halftone images are used to simulate color offset printing procedure and the color difference between expected color and color in different overlay misalignment configurations is calculated. Through comparing the color shift for hybrid halftone and AM halftone, it is possible to make sure if the color shift for hybrid halftone is acceptable in current printing procedure.

The rest of this paper is organized as follows: related research is introduced in section II; section III explains color equation and color difference formula; the proposed approach of simulating color printing procedure with halftone images overlay is discussed in section IV; section V is experiment design. Finally we make the conclusion in section VI.

II. RELATED WORKS

Offset printing color can be predicted with Murray-Davies color equation. This color predicting model is established with linear interpolation method. First measure the color of region without any ink (0% halftone dots) and region with solid ink (100% halftone dots). The color of other percentage of ink can be calculated by interpolation with color values of the two fixed percentage ink above. Neugebauer color equation is an extension to Murray-Davies equation for multi-color ink overlay.

There are several different researches to simulate color printing procedure by halftone images overlay, in which color is calculated with Neugebauer equation [2,3,6,7]. Before calculating average color of a region with Neugebauer color equation, we need to know the percentage of all primary color combinations and color value of each primary color combinations. The percentage primary color combinations vary with separations overlay misalignment. This is the reason that brings about color shift. If the halftone dots overlay pattern is formed in a random style, the color can be calculated with Demichel equation, in which there is no need to consider the halftone dots overlay pattern [2]. In addition to that, color shift can be avoided when the separations overlay satisfying

Demichel condition.

Rogers investigated overlay of two AM halftone images with the same frequency and concluded that the difference between the screen angles of the two halftone images decides if the Demichel equation condition is satisfied [2]. Amidror extended the conclusion to multiple halftone images overlay [3]. Based on earlier research on the Moire [4] and micro structure pattern [5] of halftone images overlay, if the screen frequency vectors of all halftone images are not singular, the multiple halftone images overlay satisfies Demichel condition. The screen frequency vectors of all halftone images are not singular means there is no numeric set $\{c_i\}$, to satisfy $\sum_{i=1}^{N} c_i \overline{f_i} = 0$, where c_i is not all zero, $\overline{f_i}$ is the frequency vector.

Basak investigated the problem of color shift for AM halftone by simulating printing with halftone images [6]. It showed 30 degree of angle difference for two halftone images overlay can not guarantee eliminating color shift for misalignment of separations. But 30 degree of angle difference for three halftone images overlay satisfies Demichel condition. In [7] Basak established a semi-analytic model and proofed color shift of AM halftone was not only related to screen angle and frequency, but also to halftone dot shape. In the paper he proposed color shift may be reduced by changing the dot shape.

All above research to color shift is for AM halftone. There is no specific research to color shift for hybrid halftone [8 , 9 , 10]. This paper presents an experiment to investigate color shift for hybrid halftone.

III. COLOR EQUATION AND COLOR DIFFERENCE

There are two kinds of color predicting model: regression model and physical process model. Regression model is usually expressed in simple formula with parameters fit to a set of empirical data. Because of its simplicity, regression model is often used to predict output of printer. Physical process model try to simulate physical process of producing the color. However the practical physical process is so complicated that it needs a lot of computation and its result is not as accurate as that of regression model. Murray first published a regression model to predict output color density from input dot area. This is frequently referenced as Murray-Davies formula (1).

$$R(h,\lambda) = f(h)R_I(\lambda) + (1 - f(h))R_B(\lambda) \quad (1)$$

 Human eye perceive the color through the reflected visible light of a certain wavelength. The wavelength of visible light ranges from 400nm to 800 nm. Color is often expressed in three stimulus values. The subscripts indicate all three reflectance values are a function of the wavelength. $R_B(\lambda)$ is the color of the reflected light of paper in the natural daylight. $R_I(\lambda)$ is color of ink. $f(h)$ is fractional dot area of ink.

Murray-Davies formula is applied to monochrome printer. When modeling a color print, multiple colorants must be considered. Neugebauer equation accounts for multiple colorants overlay. For example, in the overlay of three primary color (CMY) halftone images, there are 8 primary color combinations that exhibit different color. Equation (2) is Neugebauer equation for multiple colorants overlay. Fig. 1 shows 7 primary color combinations and each is coded in binary x from '001' to '111'. fx is fraction area of primary color combination x. R and Rx is color value of the region interested and color value of a primary color combination. x =000 represent the blank paper without any ink on it.

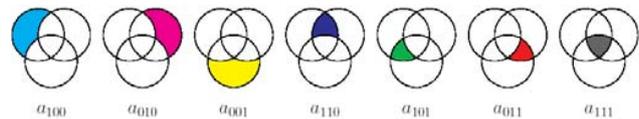$$R(\lambda) = \sum_x f_x R_x \quad (2)$$

Fig. 1 primary color combinations

CIElab is the color space of three stimulus value that is uniformly distributed. So it is reasonable to use CIElab color space to represent the color in Neugebauer equation. So equation (2) can be rewritten as equation (3)~(5).

$$L = \sum_{x=000}^{111} f_x L_x \quad (3)$$

$$a = \sum_{x=000}^{111} f_x a_x \quad (4)$$

$$b = \sum_{x=000}^{111} f_x b_x \quad (5)$$

As we know that blank area is coded as "000". So $f_{000} = 1- \sum_{x=001}^{111} f_x$. The color of the interested region is (L, a, b) . (L_x, a_x, b_x) is the color value of all primary color combinations and paper from ISO 12647[2].

TABLE I
COLORIMETRIC VALUE OF PAPER AND INKS

	L	a	b
Paper	95	0	-2
C	-37	-50	58
M	48	74	-3
Y	91	-5	93
CM	20	25	49
CY	50	-68	33
MY	49	69	52
CMY	16	0	0

ΔE94 is color difference based on CIELAB94 color space. CIELAB94 is defined by International Commission On Illumination, which is also called L a^* b^* color space. ΔE94 is sometimes referred as ΔE_{ab}^* . When $\Delta E_{ab}^* = 1$, ΔE_{ab}^* is called one NBS color difference unit. NBS is the abbreviation of National Bureau of Standard. Color difference in CIELAB94 is

uniformly distributed. This means color difference of one NBS in any place of CIELAB94 color space represents the same human perceived color error. One NBS is 5 times of the minimum color difference human can perceive in the best observing condition. Table 2 reveals corresponding relationship of ΔE_{ab}^{*} and subjective terms for color difference.

If two color values are (L1, a1, b1) and (L2, a2, b2),the color difference between them is calculated with following formula:

$$\Delta E_{ab}^{*} = \sqrt{(L_1 - L_2)^2 + (a_1 - a_2)^2 + (b_1 - b_2)^2} \qquad (6)$$

TABLE II
COLOR DIFFERENCE AND SUBJECTIVE TERMS

ΔE_{ab}^{*}	Subjective Terms
0⋯0.25	Tiny
0.25⋯0.5	Small
0.5⋯1.0	Small to medium；acceptable in some application
1.0⋯2.0	Medium；acceptable in specific application
2.0⋯4.0	Considerable；acceptable in specific application
Above 4.0	Big；unacceptable in most application

IV. SIMULATE COLOR SHIFT OF COLOR PRINTING WITH HALFTONE IMAGES

We can use PhotoShop to demonstrate color shift of halftone images overlay by moving an image layer. Display color variation reveals that color shift may appear if these halftone images were used in color printing. First create a new image window which has two CMYK layers. Copy and paste a halftone image into M channel of Layer 1 and C channel of Layer Background and clear all other channels. Set the opacity value of Layer 1 to 50% and current tool to 'Move Tool' (Fig. 2). When use left key to move Layer 1, you can notice the display color of image window changes. This shows color shift resulted from overlay of two halftone images in cyan and magenta inks of the same frequency and angle when registration of the images changes.
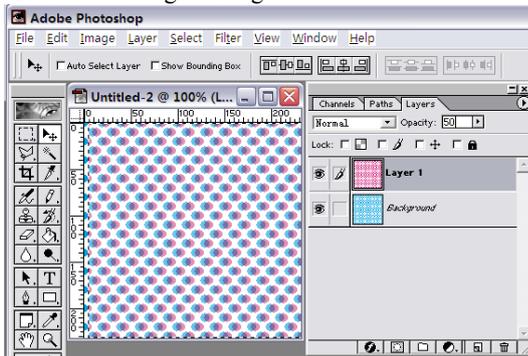

Fig. 2 Simulate color shift of color printing with halftone images

There are two kinds of defects of color shift brought by alignment error:

(1) The color density changes in different alignment configurations;

(2) Color density of the same image on the page in different position is different；

We try overlaying halftone images of width w and height h in different alignment configurations to simulate color print (Fig. 3). Let plate C static as reference of relative position. Position of plate M and Y relative to plate C changes from -40um to 40um in horizontal and vertical direction by the step s. Calculate the average color of the area (w-b) pixels x (h-b) pixels centered C plate. This step is to crop the interested area to what are covered by all 3 plates. Further more we divide the interested area into sub-regions. The sub-regions are arranged in NxN. When the sub-region is small, for example its edge is smaller than 1mm, the color difference between sub-regions reflects the image evenness. When the sub-region is big, for example its edge is bigger than 5cm, the color difference between sub-regions reflects color variation of different parts on the page.

For every alignment configuration tested, calculate the average color of the image $Color_{avg}$. The average color $Color_{avg0}$ is obtained when all 3 halftone image register accurately. This is also the average color expected. The color difference between $Color_{avg0}$ and $Color_{avg}$ is memorized as ΔE_{ab}^{*}. $(\Delta E_{ab}^{*})_{avg}$ is average value of ΔE_{ab}^{*}. $(\Delta E_{ab}^{*})_{max}$ is the maximum value of ΔE_{ab}^{*}. $(\Delta E_{ab}^{*})_{min}$ is the minimum value of ΔE_{ab}^{*}. Similar values for sub-region are also calculated: $(\Delta E_{ab}^{*})_{ravg}$, $(\Delta E_{ab}^{*})_{r\max}$, $(\Delta E_{ab}^{*})_{r\min}$. The total number of the misalignment configurations is: $\frac{80}{s}$ x $\frac{80}{s}$ x $\frac{80}{s}$ x (s is the step of changing relative distance of halftone image center, $-40 < s < 40$).

In the process of simulating offset printing, first step is to calculate the percentage of all primary color combinations in the interested area. That is the number of pixels belonged to a certain primary color combination divided by total pixel numbers. Then calculate the color with Neugebauer equation with parameters from Table 2. From the final statistic values of maximum, minimum and average color difference, we can evaluate color shift quantity in case of misalignment of plates of halftone images. Fig. 4 is the flow chart of simulating color offset printing with halftone images.
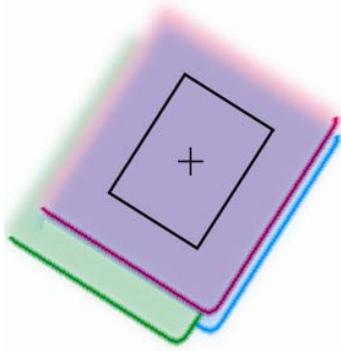
Fig. 3 overlaying halftone images of width w and height h in different alignment configurations to simulate color print
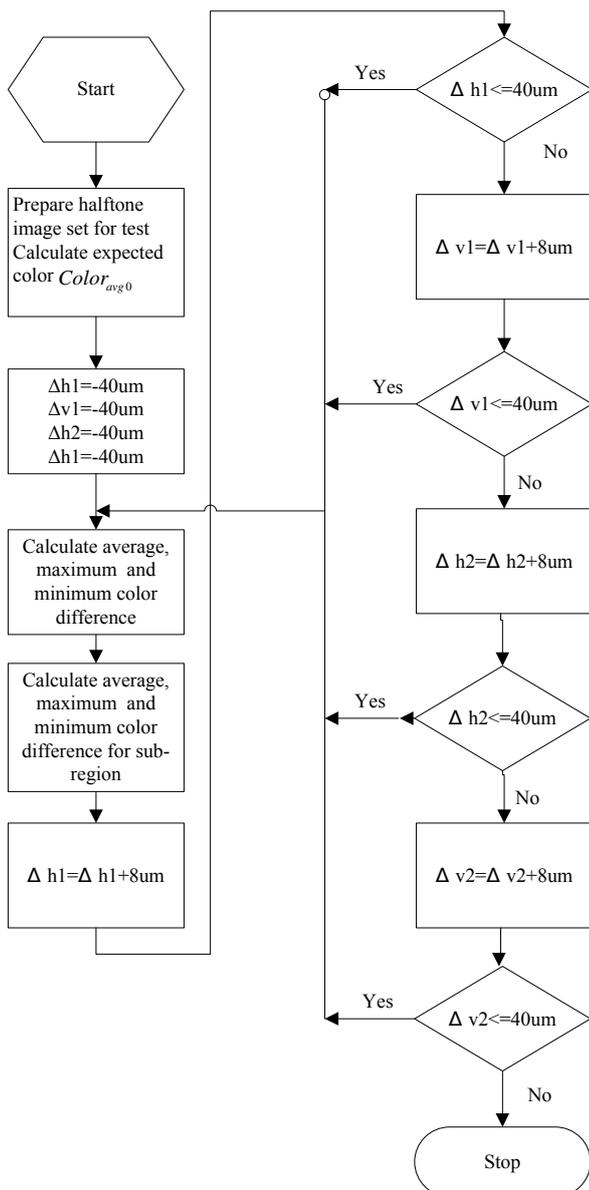

Fig. 4 the flow chart of simulating color offset printing with halftone images

V. EXPERIMENTAL

Experiment steps：

1. Prepare AM halftone image for test: in PhotoShop we create a 1cmx1cm gray mode image filled with 25% tint. Produce 3 halftone images in Harlequin RIP with parameters: output resolution 2400DPI; Euclidean dot shape; 175LPI; screen angle 15, 45 and 75. The size of halftone images is 948pixelsx948pixels.

2. Get colorimetric value for all primary color combination and paper from ISO 12647 [12] for initialization data of the experiment software. We assumed 115gram glossy coated paper used.

3. Calculate $Color_{avg}$ which is color when all plates register accurately. $Color_{avg}$ is the expected color in print. So always use it as reference when calculate color difference in simulation (Fig 4).

4. Let plate be static. Change the relative position of plate M and Y in horizontal and vertical direction from -40um~40. 80um is the maximum misalignment error for color offset printing. When 80um is measured by pixels of 2400 DPI, it is 48 pixels. We use step value of 8um (5 pixels) to simulate printing in different misalignments. 10000 loops of color calculation will be repeated. Average color is calculated according to formula (3)~(5). Color difference is calculated according to formula (6). The size of interested area is set as 500pixelsx500pixels.

5. Prepare hybrid halftone images: first, produce hybrid dithering matrix according to [10] with three different pseudo seeds; then install it into Harlequin RIP as 3 new hybrid dot shapes and print the gray image made in (1) to produce 3 halftone images.

6. Counts the number of clustered of AM halftone image and got C_2 =5155. Counts the number of clustered of hybrid halftone image and got C_1=210. To make the comparison of color shift in similar clustered dot density, we scale the AM halftone images with factor s. With formula (8) and parameters above, s is 4.95.

$$s = \sqrt{C_2 / C_1} \qquad (8)$$

PhotoShop can not scale the monochrome image. So convert the AM halftone images into gray mode first. Then scaled it to 4697pixelsx4697pixels and cropped it to 948pixelsx948pixels. Use 'curve adjust' function of PhotoShop to clear pixels under 50% and set the pixels above 50% to 100%.

7. Prepare hybrid halftone image set Hybrid R1: first, produce hybrid dithering matrix according to [10] with three different pseudo seeds; then install it into Harlequin RIP as 3 new hybrid dot shapes. Print a 3cmx3cm gray image with 25% tint at resolution of 2400DPI in Harlequin RIP. Rotated the halftone image for Cyan plate 30 degree and cropped all the three images to 948pixelsx948pixels.

8. Prepare hybrid halftone image set Hybrid R2: first, produce hybrid dithering matrix according to [10] with three

different pseudo seeds; then install it into Harlequin RIP as 3 new hybrid dot shapes. Print a 3cmx3cm gray image with 25% tint at resolution of 2400DPI in Harlequin RIP. Rotate the halftone image for Cyan plate 30 degree and the halftone image for Magenta plate 60 degree. Crop all the three images to 948pixelsx948pixels.

9. Prepare hybrid halftone image set Hybrid R3: first, produce hybrid dithering matrix according to [10] with three different pseudo seeds; then install it into Harlequin RIP as 3 new hybrid dot shapes. Print a 3cmx3cm gray image with 25% tint at resolution of 2400DPI in Harlequin RIP. Rotate the halftone image for Cyan plate 30 degree, the halftone image for Magenta plate 60 degree and the halftone image for Yellow plate 15 degree. Crop all the three images to 948pixelsx948pixels.

10. Follow step 4 to do color printing simulation test with data set AM, Hybrid, R1, R2 and R3. Fill the table 3 with data from the experiment.

TABLE III
COLOR SHIFT SIMULATED

	$(\Delta E_{ab}^*)_{avg}$	$(\Delta E_{ab}^*)_{max}$
AM	0.0846	0.2449
Hybrid	0.1040	0.2639
Hybrid R1	0.0253	0.0566
Hybrid R2	0.0169	0.0343
Hybrid R3	0.0319	0.0669

Note R1: Rotate C plate 30 degree
R2: Rotate C plate 30 degree and Magenta plate 60 degree
R3: Rotate C plate 30 degree and Magenta plate 60 degree and Yellow plate 15 degree

TABLE IV
COLOR DIFFERENCE OF DIFFERENT SUB-REGION

	$(\Delta E_{ab}^*)_{ravg}$	$(\Delta E_{ab}^*)_{r\,max}$	$(\Delta E_{ab}^*)_{r\,min}$
AM	3.9485	31.7518	2.0950
Hybrid	3.5881	28.8969	1.9009
Hybrid R1	7.6315	61.8535	4.0167
Hybrid R2	7.5222	61.1684	3.9457
Hybrid R3	7.5402	61.6313	3.9341

VI. CONCLUSION

Table 3 shows that color shift for hybrid halftone images produced by 3 different pseudo seeds in misalignment allowed by printing industry standard is very close to that for AM halftone images with same clustered dot density (0.0846 NBS:0.1040 NBS) . So color shift for the hybrid halftone images is within the range that printing industry allowed.

If the hybrid halftone images are rotated to make 30 degree angle differences, the color shift will be reduced considerably (from 0.1040 NBS to 0.0253NBS). However the color difference between different sub-regions will increase at the same time (from 3.5881 NBS to 7.6315). Because the sub-region is of size 1mm, this indicates that rotated overlay of

hybrid halftone images looks more grainy than original one. After rotating hybrid dithering matrix, it is very difficult to make it mosaic seamlessly. It is not necessary to loss the advantage of being seamless to reduce the color shift further.

REFERENCES

[1] D.R. Wyble, R.S. Berns , "A Critical Review of Spectral Models Applied to Binary Color Printing", J. Color Res. Appl., Vol. 25, No. 1, pp.4-19, 2000.
[2] G. L. Rogers, "Neugebauer revisited: random dots in halftone screening" , Color Res. Appl. Vol. 23, No 2, pp.104–113, 1998.
[3] I. Amidror and R. D. Hersch, "Neugebauer and Demichel: dependence and independence in n-screen superpositions for colour printing," Color Res. Appl. Vol. 25, No. 4, pp. 267–277, 2000.
[4] Isaac Amidror, Roger D. Hersch, Victor Ostromoukhov "Spectral Analysis and Minimization of Moiré Patterns in Colour Separation" Journal of Electronic Imaging, Vol.3 , No. 3, pp. 295-317, 1994.
[5] I. Amidror and R. D. Hersch, " Analysis of the microstructures ('rosettes') in the superposition of periodic layers," Journal Electron. Imaging, Vol. 11, No.3, pp.316– 337, 2002.
[6] Basak Oztan, Gaurav Sharma and Robert P. Loce "Quantitative Evaluation of Misregistration Induced Color Shifts in Color Halftones" Proc.of SPIE-IS&T Electronic Imaging, SPIE Vol. 5667, pp.501-12, 2005.
[7] Basak Oztan, Gaurav Sharma and Robert P. Loce "Misregistration sensitivity in clustered-dot color halftones"Journal of Electronic Imaging, Vol.17, No.12, pp.1-28, 2008.
[8] Ostromoukhov V, Hersch R D. "Stochastic clustered-dot dithering", Journal of Electronic Imaging, Vol.8, No.4, pp. 439-445, 1999
[9] Tu Chang-He, Pan Rong-Jiang, Meng Xiang-Xu, "An algorithm for building stochastic clustered-dot screens". Chinese journal of computers, vol 23, pp.931-937, Sept. 2000 (in Chinese)
[10] Xu Guoliang, Tan Qingping, "Research on balancing clustered dot density for hybrid halftone dithering algorithm". Chinese journal of computers, vol 32, pp.1550-1559, August, 2009 (in Chinese)
[11] R.D. Hersch, F. Crété, "Improving the Yule-Nielsen modified spectral Neugebauer model by dot surface coverages depending on the ink superposition conditions", SPIE Vol. 5667, pp434-445, 2005.
[12] DIN ISO 12647 "L*a*b* values of process inks for commercial printing" Technical information, pp820-823, Oct, 2004

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