RESEARCH ON SECONDARY COLOUR OPTICAL DOT GAIN MODEL IN ELECTROSTATIC DIGITAL COLOUR PRINTINGS

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Screening dot is the basic printing element to reproduce continuous image and to form the printing image. Printing quality depends on the transfer quality of the screening dot. It is important to control the dot gain, sharpening, deformation, doubling and slurr. In practice, some specific quality control techniques are used to monitor the screening dot variation. For dot gain control technique, multi-colour scales are often used to investigate dot gain or tone change. This article aims to investigate the secondary colour dot gain in electrostatic digital printing, by considering dot gain of the colour scales, Cyan, Magenta, Yellow, Blue, Red and Green. The relations between secondary colour dot gain and primary colour dot gain are studied. Three primary colour scales, Cyan, Magenta, Yellow, and three secondary colour scales, Blue, Red and Green, are designed from 2 % to 90 %. The colour scales are output by electrostatic colour press and measured by spectrophotometer. The dot gain of the secondary colour scales is modelled according to the dot gain rules of the primary colour scales using multiple linear regression method. The results illustrate that the dot gain of secondary colour changes with the dot gain of primary colour scales synchronously, and that further research is needed to make for dot gain compensation and printing process control.

Keywords: dot gain; Murray-Davis formula; multiple linear regression; primary colour scale; secondary colour scale

1 Introduction

Screening dot is the basic unit to form printing tone level and to reproduce colour in printing process [1, 2]. And it is the basic unit of halftone image. Colour reproduction, tone level reproduction, and image texture reproduction are determined by the screening properties in colour printing [3, 4]. Dot gain is an inherent property for printing in actual production process [5, 6]. What we should note is that dot gain has a great effect on colour reproduction in colour printing. For example, the overall contrast of image would change because of dot gain in printing monochrome or colour halftone image [6, 7]. Moreover, the image details and sharpness would lose too. In addition, dot gain also causes the loss of contrast, tinting of shadow tone area, and the sudden change of tone level or colour [8, 9]. Consequently, it is important to control the dot gain and to compensate the tone change caused by the dot gain to ensure the printing quality [10, 11]. Dot gain within a control to a certain extent is good to colour reproduction.

2 Types of dot gain

Dot gain is a phenomenon in printing process which causes printed material to look darker than intended. Usually it is caused by halftone dots growing in area between the primary printing film and the final printed result. It is often defined as the increase in the diameter of a halftone dot during the prepress and printing processes. Dot gain is classified into two types, i.e., mechanical dot gain and optical dot gain. Mechanical dot gain is often caused by the mechanical pressure and the paper slipping caused by the distortion of the blanket in printing process [1, 9]. The dot gain perceived is usually made up by the actions of mechanical dot gain and optical dot gain [12]. However, it is the optical dot gain that leads the key role in digital colour printing, e.g. inkjet printing and xerographic digital printing [13, 14, 15].
except the absorbed. For incident light 2 injecting from dot area, some, 2b, reflects from ink surface, and some, 2d, passes through the ink layer and goes into the paper inside and some of 2d goes out of the paper through the ink layer except the absorbed. So the total amount of outgoing light or related total light reflectivity perceived can be computed as follows:

$$R_t = (1 - A) \times R'_0 + A \times R'_s,$$

where, $R_t$ is total light reflectivity which consists of two parts such as the reflectivity of blank paper surface, $(1 - A) \times R'_0$, and the reflectivity of dot area, $A \times R'_s$. $A$ is dot area. $R'_0$ is the effective reflectivity of paper, and $R'_s$ is effective reflectivity of solid dot.

2.2 Relation between density and dot area

The effective method to measure the cluster dot area is to measure the dot area density. And it is widely used in many colour measuring equipments. Simultaneously, a number of studies indicate that solid density has more influence on dot gain than any other factors in measuring dot gain process [3, 14, 18]. Density in printing process is usually optical density. It can be computed by logarithmic computation of the amount of incident light and outgoing light as follows:

$$D = \lg \frac{R_{in}}{R_{out}},$$

in which, $D$ is optical density. $R_{in}$ is the amount of incident light. And $R_{out}$ is the amount of outgoing light.

To compute the dot area of printed matter, $D_s$ was set as the solid density and $\rho_a$ as the corresponding reflectivity, then the relation between the density and reflectivity can be shown as follows:

$$D_s = \lg \frac{1}{\rho_a}.$$

Theoretically, set the reflectance of the blank area of the substrate, e.g., paper, as 1. Set the dot area on the paper is $a$, so the rest area of the paper is $1 - a$. Then the corresponding reflectance is $\rho_a$ and $1 - a$ respectively. So the total reflectance of the substrate can be computed as follows:

$$\rho = a \times \rho_a + (1 - a).$$

It is shown in Fig. 2 as follows:

Thus, $D_s$, the reflectance density of the dot area, $a$, can be computed as follows:

$$D_s = \lg \frac{1}{\rho} = \lg \frac{1}{a \times \rho_a + (1 - a)} = \lg \frac{1}{1 - a(1 - \rho_a)}.$$  \hspace{1cm} (5)

According to Eq. (3), $\rho_a$ can be computed as follows:

$$\rho_a = 10^{-D_s}.$$  \hspace{1cm} (6)

Then plug Eq. (6) into the Eq. (5) and $D_s$ can be computed as follows:

$$D_s = \lg \frac{1}{1 - a(1 - 10^{-D_s})}.$$  \hspace{1cm} (7)

For random cluster dot area, the reflectance density $D_s$ can be measured by densitometer or spectrophotometer. Finally, the cluster dot area can be computed according to Eq. (5), Eq. (6) and Eq. (7):

$$a = 1 - 10^{-D_s},$$  \hspace{1cm} (8)

in which, $a$ is the cluster dot area of printing sample to be measured. $D_s$ is reflectance density, and $D_s$ is solid density. Eq. (8) is the famous formula to compute the relation between dot area and dot density, i.e., Murray-Davis formula [5, 19, 20, 21]. Although some corrections have been done to the formula by the researchers in this area, e.g., Yule-Nielson formula [21, 22]. Murray-Davis formula remains to be the most popular model in measuring dot area and dot density. In this paper, Murray-Davis formula was used to compute the relation between dot area and dot density.
3 Modelling and experiment part
3.1 Development, analysis and hypothesis of secondary colour scale dot gain model

Given the primary dot area of primary dot area is $S_0$ and the measured dot areas of primary are $S_C$, $S_Y$, and $S_M$ respectively. So the corresponding secondary colour scale dot areas are $S_B$, $S_M$, and $S_C$. Theoretically, the final perception of dot paralleling is the same as that of dot overprinting according to halftone image reproduction law [23]. For secondary colour scale, Blue is made up by primary colour Cyan and Magenta scale. There would be several cases as follows:

**Case 1:** Cyan and Magenta colour scale do not overlap at all (Fig. 3). So the total dot gain of this scale can be shown as follows:

$$\Delta S_B = \Delta S_C + \Delta S_M, \quad (9)$$

in which, $\Delta S_C$ is dot gain of Cyan colour scale. $\Delta S_M$ is dot gain of Magenta colour scale. $\Delta S_B$ is dot gain of secondary colour, Blue colour scale.

**Case 2:** Cyan and Magenta colour scale overlap completely (Fig. 4). So the total dot gain of blue scale can be shown as follows:

$$\Delta S_B = \text{max}(\Delta S_C, \Delta S_M), \quad (10)$$

where, $\Delta S_B$, $\Delta S_C$ and $\Delta S_M$ have the same meaning in Eq. (9). Max is to find the maximum dot gain from Cyan dot gain and Magenta dot gain.

**Case 3:** Cyan dot area partly overlaps Magenta dot area (Fig. 5). For this case, secondary colour, Blue, consists of both overlapping and paralleling case. So the total dot gain can be shown as follows:

$$\Delta S_B = S_C + S_M - \Delta S - 2S_0, \quad (11)$$

in which, $\Delta S$ is the overlapped dot area. $S_0$ is the primary dot area.

Therefore, dot gain of secondary colour scale, $\Delta S_B$, can be illustrated as the function of dot gain of the primary colour scale, $\Delta S_C$ and $\Delta S_M$. And it can be expressed as follows:

$$\Delta S_B = f(\Delta S_C, \Delta S_M). \quad (12)$$

Further it can be shown as:

$$\Delta S_B = a\Delta S_C + b\Delta S_M + c, \quad (13)$$

in which, $c$ is adjustment coefficient. And this prototype model of dot gain of secondary colour scale is developed. Similarly, the prototype of dot gain of secondary colour scale, Red and Green, can be formed using the same method above. In this paper the prototype model is simulated using Multiple Linear Regression method as follows.

3.2 Multiple Linear Regression

Secondary colours, Red, Blue and Green, are obtained by overlapping or paralleling the primary colour, Cyan, Magenta and Yellow in this paper. So the dot change of Red, Green and Blue colour scale is determined by the dot change of Cyan, Magenta, and Yellow colour scale. In particular, the dot change of Blue colour scale is determined by Cyan colour scale and Magenta colour scale. The dot change of Red colour scale is determined by Yellow colour scale and Magenta colour scale. And the dot change of Green colour scale is determined by Yellow colour scale and Cyan colour Scale. According to the above analysis, multiple linear regression method is used to analyze the dot gain of secondary colour scale in this paper.

The common form of multiple linear regression model can be shown as follows:

$$y = \beta_0 + \beta_1 x_{1i} + \beta_2 x_{2i} + \cdots + \beta_k x_{ki} + e_i, \quad i = 1, 2, \ldots, n. \quad (14)$$

In which, $k$ is the number of variables, $\beta(j = 1, 2, \ldots, k)$ is regression coefficient.

For the parameter estimation of Eq. (14), it can be done by least square method or maximum likelihood estimation method under the condition of satisfying the minimum of error sum of squares. Given $(x_{1i}, x_{i2}, \ldots, x_{ip}, y_1, \ldots, y_n, x_{ip}, y_n)$ to be a group samples, and maximum likelihood estimation method is used.

Set $\hat{b}_0, \hat{b}_1, \ldots, \hat{b}_p$. When $b_0 = \hat{b}_0, b_1 = \hat{b}_1, \ldots, b_p = \hat{b}_p$, $Q = \sum_{i=1}^{n} (y_i - b_0 - b_1 x_{i1} - \cdots - b_p x_{ip})^2$ has the minimum value. Take partial derivative to each component of $Q$ and make them equal to zero, i.e.,

$$\frac{\partial Q}{\partial b_0} = -2 \sum_{i=1}^{n} (y_i - b_0 - b_1 x_{i1} - \cdots - b_p x_{ip}) = 0$$

$$\vdots$$

$$\frac{\partial Q}{\partial b_j} = -2 \sum_{i=1}^{n} (y_i - b_0 - b_1 x_{i1} - \cdots - b_p x_{ip}) x_{ij} = 0$$

where $j = 1, 2, \ldots, p$.

And Eq. (15) is simplified to Eq. (16) as follows:
\[
\sum_{j=1}^{s} y_j = b_0 + b_1 \sum_{j=1}^{p} x_{i1} + b_2 \sum_{j=1}^{p} x_{i2} + \cdots + b_p \sum_{j=1}^{p} x_{ip} \\
\sum_{j=1}^{s} x_j y_j = b_0 \sum_{j=1}^{p} x_j + b_1 \sum_{j=1}^{p} x_j x_{i1} + b_2 \sum_{j=1}^{p} x_j x_{i2} + \cdots + b_p \sum_{j=1}^{p} x_j x_{ip} \\
\vdots \\
\sum_{j=1}^{s} x_j y_j = b_0 \sum_{j=1}^{p} x_j + b_1 \sum_{j=1}^{p} x_j x_{i1} + b_2 \sum_{j=1}^{p} x_j x_{i2} + \cdots + b_p \sum_{j=1}^{p} x_j^2 
\]

(16)

Then set

\[
Y = \begin{pmatrix} y_1 \\ y_2 \\ \vdots \\ y_s \end{pmatrix}, \quad X = \begin{pmatrix} 1 & x_{i1} & x_{i2} & \cdots & x_{ip} \\ 1 & x_{i1} & x_{i2} & \cdots & x_{ip} \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ 1 & x_{i1} & x_{i2} & \cdots & x_{ip} \end{pmatrix}, \quad B = \begin{pmatrix} b_0 \\ b_1 \\ \vdots \\ b_p \end{pmatrix}
\]

respective, Eq. (17) can be set as follows:

\[
X'Y = X'XB. \tag{17}
\]

Therefore, maximum likelihood estimator is obtained:

\[
\hat{B} = (X'X)^{-1}X'Y, \tag{18}
\]

So the estimator of \(u(x_1, x_2, \ldots, x_p) = b_0 + b_1 x_1 + \cdots + b_p x_p\) is:

\[
\hat{y} = \hat{b}_0 + \hat{b}_1 x_1 + \cdots + \hat{b}_p x_p. \tag{19}
\]

And Eq. (19) is the \(p\) variables experience linear regression equation. In this paper, secondary colour scale consists of two primary colour scales, so set \(p = 2\). And such process is to solve the two variables linear regression equation.

### 3.3 Experiment

Dot gain is inevitable in printing process. Even in non-impact printing, optical gain is still in dot area [14]. Six colour scales were designed and output in this paper (Fig. 6). From the top to the bottom the colour scales are Cyan, Magenta, Yellow, Blue, Green and Red respectively. And static digital printing was chosen as the output mode and the dot area of primary colour scale, Cyan, Magenta and Yellow, were measured. The dot areas of second colour scale, Blue, Red and Green were also measured. 500 samples were output using Konica Minolta bizhub Press C6000 and about 50 samples were extracted randomly and measured by spectrophotometer. The average values are shown in Tab. 1 and Tab. 2. And coated color laser printing paper was used as printing substrate. The weight is 120 g/m². X-Rite SpectroEye LT was used to measure the color patch with the viewing condition of D65, 2° standard viewing angle and 45°/0° of geometry. CIE1931 standard observers was used in this paper.

\[\text{Figure 6 Colour scales of Cyan, Magenta, Yellow, Blue, Green and Red}\]

<table>
<thead>
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<th>Table 1 Primary colour dot area</th>
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<td>Primary dot area</td>
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<th>Table 2 Secondary colour dot area</th>
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<td>Dot area of secondary colour scale</td>
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<td>Primary dot area</td>
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<td>Measured dot area</td>
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### 4 Results and discussion

The research in this paper comprised the research of dot gain of primary colour Cyan, Yellow and Magenta, dot gain of secondary colour Blue, Red and Green, and the relation model between secondary and primary colour. The results of the research were put into correlation in order to get the objective recommendations of the relation between secondary colour dot gain and primary colour dot gain for the xerographic digital printing.

#### 4.1 Primary dot gain curves

The research of dot gain was performed on fields of the colour scales in the range from 2 to 90% screen value. By calculation of dot gain for the designed colour scales the curves for the primary colour were constructed.
as the average value of all Cyan, Magenta and Yellow samples. The obtained results are shown in Fig. 7.

In Fig. 7, dot gain of Cyan, Magenta and Yellow is basically the same in the high-light area. Dot gain of Yellow is the most obvious or serious in light area (20 ÷ 40 %) and mid-tone area (40 ÷ 60 %), while dot gain of Magenta is less serious in the same area. However, dot gain of the three primary colour scales tends to be basically the same in the shadow area (70 ÷ 100 %). The point is that dot gain is most serious in 40 % tone area, not in 50 % tone area because it is dependent on dot shape.

4.2 Modelling for secondary colour dot gain

According to the above analysis, assume that secondary colour dot gain depends on the primary colour dot gain. For secondary colour Blue, its dot gain is based on dot gain of primary colour, Cyan and Magenta according to the multiple linear regression method. Dot gain of Blue is given to have the follow relations with Cyan and Magenta according to Eq. (19):

\[
\Delta B = b_0 + b_1 \Delta C + b_2 \Delta M .
\]

Similarly, secondary colours Green and Red have similar relations with primary colour Cyan, Magenta and Yellow.

\[
\begin{align*}
\Delta B &= b_0 + b_1 \Delta C + b_2 \Delta M \\
\Delta G &= g_0 + g_1 \Delta C + g_2 \Delta Y \\
\Delta R &= r_0 + r_1 \Delta M + r_2 \Delta Y
\end{align*}
\]

Eq. (21) also can be expressed as:

\[
\Delta S(B, G, R) = A \cdot \Delta P(C, M, Y),
\]

where, \( \Delta S \) is dot gain of secondary colour, \( \Delta P \) is dot gain of primary colour and \( A \) is conversion matrix.

50 samples were extracted from the output samples randomly and were measured by spectrophotometer to get the dot gain data. The average data is shown in Tab. 2. Multiple linear regression method was used to compute the related coefficient for Eq. (21) and Eq. (22). And the result is shown as follows:

\[
A = \begin{pmatrix}
 b_0 \\
 b_1 \\
 b_2 \\
 g_0 \\
 g_1 \\
 g_2 \\
 r_0 \\
 r_1 \\
 r_2 \\
\end{pmatrix} = 
\begin{pmatrix}
-0.6203 & 1.3865 & 0.0955 \\
0.0033 & 0.0418 & 1.0147 \\
3.4423 & -0.9240 & 1.8397
\end{pmatrix}
\]

Then the prototype of relation between secondary colour scale dot gain and primary colour scale dot gain is developed as follows.

\[
\begin{align*}
\Delta S(B, G, R) &= A \cdot \Delta P(C, M, Y) \\
\Delta B &= -0.6203 + 1.3865 \Delta C + 0.0955 \Delta M \\
\Delta G &= 0.0033 + 0.0418 \Delta C + 1.0147 \Delta Y \\
\Delta R &= 3.4423 - 0.9240 \Delta M + 1.8397 \Delta Y
\end{align*}
\]

So the dot gain of secondary colour scale can be calculated based on the dot area of primary colour scale. Then the measured dot gain (Tab. 2) and calculated dot gain can be compared and some effective analysis can be done. Finally, the effective prototype system for secondary colour scale dot gain compensation and prediction system based on the primary colour scale dot gain can be developed.
secondary dot gain is shown in Fig. 9. In a similar way, the relation between measured dot gain and calculated dot gain of Red based on primary Magenta and Yellow is shown in Fig. 10. And the residual plot of calculated secondary dot gain is shown in Fig. 11. For secondary Green, the comparison was shown in Fig. 12 and Fig. 13.

From Fig. 8 to Fig. 13, it is found that the model developed in this paper to calculate and to predict secondary colour dot gain has more efficiency in light-tone and mid-tone area of Red and Green while has some error in high light tone and shadow tone. For modeling and prediction of Blue, it is found that the model has more error than that for Red and Green, especially in the 50 % tone area. So it is necessary to do some further research to the error area and the model for Blue. Moreover, it is also necessary to do research on the other types of printing for secondary dot gain.

5 Conclusion

The purpose of digital printing is to enable the printing of high efficiency and of high quality reproduction. To obtain the qualitative reproduction depends on a series of parameters, e.g., paper, pigments and equipments, digital prepress image processing. However, one of the most important is the standardized and defined dot gain in a regular production process. Dot gain control is the most effective and simple method to control printing quality. The research in this paper confirmed that the screening dot is the basic printing element to reproduce continuous image and to form the printing image. On the basis of the obtained results and analysis, with the aim of increasing the quality of the printing product, the new dot gain control technologies should be recommended during the digital printing process.

From all the mentioned, the research in this paper established the model of the secondary colour dot gain according to the primary colour dot gain so that it was used to evaluate and to control the dot gain in a larger scope. The secondary colour dot gain in electrostatic digital printing is studied by considering dot gain of the colour scales, Cyan, Magenta, Yellow, Blue, Red and Green. The relations between secondary colour dot gain and primary colour dot gain are also studied. Three primary colour scales, Cyan, Magenta, Yellow, and three secondary colour scales, Blue, Red and Green, are designed from 2 % to 90 %. The colour scales are output by electrostatic colour press and measured by spectrophotometer. The dot gain of the secondary colour is modeled according to the dot gain rules of the primary colour using multiple linear
regression method. The results illustrate that the dot gain of secondary colour changes with the dot gain of primary colour synchronously, and that further research is needed to make for dot gain compensation and printing process control.

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