The Effect of Printing Element Physical Extension on Print Properties

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The theoretical model of physical dot gain, based on division of this phenomenon mechanisms on two groups, is proposed. The theoretical predictions produced by the model are in conformity with the experimental reflectivity data measured on test-charts produced by electrophotographic and ink-jet printing. The comparison of these modeled and experimental data allows for quantitative characterization the influence of a particular physical dot gain mechanism on optical properties of prints.

Introduction

The ink penetration into blank areas results in the printed element extension or so called physical dot gain, which, in its turn, reduces the printing equipment resolution and, as result, the definition of an image copy. This extremely undesirable phenomenon can be caused by the numerous factors, such as:

1. spreading of ink or melted toner over the surface of a substrate (paper sheet);
2. mutual slur of a substrate, offset cylinder or plate in the nip;
3. ink advance into paper capillaries;
4. doubling of halftone dots or thin lines in impact printing;
5. presence of an ink in certain amount at non-printing areas of some real plate;
6. ink splashing at impact of drops on a substrate in ink-jet printing;
7. dye sorption by a paper due to heating of impression.

The purpose of this study is finding of a way to estimate the integral influence of groups of factors (1 – 3 and 4 – 7) on physical dot gain. Such information should assist the proper choice of printing equipment, paper grades and inks to minimize this effect and thereby to increase the printed image quality.

The grate variety of factors effecting on physical dot gain sophisticates study of its mechanisms. Besides, the real increase of printed elements related to presence of ink at blank areas is accompanied by this element apparent increase due to the Yule-Nielsen effect or optical dot gain (Gustavson S., 1997; Arney J.S., Wu T., Blehm C., 1998; Zuffi S., Santini S., Schettini R., 2006). Optical dot gain takes place due to the trapping by print element edge the fraction of blank area illumination this fraction being diffusion scattered within a paper in said edge direction. Microphotographs of test-target areas on figure 1 show that the line edges aren't sharp enough to make such trapping effective but comprise rather smoothed boundaries. That allows for assuming the minimal influence of optical dot gain on increase of print element dimension in this study.

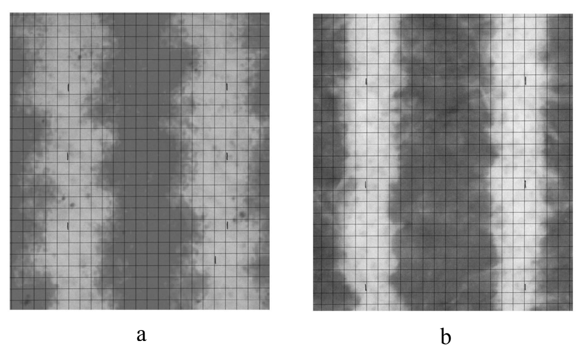


Figure 1:
Microphotographs of test-charts areas with equally defined inked and non-inked widths of $d = 2$ pixels or 1/300 of inch ($200X$: electrophotography a; ink jet b).

Two-parametric model of the print reflectivity with the account taken of a physical dot gain

It is possible to divide the above listed factors of blank areas partial coloration on 2 groups with first three of them resulting in increase of the ink applied areas when the optical properties of a substrate along their boundaries approach to the properties of solid ink films and the total blank area is just reduced preserving its initial properties. At the same time, the factors 4 – 7 can be concerned as not reducing the blank area itself but changing its reflectivity.

When there is no physical dot gain the light flow Φ_R, reflected by a printed image, according to Murrey-Davis model is:

$$\hat{O}_R = \boldsymbol{R}_p S_p + \boldsymbol{R}_s S_s = IRS, \qquad (1)$$

where I is intensity of radiation directed on a print; R, Rp, Rs are correspondingly coefficients of the light reflection by a repetitive test print unit area, paper and solid ink film; Sp and Ss are target non-inked and inked areas; S = Sp+ Ss is test print unit area. From the formula (1) follows that

$$R = R_p(1-\sigma) + R_s\sigma = R_p - \sigma\,(R_p - R_s) \qquad (2)$$

where $\sigma = \frac{S_s}{S}$ – relative area of the solid ink film. If the print comprises a b/w resolution test (made by means of the Adobe Photoshop CS2) with $\sigma = 0{,}5$, its mean reflectance is defined by

$$R = R_0 = \frac{R_p + R_s}{2}$$

Physical dot gain effected by the factors 1 – 3 reduces R due to increase of the resulting ink solid area σ while the factors 4 – 7, in their turn, reduce reflectivity of blanks (see Fig. 1 and equation (2)).

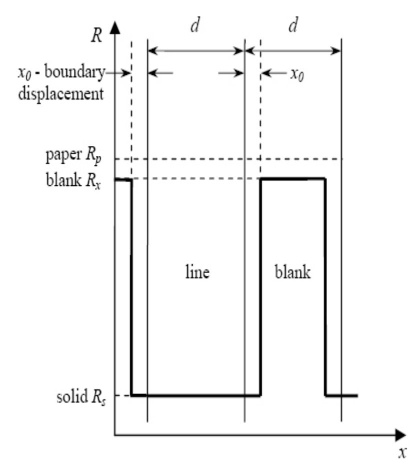


Figure 2:
The distribution of reflectance across the elements after printing of the test-chart.

Let's assume that the intervals between the N_i dark lines of an i-th patch of a resolution target are shortened by $2x_0$ due to some spread of an ink film and the reflectance over these intervals is also reduced to $R_x < R_p$ because of its partial inking. Then it follows, within the limits of Murrey-Davis model, that

$$\hat{O}_{R_i} = R_x l(d_i - 2x_0)N_i + R_s l(d_i + 2x_0)N_i = R_i l 2 d_i N_i \qquad (3)$$

$$R_i = \frac{R_x(d_i - 2x_0)}{2d_i} + \frac{R_s(d_i + 2x_0)}{2d_i} = \frac{R_x + R_s}{2} - \frac{x_0}{d_i}(R_x - R_s) \qquad (4)$$

where Φ_{Ri} – light flow reflected by i-th patch; R_i – its reflectance ($R_i < R_0$); l and d_i – predetermined length and width of lines on i-th patch of a target.

This is the simplified two-parametric model of reflectivity variation of the specially prepared print (test-chart) due to the physical dot gain. In particular, it doesn't take into account the possible overlap of an ink moved from the opposite boundaries of the adjacent dark lines. Besides, the real continual distribution of an ink within intervals of a target is replaced in final equation (4) by the two-step distribution. It is considered, that at the distance x_0 from a target line boundary the blank area is covered by the ink solid, while the rest part of a blank area is much less inked, i.e. $R_p > R_x >> R_s$. So, the adequacy of two-parametric model is not obvious and should be experimentally proved. With proper correlation of the model the experimental relationship $R_i = f(\frac{1}{d_i})$, as it follows from the formula (4), should represent a direct line crossing an ordinate in a point $\frac{R_x + R_s}{2}$ and abscissa in a point $\frac{R_x + R_s}{2x_0(R_x - R_s)}$.

If the experimental measuring of values R_i and R_s in function $R_i = f(\frac{1}{d_i})$ will prove its linearity, it would be possible to calculate both parameters of the model (R_x and x_0) and to get certain representation concerned of physical dot gain mechanisms, which are somehow different for various types of the printing process, equipment and consumables.

Experimental research of physical dot gain

Two methods of the physical dot gain study are known, the both of them being applied when optical dot gain is neglected. The first of them is based on providing the digital microphotographs of prints and subsequent computer analysis of the captured images (Kowalczyk G.E., Trksak R.M., 1998). The second one comprises the spatially integrated densitometric analysis of resolution test targets (Liu C.-H., Chen C.-J., Yang M.-D., Li Y.-J., 2003). We preferred to use the latter one for it doesn't require the special instrumentation and data processing.

The example of successful use of a densitometry for an estimation of physical dot gain influence on the ink-jet printer resolution is given in paper (Har D., Kim Y., Noh Y., 2006). We carried out the similar experiments with spectrodensitometer Gretag Macbeth SpectroEye. Densities D_i were measured on the black-white resolution test-charts output by the electrophotographic printer Samsung SCX-5112. The test-charts were printed on two kinds of paper for five values of computer-programmed lines (blanks) width d_i (from 1 to 5 pixels). The reflectance R_i was calculated five times for each chart as

$$R_i = 10^{-D_i} \tag{5}$$

and averaged. The relative error of reflectance measurement hasn't exceed 5,5 %.

Results

The experimental data received with the use a melted powder toner layer Lexmark Laser Black 13-001 $\langle R_s \rangle = 0{,}05$ are given in Tab. I. The reflectances of paper substrates and solid ink films were also determined.

Discussion

To check the adequacy of two-parametric model of physical dot gain influence on reflectivity of test-charts we submitted our experimental data and that from the other study (D.Har, Y.Kim, Y.Noh, 2006) in coordinates $\langle R_i \rangle - \dfrac{1}{d_i}$ (Fig. 3).

It has appeared, that the equation (4) satisfactorily approximates the observed decrease of factors $\langle R_i \rangle$ at increasing of $\dfrac{1}{d_i}$ value.

The experimental values are with displacement positioned on direct lines of a negative inclination to abscissa. However, the initial parts of experimental dependences $\langle R_i \rangle - 1/d_i$ were represented by right lines, and the tendency to increase $\langle R_i \rangle$ is noticeable for $d_i = 1$. Probably, it can be explained by the ink spreading across the lines with increase of their frequency, i.e. by the ink advance from inked to non-inked areas. It is expected that offered theory and scheme of Fig.2 are adequate for rather low lines frequency and they require some further development for d_i pixels.

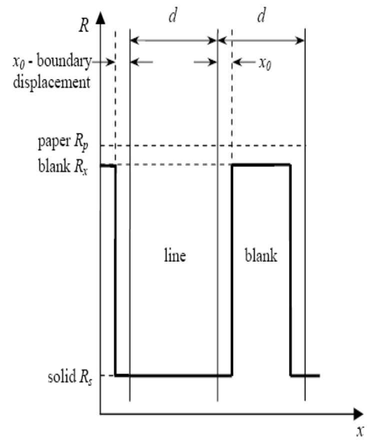
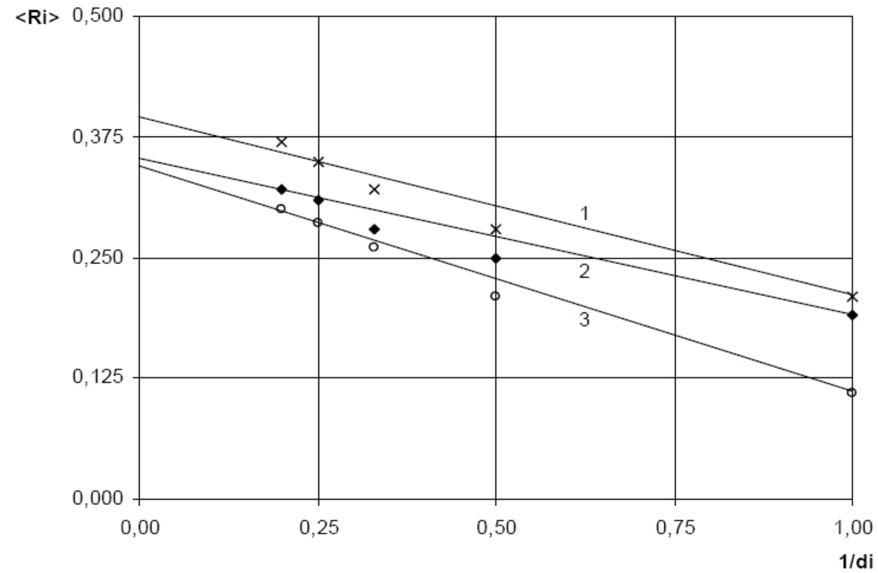


Figure 2:
The distribution of reflectance across the elements after printing of the test-chart.

Table I: The average reflectances R_i of printed resolution test-charts

Substrate	Lines width d_i (pixels)				
	5	4	3	2	1
Paper with filler (948 kg/м^3, $\langle R_p \rangle = 0{,}92$)	0,37	0,35	0,32	0,28	0,21
Paper without filler (612 kg/м^3, $\langle R_p \rangle = 0{,}62$)	0,32	0,31	0,28	0,25	0,19

Figure 3:
Experimental dependences
$\langle R_i \rangle = f(\dfrac{1}{d_i})$
1 - a heavy paper, 2 - a high-porous paper without filler, 3 - data of study (Har D., Kim Y., Noh Y., 2006).



The physical dot gain parameters x_0 and R_x were then calculated with taking into account the initial ordinates and angles tangents of direct lines on Fig. 3. These calculation data are given in Tab. II.

Table II: Characteristics of physical dot gain

The investigated samples	x_0 (pixels)	R_x
Test-charts on a heavy paper (electrophotography)	0,31	0,77
Test-charts on a high-porous paper (electrophotography)	0,28	0,62
Test-charts received on an ink-jet printer	0,37	0,69

Conclusions

1. Densitometric data analysis of b/w resolution test targets, where the optical dot gain isn't meaningful, allows to quantitatively characterize the effect of physical dot extension on the optical properties of a print on the basis of two-parametric model of phenomena.
2. The degree of spread x_0 of a solid ink layer at the line boundary of an electrophotographic print comprises about 0,3 of a pixel and doesn't essentially depend on the substrate porosity. That's why such additional inking may result from spreading of viscous melted toner over substrate surface, from the slur of the latter, etc. The capillary effects are in this case non significant.
3. Parameter x_0 for tests printed by ink-jet comes nearer to 0,4 pixel; this parameter, by our opinion, increases as result of liquid low-viscosity ink advance through capillaries of porous substrate.
4. The effect of some inking over the blank intervals becomes meaningful when the reflectivity of a substrate is rather high ($R_x < R_p$ both for the high-quality coated paper of electrophotography and for the paper with $R_p = 0{,}85$ in ink-jet printing (Har D., Kim Y., Noh Y., 2006), while $R_x = R_p$ for the low-quality newspaper). The probable reasons of such inking are caused by the factors 5 and 7 in case of a laser printer and by the factor 6 in ink-jet. As a whole, the carried out work confirms the usefulness of densitometry to physical dot gain investigation and proves the essential increase of informative data by comparison of experimental dependences

$$R_i = f(\frac{1}{d_i})$$

resolution test-targets and target line widths of their patches.

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