Estimating Physical Dot Gain of Offset Using a Scanner

Li Yang (li.yang@holmenpaper.se)
Holmen Paper Development Center (HPD), Holmen AB, Sweden
(li.yang@holmenpaper.com)

Abstract
The methodology for estimating physical dot gain from scanned images is proposed, taking into consideration of light scattering inside the paper substrate and the light reflection at air-paper and air-ink interfaces. The physical dot gain obtained reveals significant differences in the light tones compared to the middle and the dark tones. This indicates different mechanism governing the physical dot gain of the light tones (well isolated dots) compared with that of the middle and the dark tones comprising overlapping dots.

1. Introduction

Physical dot gain, referring to the difference between the printed area and the corresponding dot geometry on the plate (offset), relates closely to the printing press, ink-transfer, and ink-paper interaction. Ink transfer and ink-setting are complicated processes depending on operation settings of the press (pressure and speed), the physical and chemical properties of the ink and the substrate, and their bilateral interactions (Aspler, 2006). In offset an ink transfer process may be simplified into three consecutive steps (Walker and Fetsko, 1955): contact between plate and paper; immobilization of ink in the paper surface; and free ink-film splitting. During the contact, the ink is under the nip pressure and consequently propagates in both x-y and z (expansion and penetration) directions. In addition to the pressure applied and the dwell time, the spreading and penetration depend also on the physical and chemical characteristics of ink and the substrate. After part of the ink has been immobilized in the paper surface, the ink splits between printing blanket and paper, forming ink filaments due to print tack. Opposite to the pressure that presses the ink outwards and downwards, causing ink expansion and penetration, the tack force pulls the printed ink off the surface. It is therefore not surprising that the ink tack plays an important roll in forming the dot and then physical dot gain (in addition to the pressing), as explained later on.

Extensive studies in light of understanding the mechanisms that govern these processes have been made (Aspler 2006; Donigian 2006; Gane et al 2003; Preston 2000; Walker and Fetsko 1955; Xiang and Bousfield 1998). However, much attention has been given to ink-transfer and ink-setting processes of full-tone print, while halftone print has rarely been studied. Compared to a full tone print, a halftone print differs in at least two ways: for ink-setting, the ink (dot) spreads by advancement of the three-phase line on the substrate; when splitting the ink builds only thin filaments (especially for the light tones) connecting the blanket and the halftone dot.

Physical dot gain often coexists with so-called optical dot gain in measured colors (spectra). Different from a physical dot extension/contraction, an optical dot gain originates from light scattering inside the substrate (Ruckdeschel and Hauser 1978; Arney et al 1997; Rogers 1998, Yang et al 2001; Hersch 2006). The coexistence of physical dot gain with optical dot gain makes the experimental measurement of either type of the dot gains a difficult task. The goal of the study is two folds: to find a simple and reliable way to determine the physical dot gain of offset print; to understand the physical causes that govern the dot gain.

2. The methodology

The test charts of primary colors and black were printed with a commercial 4-color offset press (Heidelberg GTO52) in the order of ink application: black, cyan, magenta, and yellow, on both coated and un-coated substrates. The test charts consist of FM (frequency modulation) screening dots of 1200 dpi in resolution. The nominal dot percentages of the test patches are 2, 5, 10, 20,..., 80, 90, 95, 98, and 100%, respectively. The test charts were measured by employing a flat-bed scanner: FujiFilm FineScan 2750. The test charts were scanned in both reflective and transmission modes. We obtained, therefore, the intensities of light reflected from and respectively light transmitted through the test patches. The scanned images were stored in jpeg format with three color channels (red, green, and blue). For a halftone of ink percentage, *a*, the measured intensity of reflection, fulfil the following equation (Yang and Lundström, 2007),

$$\frac{(1-a+at)^2}{1-r_1R_0(1-a+at^2)} = \frac{I_r(a)}{I_r(0)}\frac{1}{1-r_1R_0} - \frac{\left[1-{I_r(a)}/{I_r(0)}\right]Kr_0}{R_0(1-r_0)(1-r_1)}, \qquad (1)$$

where $I_r(0)$ and $I_r(a)$ are the intensities of the unprinted substrate and the color halftone, respectively; R_0 the reflectance of the substrate; t the transmittance of the ink dot; r_0 and r_1 the external and internal surface reflections at ink/air interface. In Eq. (1), the quantity K is the portion of the external surface reflection contributing to the measured intensity. Depending on the illuminating/measuring geometry, the quantity K takes a value between zero and unity.

In a similar manner, we obtained the equation for the intensities of light transmission,

$$\frac{(1-a+at)}{1-r_1R_0(1-a+at^2)} = \frac{I_t(a)}{I_t(0)}\frac{1}{1-r_1R_0}., \qquad (2)$$

with $I_t(0)$ and $I_t(a)$ being the intensities of the unprinted substrate and the halftone.

Equations (1) and (2) are the principal equations of the methodology. Either of the equations can be used for computing the physical dot percentage, *a*. The surface reflectance values, r_0, and r_1, can be computed using the Fresnel equation when the refraction index of the substrate (ink), n, is known. In the present study, $n=1.5$, is used. Finally, the ink transmittance, t, is obtained from the reflection of a full tone print.

The physical dot gain equals to the difference between the real physical dot percentage, *a*, and the corresponding nominal tone value or the tone value on the printing plate, a_0, namely

$$\Delta a_{phy} = a - a_0 \qquad (3)$$

3. Results and Discussions

Figure 1 depicts the measured physical dot gain with respect to the nominal tone values for the primaries and black. The solid lines are the estimations from scanned images of transmitting light, employing Eq. (2), while the dotted lines are obtained by fitting the calculated spectra (Yang and Lundström, 2007) to the experimental spectra, see Fig. 2. Clearly, the physical dot gains obtained by these methods agree fairly well with each other.

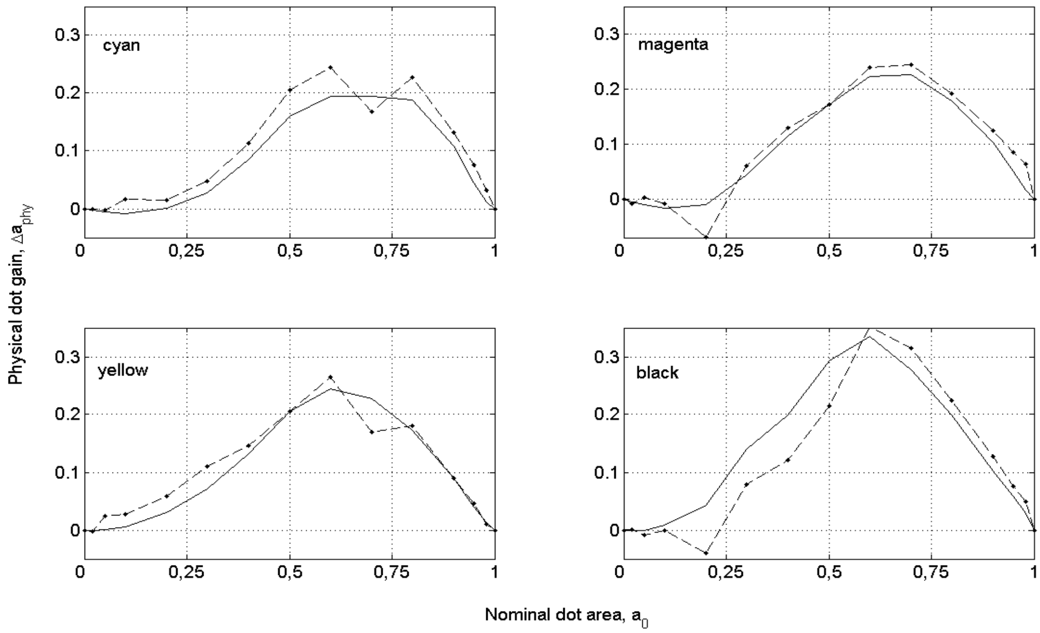

Figure 1. The physical dot gain of the prints with the primaries and black on coated paper. Solid lines: estimated from scanned images of light transmission; dashed lines: obtained by fitting the calculated spectra to the measured spectra, see Fig. 2.

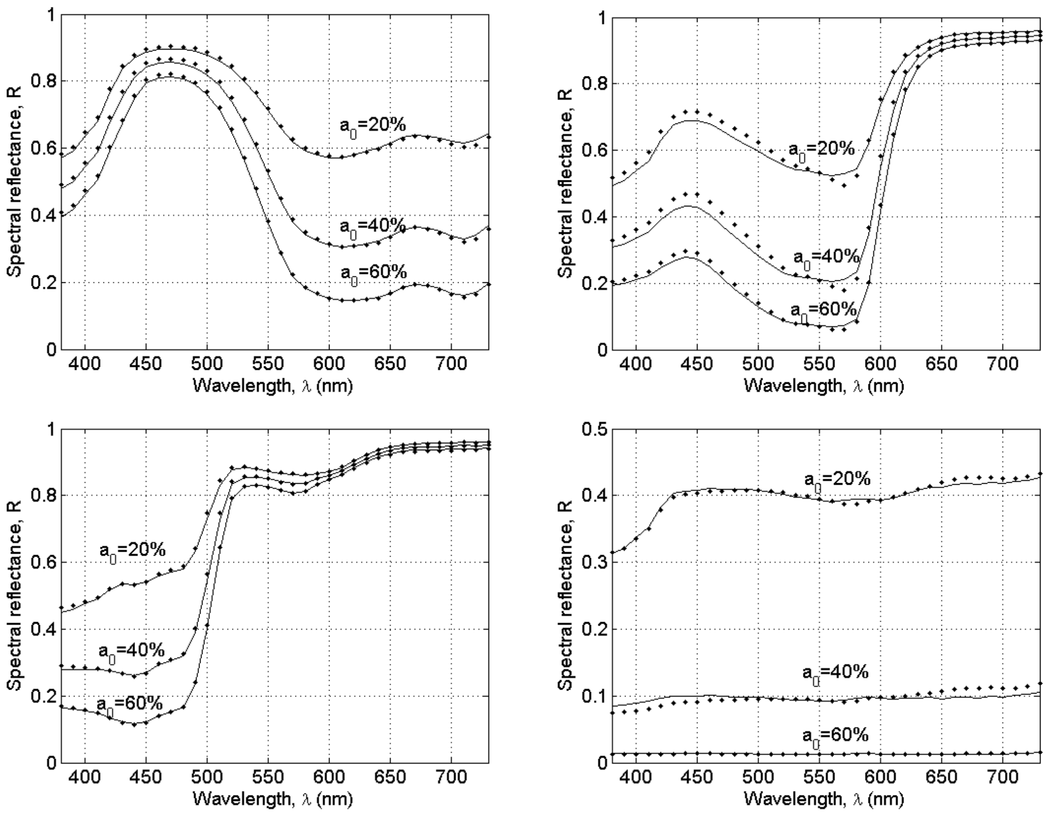

Figure 2. The computed (solid line) and experimental (dots) spectra of cyan (top left), magenta (top right), yellow (low left), and black (low right).

This indicates the reliability of the method. Compared with the conventional measurements with the spectrophotometer such as Elrepho and Spectrolino, using a scanner is much more time-effective. In the current study, only one scan was necessary: imaging of light transmission.

The most eye-striking feature in Fig.1 is the different behaviour of physical dot gain with respect to the tone values. For the light tones (a_0<25%), the physical dot gain is very small or even negative, while for the middle tones the physical dot gain is much bigger. Considering the fact that a frequency modulation is used for halftoning, the sizes of the individual dots (on the plate) are identical and independent of tone values. Therefore, the causes for different dot gain behaviour have probably something to do with the reduced distance between adjacent dots, leading to dot-overlapping, when the color tone increases. For the light tones, the interaction of ink with the plate and with the paper (ink-transfer under nip press, ink splitting, and ink setting) is of the form of individual separate dots as they are well separated from each other. Under such a circumstance, the printed dot demonstrates little size extension or rather contraction after the ink is transferred onto the substrate and then spreading on the paper surface. In contrast, for the middle tones, dots under a nip pressure have great possibilities to overlap with their neighbouring dots. This is supported by the microscopic inspections with the optical microscope (Yang and Lundström, 2007).

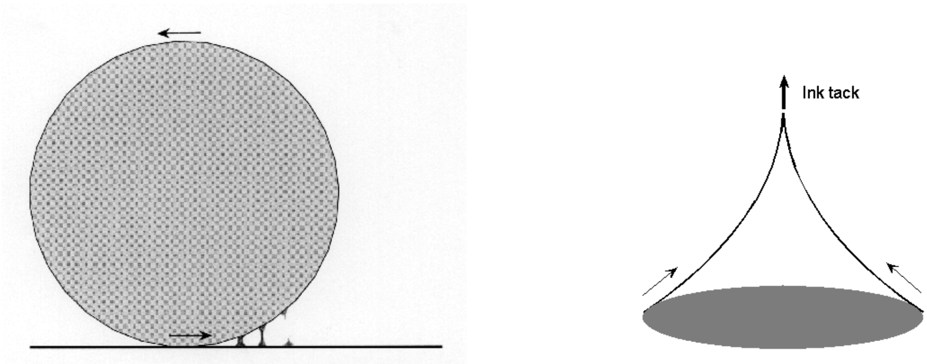

Figure 3. An illustration of ink splitting (left) and ink tack of a screen dot, which causes contraction of an ink dot (right).

For offset with typical coated paper properties, studies showed that only a small portion of the transferred ink (ink vehicles) is pressed into the pore structure under the nip pressure (Aspler 2006). Ink-setting in form of spreading and penetration free from external pressure is therefore important process that affects the physical dot gain. Besides the press and the ink setting processes, there is another process: free-ink splitting that affects the final dot size. When ink-splitting occurs, the ink tack pulls the printed ink towards the nip, causing dot contraction. Therefore, a possible scenario is that counter to the ink spreading that causes dot enlargement, the inked area contracts under the pulling of the ink tack, as illustrated in Fig. 3. Naturally, this effect is particularly significant for an isolated dot since the contraction occurs in all directions. While for overlapping dots there is little contraction in the overlapping areas. Consequently, there is less dot contraction for the middle tones. Moreover, the ink layer is possibly thicker in the overlapping area when ink-splits, resulting in a weaker ink tack according to the Stefan's Law. Competing with the press and ink spreading processes, the ink tack is important factor that affects the final dot size (and physical dot gain). The small and even negative physical dot gain may indicate that the ink tack is in dominance for the light tones consisting of tiny (1200 dpi) and isolated ink dots. While for the middle and dark tones with overlapped and clustered dots, the press and ink spreading are the dominant factors.

Reference

Arney, J.S., 1997, "A probability description of the Yule-Nielsen effect, I", J. Imaging. Sci. Technol., vol 41, pp. 633-636.

Aspler, J. 2006, "Ink-water-paper interaction in printing: An uppdated review", Proc. Adv. Coating Fundamental Symposium, TAPPI Press, Atlanda GA, pp. 117-146.

Gane, P.A.C., Matthews, G.P., and Schoelkope, J. 2003, "Offset ink tack and rheology correlation Part 1: Ink rheology as a function of concentration", Tappi J. vol. 32, 13-19.

Hersch R. D., Hébert, M., 2006, "Interaction between Light, Paper and Color Halftones: Challenges and Modelization Approaches", Keynote Talk, Proc. IS&T Third European Conference on Color in Graphics, Imaging and Vision (CGIV), Leeds, June 2006, pp. 1-7.

Preston, J.S., Elton, N.J., Husband, J.C., Legrix, A., Heard, P.J. and Allen, G.C. 2000, "Sims analysis of printed paper surface to determine distributions of ink components after printing", Proc. Intl. Printing Graphic Arts Conf., TAPPI Press, pp. 101-120.

Rogers, G.L. 1998, "Effect of light scatter on halftone color", J. Opt. Soc. Am. A, vol. 15, pp. 1813--1821.

Ruckdeschel, F. R. and Hauser, O. G. 1978, ''Yule–Nielsen effect in printing: a physical analysis,'' Appl. Opt. vol. 17, pp. 3376– 3383.

Walker, W.C. and Fetsko J.M.1955, "A concept of ink transfer during printing", Am. Ink Maker, vol. 3, p. 38.

Xiang, Y. and Bousfield, D.W. 1998, "The influence of coating structure on ink tack development". Reprients Pan-Pacific Intl. Printing Graphic Arts Conf.,Tech. Sect. CPPA, pp. 93-101.

Yang, L., Gooran S., and Kruse B., 2001, "Simulation of optical dot gain in multi-chromatic tone reproduction", J. Imaging Sci. Technol. vol. 45, pp.198-204.

Yang, L. and Lundström, N. 2007, "Physical Dot Gain of Offset: Understanding and Determination", Nordic Pulp & Pap. Res. J., vol. 22, pp. 388-393.