Faithful Printing of Digital Source

Dror Kella[1], Ayelet Pnueli[2], Ron Maurer[2], Mani Fischer[2], Doron Shaked[2], Gidi Amir[1], Amiran Lavon[1], Eyal Shelef[1]

[1]**Indigo Digital Press Division, Hewlett-Packard Company, Kiryat Weizmann, P.O. Box 150, Rehovot 76101, Israel.**

[2]**Hewlett-Packard Laboratories Israel, Technion City, Haifa, Israel.**

Abstract

Faithful printing of digital source images requires simultaneous control of solid patch colors (optical density - OD), and graphic element dimensions (dot gain - DG). In Electro-Photography laser based printing, the dot-gain and the optical-density are coupled through process parameters such as toner thickness. Decreasing the DG usually decreases the OD. Since OD deviations cause color shifts, OD calibration takes precedence over DG setting, thus limiting the possible values of the attainable dot gain. The latter is determined by the writing system and by variable consumable properties such as the toner charge density. Thus, the dot gain varies in time and between printers. This causes a print fidelity problem that manifests itself in variability of graphic element dimensions and instability of highlights in halftones.

*We present a novel method for resolving this problem using a **locally-adaptive** variable laser exposure that affects only selected dots on edges of elements, thus **decoupling** the **OD** and the **DG** controls. The solution we present consists of a template-based algorithm combined with a novel calibration mechanism for attaining **zero** DG. The results show ~50% improvement of the de-facto resolution for graphics printing, and a reduced sensitivity of halftone patterns to press conditions. The new DG control, combined with existing color control, brings us significantly closer to print consistency across presses.*

Problem Description and Motivation

One would expect a printing system to reproduce precisely the input digital image. This includes in particular color consistency and graphics fidelity. Although these seem to be obvious requirements, in real life they are not trivial to achieve. Two measurable parameters which define any printing system are the Optical Density (OD) of a solid patch and the Dot Gain (DG). The DG is defined as the difference between the coverage of designed (digital) patterns and the actual coverage on print. Thus zero DG is obtained when the designed and actual coverage are equal. The two parameters, OD and DG, vary in time and between presses/printers and must be controlled to keep print consistency. The OD setting takes precedence since it defines the baseline for the final result. Any color lighter than the solid coverage may be achieved by different coverage while the solid coverage is unique. In (Liquid) Electro-Photography - (L)EP systems the OD and DG are predominantly controlled by the developer voltage and laser power respectively[1]. The model described in [1] shows that for a given printing system and for a given OD, the range of DG attainable (or line width for the model) by varying these two parameters is limited, as illustrated in Figure 1. Hence, we cannot obtain zero dot gain for all selected values of the OD, in particular we cannot have zero DG for the conditions and requirements of the Indigo presses (red arrow range). DG variation is manifested in halftone dot-size variation causing color shifts, and graphics element thickness variations. For very small elements, including single halftone dots, DG variation causes instabilities, such as missing or broken elements for small DG and excessive granularity for large DG. Some of the problems caused by DG in

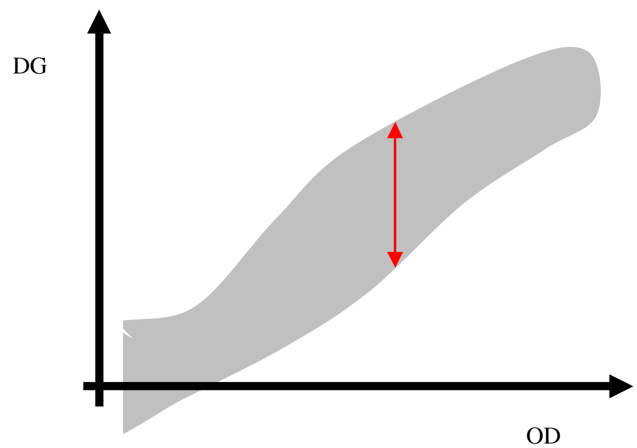

***Figure 1**: A schematic illustration of the attainable DG range as a function of OD. Note that there are OD values that do not permit a zero DG.*

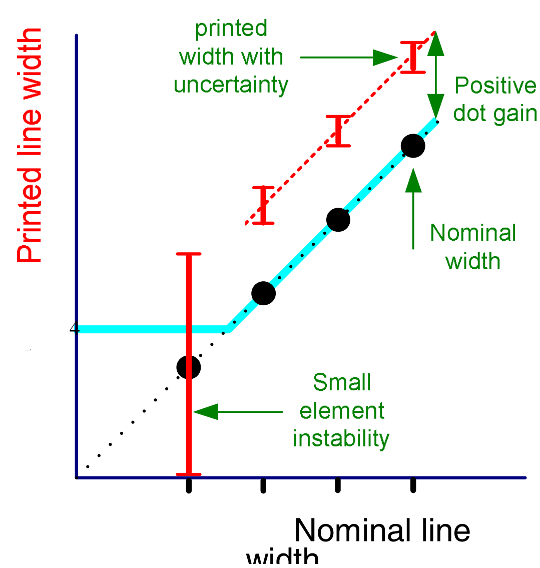

***Figure 2**: A schematic illustration for the effects of dot gain and small element instability.*

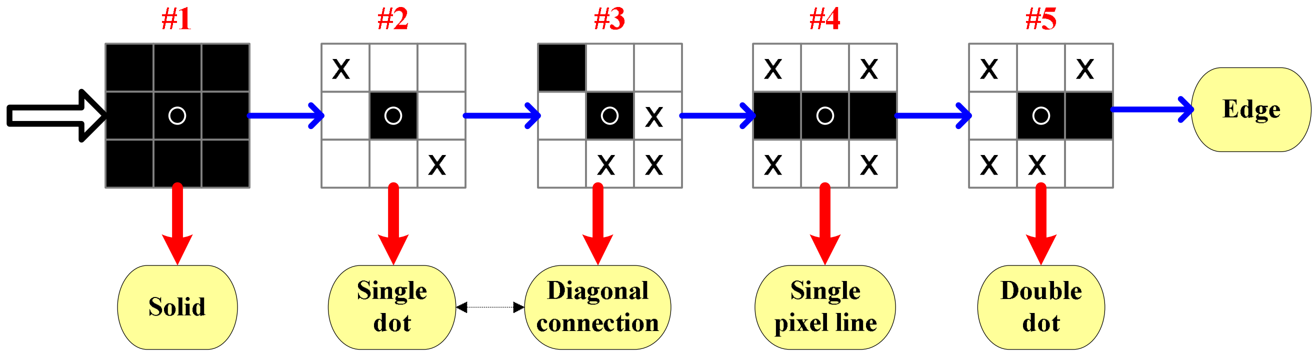

Figure 3 Sequential template matching algorithm for classifying and tagging binary line-art pixels according to their 3x3 neighborhood. Black is 'on' white is 'off' and X is 'don't care. Every template is taken as a collection of templates with all possible rotations and inversion. "Edge" is the default tag given to pixels that failed to match any of the templates..

LEP have been addressed in the past[2]. The color-shift problem for halftone patches was solved through a lookup table (LUT) mechanism, compensating in advance for the dot gain in the digital domain. Such compensation cannot be applied to binary graphics (0% or 100% coverage). In addition, it cannot address the small element instability problem affecting small fonts and highlight halftones consisting of single dots.

Figure 2 illustrates the effects of dot gain and small element instability on narrow diagonal lines. The uncertainty bars denote the range of actual printed widths corresponding to each nominal width. The dot gain is the mean bias of the printed width. Notice that the single pixel wide line has larger uncertainty, exhibiting instability artifacts such as line breaks. For single dots the instability is even larger. We refer to this effect as small element instability.

In this paper we present a method to control the dot gain so that a graphic object would print exactly as digitally designed, except when it at danger of not being printed reliably. In such cases we protect it, and print it in the minimal stable size, as illustrated by the solid cyan line in Figure 2. The DG control also assures print consistency over time and between presses[3].

Solution method

The basic principle of our solution is to vary exposure only on selected pixels: edges of binary linework, and single halftone dots. Overall DG may be controlled by a constant laser power for all elements but, when constrained by a given requirement for OD, the range of attainable DG is limited. Our solution decouples between DG (measured on edges), and OD (measured on solid patches). Thus, we can select any desired DG independently of OD.

For line work the solution has two components: **real-time** digital pre-processing, and **offline** variable-exposure calibration.

The principle of the algorithm is tagging pixels as belonging to one of various classes: 'Solid', 'Edge', 'Unstable' and 'special'. Tagging is done in real-time using simple template matching displayed schematically in figure 3.

We tag the inside of solid patterns as 'Solid' indicating that these pixels will attain the nominal exposure.

The tag 'Unstable' is given to sensitive pixels (*e.g.* single pixels and diagonal connection) indicating they need to be protected. The identification of sensitive pixels is done based on expert knowledge of the specific system and needs revisiting per different system types. Based on the same expert knowledge we may define some special cases (e.g. single pixel line and double dot) and later treat them specifically. The rest of the pixels are tagged as 'Edge', where the exposure value of 'Edge' is used to achieve the required (zero) DG via analog thinning. The 'Edge' and 'Unstable' tags may be further refined into sub-tags.

The half-tone single dots are tagged already in the screen data. By tagging the nucleus (first pixel) of halftone cells (in AM screening) as 'Unstable' we protect single-pixel highlight dots from vanishing, and improve print stability for larger dots.

Offline variable exposure calibration maps the tags to laser exposures required to achieve the desired effects. 'Edge' calibration is done by printing a set of patterns with equal digital coverage and different spatial frequency. When DG is positive (negative) the higher frequency pattern is darker (lighter) since there is a larger portion of edge-pixels on this pattern. When laser exposure is calibrated to zero DG, both patterns appear to have the same gray-level. 'Unstable' calibration is done using stable elements, *e.g.* for single dots it is done using single pixel wide lines at 45°. Their DG behavior is similar to that of single dots, but unlike the latter, diagonal lines are stably reproducible.

Benefits and Results

The locally adaptive variable exposure method presented here offers many practical benefits relative to traditional methods.

The main benefit is **high print accuracy and consistency** for

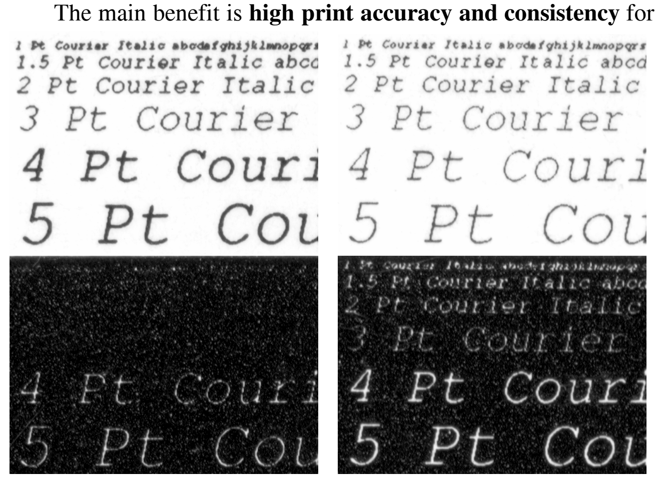

***Figure 4**: Regular 800dpi printing without dot-gain control (left) versus dot-gain controlled printing (right).*

line-work such as drawings and fonts, as demonstrated by Figure 4. The right side is printed with zero-DG calibration, while the left side is a conventional print (uncalibrated DG). The input digital image is the same. It is clear that we obtained the desired zero-DG, since the thickness of the foreground and inverse fonts is the same. Note that the smallest foreground fonts are printed stably using thinner lines, which improves readability of these fonts due to reduced hole-filling. Also note that printing small inverse fonts is impossible without DG control, as appears on the right side of Figure 3. Note that zero-DG provides press / printer independent fidelity.

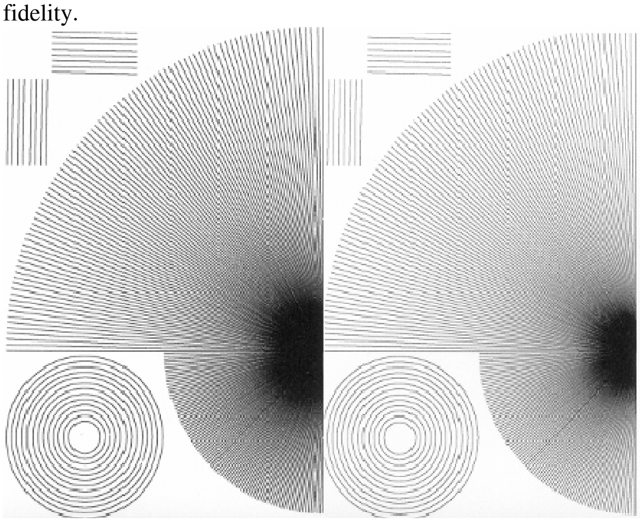

Figure 5: Resolution stars: regular 800dpi printing without dot-gain control (left) versus dot gain controlled printing (right).

Another benefit is **higher print resolution**: As demonstrated in Figure 5, zero-DG enables separation between closely spaced digital elements (even one pixel apart), which was not possible before. Overall we deliver 50% improvement in the element separation resolution.

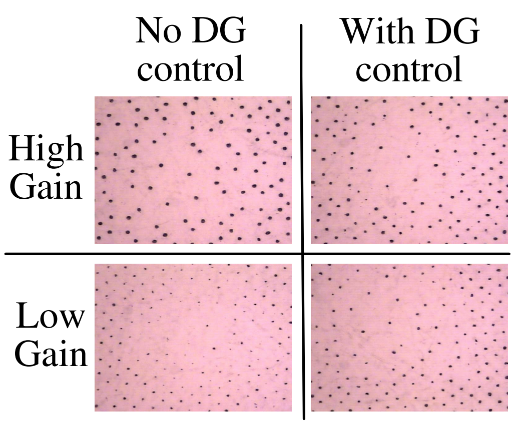

Figure 6 *Single pixel control*

For highlight halftones, we get the desired **print stability and consistency**. Figure 6 shows that DG control of small dots (on the right) stabilizes their size, thereby considerably reducing their sensitivity to press conditions. This results in a more consistent color reproduction, especially for highlight tones, and also simplifies the color calibration process.

Discussion

By applying a local real-time modulation we enable accurate and stable printing. This, in turn, ensures also press to press compatibility, using only a simple one dimensional calibration process. All of this was made possible using the variable laser exposure to decouple OD from DG by performing element-dependent accurate dot-gain control.

References

[1] Dror Kella, and Amiran Lavon, "Optimizing Laser Print Quality: Phase Space Modelling", Proceedings of IS&T NIP23, pp 73-76 (2007)

[2] (WO/2006/046224) DOT GAIN AND COLOR LINEARIZATION DUAL CALIBRATION

[3] (WO/2008/033126) ELECTROGRAPHIC DOT GAIN AND OPTICAL DENSITY DECOUPLING METHOD, XEROGRAPHIC IMAGE REPRODUCTION, AND SYSTEMS, METHODS AND SOFTWARE RELATING THERETO

Author Biography

Dror Kella received his BSc degree in Physics and computer sciences form Tel-Aviv University, Israel (1987) and his MSc and PhD in physics from the Weizmann Institute of Science, Israel (1989 and 1994). He was employed on a postdoctoral position at Aarhus University from 1994 till 1997. From 1997 to 2001 he was employed by Applied Materials, Israel in designing scanning electron microscopes. Since 2001 he is employed by HP-Indigo researching various aspects of LEP.