Screening for Digital Printing: A Multi-parameter Task

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Introduction

Changing demands in advertising and printing business has made the digital press systems valid competitors to offset technology for specific markets. Whereas offset is still superior in quality and high volume printing the time consuming and costly prepress activities, as well as the need for huge investments in the press, make the all-in-one formula very attractive. How to link a fast/ cheap machine with decent output-quality, making use of electrophotography?

We will use electrophotography as a pretext for making a stability analysis of several halftoning systems. As shown in a previous article (Ref 3) we will use the Fourier characteristics to figure out its dependence.

In a first introduction we point out why electrophotography brings us to this matter. The further outline of the article scans through a list of opposite screening systems where we will focus on the color stability in function of registration.

1 Electrophotography

1.1 Jones Plot of the Continuous Tonal Behavior

The main steps of the electrophotographic process can be cascaded into a four-leafed Jones-plot (Fig. 1) as taken from Ref. (1) to obtain a tonal transfer curve of a practical xerographic system. This curve can then be used as a model for designing screening output.

There is the *Exposure Subsystem*, comprising a laser or laser diode. These systems should be stable and should have a flat MTF (That is focus all line widths equally, and have no chromatic aberrations).

There is secondly the *Photoconductor Subsystem* which transforms an input exposure into an electrostatic latent image on the surface of the photoconductor. Finally there is the *development Subsystem*, which is different for line and solid area images.

Important here is that these empirical curves differ for the type of images. This is what often is referred to as **cross talk** between picture elements (pixels) typically

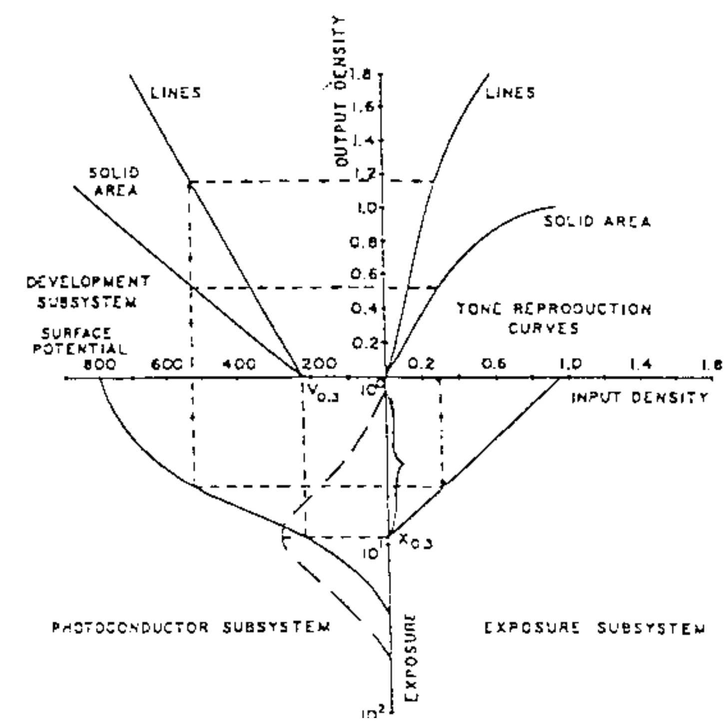

Figure 1. Electrophotographic systems four quadrant plot.

for electrophotography. In addition to this core part of electrophotography the final developed density on paper depends on the transfer efficiency and fusing effects also.

All of the physical parameters involved contribute to a very fragile system when wanting to use the contone aspects of electrophotography. It is clear that a non-stable transfer function will alter the output of multi-level halftone screens which tries to use the multiple output levels. However, also the binary halftoning is affected since the threshold level seems to be shifted when the development level is shifted.

1.2 Restriction on Positioning Accuracy

For the reproduction of color images the electrophotographic process is repeated 4 times, once for each of the traditional colors. Extreme care is taken for cleaning rest-charges between the different color stations in order to avoid "ghost" images between the separations.

It is clear that four passes of the same paper result again in a non-perfect allineation of the image in that direction.

2 Rational versus Irrational Screens

The family of rational screens reduce to screens which are defined by an angle of which the tangent is made up by a rational number, and therefore can be characterized by a matrix with one complete dot in it. An irrational screen is a screen which is defined by an irrational tangent such as a 30 degree screen. In between we have the super cell screens which are made up by several dots, and match as a group in a matrix structure of finite size. The use of multilevel extends the two dimensional matrix structure (referring to the spatial extension) to a matrix with an additional dimension for the number of output levels (m bit output requires 2^M - 1 spatial matrices).

The advantage of a rational screen is the small structure which can easily be stored. A disadvantage is the fact that the shape is locked to the grid, and turns out into structure-artifacts when the number of pixels per dot is small (high rulings for its resolution). The super cell approach may solve the artifact but requires a much larger memory. Also, the artifact talked about appears much stronger in binary mode as in multi-level mode.

Another advantage of the rational screen method for electrophotography is the fact that a small matrix can be compensated for pixel-cross-talk more easily.

3 Line versus Dot screens

A dot screen which contains the same tonal information as a line screen will have a lower ruling as the one-dimensional screen. Of course, the price for the line screen is that in the perpendicular direction the ruling is zero! Line screens have been used in early days for low resolution devices. We see them popular again in color screening since the one-directionality is partially solved by distributing the different separations in opposite directions so that the image content will be captured at least by one printing color.

If line screens are inferior to dot screens for rendering image content, the same can be said for subject-moiré. There is less chance to capture image moiré with line screens than there is with dot screens. However when that occurs, it will be more pronounced.

Another advantage of using line screens is the smaller circumference of the "dot shape", and is therefore less subject to dotgain. The pixel cross talk in electrophotography produces its own dotgain. Another example of a large dotgain process is flexography.

A line screen is not sensitive for misregister along its zero-ruling direction. However it is more sensitive than its equivalent dot screen along the perpendicular direction, since the ruling is higher. If we continue the same reasoning for a set of color screens, we expect a stronger register dependence for line as for dot screens. Indeed the following paragraph will show clearly the registration dependence of rotated line screens, compared to previously analyzed rotated dot screens (Ret 3). The corresponding rosette structures in line screens are far less objectionable as in dot screens.

4 Dot versus Clear Centered Screens

A "moiré-free" set of three screens is based on a set of screens whose frequency diagram form a closed triangle Ref. (2). It means that the composed frequency of two screens is equal to the third and therefore causes a zero order moiré of infinite wavelength. It is most evident that the result of the superposition of two equal binary screens relies heavily on their relative position, if they act on some common color. Therefore, it is clear that when the separate color channels show spectral overlap, the physical overlap should be stable for register in order to have consistent color. The two extreme appearances of the zero order moiré are referred to as a dot and clear centered rosette.

The physical overlap can be calculated by considering the DC component of the combined frequency spectrum $F(f_x, f_y, \alpha)$, of the screens. Whereas the Fourier spectrum of an amplitude modulated dot screen is characterized by two orthogonal frequency vectors, line screens are also one dimensional in frequency domain $F(f_x,\alpha)$. The power spectrum can be looked at as a line-grid itself with diminishing amplitudes for higher harmonics.

The expression for the Fourier transform of the combined screen can be written as:

$$F(f_x,\alpha,\beta,\gamma) = F(f_x,\alpha) \otimes F(f_x,\beta) \otimes F(f_x,\gamma) \qquad (1)$$

in which the symbol (⊗) refers to the convolution operation and the angles of rotation (α, β, γ) are restricted by the requirements that $\alpha + \beta + \gamma = 0$.

For the clear centered rosette in the dot screens in which the values I_1,I_2,I_3 refer to the intensity values of the individual screens, the DC component equals:

$$F(f_x = 0, f_y = 0, \alpha, \beta, \gamma) =$$

$$I_1 I_2 I_3 \sum_{n=-\infty}^{n=\infty} \sum_{m=-\infty}^{m=\infty} \left\{ \mathrm{sinc}^3\left(\frac{w(n+m)}{T\sqrt{2}}, \frac{w(m-n)}{T\sqrt{2}} \right) \right\} \qquad (2)$$

while for its equivalent line set:

$$F(f_x = 0, f_y = 0, \alpha, \beta, \gamma) =$$

$$I_1 I_2 I_3 \sum_{m=-\infty}^{m=\infty} \left\{ \mathrm{sinc}^3\left(\frac{wn}{T\sqrt{2}}\right) \right\} \quad (3)$$

Similar evaluating in the case of the dot centered rosette yields for the DC component of a dot screen:

$$F(f_x = 0, f_y = 0, \alpha, \beta, \gamma) = \quad (4)$$

$$I_1 I_2 I_3 \sum_{n=-\infty}^{n=\infty} \sum_{m=-\infty}^{m=\infty} \left\{ (-1)^{(n+m)} \mathrm{sinc}^3\left(\frac{w(n+m)}{T\sqrt{2}}, \frac{w(m-n)}{T\sqrt{2}}\right) \right\}$$

and of its line equivalent :

$$F(f_x = 0, f_y = 0, \alpha, \beta, \gamma) =$$

$$I_1 I_2 I_3 \sum_{m=-\infty}^{m=\infty} \left\{ (-1)^n \mathrm{sinc}^3\left(\frac{wn}{T}\right) \right\} \quad (5)$$

When evaluating these results, it has been confirmed that line screens are more register dependent than equivalent dot screens, since dot and clear centered rosette configurations result in a larger difference of physical overlap.

5 Moiré-free versus Controlled Moiré Behavior

This analysis leads to the acceptance of more than only zero order moiré systems in case of bad register. Indeed, moiré can be considered as an oscillation between clear and dot centered rosettes which only differ from each other by a different relative positioning of the screens. If the moiré expands a full wavelength within the repetitive unit cell of the composed screens considered, a change in relative register will only move the moiré pattern, but it will not alter it. Therefore a system with moiré of high enough frequency may be acceptable for obtaining a stable screening configuration.

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❋ Previously published in *Europto Proc.* pp. 363–366, 1996.