Advances in Technology of KODAK NEXPRESS Digital Production Color Presses

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Abstract

The stochastic screen has traditionally been used to preserve images with fine features as well as to reduce printing Moiré of images that contain input periodic structures. However, the stochastic screen also has experienced more difficulty in maintaining color stability in long press runs. Kodak, using its multilevel printing architecture, has created a new stochastic screening technology, with long-run color stability comparable to that of traditional screens. The new screening process has a unique AM and FM structure consisting of variable dot size, dot shape, dot density, and dot positions. The structure simulates the receptive field structure of the human retina to achieve the desired image smoothness. Kodak's high information capacity, multilevel printing technology in conjunction with nonlinear LED exposure, can further be expanded to production printing with even finer contone-screen printing. This paper will discuss the advances of these technologies.

Introduction

Digital color halftoning [1] is commonly used in color image printing to either create the illusion of continuous tone when few intensity levels per primary colorant are available, or to affect visibility and objectionability of noise artifacts relative to direct continuous-tone ("contone") printing. *Rational tangent (RT) screening* [2] is a popular technique for binary halftoning extended to multilevel halftone printing by Tai [3]. We generalized Tai's approach to *supercells* [4] composed of cells of arbitrary polygonal shapes to facilitate AM/FM halftone screening under Kodak's 8-bit multilevel electrophotographic (EP) printing architecture [5, 6], which allowed us to compare halftone and contone-screen reproduction of digital images at 600 dpi.

Halftone image quality is known to be linked to whether quantization noise is white, blue [7], or green [8, 9], depending on its Fourier magnitude spectrum, which is useful to visualize in 2D as recommended in [10], because it matters how radially isotropic the spectrum is. Figure 1 shows a Fourier magnitude spectrum of a noise image corresponding to classical error diffusion [11].

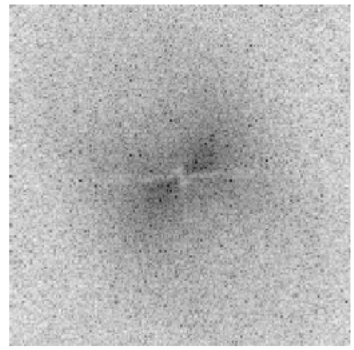

***Figure 1**. Fourier magnitude spectrum of radially anisotropic blue noise*

Blue-noise masks [12, 13] and *green-noise masks* [14, 15] allow efficient implementation and yield more radially isotropic magnitude spectra, thus reducing correlated artifacts in the toe and shadow areas. Under the supercell approach, the fundamental frequency of a halftone screen in lines per inch (lpi) can be computed by the formula

$$f = \sqrt{N / S}, \tag{1}$$

where N is the number of cells per supercell, and S is the supercell's area expressed in square inches. For the purpose of EP printing, we are primarily interested in the green-noise frequency range from 130 to 220 lpi. The main problem with the traditional green noise is the worm-like artifacts like those shown in Figure 2. Ostromoukhov and Hersch [16] found a good solution for binary black-and-white reproduction.

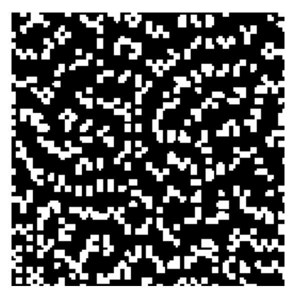

***Figure 2**. Green-noise worm-like artifacts*

In the next section, we will describe our new stochastic screening technology for multilevel color printing.

Kodak Staccato DX Screening

For any finite set of distinct points in a repeating supercell, we can divide the supercell into individual units so that each cell contains exactly one point from the set. In particular, this can be achieved by drawing a Voronoi diagram [17], as shown in Figure

3, where nine zero-degree square supercells are repeated for the purpose of subsequent processing.

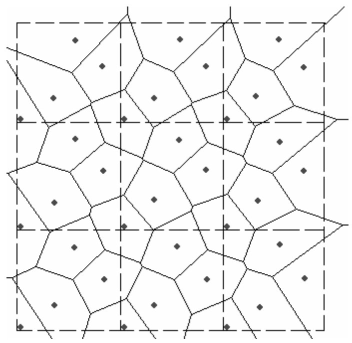

Figure 3. *Dividing supercells into cells by the Voronoi diagram*

Starting with a random or pseudo-random set of points, we improve uniformity of their distribution by iteratively replacing all points by the centers of mass of the surrounding Voronoi vertices, as depicted in Figure 4, and then recomputing the Voronoi diagram for the new set of points.

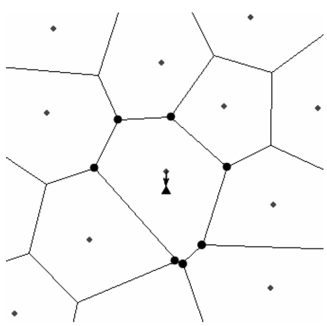

Figure 4. *Voronoi iteration*

We then create a lookup table (LUT) for multilevel halftoning by growing halftone dots within cells around the points (dot centers) as shown in Figure 5, where the pixels in the "darker" areas of the cell reach maximum colorant intensity earlier than do those in the "lighter" areas. For any given plane of the LUT, the pixels on the dot border are assigned intermediate intensity values approximately proportional to the areas of the "filled" parts of their respective pixel unit squares. Dot growth is controlled to achieve desired tone scale behavior.

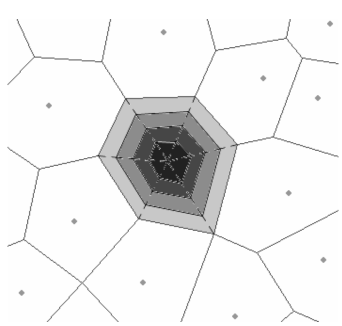

Figure 5. *Growing a halftone dot within a cell*

The LUT planes can then be filtered in order to control contrast and smoothness of the halftone screen. Figure 6 features a small fragment of a monochrome image digitally halftoned using a LUT of this kind and displayed at a low resolution.

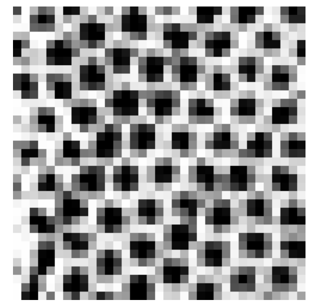

Figure 6. *Staccato DX screening: The look and feel of a dot design*

The Fourier magnitude spectrum of the corresponding noise image is shown in Figure 7.

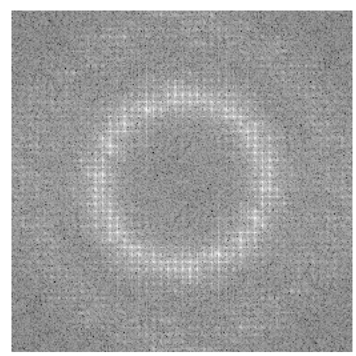

Figure 7. *Fourier magnitude spectrum of Staccato DX screening's green noise*

This is a radially isotropic green-noise spectrum. It is worth noting that the phase, which is not visualized here, has long been known to have considerable impact as well [18], so perception of green noise varies because of phase differences. Our solution resolves the worm-like artifact problem.

We proceeded to build complementary halftone screens by using the appropriate Voronoi vertices as dot centers. The complementary LUTs were subsequently used for weighted blending with the original LUTs to produce hybrid designs. Note that there are more Voronoi vertices (and, correspondingly, "holes") than dots, the frequency ratio ranging from 1.1 to 1.3, so we created AM/FM hybrids. Overprint Moiré is not an issue with them, as long as all supercell areas are sufficiently large (1024 pixels or larger for printing at 600 dpi), and it seems mildly helpful, but not necessary, to choose the RT screen angles so that the angle difference for each pair of screens is at least 9°. Moreover, we discovered that color overprint grain and mottle can be reduced considerably by spacing the fundamental frequencies of Staccato DX screens for the primary colorants allowed to overlap at least 10 lpi apart (preferably, 20 lpi or more).

In the next section, we analyze color consistency of Staccato DX screening as compared to the NexPress default Classic screening option previously reported to achieve superior performance [19] using adaptive screening and anti-aliasing [20, 21]. Figure 8 shows a magnified view of a printed CMYK color image halftoned using the Classic screen set. Higher fundamental frequencies of black and cyan Staccato DX screens resulted in improved reproduction of small details in the image, as illustrated in Figure 9.

***Figure 8**. Color image fragment halftoned using the Classic screen set*

***Figure 9**. Color image fragment halftoned using Staccato DX screening*

Color Consistency of Staccato DX Screening

For two 190-page print runs made on a Kodak NexPress 2100 plus digital production color press using Classic and Staccato DX screening, we measured color patches in every tenth page containing a 928-patch IT8.7/3 target. We computed dE-1976 distances of each patch from the 19-sheet mean CIELAB patch values, averaged them over 928 patches separately for each screening option, and computed the 90 percentile values as well. We then calculated color consistency ratios describing performance of Staccato DX screening relative to the Classic screening. They are plotted in Figure 10 as a radar chart.

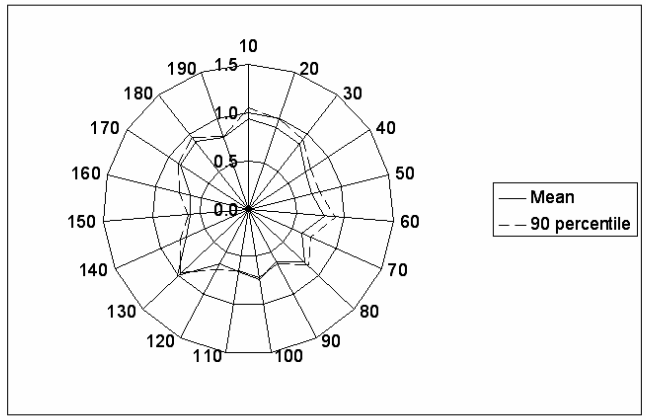

***Figure 10**. Color consistency ratios, Staccato DX screening/Classic screening*

The page number for the print runs is shown on the perimeter of the radar chart and the color consistency ratio is shown on the vertical axis. While the ratios below 1.0 in these two runs in Figure 10 may indicate superior performance of Staccato DX screening, the actual perceived color consistency of Classic and Staccato DX screenings is comparable when many print runs performed over time with many print engines, as well as measurement instrument color accuracy and repeatability tolerance, are taken into consideration. Also, none of the mean or 90 percentile dE-1976 values involved are objectionable in practice, as the default Classic screen color consistency exceeds the expectation of offset printing [22].

EP Printing of Satellite Images

For more detail demanding applications, nonlinear exposure with stretch-bit LED PWM technology [5, 6] can be used to produce an equivalent of 9.5 linear-bit contone screen images with the Kodak NexPress 8-bit 600-dpi printing system. The detail-preserving effect of our experimental "contone screen" can be observed by comparing Figures 11 and 12, where 2400-dpi scans of a fragment of a 0.9 m/pixel satellite image reproduced at 600 dpi using the Classic and Staccato DX screening options are featured, to a scan of a contone print featured in Figure 13.

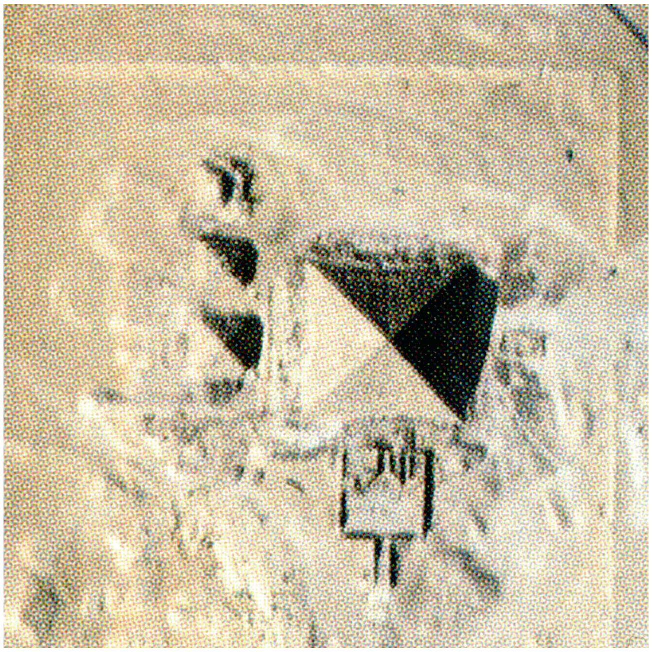

***Figure 11**. Pyramid of Menkaure: Classic screening*

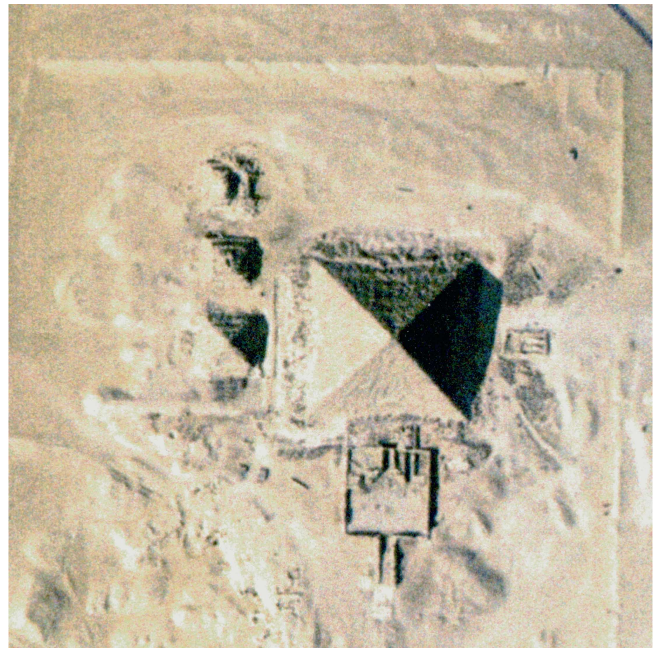

***Figure 13**. Pyramid of Menkaure: Contone screening*

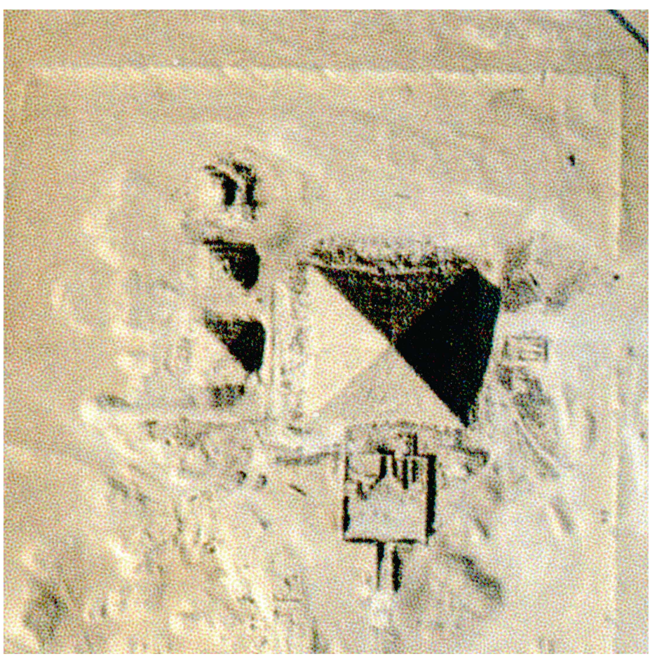

***Figure 12**. Pyramid of Menkaure: Staccato DX screening*

Acknowledgments

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