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Security Printing Deterrents: A Comparison of Thermal Ink Jet, Dry Electrophotographic, and Liquid Electrophotographic Printing

Steven J. Simske▲, Jason S. Aronoff▲ and Margaret M. Sturgill
Hewlett-Packard Laboratories, 3404 E. Harmony Rd., Mailstop 36, Fort Collins, Colorado 80528
E-mail: Steven.Simske@hp.com

Galia Golodetz
Hewlett-Packard Indigo Ltd., Einstein 10, Kiryat Weizmann Ness Ziona, Rehovot Israel 76101

Abstract. *Security printing is the use of variable data printing (VDP) to add readable information to printed regions. This is used for brand identification, track and trace, product authentication, and, if applicable, for investigation and evidentiary purposes. Well-crafted, multiregion deterrents can be a powerful means to simultaneously provide readable information and deter would-be counterfeiters through the crafting of difficult-to-reproduce printing effects. This allows the brand owner to select the best printing technology for the deterrents (or for different aspects of a multiregion deterrent), and to gain insight into how the counterfeiter may attempt to reproduce their deterrent with a different printing approach. In this article, repeated line patterns, two-dimensional (2D) bar code reading, and authentication of a color deterrent (color tile) are considered. These features are printed using thermal ink jet (TIJ), dry electrophotography (DEP), and liquid electrophotography (LEP) digital printers. Line patterns and 2D bar code differences are representative of the printer's binary print quality. Color tiles are representative of the printer's ability to produce color-based deterrents with fidelity, and are also used to show authentication accuracy on multiple printers and on multiple substrates. Authentication of TIJ printed color tiles is better on glossy paper than on plain office paper, whereas the opposite was observed for DEP printed color tiles. Finally, meaningful metrics for comparison are discussed, including security payload density, deterrent reproducibility, color and spatial frequency fidelity, deterrent precompensation, and the sensitivity of deterrent authentication to image capture settings and devices. © 2008 Society for Imaging Science and Technology.*
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INTRODUCTION

Variable data printing techniques allow potentially authenticable information to be added to any printed region. However, the density of information and readability of the information depends on a number of factors. These include the printing technology and settings, ink, substrate, and the reader and its settings. To test the suitability of a deterrent for use in brand protection, one can also vary the size of the deterrent (and concomitantly the density of information printed).[1] This article considers the qualification of three different types of security printing deterrents, which when combined tell us much about authentication-related, or "security," print quality. First, the materials and methods used are described. Next, the results are present for the repeated line test patterns, two-dimensional (2D) bar codes and color tile security deterrents. The authors discuss them in terms of security payload density, reproducibility, spatial frequency, and color fidelity. Finally, we introduce the concept of deterrent precompensation to make counterfeiting more difficult.

▲IS&T Member.

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METHODS AND MATERIALS

Three different printing technologies were investigated. Dry electrophotography (DEP) was tested using the HP color Laserjet™ 3600, 4600, and 4700dn printers. Liquid electrophotography, (LEP) was tested using the HP Series 1 Indigo Press. Thermal ink jet, (TIJ) was tested using the HP Deskjet™ 5440 and 6127, and the HP Photosmart™ 6280 printers. These printers are hereafter referred to as the "3600," "4600," "4700dn," "Indigo," "5440," "6127," and "6280," respectively. The 6280 is a six-ink printer.

Repeated Line Pattern Tests

The objective of the line feature pattern was to examine spatial frequency fidelity for TIJ and DEP printers. Three printers were used; the 5440 (TIJ), the 6127 (TIJ), and the 4700dn (DEP). All prints were generated from the same digital image described here. For the ink jet printers, the default factory settings were used except that the "best quality" option was chosen. For the 4700dn laser printer, only factory default settings were used. For all three printers the horizontal and vertical setting for dots/inch (dpi) was 600.

The final uncompressed raster image master was comprised of an eight by eight layout of line features of 100 lines per inch (lpi). For testing purposes the line colors were constrained to the primary printing pigments of a color printer; cyan, magenta, yellow, and black. This decision was motivated by the goal of reducing half toning and color aliasing artifacts. For each of these colors two columns of line features were rendered, one in a vertical line orientation and the other in a horizontal orientation. Each line feature was 1.27 cm by 1.27 cm with a horizontal and vertical spac-

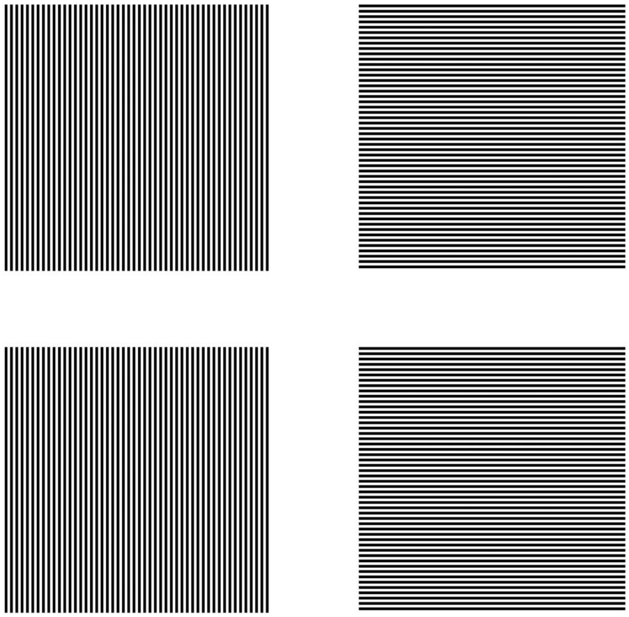

Figure 1. Sample of four line features. (Left) Two features comprise 50 vertical lines 3 pixels thick each and (right) two features comprise 50 horizontal lines 3 pixels thick each. Original size of each feature is 1.27 cm by 1.27 cm.

ing of 1.27 cm between adjacent line features. Figure 1 depicts a sample of four line features.

After the image was printed, the page was scanned at 600 pixels per inch (ppi) using a HP Scanjet 8300. The scanned images were segmented and individual line features were extracted for assessment. For each line feature a fast Fourier transform (FFT) was performed on the individual R, G, and B channels, perpendicular to the direction of the printed lines, to examine how well each line feature reproduced the print raster line frequency of 100 lpi after the printing/scanning cycle.

2D Bar Code Reading

2D bar code test pages were created with 23 character payloads using the 2D DataMatrix symbology,[2] and module (individual tile) sizes were varied from 10 to 30 mil $\{10,11,12,\ldots,30 \text{ mil}\}$, which corresponds to 254–762 micrometers (μm). Ten bar codes of each size were printed after being generated using B-Coder Bar Code Graphic Generator Version 4.0,[3] using the Symbology.DataMatrix menu, with Comment Line “xx mil” and Bar Code Message (payload) “TestPatternSet3_yyMil_x.” They were copied from the B-Coder software and pasted into Microsoft Word in Windows Metafile format. Separately, extra spacing was added between the black tiles in Enhanced Metafile format to generate an entire set of “precompensated” 2D bar codes (see Figure 2).

These “normal” and precompensated bar code pages were printed using three different printing technologies: (1) TIJ using the 5440 printer and HP office paper as the substrate, (2) DEP using the 4600, also with HP office paper as the substrate, and (3) LEP using the Series 1 HP Indigo Press. Black Indigo ElectroInk™ was used for printing on

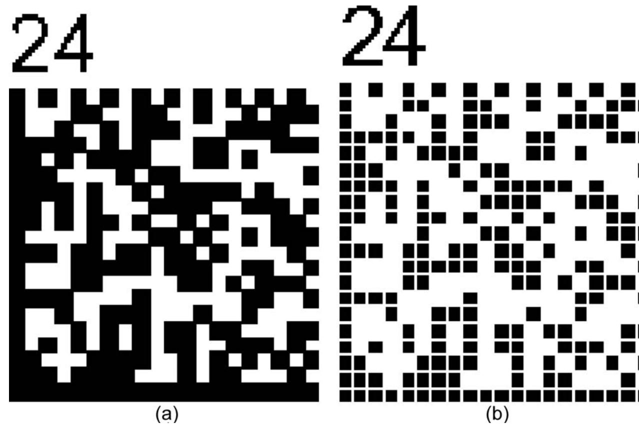

Figure 2. Sample (left) normal 2D bar code and (right) precompensated 2D bar code. The method for generating these barcodes is described in the text.

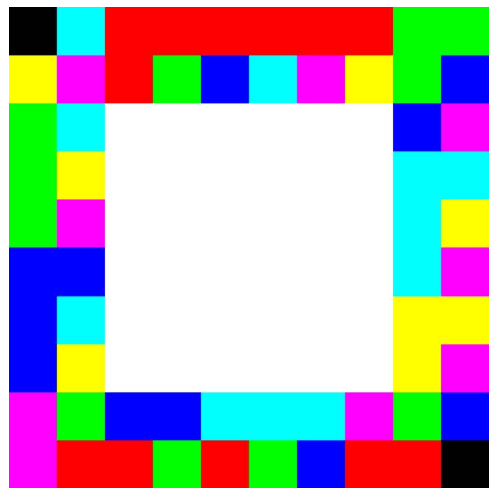

Figure 3. Print master of the color tile deterrent tested in this article.

the following substrates: White Teslin (Teslin® Synthetic Printing Sheet[4] SP 1000), White Matte (HPIPP Coated Matte 135 gsm), White Glossy (HPIPP Coated Glossy 135 gsm).

All bar codes were read using an InData Systems LDS-4600 reader with either 365 nm wavelength of peak emission (wpe) or 405 nm wpe LEDs for its light source. The 365 nm LEDs permit reading of the Indigo UV ElectroInk, whereas the 405 nm light emitting diodes (LEDs) do not. The Data Matrix 2D bar code symbology was used to ensure that both x and y directions are factored into the authentication. Successful reading of all 10 bar codes (at a particular module size) was required to consider the specified size as “readable.”

Color Tile Authentication

Color tile[1] deterrents are a form of 2D color bar code that can also be associated with microtext and other security features. For our purposes, test sheets of static (fixed sequence) square color tile features (Figure 3) were created for testing patterns with individual tile sizes varied from 5 to 10 pixels at a printing resolution of 600 dpi (0.21–0.42 mm). The tiles were arranged in a 10×10 array with the middle 6×6 tiles white (for association with another deterrent when shipped on a label). This "deterrent" thus comprises 56 color tiles to be identified by the authentication algorithm. Pages containing from 117 (tile size$=10\times10$ pixels) to 165 of these deterrents (tile size$=5\times5$ pixels) were printed at 600 dpi using the 3600 (DEP), 4600 (DEP), 6127 (TIJ), and 6280 (TIJ) printers, and then scanned using a HP 8300 Scanjet scanner. For all four printers, plain office paper and gloss photograph paper was used. For the 6127 and 6280, soft gloss photograph paper was also used. Scanning was also performed at the same 600 ppi resolution, and 24 bits per pixel uncompressed color images thus obtained.

After scanning, the scanned pages were authenticated using a modified version of the authentication algorithm described in Ref. 1. Briefly, this authentication consists of: (1) thresholding (binarizing the image), (2) formation of regions (segmentation[5]), (3) identification of deterrent regions (classification), (4) skew detection and deskew, (5) sub-segmentation to find tiles, (6) assigning color type to each tile ("decoding"), (7) output of color type sequence, and (8) comparison of "decoded" and "encoded" sequences.[1]

To aid in the task of orientation and decoding, 8 of the 64 color tiles in Fig. 3 are "nonpayload" indicia. Two black color tiles are located in the upper-left-hand and lower-right-hand corners. Adjacent to these orienting color tiles are six color tiles, one each of the six colors (red, green, blue, cyan, magenta, and yellow) used in the deterrent. These nonpayload indicia generally allow significantly greater density to be decoded successfully (authenticated).

RESULTS

Repeated Line Pattern Tests

As the FFT was performed on each color channel, it was important to differentiate the amount of information extracted by the FFT and to determine whether one color channel provided more information than another. Defined is the ratio of the magnitude of the ac component of the FFT to the sum of the magnitudes of the ac and dc components of the FFT, as written in the following equation, as the information content ratio (ICR) of the signal, the closer the ratio is to unity the more the (intended) ac component shows in the FFT:

$$\mathrm{ICR} = \frac{\mathrm{ac}}{(\mathrm{ac}+\mathrm{dc})}. \tag{1}$$

Also examined was the distribution of the *energy spectral density* (ESD) (FFT, without the dc component, normalized to sum to 1.0) as defined in the following equation; this metric was used for both interchannel and intrachannel comparison:

$$\mathrm{ESD}(x) = \frac{\sqrt{(x_{\mathrm{real}}^2 + x_{\mathrm{imaginary}}^2)}}{\sum \sqrt{(x_{\mathrm{real}}^2 + x_{\mathrm{imaginary}}^2)}}. \tag{2}$$

Table I. Mean ICR of vertical line features by color channel, Deskjet 5440 printer.[a]

Line Feature Color	ICR (R)	ICR (G)	ICR (B)
C	**0.7294**	*0.3788*	0.0010
M	0.0045	**0.7435**	*0.4742*
Y	0.0009	0.0052	**0.7294**
K	*0.7494*	*0.7584*	**0.7794**

[a]PIC is in boldface; SIC and TIC channels, if present, are italicized.

Table II. Mean ICR of vertical line features by color channel, HP Deskjet 6127 printer.[a]

Line Feature Color	ICR (R)	ICR (G)	ICR (B)
C	**0.7304**	*0.3217*	0.0009
M	0.0463	**0.7230**	*0.4338*
Y	0.0002	0.0407	**0.8841**
K	*0.6246*	*0.6404*	**0.6645**

[a]PIC is in boldface; SIC and TIC channels, if present, are italicized.

Table III. Mean ICR of vertical line features by color channel, HP color LaserJet 4700dn printer.[a]

Line Feature Color	ICR (R)	ICR (G)	ICR (B)
C	**0.7249**	*0.4533*	*0.2685*
M	0.0009	**0.7307**	*0.5293*
Y	0.0010	0.0011	**0.7361**
K	*0.7475*	*0.7610*	**0.7785**

[a]PIC is in boldface; SIC and TIC channels, if present, are italicized. Note the existence of a C-colored line feature TIC (top of last column).

The results from Eqs. (1) and (2) showed a distinct trend (Tables I–III). For the primary subtractive colors—cyan, magenta, and yellow—the FFT color channel having the highest ICR was the complementary color. However, the percent of the ESD at the line frequency was consistent (typically 30%–40%) across all the channels with an ICR of 0.05 or above (we considered ICRs<0.05 to be insignificant). The channel with the highest ICR is referred to as the primary information channel (PIC). The channel with the next highest ICR, if greater than 0.05, is termed the secondary information channel (SIC). If all three channels have a relevant ICR, then the channel with the third highest ICR is termed the tertiary information channel (TIC).

For the cyan and magenta line features, SIC was apparent (ICR>0.05) with a peak ESD frequency matching the line frequency. The yellow channel, on the other hand, did not contain a SIC, as both the red and green channels had ICR<0.05. The black line features demonstrated a different trend than the primary subtractive colors. For the black inks, each (RGB) channel conveys roughly the same information (0.76 ± 0.2 for the 5440 printer, 0.64 ± 0.2 for the 6127 and 0.76 ± 0.2 for the 4700dn) and the line frequency was correctly identified by all three channels as well.

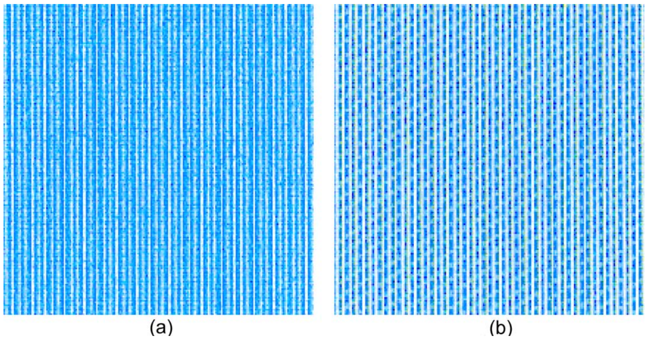

Figure 4. Sample cyan color line feature. (Left) HP Deskjet 5440 and (right) HP color Laserjet 4700dn.

The trending of the information content ratio is consistent across all three printers with one exception. For the cyan line features on the laser printer, ICR is significant across all three channels. But unlike the red (primary) and green (secondary) channels of distinction, the peak ESD frequency for the blue channel correctly identified the line frequency in only 25% of the cyan line feature samples: The remaining samples identified a frequency of 50 (half the line frequency) as the peak frequency. The differences in printer output between TIJ (5440) and DEP (4700dn) are illustrated in Figure 4.

2D Bar Code Reading

2D bar codes printed on LEP, TIJ, and DEP printers were read with both 365 nm and 405 nm LEDs, as described previously (Table IV). For the LEP printer, the default substrate was Teslin,[4] whereas for the TIJ and DEP printers, HP office paper was used. In all cases, the precompensated bar codes were readable at a smaller scale: 8% smaller for the LEP prints using either 365 nm or 405 nm LEDs for reading; 21% smaller for the DEP prints using either 365 or 405 nm LEDs for reading, and either 42% (365 nm LEDs) or 35% (405 nm LEDs) smaller for the TIJ (Table IV). Interestingly, with precompensation, all three printing technologies produced readable 2D bar codes when module size was as small as 11 mil (279 μm). This was true for both far blue (405 nm) and ultraviolet (365 nm) illumination.

The sensitivity of bar code reading to the substrate printed on was tested for the LEP printer (Table V). Uncompensated 2D bar codes were readable on all three substrates when module size was as small as 12 mil (305 μm). The effect of precompensation on readability differed considerably for the three substrates. For the Teslin substrate, precompensation afforded 8% reduction in module size for readability. However, none of the precompensated bar code indicia could be read from the glossy substrate, and precompensation negatively affected bar code reading on the matte substrate.

Printed Colors

The authenticated 56 tiles of the color tile deterrents are defined as pure colors (red, green, blue, cyan, magenta, and yellow, hereafter referred to as R, G, B, C, M, and Y, respectively). Although the data tile colors are specified to print at R, G, B, C, M, and Y, different printer/paper combinations result in “color drift,” wherein after the printing and scanning process the *hue-as-read* no longer matches the *hue-as-specified*. Hue-as-read was computed from the vector addition of the red, green and blue channel values of the scanned tiles, where the red was projected at 0°, the green projected at 120° and the blue projected at 240°. The hues-as-read are shown in Figure 5. In Fig. 5, the intended hues are placed at 60° apart, with R at 0°, Y at 60°, G at 120°, C at 180°, B at 240°, and M at 300°. The data shown in Fig. 5 are also given in Table VI.

Table IV. Black 2D bar code reading results, default substrate.[a]

	Minimum Module Size (μm)		
LEDs (nm)	Indigo LEP	Ink jet	Laserjet
405	305	432	356
405[b]	279	279	279
365	305	483	356
365[b]	279	279	279

[a] Teslin for Indigo LEP, HP Office Paper for Ink jet and Laserjet).
[b] Precompensated bar code.

Table V. Black 2D bar code reading results, differing indigo LEP substrates.[a]

	Minimum Module Size (μm)	
Substrate	Normal 2D Bar Codes	Precompensated 2D Bar Codes
Teslin	305	279
Glossy	305	Could not read
Matte	305	406

[a] 365 nm LEDs used for reading.

These data show that G and B have the highest overall variability in hue. LEP-printed G is significantly more yellow than TIJ-printed G, which is generally quite accurate. DEP-printed G is shifted toward B. For all printer types, R and especially Y colors tend to be quite accurate. Also, for all printer types, C is slightly, but consistently, shifted toward B; and M is strongly and consistently shifted toward R. DEP-printed colors appear to be the most sensitive, of the samples tested, to changes in paper used (highest between-paper variability of the three printing technologies). DEP-printed colors also have the highest variability among samples using the same printing technology and paper (specifically for G).

Color Tile Authentication

Color tile deterrent test sheets were printed and scanned as described earlier. Authentication was considered successful when all 56 tiles were read correctly for a deterrent. Authentication results were obtained for 10 TIJ and DEP printer/paper combinations, as given in Table VII. For DEP testing, the 3600 and 4600 printers were used with both plain and gloss paper; for TIJ testing, the 6127 and 6280 printers were used with plain, gloss, and soft gloss paper.

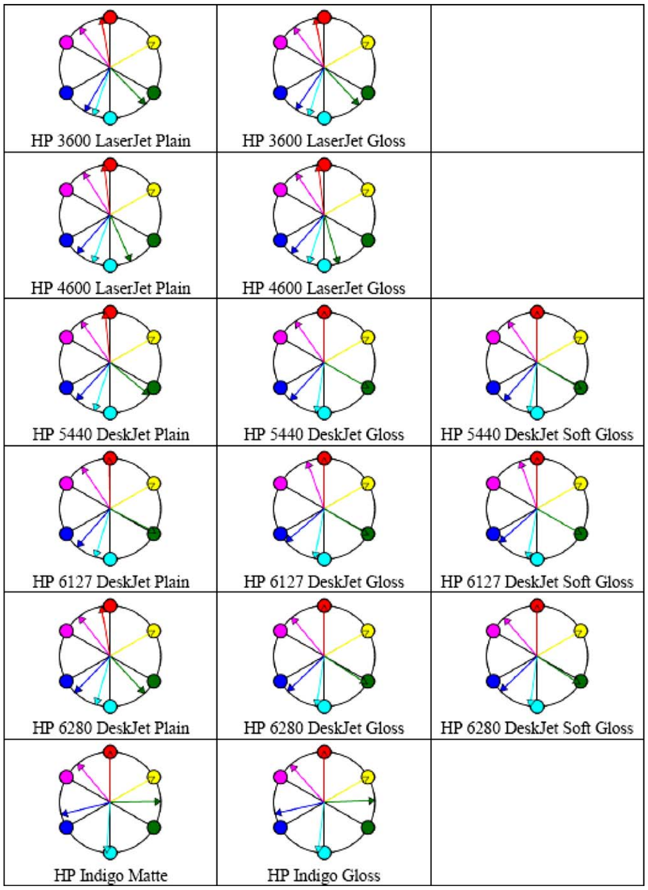

Figure 5. Targeted color tile hues ("hues-as-specified," circles) and measured hues after printing and scanning ("hues-as-read," triangles) for the various printer and paper combinations as described in the text.

The following key trends were observed for the authentication accuracy. First, authentication accuracy was higher when using TIJ printing than when using DEP printing. Second, authentication accuracy using TIJ printing was higher for gloss and soft gloss paper than for plain paper. Third, the difference in authentication accuracy was greater between the 3600 and the 4600 than it was between the 6172 and 6280. Finally, using TIJ printing, the results for the gloss and soft gloss papers were similar.

In order to compare among different printer/paper combinations, the size at which 50% authentication accuracy was achieved was estimated (i.e., 50% of the 56 data-tile deterrents read with 100% accuracy). The value, named S50, is the size at which 50% accuracy was achieved, and is given in pixels—as the tiles are rectangular, S50 refers to both the height and width of the tile size. S50 was 8.1 and 7.7 pixels, respectively, for the 3600 printer on gloss and plain paper. For the 4600 printer, however, S50 was 10.1 and 10.0 pixels, respectively, for gloss and plain paper (substantially poorer than for the 3600 printer). For the 6127 TIJ printer, the S50 values were 6.8, 8.4, and 7.0 pixels for gloss, plain, and soft gloss paper, respectively. The best overall values were for the six-ink 6280 TIJ printer: S50 values were 6.1, 6.8, and 6.5 pixels for gloss, plain, and soft gloss paper, respectively.

DISCUSSION

The security deterrent printing experiments reported here were performed to compare and contrast the quality of printing and reading for different substrates, printing approaches, and reading devices. In addition, the types of deterrents used afford views of different aspects of printing and imaging quality. The repeated line deterrents, like modulation transfer function or MTF deterrents,[6] can be used to simultaneously check scanner capabilities and encode information in the frequency domain. The 2D bar codes use an industry standard reading algorithm and allow for ready assessment of ink, print, substrate, and deterrent quality and the crafting of ink-specific handheld readers.[7] The experiments performed here also illustrated the potentially large impact on readability afforded by structural precompensation,[8] as shown in Fig. 2.

Security Payload Density

Briefly, the security payload density (SPD) is determined by the number of reliably readable bits that can be packed in a given area.

$$\text{SPD} = \text{number of authenticable bits/unit area}. \quad (3)$$

The payload density of 2D bar codes is largely determined by the error code checking information specified by the standard. For crafted deterrents, such as the color tile deterrent described herein, wherein each tile is authenticated, the SPD trade off is between size reduction (to increase density) and the inclusion of more nonpayload indicia (to increase accuracy and reduce density). The same set of nonpayload (nondata) indicia were used for TIJ and DEP testing herein. In general, the color tile deterrents printed using DEP had to be printed larger to achieve a comparable (e.g., 50%) authentication, meaning the SPD was reduced in comparison to color tile deterrents printed using TIJ. For example, using the S50 values as a comparative measurement, relative SPD densities on gloss paper are 1.0, 0.64, 1.42, and 1.76, respectively, for the 3600, 4600, 6127, and 6280 printers. Thus, the SPD for the 6280 is nearly three times that for the 4600 on gloss paper. On plain paper, the respective relative values are 1.0, 0.59, 0.84, and 1.28. The SPD for the 6280 is more than twice that for the 4600 on plain paper. Testing the impact of adding more/different nonpayload indicia to drive the size of the individual tile downward is a next step in the productization of these deterrents.

Deterrent Reproducibility

The deterrent reproducibility (DR) is the ability to reverse engineer the information in the deterrent, and as such is a measure of how secure a deterrent is from a counterfeiter. For the color tile deterrents as presented herein, there is no added steganographic information (such as a microtext sequence) to the deterrents. For such an "overt-only" deterrent, the security protection comes from having a much larger number of possible deterrent sequences than the number of products with the deterrents. A 56-tile six-color deterrent contains approximately 145 bits of data, meaning more than 4×10^{43} different sequences are possible.

Table VI. Observed colors (in degrees, mean ±1 standard deviation for 5 samples) after printing and scanning for red (R), yellow (Y), green (G), cyan (C), blue (B), and magenta (M) tiles. The colors specified in the raster images prior to printing are at angles 0° (R), 60° (Y), 120° (G), 180° (C), 240° (B), and 300° (M).

Printer	Paper	R	Y	G	C	B	M
3600	Gloss	350.0±1.9	60.0±0.0	137.4±2.6	198.0±0.0	213.8±0.4	322.8±0.4
3600	Plain	350.2±0.4	60.0±0.0	135.8±1.6	199.0±0.0	210.0±0.0	323.0±0.0
4600	Gloss	352.8±0.4	60.0±0.0	164.2±2.6	198.4±0.5	221.4±0.5	326.2±0.8
4600	Plain	353.2±0.4	60.0±0.0	155.8±1.3	200.2±0.4	220.6±0.5	328.0±0.0
5440	Gloss	0.0±0.0	60.0±0.0	120.4±0.5	189.4±0.5	221.6±0.9	325.2±0.4
5440	Plain	354.0±0.0	60.0±0.0	129.6±0.9	198.0±0.0	222.4±0.5	325.0±0.0
5440	Soft	0.0±0.0	60.0±0.0	120.8±0.4	189.0±0.0	221.2±1.1	325.0±0.0
6127	Gloss	0.0±0.0	60.0±0.0	121.0±0.0	191.0±0.0	229.0±0.0	340.0±0.0
6127	Plain	359.0±0.0	60.0±0.0	118.0±0.0	197.2±0.4	221.0±0.0	326.0±0.0
6127	Soft	0.0±0.0	60.0±0.0	120.0±0.0	190.8±0.4	228.2±1.1	340.0±0.0
6280	Gloss	0.0±0.0	60.0±0.0	123.0±0.7	188.8±0.4	226.0±0.0	320.0±0.0
6280	Plain	350.2±0.4	60.0±0.0	136.8±0.4	196.0±0.0	224.0±0.0	322.0±0.0
6280	Soft	0.0±0.0	60.0±0.0	123.2±0.4	188.2±0.4	225.6±1.1	319.2±0.4
indigo	Gloss	0.0±0.0	60.0±0.0	88.2±0.4	187.4±0.5	257.0±2.0	318.2±0.8
indigo	Matte	0.0±0.0	60.0±0.0	89.4±0.9	183.8±2.2	256.4±1.8	319.6±0.5

Table VII. Authentication accuracy (%) for color tile features with respect to tile size (in pixels at 600 dots/in.).[a]

Printer	Paper	Size 5 (n=165)	Size 6 (n=150)	Size 7 (n=140)	Size 8 (n=140)	Size 9 (n=130)	Size 10 (n=117)
3600	Gloss	0.0	2.7	2.1	48.6	62.3	94.9
3600	Plain	0.0	3.3	9.3	66.4	86.2	99.1
4600	Gloss	0.0	0.7	5.7	9.3	14.6	47.0
4600	Plain	0.0	8.0	4.3	20.7	21.5	50.4
6127	Gloss	16.4	36.7	54.3	92.1	99.2	99.1
6127	Plain	0.0	0.0	4.3	27.1	92.3	99.1
6127	Soft	16.4	40.7	49.3	86.4	100.0	100.0
6280	Gloss	15.2	48.7	69.3	97.9	99.2	100.0
6280	Plain	1.2	13.3	60.0	74.3	92.3	100.0
6280	Soft	12.7	38.0	62.9	97.9	100.0	100.0

[a]The number of 56-data color tile deterrents, n, at each size is given in parentheses; for example, at Size 9, 100% accuracy means that 56×130, or 7280, individual color tiles were correctly read.

The color tile deterrent was authenticated with 90% or higher accuracy when printed on gloss paper using a TIJ printer at a size of 8×8 pixels at 600 ppi, with a statistically relevant sample set of more than 6000 data tiles at each size in the range tested. A counterfeiter using a DEP printer on the same gloss paper will produce a deterrent that authenticates less than 50% (3600) or less than 10% (4600) of the time. Such an authentication rate may raise suspicion at the point of authentication.

Color Fidelity

Relative color fidelity is measured indirectly with the color tile authentication studies, and somewhat more specifically with the hue results shown in Fig. 5. The results indicate better relative color fidelity for the TIJ compared to DEP technology evaluated herein. Printed and scanned cyan and blue are closer together, and red and magenta are closer together, when using DEP in comparison to TIJ.

The nonpayload indicia added to the color tile deterrent greatly increase the relative color fidelity of the authentication algorithm, even if the absolute color fidelity (which was not measured) is poor. So long as the color distortions are consistent, these nonpayload color indicia generally greatly increase SPD. The nonpayload indicia used for the color tile deterrents in this sense provide relative color calibration (i.e., for authentication).

Spatial Frequency Fidelity

Repeated line tests indicate that there are differences in the spatial frequency information contained in the scanned color channels after printing with TIJ or DEP technologies. Also, yellow color lines behave distinctively from the cyan and magenta lines, likely due to full saturation of both red and green channels by the yellow ink.

2D bar codes also test spatial frequency fidelity. The better performance of the Laserjet 4600 compared to the Deskjet 5440 is consistent with the generally better text and line quality of the Laserjet printer.

Deterrent Precompensation

As described for the 2D bar code test sheets, structural precompensation of a deterrent is a potentially powerful means of increasing SPD, and for making counterfeiting more difficult. 2D bar codes precompensated to leave whitespace between the black modules read at a smaller size due to a combination of, at least, ink spread during printing and blur during reading. The efficacy of precompensation increased from the LEP (8% improvement) to the DEP (21% improvement) to the TIJ (35% or 42% improvement) printing, most likely as a consequence of increasing ink spread.

The LEP-printed 2D bar codes were scanned using both 365 and 405 nm LEDs. Only the 365 nm LEDs permit reading of the Indigo UV ElectroInk. This sensitivity to LEDs permits the creation of ink-specific readers,[7] and the combination of overt and covert inks makes the would-be counterfeiter's task more difficult.

CONCLUSIONS

The results in this article illustrate an impact of different printing technologies and substrates on security printing quality, and thus on security deterrent readability. In turn, this directly impacts SPD and DR. This article highlights how the optimum selection of printing strategy (print technology, substrate, printed pattern and pattern precompensation) may reduce the options of a would-be counterfeiter, and so make counterfeiting more difficult.

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