Spectral Pre-Compensation and Security Print Deterrent Authentication

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Abstract

Security printing and imaging is the application of printing to provide product authentication and brand protection through the use of difficult to reproduce (overt) effects and the addition of data (overt, steganographic, covert and forensic) to the printed elements. The density of data added to security deterrents can be improved through the process of pre-compensation. Structural pre-compensation involves altering the size and shape of a printing element so that after reading (printing and scanning) the element better matches its intended size and shape. In this paper, we address spectral pre-compensation, in which the colors of the color tile, a 3D bar code, are changed before the printing and scanning take place. We show the increased security deterrent density possible using this approach using inkjet and dry electrophotographic printing technologies. We also show that the technology is generally applicable except in cases where there is a printing quality issue. Thus, spectral pre-compensation is shown to be generally applicable for testing print quality and increasing security deterrent density simultaneously.

Introduction

Branded products—from labels to packaging to single-use items such as tickets, coupons and game pieces—require difficult-to-reproduce printed elements to deter copying, diversion, reuse and other forms of fraud. Since trying to outspend counterfeiters is in general a self-defeating approach (the more you spend, the more margin you give them since they will typically find cheaper ways to imitate your added-on features), optimizing the printing to make unauthorized replication of the printing as difficult as possible without adding cost to your printing is sensible.

In this paper, we show how color-based security features can be spectrally pre-compensated to increase their authentication accuracy at a given feature element size. This increased security payload density, or SPD, increases the utility of the deterrent. We explore situations in which spectral pre-compensation does not result in measurable improvement in SPD and discuss the utility of spectral pre-compensation to inspection and print quality assurance.

Experiments Performed

Tests were performed on six printers and six types of paper. The printers belonged to three print technologies: inkjet (HP IJ 5440, HP IJ 6127, and HP IJ 6280), dry electrophotography (HP color LJ 3600 and HP color LJ 4600), and liquid electrophotography (HP Indigo 4500). The three inkjet (IJ) paper types used were plain office paper, glossy photo paper, and soft gloss photo paper. For the HP color laserjet (LJ) printers, plain office paper and glossy cardstock were used. For the Indigo 4500, Indigo-compatible matte and glossy paper were used. Subsequent tables specifically identify the printer/paper combination corresponding to accompanying results.

For all printer and substrate combinations, the same digital image [1,2] was used. This image was generated at 600 ppi and stored as a lossless raster image. Prints were then performed at 600 dpi for all printers. For each printer and paper combination used five sample pages were printed. All prints were then subsequently (manually) scanned at 600 ppi resolution on a HP ScanJet 8300 and saved in lossless raster format. The image consists of 192 color patches which sequentially move from R to M (first two columns), R to Y (next two columns), B to M (fifth and sixth column), B to C (seventh and eighth columns), G to Y (ninth and tenth columns) and G to C (last two columns) in increments of approximately 2 degrees [2], and represents the "pre-compensation" test sheet. After printing and scanning of these sheets, the actual colors corresponding to the intended R, Y, G, C, B and M locations (0, 60, 120, 180, 240, 300 and 360 degrees, respectively, see Figure 1, right) could be determined (Table 1). Finally, these "pre-compensated" colors were then used to create a new color tile deterrent (see Figure 1, left), which was printed (on many of the printer/substrate combinations) and scanned using the HP 8300 ScanJet scanner.

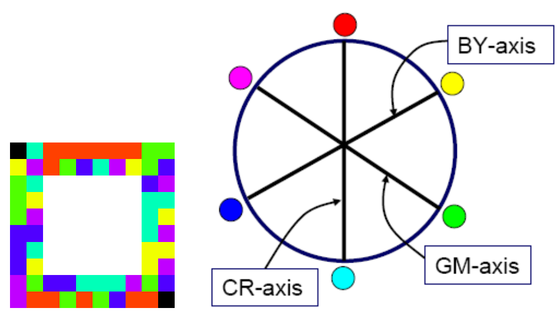

Figure 1.*Diagram illustrating a single color tile deterrent (left) and the angular location of the 6 colors used in the color tiles (right). In the left image, the 4 tiles in the upper left and lower right are used for skew, orientation and color calibration, and the other 56 colored tiles contain the deterrent security payload. In the right image, red, yellow, green, cyan, blue and magenta colors are at 0, 60, 120 180,240 and 300 degrees, respectively. Three color opponency axes exist.*

To test for the efficacy of the pre-compensation, we used color tile authentication as a means of assessing image quality. Our authentication experiments involved the use of 64-tile (56 tiles used for authentication, 8 tiles for orientation and color calibration, Figure 1, left) color tile deterrents. Authentication was performed by comparing the 56-tile sequence to that obtained by an authentication algorithm described next.

As described in reference [1], test sheets of static (fixed sequence of color tiles) square color tile features (Figure 1, left) were created for testing patterns with individual tile sizes varied from 5-10 pixels at a printing resolution of 600 dpi (0.21-0.42 mm). The tiles were arranged in a 10x10 array with the middle 6x6 tiles blank (for association with another deterrent when shipped on a label). Pages containing from 117 (size=10 pixels) to 165 deterrents (size=5 pixels) were printed at 600 dpi and then scanned using an HP 8300 ScanJet scanner. Scanning was also performed at the same 600 pixels/inch (ppi) resolution, generating 24 bit/pixel uncompressed color images. After scanning, the scanned pages were authenticated using a modified version of the authentication algorithm described in references [1,2].

Table 1: Measured angular colors (R, Y, G, C, B, M = Red, Yellow, Green, Cyan, Blue and Magenta) after printing (600 dpi) and scanning (HP Scanjet 8350 without ADF, at 600 ppi). Values are the mean of 5 target sheets in degrees where R, Y, G, C, B, M are at 0 [=360], 60, 120, 180, 240 and 300 degrees. Standard deviations (not shown) are quite low, with a median value of less than 1 degree (max of 6).

Printer	Paper	R	Y	G	C	B	M
LJ 3600	Gloss	350	60	137	198	214	323
LJ 3600	Plain	350	60	136	199	210	323
LJ 4600	Gloss	353	60	164	198	221	326
LJ 4600	Plain	353	60	156	200	221	328
IJ 5440	Gloss	0	60	120	189	222	325
IJ 5440	Plain	354	60	130	198	222	325
IJ 5440	Soft	0	60	121	189	221	325
IJ 6127	Gloss	0	60	121	191	229	340
IJ 6127	Plain	359	60	118	197	221	326
IJ 6127	Soft	0	60	120	191	228	340
IJ 6280	Gloss	0	60	123	189	226	320
IJ 6280	Plain	350	60	137	196	224	322
IJ 6280	Soft	0	60	123	188	226	319
Indigo	Gloss	0	60	88	187	257	318
Indigo	Matte	0	60	89	184	256	320

The authentication algorithm consists of (1) thresholding, or binarization of the image for use in Step 2, (2) formation of regions (segmentation), (3) identification of deterrent regions, or classification, using the original image, (4) skew detection and de-skew, (5) sub-segmentation to find individual tiles, (6) assigning color type to each tile based on the smallest Cartesian distance in {r,g,b} space between the color tile and the color calibration tiles, (7) output of the sequence, and (8) comparison of the sequence to the intended 56-color sequence. Aiding the task of orientation and decoding, 8 of the 64 color tiles in Figure 1 are "non-payload" indicia. Two black color tiles are located in the upper left and lower right 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 non-payload indicia generally allow significantly greater density to be decoded successfully (authenticated). The first four steps of the authentication algorithm were also used to determine the effect of printing and scanning on each of the 192 color patches mentioned above.

To examine the effects of spectral pre-compensation on this authentication, we used the HP LJ 3600, IJ 5440, IJ 6127 and IJ 6280 printers with each of the substrates investigated. After obtaining the actual colors corresponding to the intended R, Y, G, C, B and M locations, the mean values of the colors (from the 5 test sheets) were used as the pre-compensated colors for the "pre-compensated" color tile deterrent (Table 2). For example, the hue identified as the closest representation of green on the 6280 with plain office paper was 102 degrees. This translated into a RGB color value of (80, 255, 0). This RGB value was then used for each instance of a green square within the color tile deterrent.

Table 2: Measured angular colors (R, Y, G, C, B, M = Red, Yellow, Green, Cyan, Blue and Magenta) for spectral pre-compensation. These are the colors, in degrees, actually printed (substituting 0, 60, 120, 180, 240 and 300 degrees) for spectral pre-compensated tiles. Data presented as in Table 1.

Printer	Paper	R	Y	G	C	B	M
LJ 3600	Gloss	20	63	112	169	280	291
LJ 3600	Plain	15	63	92	168	278	290
LJ 4600	Gloss	8	66	92	155	262	289
LJ 4600	Plain	8	66	100	160	261	287
IJ 5440	Gloss	0	63	119	164	260	286
IJ 5440	Plain	5	65	110	164	258	286
IJ 5440	Soft	0	63	116	164	258	286
IJ 6127	Gloss	0	63	115	166	260	287
IJ 6127	Plain	3	66	128	164	266	290
IJ 6127	Soft	0	63	120	167	260	286
IJ 6280	Gloss	0	65	117	166	259	288
IJ 6280	Plain	15	64	102	164	258	286
IJ 6280	Soft	0	66	119	166	260	288
Indigo	Gloss	0	61	154	176	220	282
Indigo	Matte	0	62	154	181	218	287

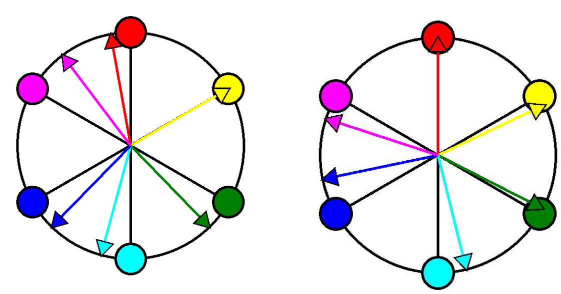

***Figure 2**. IJ 6280/Plain paper intended and actual colors after printing and scanning (Scanjet 8300), left. Pre-compensated colors (right).*

The effect of printing and scanning on the actual colors for the IJ 6280/plain paper/8300 scanner combination is shown in Figure 2 (left). The pre-compensation colors required to offset this printing+scanning effect is shown in Figure 2 (right).

Results

The authentication accuracies for the uncompensated color tile deterrents are presented in Table 3. The results vary considerably depending on printer and substrate, but a direct comparison shows the IJ 6280 performs better—meaning it reaches 90% or higher authentication accuracy faster as tile size increases—than the LJ 3600 on plain paper, which in turn performs better than the IJ 6127 and IJ 5440.

Table 3: Authentication accuracy in percent (for entire 56-tile sequence) of colors after printing, scanning and execution of the authentication algorithm, un-compensated colors where R, Y, G, C, B, M are at 0 [=360], 60, 120, 180, 240 and 300 degrees. Size is individual tile span (width=height) at 600 dpi.

Printer	Paper	Size (tile span in pixels at 600 dpi)					
		5	**6**	**7**	**8**	**9**	**10**
LJ 3600	Gloss	15	26	41	39	45	42
LJ 3600	Plain	9	35	74	90	88	99
IJ 5440	Gloss	18	59	76	94	93	92
IJ 5440	Plain	0	0	1	1	18	88
IJ 5440	Soft	26	53	79	91	98	100
IJ 6127	Gloss	5	11	44	89	98	100
IJ 6127	Plain	0	1	9	31	55	85
IJ 6127	Soft	6	15	30	80	95	100
IJ 6280	Gloss	1	13	49	90	98	100
IJ 6280	Plain	4	20	57	77	96	100
IJ 6280	Soft	2	19	44	86	97	100

After pre-compensation, the authentication accuracy results improved for most printer/substrate combinations (Table 4). Where they do not, they are highlighted. In particular, only two combinations of printer and substrate resulted in lower authentication accuracy at or above 90% (a threshold for reliable authentication accuracy): LJ 3600 and IJ 5440.

Table 4: Authentication accuracy in percent, spectrally pre-compensated colors, presented as in Table 1. Boldface accuracy percentages indicate values less than the corresponding value in Table 3.

Printer	Paper	Size (tile span in pixels at 600 dpi)					
		5	**6**	**7**	**8**	**9**	**10**
LJ 3600	Gloss	**5**	31	**36**	**37**	**42**	93
LJ 3600	Plain	11	36	**47**	**64**	**85**	**94**
IJ 5440	Gloss	19	**44**	**74**	**91**	95	100
IJ 5440	Plain	0	7	24	56	78	92
IJ 5440	Soft	**9**	**49**	**61**	**85**	**92**	**92**
IJ 6127	Gloss	18	47	77	99	100	100
IJ 6127	Plain	0	1	12	67	72	100
IJ 6127	Soft	**4**	42	62	94	98	100
IJ 6280	Gloss	25	45	75	97	100	100
IJ 6280	Plain	9	45	82	95	100	100
IJ 6280	Soft	7	21	50	89	100	100

Where the pre-compensation worked, the effects could be dramatic. For example, the uncompensated IJ 6127/plain paper combination did not reach 100% authentication accuracy until Size=12 (data not shown), whereas the pre-compensated IJ 6127/plain paper combination reached 100% authentication accuracy at Size=10. The latter thus provides 44% higher SPD.

To determine why two of the 11 tested printer/substrate combinations did not respond to pre-compensation, we looked at images for these cases closely (Figures 3 and 4). For the LJ 3600/plain paper combination (Figure 3), we observed a significant mis-registration between the black and the color (particularly yellow) channels. This results in the averaging of two or more tiles during authentication (sub-segmentation step), with a predictable decrease in authentication accuracy.

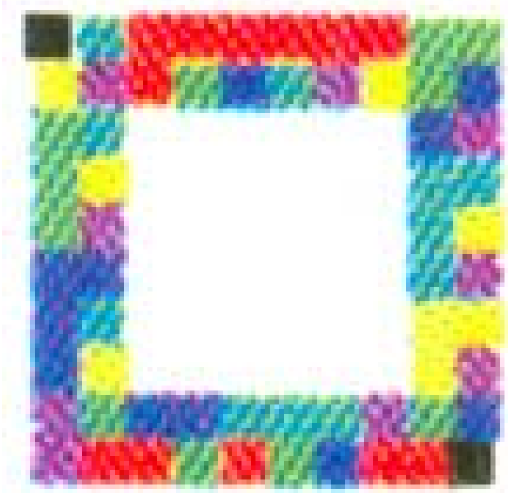

Figure 3. *Image quality defect for the pre-compensated IJ 3600/plain paper combination. Note the mis-registration between the upper left (black) tile and the yellow tile directly below it. This mis-registration results in consistent failure of the authentication algorithm due to tile-tile overlap in the sub-segmentation.*

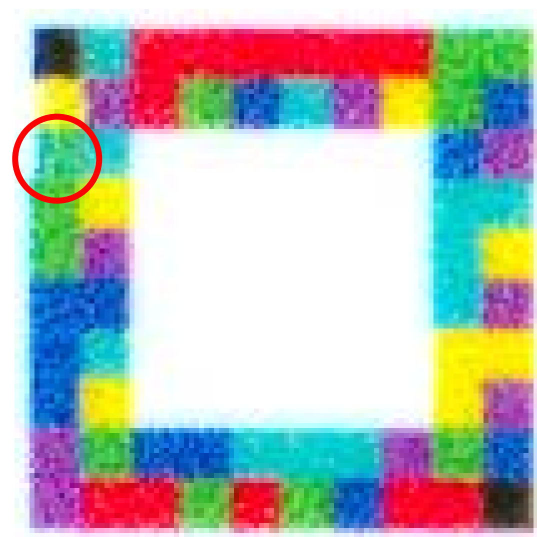

Figure 4. *Image quality defect for the pre-compensated IJ 5440/soft gloss paper combination. Note the tile third down from top on the left (enclosed by a red circle) is not green as intended, but instead very cyan in color (and thus it fails authentication).*

For the IJ 5440/soft gloss paper combination, a single tile mis-classification was responsible for the authentication failures of the pre-compensated compared to compensated images (Figure 4). This tile, third from the top along the left side, was consistently printed (and so classified) with a distinct cyan (rather than green) hue across and up/down the test sheet. Replacement of the color cartridge removed this image defect.

Discussion and Conclusions

Spectral pre-compensation was shown to improve authentication accuracy, and thus security payload density (SPD), in 9 of 11 cases. Excepting print quality issues, pre-compensation should provide a general method for increasing SPD in color-based security deterrents, especially 3D barcodes.

If spectral pre-compensation is successful, the colors after printing and scanning are 60º apart in the 360º color circle. As a consequence, tile substitution errors should become more entropic after pre-compensation—that is, the odds of substituting a color, C_i, for the neighboring color C_{i-1} should be more similar to the odds of substituting C_i for the other neighboring color, C_{i+1}. Note that $C_{i\%6} = C_i$ for all i=1,2,…,6 where % is the modulus operator, and so $C_0=C_6$, etc. The colors C_{i-1} and C_{i+1} are termed the sidelobes for color C_i and so the sidelobe entropy, a measure of how entropic the color mistakes are, is given by:

$$e_{SL} = \sum_{i=1}^{6} K(i) \quad (1)$$

where

$$K(i)=p(C_{i+1})*\ln(p(C_{i+1}))+p(C_{i-1})*\ln(p(C_{i-1})) \quad (2)$$

and

$$p(C_{i\pm1}) = \left[\frac{C_i \to C_{i\pm1}}{C_i \to C_{i+1} \parallel C_{i-1}} \right] \quad (3)$$

That is, $p(C_{i+1})$ is the probability of incorrectly substituting (is the substitution operator) color C_i to C_{i+1} divided by the probability of incorrectly substituting color C_i to C_{i-1} or C_{i+1}.

To account for different error rates for each of the 6 colors, we also computed $e_{SL}(w)$, or weighted side lobe entropy, defined as:

$$e_{SL}(w) = \sum_{i=1}^{6} w(i) * K(i) \quad (4)$$

In Equation (4), w(i) is the percentage of substitution errors for color I; that is, $\sum w(i)=1.0$. Representation data for e_{SL} and $e_{SL}(w)$ are given in Table 5, where color tile size=7 is shown. Table 5 illustrates that $e_{SL}(w)$ appears to be the better indicator of the effects of spectral pre-compensation in making the tile authentication errors more entropic, and that both e_{SL} and $e_{SL}(w)$ increase with spectral pre-compensation efficacy.

Our results and observations presented here indicate that spectral pre-compensation, as anticipated, is a generally useful technique for increasing SPD. Moreover, when spectral pre-compensation was not useful for increasing authentication accuracy, the printing quality was responsible. Thus, our findings indicate that spectral pre-compensation workflows can be used, more generally, to provide process quality assurance and print quality inspection. Increases in both authentication accuracy and $e_{SL}(w)$ are anticipated for a print run to pass inspection.

Finally, our findings support results presented earlier [1] highlighting the different authentication accuracies for different printers and substrates. Among the printers of the same technology (e.g. LJ 3600 and LJ 4600), the effects of printing and scanning (Tables 1 and 2) are usually more similar in comparison to differences in substrates or differences in printing technology.

Table 5: Side lobe entropy and weighted side lobe entropy values for color tiles, size = 7. PC=pre-compensated, UC=un-compensated. Please see text for details. Boldface indicates side lobe entropy is at or above PC level for the UC images.

Printer	Paper	PC e_{SL}	PC $e_{SL}(w)$	UC e_{SL}	UC $e_{SL}(w)$
LJ 3600	Gloss	3.55	3.53	3.71	**3.75**
LJ 3600	Plain	0.71	1.68	0.69	0.16
IJ 5440	Gloss	0.22	0.19	0.00	0.00
IJ 5440	Plain	2.54	3.79	0.00	0.00
IJ 5440	Soft	0.65	0.74	0.00	0.00
IJ 6127	Gloss	0.00	0.00	0.00	**0.00**
IJ 6127	Plain	0.77	0.52	0.04	0.06
IJ 6127	Soft	0.10	0.21	0.21	0.08
IJ 6280	Gloss	0.65	0.87	0.32	0.31
IJ 6280	Plain	0.87	2.31	0.00	0.00
IJ 6280	Soft	0.77	0.85	0.43	0.61

Future studies will focus on how spectral pre-compensation can be used further in QA, inspection and print quality assessment. Additional predictive metrics will also be investigated to complement e_{SL} and $e_{SL}(w)$, which were introduced here. Also, future work will focus more on industrial grade printers, which are expected to have greater consistency and reliability.

References

[1] Simske, Steven J., and Jason S. Aronoff, "Qualification of a Layered Security Print Deterrent", *J. Imaging Sci. and Technol.*, pp. 86-95, 2007.

[2] S.J. Simske, J.S. Aronoff and M. Sturgill, "Spectral Pre-Compensation of Printed Security Deterrents", Proc. Optical Doc. Security, http://www.opticaldocumentsecurity.com/index.php?page=agenda.htm. (2008).

Author Biography

Steven Simske is the principal scientist in security printing and imaging for Hewlett-Packard laboratories. He has worked in biomedical imaging and signal processing; image, text and speech understanding; classification and security printing over the past 20 years. He holds more than 20 U.S. patents, and has published nearly 200 journal and conference articles. He is a member of IEEE, ACM, IST and SPIE. His blog is at http://www.communities.hp.com/online/blogs/securityprinting/default.aspx.