Hiding Data in the Blue Channel

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Abstract

To enable the track and trace of pages from a color printer, data must be embedded and recoverable across the entire page regardless of the content on that page. This paper describes a solution that allows low visibility and high detectability of data-bearing "dot signatures". An analysis of optimum dot-color to background-color combinations uncovers the serendipitous method of "Blue Clipping," operating only on the blue component, exploiting low visual sensitivity to the blue channel. Blue Clipping is compared to the method of yellow dots, and the problem of dot gain for shadow dots is addressed. While initially designed for enterprise printers, this new technology is also adding functionality to 3D objects. It enables visually pleasing yet robustly recoverable data markings from a small region anywhere on a printed surface, without the need for costly special inks.

Introduction

How can we cover the surface of a document or 3D part with a data payload such that the data can be recovered from any sub-region of the surface regardless of the underlying color, while minimizing impact on visual aesthetics, and without requiring costly invisible inks? This challenge was presented to us by customers in need of a solution for tracking sensitive documents, including trimmed portions of those documents. In this application a typical data payload could involve, for example, a user name, time stamp and location of the print.

The problem of embedding information in documents has a long history of research. Since the 1980's color laser printers have used a yellow microdot Machine Identification Code [1] on every page to enable identification of the device that printed the document, an approach that has been used to track leaked documents [2]. Anoto, Inc. provides technology [3] that covers an entire page with dots of the same size and shape where every dot is shifted from a nominal position as a form of encoding, but is not used to encode an arbitrary payload or survive recoverability in areas of non-white background. There are many 1D and 2D monochrome and color barcodes in wide use, but those patterns do not cover an entire document, do not recover reliably when overlaid on over content, and considerably change the visual appearance of the source document. Conventional watermarks will not work over dark solid areas, and, like barcodes, can be associated with minimal area requirements.

Various efforts embed information in the halftone of continuous-tone images, and most apply to dispersed-dot dithering applications. A survey [4] of such techniques show that in many cases the entire image must be captured for payload recovery. A common approach is to use a form of error-diffusion. One such solution was developed at HP where the error diffusion algorithm used blocks of output pixel shapes [5]; this approach was built on earlier work, where the concept of a "visually significant barcode" (VSB) [6] was introduced. Other dispersed-dot dithering approaches include hiding data in the edges of the image [7], or toggling pairs of pixels [8]. Clustered-dot halftones have been used

to carry information by creating asymmetric shapes in the clusters, such as ovals [9] and using shape orientation to encode a bit. Information can be embedded in clustered-dot screens by altering their phase and frequency [10], but the data payloads are limited to a small size.

The technique proposed in this paper advocates a clustered-dot version of VSBs that embed data in a way that is visually pleasing by taking a conventional clustered-dot halftone and altering the positions of individual dot clusters [11]. The method is robust over a wide range of dot sizes across the full range of highlights and shadows and allows relatively large data payloads. We describe a solution using "dot signatures, " featuring halftone-based VSBs derived from a fixed light gray image the size of the document. Figure 1 shows an example of a small portion of the resulting halftone in (a) and the VSB with data embedded in (b) at about 3x enlargement for illustration purposes. The data is arranged using a circular coding scheme [12] that allows full data recovery from a small portion of the pattern. We further describe how to render this pattern in a color document regardless of the background color and how to reliably recover the data.
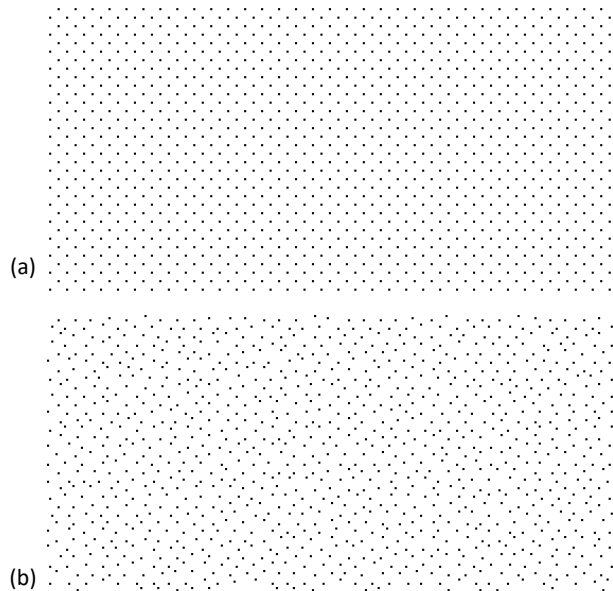

Figure 1. (a) Portion of a classical halftone of a fixed gray image, and (b) the resulting VSB carrying data.

The Use of Yellow Dots

One approach to consider is to overlay our dot signature as yellow dots because of its relatively low visibility over white space and recoverability when examining the blue channel of an RGB capture. As mentioned above, yellow dot Machine Identification Codes have been in use for almost four decades; this low visibility feature has also been used to hide data [13]. A test source document

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into which we will attempt to embed our dot signature is shown in Figure 2. It contains text on a white background. Because of the requirement that a solution be recoverable on any background, the document includes patches of solid color representing the corners of the RGB cube, along with three intermediate grays values. We form a dot signature similar to Figure 1(b) the same size as the test document; we replace the pixels for every dot in the document with yellow.
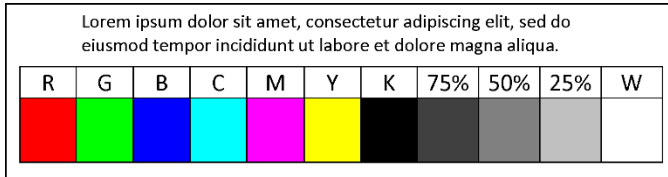
R	G	B	C	M	Y	K	75%	50%	25%	W

Lorem ipsum dolor sit amet, consectetur adipiscing elit, sed do eiusmod tempor incididunt ut labore et dolore magna aliqua.

Figure 2. Experimental source document.

The result can be seen in Figure 3(a), and the blue channel separation of the visible image results in the monochrome image shown in Figure 3(b). As expected, in white spaces the yellow dot overlay method hides data in the visible image, and is well recovered in the blue channel. On the other hand, however, the yellow dots impart a disturbing visible pattern over many of the solid colors. Worse, the pattern is not detectable at all over red, green, yellow, or black solid areas.
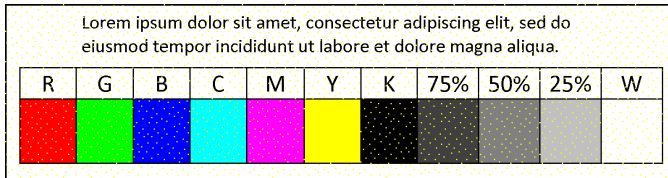
(a) Visual Image
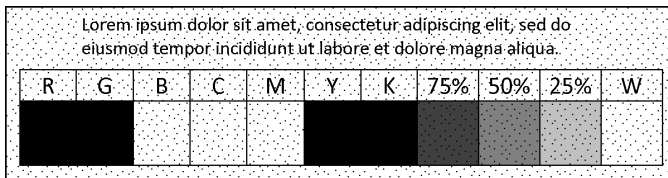
(b) Blue Channel Detection Image

Figure 3. Yellow-dot overlay method. Note failures in both visual quality and detection.

Dot Color Evaluation

Selecting a dot color to be placed over a specific background color requires evaluating two features: visual appearance and detectability. One aspect of this evaluation is illustrated with a test chart that shows candidate dot colors against various background colors. Figure 4(a) depicts a chart that places eight dot colors against eleven background colors. The eight dot colors represent to corners of RGB cube. These colors can be generated without halftoning using the solid process colors, cyan (C), magenta (M), yellow (Y), and black (K) and their combinations red (R = M+Y), green (G = C+Y) and blue (B = C+M). White (W) represents paper white. The background colors in this chart include the same eight, along with additional background colors 25%, 50%, and 75% gray. Eliminating the cases where the dot color is the same as the background, the least visible combinations are indicated by a check mark on the matrix.

(a) Visibility Test Matrix

(b) Detectability Test Matrix

Figure 4. Choosing dot colors for (a) low visibility and (b) high blue-channel detectability against a range of background colors. "Yellow Dots" are circled.
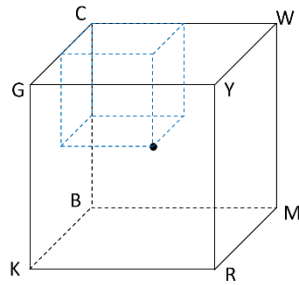
For detection of the presence of a dot, the recovery system can examine each color channel individually. It turns out that the blue channel alone can discriminate between the dot and the background in all the checked combinations. The blue channel of Figure 4(a) is shown in Figure 4(b) with the selected combinations checked in red. The well-known dot-background combination of yellow dots on white is circled. Figure 5(a) is a table representing the selected dot-background combinations of the 8 solid colors. We could divide the RGB representation of all background colors into 8 sub-regions as indicated in Figure 5(b) where each grouping is a cube delimited by the middle gray point and a corner of the larger RGB cube; the sub-cube for cyan (C) is indicated. Using this segmentation, all background pixels can be partitioned into one of the eight mappings in the table by merely using the MSB of the red, green, and blue color components. Upon examining the background color MSBs and the dot color assignment, a serendipitous relationship emerges: the dot color is the same as the background color with the bit representing the blue component inverted!

Blue Clipping

A convenient consequence of the mapping in Figure 5(a) is a straightforward implementation of dot color selection. We call the method "Blue Clipping" because the blue component of the dot color is clipped to zero if the blue component of the source document is above some threshold, and clipped to the maximum value (usually 255) if he blue component of the source is below the threshold. The algorithm is depicted in Figure 6. It is important to point out that the red and green components of the dot are the same as the background, to help preserve the original appearance while maintaining detectability in the blue channel.

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Background	RGB MSBs	Dot Color
R	100	M
G	010	C
B	001	K
C	011	G
M	101	R
Y	110	W
K	000	B
W	111	Y

(a)

(b)

Figure 5.
(a) Table of the selected dot-background combinations from Figure 4.
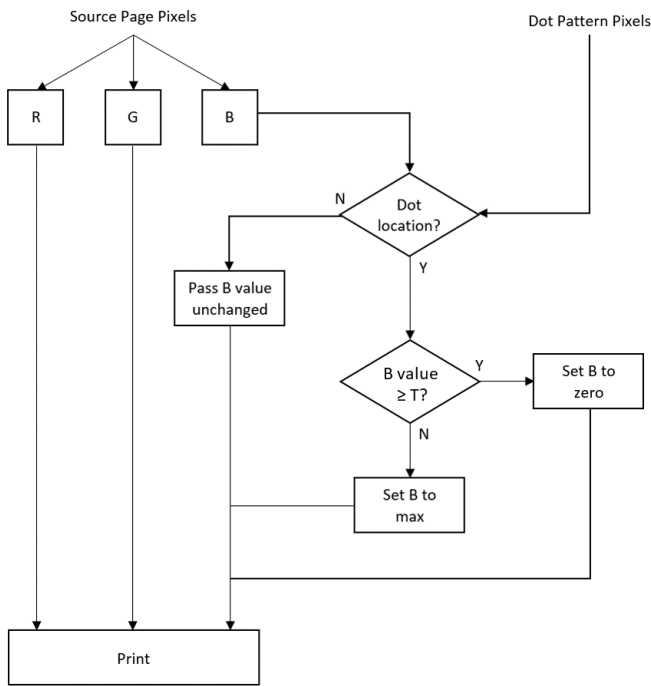*(b) Eight cubic sub regions use the middle gray point as a vertex.*

Figure 6. System for Blue Clipping.

To illustrate the effectiveness of this method, the visual image resulting from embedding our dot signature in the test document is shown in Figure 7(a), and the blue channel detection image is shown in Figure 7(b). Note that the dots are well-hidden yet detectable in all background colors. The method works well with any continuous-tone image; an example is illustrated in Figure 8. While the dots are not seen in the visible image, they are apparent in the blue channel.
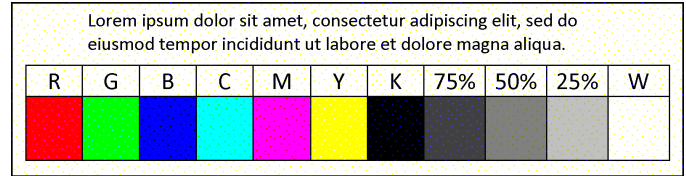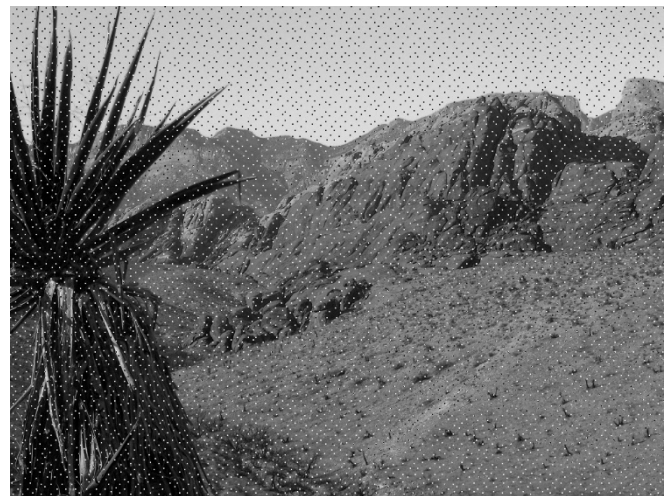
(a) Visual Image
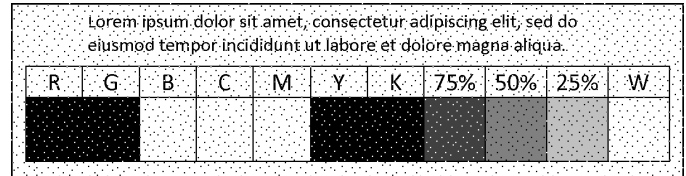
(b) Blue Channel Detection Image

Figure 7. Blue Clipping Method.
Both visual quality and detectability are improved.

(a) Visual Image.

(b) Blue channel Detection Image.

Figure 8. Blue Clipping Method applied to a continuous-tone image.

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This solution works in part due to the human visual system's insensitivity to blue, as it contributes only 7% of our perception of luminance. The CIE definition of luminance for sRGB is $Y = .2126R + .7152G + .0722B$, and a plot of the human visual system's photopic luminosity function is shown in Figure 9.
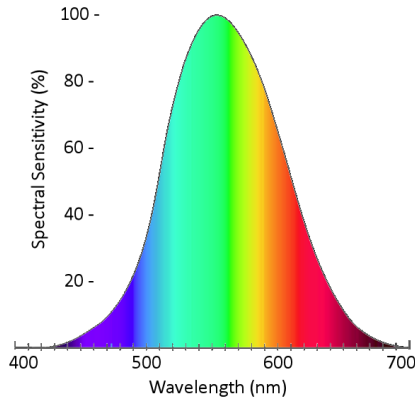

Figure 9. CIE Spectral Sensitivity function.

If we implemented the system in Figure 6 instead, for example, by operating on the red channel instead of blue, we would create the result shown in Figure 10. This method of "Red Clipping" (where the green and blue components are left untouched) would produce a result where the dots are equally easy to detect by examining the red component in Figure 10(b). Unfortunately, the visual image (a) is far from acceptable as the dots are very apparent in almost every background color. "Green Clipping" is worse still because of our even greater sensitivity to green.

Monochrome printers do not have the benefit of hiding dots in the blue channel, so we must perform the operation as shown for the blue component in Figure 6 on the source pixel; in this case the method is called "Gray Clipping" because dots over light areas are rendered black, and dots over dark areas are rendered white.

(a) Visual Image

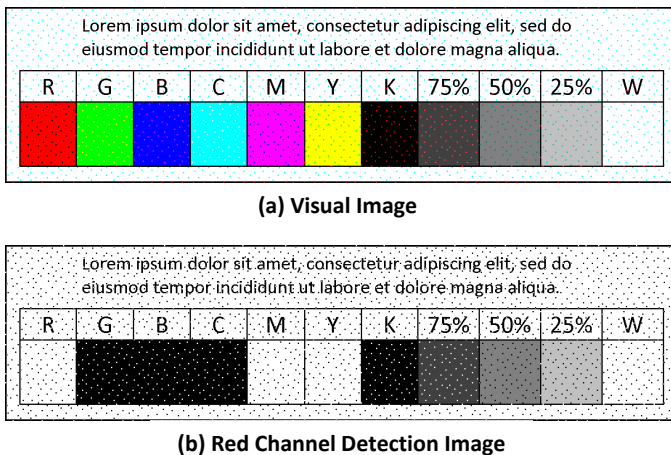**(b) Red Channel Detection Image**

Figure 10. Red Clipping Method.
Equally as detectable, but visual quality suffers.

Highlight and Shadow dots

An inconvenient reality of printing with inks is that dot gain renders highlight and shadow dots differently. Figure 11(a) illustrates an example of the digital source of a portion of a monochrome document that contains both highlight dots (black dots surrounded by light ink), and shadow dots (white dots surrounded by dark ink). A scan of a laser print of the same region of this document reveals how the white shadow dots tend to close, that is, to contract to the point of being difficult to detect, due to dot gain. Enlarging the dots such that the patterns present in shadow regions creates a more detectable signal, but at the expense of making the dots more visible than necessary in the highlight regions.

Highlight Dots are black dots surrounded by light ink

Shadow Dots are white dots surrounded by dark ink

(a) Digital Source

No problem with highlight dots

Shadow Dots render smaller and are harder to detect
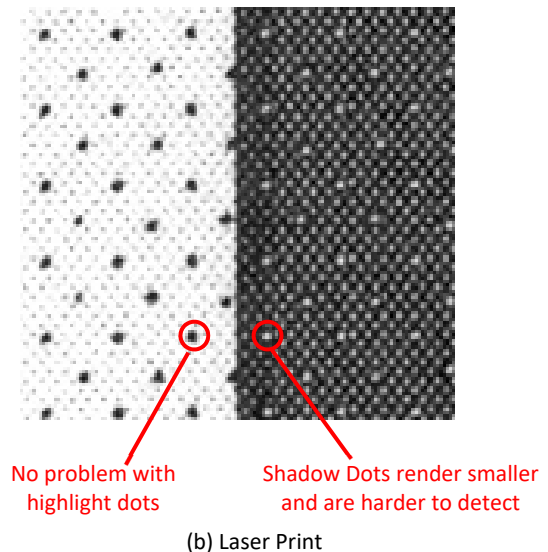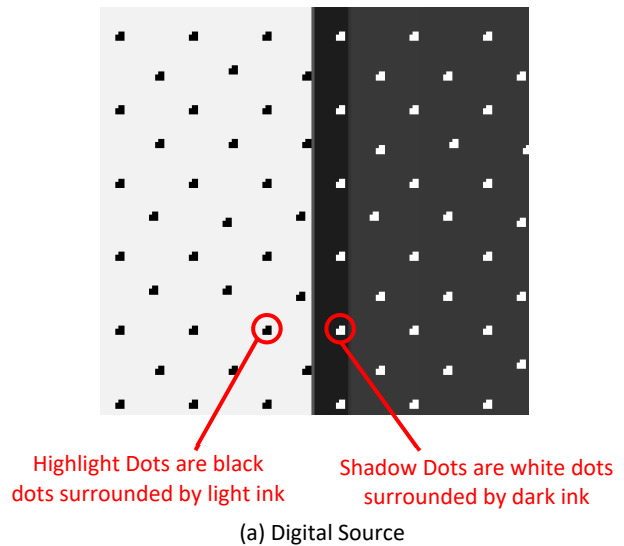
(b) Laser Print

Figure 11. Highlight and shadow dots.

Ordinarily, the dots from our dot signature occupy only one of two possible checkerboards because they are generated as a clustered-dot halftone of a fixed highlight gray image. Data to every possible cell but anticipate the checkerboard subsampling in

our circular coding. As a result, to help address the issue, we create two dot patterns, one for highlight and one for shadow on complementary checkerboards as shown in Figure 12. The shadow dot pattern uses larger dots. The system for Blue Clipping is modified in Figure 13 to accommodate these separate patterns.
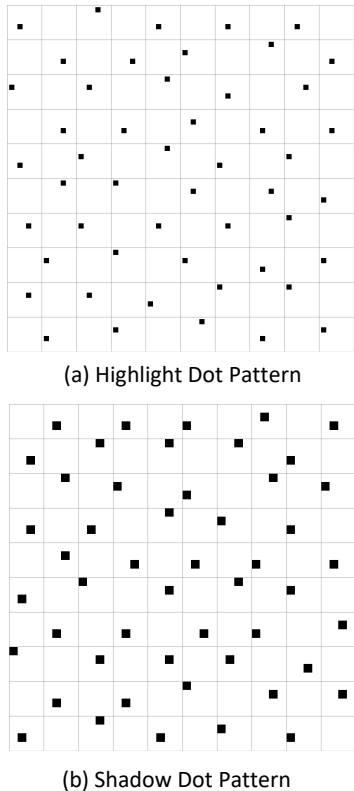

(a) Highlight Dot Pattern

(b) Shadow Dot Pattern

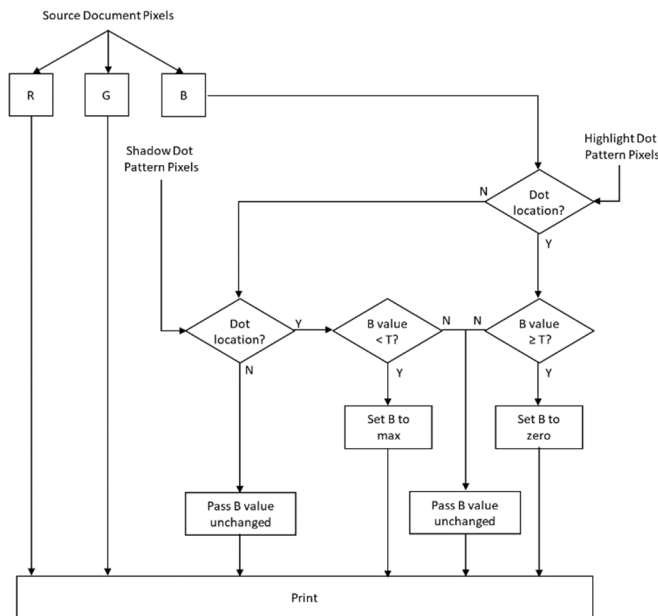Figure 12. Two dot patterns on complementary checkerboards.

Figure 13. System for Blue Clipping with separate highlight and shadow dot patterns.

3D Surface Coding

Color-enabled 3D printers can also take advantage of Blue Clipping for embedding data. A challenge associated with 3D prints is that printed surfaces are usually non-planar, but one simple means of marking an object with non-flat surfaces is to wrap a conventional 1D barcode around the entire object. Figure 14 shows an example of a standard UPC-A barcode rendered on such an object. In the case of a blue background, the barcode is rendered as cyan, and in the case of a white background, the barcode is rendered as yellow. Using the blue component of a captured image allow for standard recovery of this barcode.

Figure 14. Example 3D Prints with Blue Clipping.

Blue Clipping enables visually pleasing yet robustly recoverable data markings, on 2D and 3D surfaces, without the need for costly special inks.

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Author Biography

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