Printer Mechanism-Level Data Information Embedding and Extraction for Halftone Documents – New Results*

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Abstract

Embedded information in printed documents can be used for a number of applications such as authentication of document content, proof of ownership, and identification of the printer that produced documents. One approach is to embed information in the halftone portions at the printer mechanism-level. The advantage of printer mechanism-level information embedding is that information is directly embedded in printed documents without any further steps that might alter the intended information. In this paper, we describe a printer mechanism-level information embedding and detection scheme as an extension to our previous result. An information bit is embedded by changing the position of a dot to be developed and these information bits are grouped together to be robust to noise caused by various reasons. The previous detection algorithm is modified to improve the detection rate of embedded information in printed documents. Consequently, we are now able to embed information using a reduced level of dot shift, which better maintains the halftone image quality. The experimental results show that our proposed scheme is feasible to embed and detect information in printed documents.

Introduction

The importance of document security has increased due to ease of counterfeiting or forgery of documents such as banknotes, official documents, and passports according to the development of computer and printing technologies. Therefore, the ability to embed and extract information in printed documents would be desirable for many security applications such as verification of printed documents and copyright protection.

To embed data in the image part of printed documents, halftone algorithm-level data embedding [1]-[6] and printer mechanism-level data embedding [7]-[12] have been researched. Halftone algorithm-level data embedding modifies the halftone process to embed data based on screening [1]-[3], error diffusion [4]-[5], or searching [6]. Printer mechanism-level data embedding modulates the printing process parameters to embed information in the printed hardcopy.

In our previous work [12], we have proposed a scheme for printer mechanism-level data embedding and extraction for documents halftoned using a particular algorithm – AM/FM [13], which is used in scan-to-print applications. We have demonstrated that it is possible to identify individual printed dots, compute their centroids, and find the underlying lattice.

In this paper, we improve the previous scheme for information embedding and extraction. To embed information during the printing process, we use AM/FM halftoning algorithm with an electrophotographic laser printer that has sub-pixel modulation capability such as pulse width modulation (PWM) [13]. An information bit is embedded by changing of the position of a dot to be developed at sub-pixel precision and these information bits are grouped together to be robust to noise caused during the printing and scanning process. The previous detection scheme is modified to improve the detection accuracy of embedded information in printed documents.

The organization of this paper is as follows. In the next section, we describe a method to embed and extract the information in the halftone document. Experimental results and conclusion are given in the last two sections.

Embedding information

PWM technology provides us with sub-pixel modulation capability that changes the size and position in the pixel grid of a dot to be modulated. Since the electrophotographic process is often unstable for development of isolated single-pixel dots, clustering dots in pairs leads to more stable development [13]. Figure 1(a) shows an example of the output pattern generated by clustering dots in pairs by using PWM. In Fig. 1(a), two dots are grouped together and each row is offset relative to neighboring rows. Then there exists an underlying lattice for dot centroids shown as dashed lines in Fig. 1(b). In AM/FM halftoning, all dot centroids are in the center of horizontal and vertical lattice. Figure 1(d) illustrates the sub-pixel modulated output pattern of Fig. 1(c). The centroid of the dot pair indicated as D1 is shifted to the right where it is indicated as D3. Also, the centroid of the dot pair indicated as D2 is shifted to the left where it is indicated as D4. Then, D3 and D4 are not located where dot pairs should be since they are shifted by a half-pixel to the right or left. In this case, we can consider that the dot pairs whose centroids are not shifted represent a binary letter -1 and the dot pairs whose centroids are shifted correspond to a binary letter +1. Further, the area where there is no dot is regarded as a bit 0. But one dot pair containing a binary letter is not suitable to represent meaningful information due to several problems. In the halftone pattern, there are areas where dots do not exist due to dependence on local gray value or stochastic dot

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placement. In some cases, dots fail to develop due to instability of the electrophtographic process. To solve these problems, we partition a halftoned image into fixed blocks of size $m \times n$. In this case, all binary letters in a block are composed of -1 and 0, or 1 and 0. Figure 2(a) illustrates the halftone pattern in a block with m = 4 and n = 6. Figure 2(b) and 2(c) show examples of the information embedded in the halftone pattern in Fig. 2(a). To embed information bit of -1 as shown in Fig. 2(b), every dot pair in the block is not shifted. To embed information bit of +1 as shown in Fig. 2(c), all dot pairs in the block are right-shifted by a half-pixel.

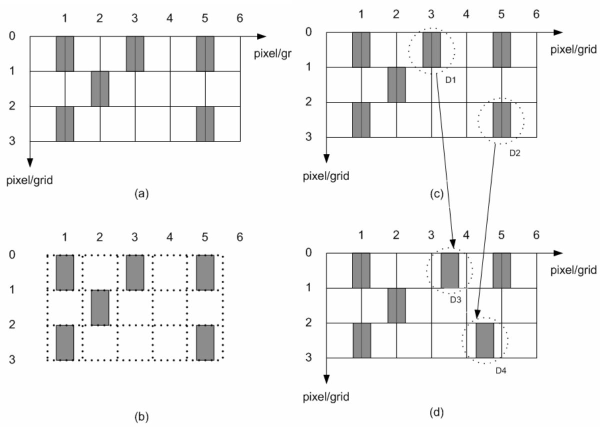

***Figure 1**. Example of (a) halftone pattern, (b) underlying lattices in halftone pattern, (c) halftone pattern before embedding information, and (d) halftone pattern with embedded information.*

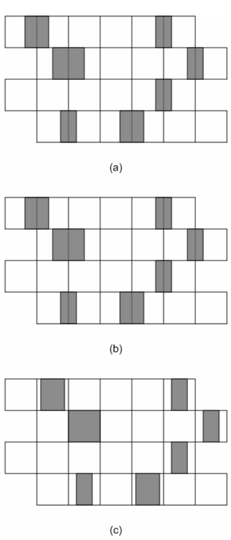

***Figure 2**. Example of (a) halftone pattern in a block of size 4 x 6, (b) output pattern embedded with information bit of -1, and (c) output pattern embedded with information bit of +1.*

Extracting the embedded information

The process of extracting the embedded information from a halftone document is depicted in Fig. 3. The scanned image is obtained by scanning the printed document that contains the embedded information. After scanning the printed document, preprocessing is performed on the scanned image to eliminate noise introduced during the printing and scanning process. Then the preprocessed image is analyzed to detect binary letters. After detecting binary letters, the embedded information is extracted on a block basis.

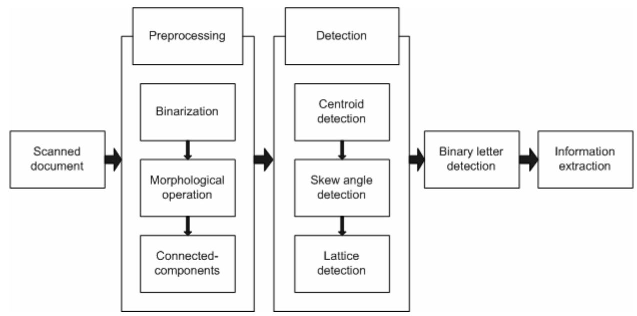

***Figure 3**. Diagram for extracting the embedded information from a scanned document.*

A. Preprocessing

Preprocessing in this paper is similar to the method in our previous work, but is different in details. It consists of binarization, morphological operation, and connected-components. Unlike our previous method, the scanned image is binarized by Kittler's minimum error thresholding method [14] instead of Otsu's method [15] since we found out that background paper and foreground dots are well modeled as a mixture of two Gaussians. After binarizing the scanned image, a binary closing operation followed by an opening operation is performed to remove some noisy toner particles and aggregate the scattered particles. To remove the remaining noise around each cluster of dots, regions that have less than a certain number of connected-components are eliminated.

B. Detection

Dot centroids are calculated after preprocessing the scanned image. Since the preprocessed image contains clusters for each dot, the dot centroids are calculated by computing weighted averages based on the spatial distribution of toner absorptance throughout the dot's corresponding preprocessed image. Then we perform skew correction by finding the angle that has the maximum number of zeros in the projection of printer scan direction over a range of angles. After finding the skew angle, we perform a Fast Fourier Transform (FFT) for N data points from the projection of the skew-corrected image. Since the unit length R of the rectangular lattice that contains the dots is related to the fundamental frequency, we can obtain the unit length of the lattice from

$$R = \frac{N}{f_{\max}}, \qquad (1)$$

where f_{max} is the frequency component that has the maximum magnitude in the FFT.

C. Finding underlying lattice

Since we can only image a limited portion of the halftone document at a time to capture the printed halftone dot pattern with adequate detail, we need a method to find the underlying lattice of the individually captured image segments. If we can find underlying lattice of the scanned image, we can distinguish whether detected dot pairs are shifted or not. Figure 4(a) shows an example of output pattern where some dots are shifted and others are not. The dashed lines in Fig. 4(b) depict the underlying lattice of this output pattern. Here cross-marks represent dot centroids of each dot pair. As shown in Fig. 4(b), the underlying lattice is completely determined with a start point of lattice, x_l for unit length of horizontal lattice, and y_l for unit length of vertical lattice. Note that all centroids are in the center of each lattice cell in case dots are not shifted or are aligned in the vertical lattice in case dots are shifted by a half-pixel. If we estimate the underlying lattice with an incorrect start point of the lattice or incorrect unit lattice length, dot centroids are not in the center of each lattice cell nor aligned in the vertical lattice as shown in Fig. 4(c) and (d). If we know the exact value of x_l and y_l, we can find the lattice start point by minimizing the average distance between centroids of the scanned image and the estimated one by using the known unit lattice lengths. Let (x_{1j},y_{1j}) denote the coordinate of dot centroid from the scanned image and (x_{2j},y_{2j}) denote the coordinate of estimated dot centroid from the known unit lengths of the lattices. The average distance, $D_{avg}(x_s,y_s)$, with start point (x_s,y_s) is given by

$$D(x_s,y_s)=\sum_j I(j)\sqrt{(x_{1j}-x_{2j})^2+(y_{1j}-y_{2j})^2},$$
$$N=\sum_j I(j),$$
$$D_{avg}(x_s,y_s)=\frac{D(x_s,y_s)}{N},$$

where $I(j)$ is an indicator function where $I(j)$ = 1 if the *j-th* estimated region of dot pair contains both scanned and estimated dot centroids and otherwise $I(j)$ = 0. Then the lattice start point is the point where the average distance is minimized as given by

$$(x_s^*,y_s^*)=\arg\min_{(x_s,y_s)} D_{avg}(x_s,y_s).$$

However, we do not know the exact value of x_l and y_l while we have an initial guess of unit lattice length for the printer scan direction from (1). Thus, we iteratively changes x_l and y_l over a range of values around R obtained from (1). Then the start point, x_l and y_l can be expressed as

$$(x_s^*,y_s^*,x_l^*,y_l^*)=\arg\min_{(x_s,y_s,x_l,y_l)} D_{avg}(x_s,y_s,x_l,y_l).$$

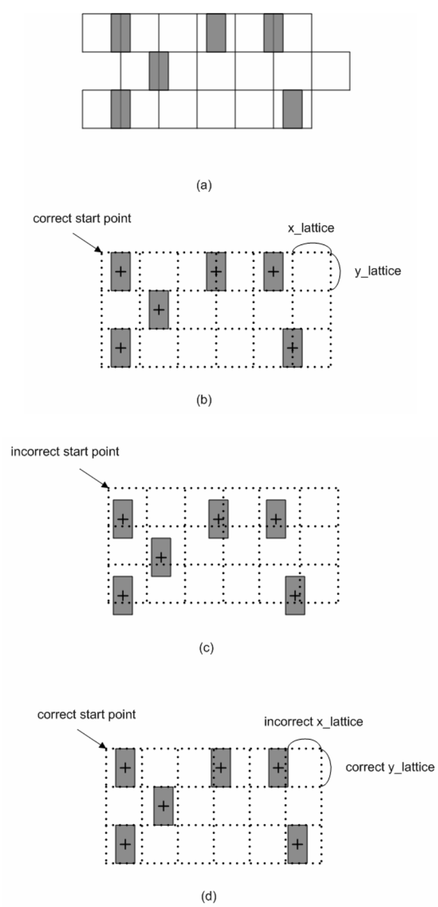

Figure 4*. Example of (a) halftone pattern, (b) underlying lattices in halftone pattern, (c) halftone pattern before embedding information, and (d) halftone pattern with embedded information.*

D. Block decoding

To extract the embedded information we group binary letters into blocks. As described in the previous section, the block representing the information bit of +1 consists of binary letters of +1 and 0. The block representing the information bit of -1 consists of binary letter of -1 and 0. Thus the embedded information can be extracted by the majority vote for each block.

Experimental results

We tested our scheme by printing a test patch at 600 dpi with an HP LaserJet 5500[f1]. The print of a test patch was scanned at 6900 dpi with a QEA IAS-1000 Automated Image Analysis System[f2]. Figure 5(a) shows the information we embedded in the test patch. The information bits of -1 and +1 were embedded alternatively. The block of size 6 × 10 was used to embed an information bit. Figure 5(b) illustrates the resulting image with dot centroids for a portion of the scanned test patch having approximately a 0.10×0.07 in^2 field of view. Figure 5(c) shows the result of a binary letter decoding. Each square in Fig. 5(c)

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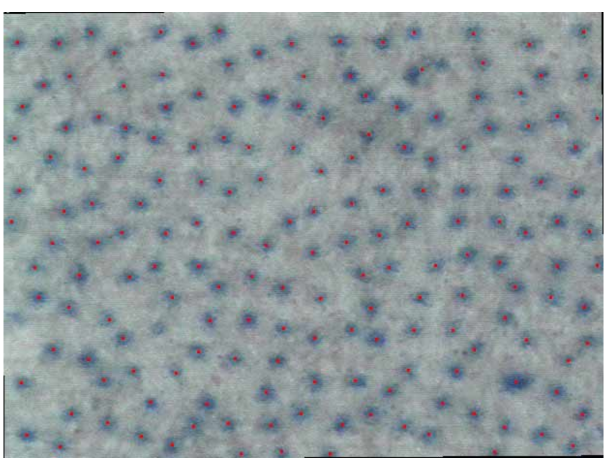
[f2] Quality Engineering Associates, Inc., Burlington, MA 01803

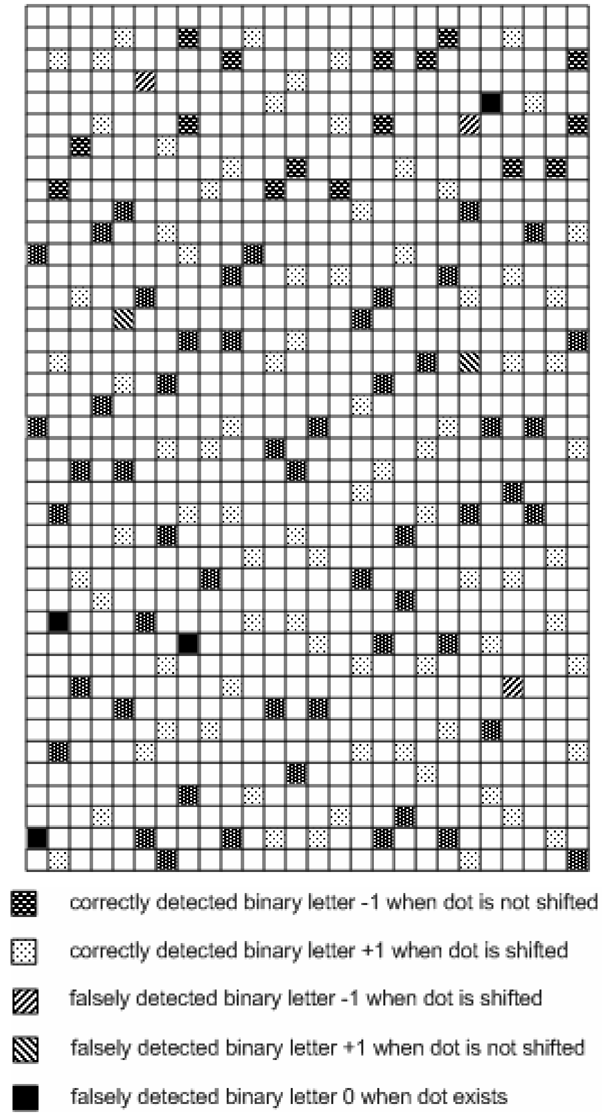
corresponds to the dots in Fig. 5(b). As shown in Fig. 5(c), we could correctly detect 82 binary letters of -1 that implies that the dot is not shifted and could correctly detect 69 binary letters of +1 that indicates that the dot is shifted. 3 binary letters of -1 was falsely detected when the dot is shifted and 2 binary letters of +1 was falsely detected when the dot is not shifted. There were 4 missed dots. Thus, we could correctly find 151 binary letters out of 160 embedded binary letters. From the detected binary letters, we extracted the embedded information on a block basis. Since the block of size 6×10 was used to embed an information bit and a dot is formed in pairs in AM/FM halftoning, cells of size 6 × 5 corresponds to a block in Fig. 5(c). The extracted information bits are shown in Fig. 5(d). We correctly extracted 29 bits out of 30 bits and 1 bit was undetermined. For the test patch, we extracted the embedded information from 10 portions and we could correctly extract 242 bits out of 250 bits and 8 bits were undetermined. There was no incorrectly extracted information.

-1	+1	-1	+1	-1
+1	-1	+1	-1	+1
-1	+1	-1	+1	-1
+1	-1	+1	-1	+1
-1	+1	-1	+1	-1
+1	-1	+1	-1	+1

(a)



(b)



(c)

-1	+1	-1	+1	-1
+1	-1	+1	-1	+1
-1	+1	-1	+1	-1
+1	-1	+1	-1	+1
-1	+1	-1	+1	-1
+1	-1	+1	-1	0

(d)

***Figure 5**. (a) Embedded information on blocks, (b) portion of scanned patch with embedded information, (c) extracted binary letters, and (d) extracted information on blocks.*

Conclusion and discussion

In this paper, we have proposed an improved scheme for printer mechanism-level data embedding and extraction for documents halftoned using AM/FM. Information is embedded by shifting dots on a block basis using PWM and is extracted by a sequence of steps that includes scanning, binarizing, morphological operation, connected-components, centroid detection, skew correction, lattice detection, binary letter detection, and block decoding. We have demonstrated that it is possible to extract data from the printed documents where the data is embedded by using a half-pixel shifting of a dot. However, our scheme works only for the highlight content. For midtone gray levels, dots tend to be aggregated with adjacent dots which would lower the detection accuracy of our scheme. Thus, we need to further develop the method to separate aggregated dots into individual dots. Further, the limited field of view of the image capture system used to scan the printed document will necessitate that the detected symbol stream be locally synchronized at the decoder.

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Author biography

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