Printer Mechanism-Level Data Hiding for Halftone Documents*

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Abstract

Techniques to embed information in printed documents have lately attracted considerable attention due to their various applications such as copyright protection and forensic document examination. One method is to embed data in the halftone portions of a document during the printing process. The printed hardcopy might then contain information about the printer that includes manufacturer, model name, and serial number, or information about the document, such as copyright, confidentiality, and date printed. However, previous approaches have mainly focused on methods that modify only the halftoning algorithm itself without considering the printer mechanism. Embedding data at the printer mechanism-level is desirable, since it is more robust and flexible. In this paper, we describe a printer mechanism-level information embedding and detection scheme for halftone documents that is suitable for electrophotographic laser printers. After we embed the information, the printed document is scanned for image analysis and data extraction. These processes include specific means to account for the inherent instability of the EP process and resulting noise in the scanned images. Preliminary experimental results suggest that our proposed scheme is feasible although much work remains to be done to fully prove out the concept.

Introduction

Due to the rapid development of computer and printing technologies, counterfeiting or forgery of documents such as banknotes, official documents, and passports can be done without any particular skill with low cost color printers and scanners. This has increased the importance of document security. Therefore, the ability to embed and detect information in printed documents would be desirable for verification of any printed documents.

Data embedding in the image part of printed documents might be classified into two categories: halftoning algorithm-level data embedding and printer mechanism-level data embedding. The first approach in halftoning algorithm-level data embedding involves screening [1]. In the halftoning process, screening-based data embeds information by using different dither cells with spatially varying thresholds. Each dither cell represents the corresponding embedded data [2]-[4]. Since these methods are based on pixel-by-pixel comparison, computational complexity is low. However, two halftone images are required to extract the embedded data from these methods, and this makes these methods impractical.

The other approach in halftoning algorithm-level data embedding is related to error diffusion [5] and search-based halftoning [6]. Error diffusion-based and search-based halftoning data embedding methods obtain a higher visual quality data-embedded image [7]-[9]. However, these methods also have higher computational complexity and are, therefore, slow for real-time printing applications.

Unlike halftoning algorithm-level data embedding, printer mechanism-level data embedding modulates the process parameters at the printer mechanism-level to embed information in the printed hardcopy. The method in [10] exploits banding artifacts as a signature to identify the printer used to produce printed documents. The method in [11] extends the method in [10] by intentionally generating banding signals. However, the methods in [10]-[11] have very limited data-embedding capacity. To expand data-embedding capacity, raggedness and laser exposure modulation are introduced in [12]-[13]. By modulating laser exposure time, each dot size is modified according to the data to be embedded.

In this paper, we develop a printer mechanism-level information embedding and detection scheme for halftone documents. To embed information during the printing process, we use the AM/FM halftoning algorithm with an electrophotographic laser printer that has sub-pixel modulation capability such as pulse width modulation (PWM) [14]. The printed document that contains the information is scanned and then the scanned image is analyzed to decode the embedded information. This paper contains only preliminary results for the proposed embedding scheme. We have developed the basic image analysis pipeline and can identify individual printed dots and measure their centroids. The development of an effective channel coding scheme that can work with this basic modulation strategy remains to be done. In addition, we need to develop a method to perform registration of the individually captured image tiles.

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 allows 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 [14]. 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

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rows. Figure 1(b) illustrates the data embedded output pattern of Fig. 1(a). 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 one pixel to the right or left. In this case, we can consider that the dot pairs whose centroids are not shifted represent information bits of 0 and the dot pairs whose centroids are shifted correspond to information bits of 1.

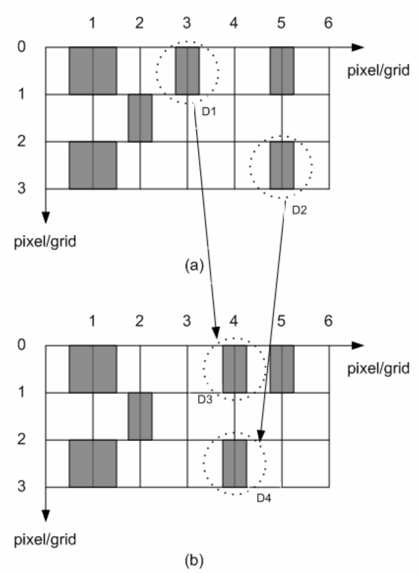


***Figure 1**. Example of (a) halftone pattern and (b) halftone pattern with embedded information.*

Extracting the embedded information

Figure 2 shows the block diagram for extracting the embedded information from a halftone document. The printed document that contains the information is first scanned. The scanned image is preprocessed to remove noise caused during the printing and scanning process. Then the preprocessed image is analyzed and the embedded information is extracted.

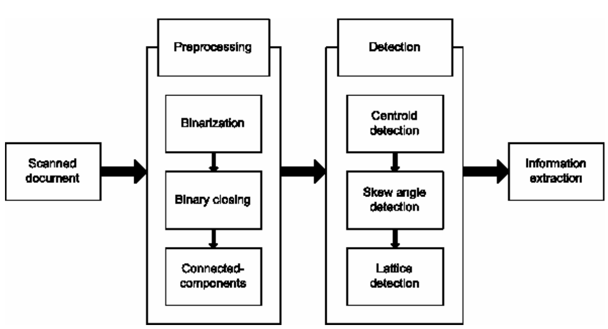


***Figure 2**. Diagram for extracting the embedded information from a scanned document.*

A. Preprocessing

The scanned image is processed to produce a binary mask image that indicates the presence of each dot. Figure 3 illustrates a portion of the resulting images through each preprocessing step. Figure 3(a) shows a portion of a real halftone document printed at 600 dpi with an HP LaserJet 5500[f1] and scanned at 6900 dpi with a QEA IAS-1000 Automated Image Analysis System[f2]. The scanned image is binarized by Otsu's method [15] to distinguish toner particles from background paper as shown in Fig. 3(b). Then a binary closing operation with 3×3 square structuring element is performed to aggregate the scattered particles since the binarized image is very noisy due to scattered toner particles. The image of the dots after binary closing forms clusters of each dot. However, the closed image in Fig. 3(c) still includes scattered toner particles. To remove the scattered toner particles around each cluster of dots, regions that have less than a certain number of connected-components are eliminated as shown in Fig. 3(d).

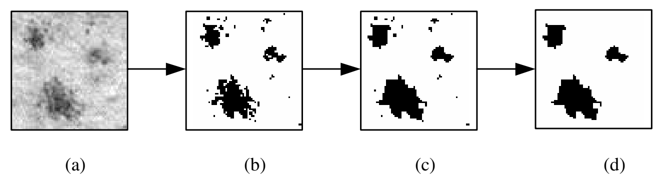


***Figure 3**. Generating the binary mask: portion of halftoned image after (a) scanning, (b) binarization, (c) binary closing, and (d) connected-components.*

B. Dot centroid calculation

With the aid of the preprocessed image shown in Fig. 3(d), dot centroids are computed. The dot centroids are calculated based on the spatial distribution of toner absorptance throughout the dot's corresponding mask image. Let D_i be the region of the i-th segmented dot during preprocessing. Then the horizontal centroid of the i-th segmented dot is given by

$$C_{x,i} = \frac{\sum_{(m,n)\in D_i} mI(m,n)}{\sum_{(m,n)\in D_i} I(m,n)}, \quad (1)$$

where $I(m,n)$ is the absorptance value of the image at the pixel with coordinates (m,n). Similarly, the vertical centroid is obtained from

$$C_{y,i} = \frac{\sum_{(m,n)\in D_i} nI(m,n)}{\sum_{(m,n)\in D_i} I(m,n)}. \quad (2)$$

Figure 4(a) shows the original image in Fig. 3(a) after application of the mask shown in Fig. 3(d). From the masked image in Fig. 4(a), dot centroids are calculated according to Eqs. (1) and (2). Figure 4(b) shows the centroid of each dot indicated as a cross.

[f1] Hewlett-Packard Company, Palo Alto, CA 94304-1185

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

(a) (b)

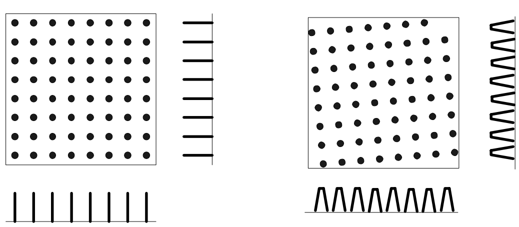
***Figure 4**. (a) binary mask image and (b) dot centroids*

C. Skew angle detection

At the 6900 dpi resolution required to capture the printed halftone dot pattern with adequate detail, our image capture system has only a 0.093×0.070 in^2 field of view. Consequently, we can only image a limited portion of the halftone document at a time. This necessitates a method for skew correction and registration of the individually captured image segments. We discuss below our proposed approach to skew correction. We have not yet addressed the registration issue.

After finding the dot centroids, the vertical and horizontal projections of these centroids are computed. As shown in Fig. 5, the non-skewed centroid image in Fig. 5(a) has a larger number of zero values in the projection than the skewed centroid image in Fig. 5(b). Based on this fact, we compute projections for the centroid image after rotation over a range of angles and choose the angle that has the maximum number of zeros in the sum of both the horizontal and vertical projections to be the skew. Let (X_2, Y_2) be a pixel point rotated from an original point (X_1, Y_1). Then the rotated pixel can be expressed as follows

$$\begin{bmatrix} X_2 \\ Y_2 \end{bmatrix} = \begin{bmatrix} \cos\theta & \sin\theta \\ -\sin\theta & \cos\theta \end{bmatrix} \begin{bmatrix} X_1 \\ Y_1 \end{bmatrix} \tag{3}$$



(a) (b)

***Figure 5**. Projections of dot centroids: (a) without skew (b) with skew*

D. Lattice detection

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

$$\mathrm{R} = \frac{N}{f_{\max}}, \tag{4}$$

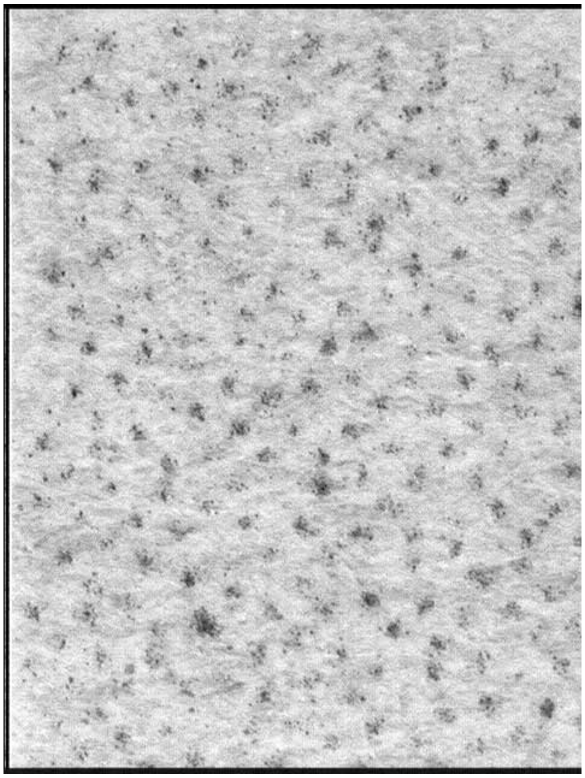
where f_{max} is the frequency component that has the maximum magnitude in the FFT.

Experimental results

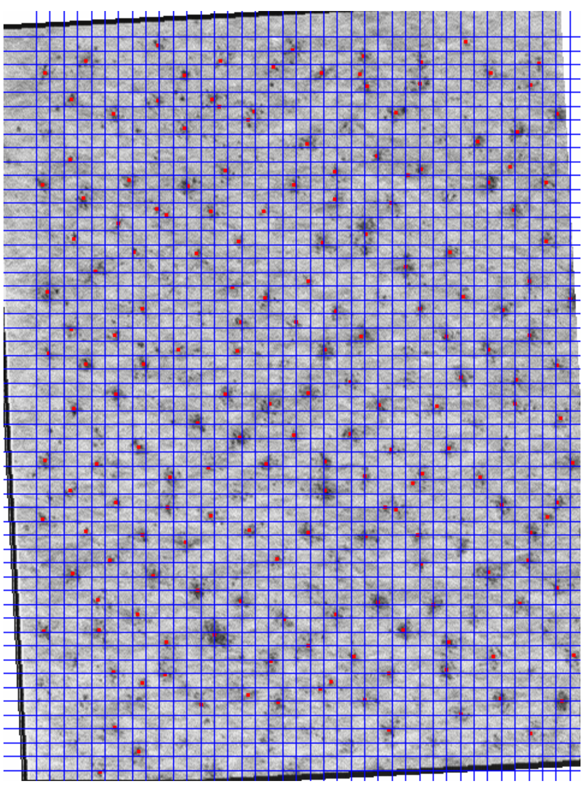
We tested our scheme by printing a test patch with a HP LaserJet 5500 at 600 dpi. Since the objective of the experiment was only to test our ability to determine the underlying lattice and identify the centroids of the printed dots, we did not displace any of the dot pairs for this experiment. The print of a test patch was scanned at 6900 dpi. The portion of the scanned test patch is shown in Fig. 6(a). Figure 6(b) illustrates the resulting image representing dot centroids and lattices. Figure 7(a) and (b) show the projections of dot centroids in vertical and horizontal directions, respectively. Figure 7(c) represents the result of 256-point FFT for vertical projection. Figure 7(d) shows the result of a 512-point FFT for the horizontal projection. Since the maximum frequency component for vertical projection is 22, the unit length of the lattices is 11.64 pixels in the scanned image according to Eq. (4). For the horizontal projection, the unit length of lattices is also 11.64 since the maximum frequency component is 44. For this test image, we correctly found 153 dot centroids out of 236 dot centroids, falsely found 30 dot centroids, and missed 83 dot centroids. Most of the missing dot centroids are due to dots that did not develop during printing.

Conclusion and discussion

Embedding information at the printer mechanism-level is desirable due to its robustness and flexibility. In this paper, we have proposed a scheme for printer mechanism-level data embedding and extraction for documents halftoned using a particular algorithm – AM/FM, which is used in scan-to-print applications. Information is embedded by using PWM and extracted by a sequence of steps that includes scanning, binarizing, binary closing, connected-components, centorid detection, skew correction, lattice detection, and displacement detection. We have demonstrated that it is possible to identify individual printed dots, compute their centroids, and find the underlying lattice. However, much work remains to be done. Our ability to encode information using this scheme is inherently dependent on the image content. We can only encode bits where there are isolated dots corresponding to continuous-tone content with highlight to midtone gray levels. In addition, due to the inherent instability of the EP process, many dots will not develop. Thus these bits of information will be lost. Finally, the content-dependence of the embedding scheme and the limited field of view of our image capture system used to scan the printed document will necessitate that the detected symbol stream be locally synchronized at the decoder. All these factors will require the use of a highly sophisticated channel coding scheme with considerable redundancy. Also, as mentioned previously, we will need a method to register the individually captured image segments.

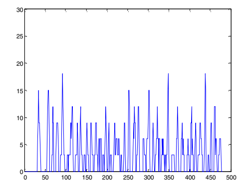


(a)

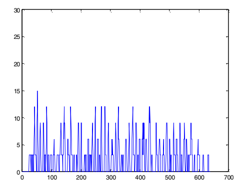


(b)

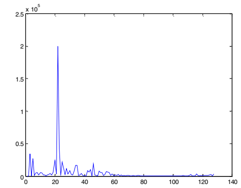
***Figure 6**. Portion of (a) scanned test patch (b) resulting image with dot centorids and lattices*



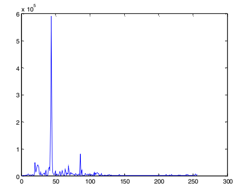
(a)



(b)



(c)



(d)

***Figure 7**. Projections and their FFT: (a) vertical projection (b) horizontal projection (c) 256-point FFT for vertical projection and (d) 512-point FFT for horizontal projection*

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Author biography

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