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Fast communication

Watermark detection from clustered halftone dots via learned dictionary

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ABSTRACT

Modulating the orientation of elliptically clustered dots in each halftone cell enables binary data to be embedded into the clustered halftone dots. In this paper, a new decoding method is proposed for recovering hidden binary data from clustered halftone dots by using learned dictionaries, which are optimized to represent clustered dots with different elliptical shapes. The basic idea is that the reconstruction errors of the clustered dots in a halftone cell are differentiable according to the dictionaries used. The experimental results showed that determining which of the learned dictionaries provides a minimum reconstruction error in a halftone cell can reveal the orientation of the clustered dots and thus indicate the embedded binary data.

1. Introduction

In digital printers, continuous-tone images with 255 discrete levels are converted into halftoned images [1], which are binary images with uniformly distributed black and white dots. The pixel locations of the black and white dots determine whether or not black toner or ink will be printed on a substrate. In other words, binary quantization occurs during printing. Conventional watermarking methods [2,3] try to embed data into the continuous-tone images; however, the embedded data suffers due to the binary quantization during halftoning. To solve this problem, hardcopy watermarking methods [4–6] that directly embed data into the halftoned images have been developed. Since the dot patterns and shapes in the halftoned images can be formed differently depending on which halftoning techniques are used, such as dithering [7], error diffusion [8], or direct binary search [9], the characteristics of these varied techniques have been considered for data hiding [10–12]. In dispersed-dot dithering [10], two types of dither matrices that can produce different halftone patterns are used to embed the binary data into each halftone cell. In direct binary search [11], halftone texture orientations are controlled by changing the shape of the contrast sensitivity function to represent different watermark values. In block-based error diffusion [12], a user-controlled shape and size are provided to embed the information into the hardcopy image. Since these halftoning methods vary the dot density to achieve the tonal rendition, higher spatial resolution can be obtained, but the isolated dot reproduction can be an issue with electrophotographic (laser) printers [13].

Thus, clustered-dot dithering [13] has been mainly used with electrophotographic printers because of its stability and reproducibility. In clustered halftoned images, where tonal rendition is achieved by varying the size of each dot, clustered dots can be generated in various shapes and orientations in order to effectively encode the watermark [14,15]. Recently, Bulan et al. [15] proposed a new data

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hiding scheme that embeds binary data into the clustered halftone dots by generating elliptical clustered dots and modulating their orientation. In each halftone cell, the orientation of the elliptically clustered dots is determined by the binary data, '0' or '1,' to be embedded. For instance, the elliptical clustered dot is oriented vertically for a bit value of 1 and horizontally for a bit value of 0. In other words, given a binary data sequence, it can be encoded as vertically or horizontally clustered dots forming a watermark. However, the moment-based decoding method for inferring the clustered-dot orientation within each halftone cell cannot provide satisfactory decoding accuracy, where accuracy is evaluated based on the bit error rate (BER) [15]. To improve the decoding accuracy, we propose a new decoding method for learning the dictionaries that optimally represent vertically or horizontally clustered dots. The proposed method reconstructs the clustered dots in each halftone cell via the learned dictionaries to infer the clustered-dot orientation that indicates the embedded '0' or '1' data.

2. Limitations of the conventional moment-based decoding method

Various clustered halftone patterns can be generated according to the comparison between the input image's pixel values and the dithering matrix's elements. The conventional method [15] uses moments to estimate the orientation of the clustered halftone dots. However, the moments used can provide an inaccurate estimation. For example, clustered halftone dots, as shown in Fig. 1, are obtained using a dithering mask, providing vertically clustered halftone dots. In this case, the moment value σ_x calculated along the horizontal axis is larger than the moment value σ_y calculated along the vertical axis. Thus, the moment-based decoding method will detect the horizontal orientation from the given clustered halftone dots in Fig. 1. This produces an inaccurate estimation. The primary limitation of the conventional moment-based decoding method is that it cannot decode various types of clustered halftone dots, such as circular, dual, or octa dots [15,16].

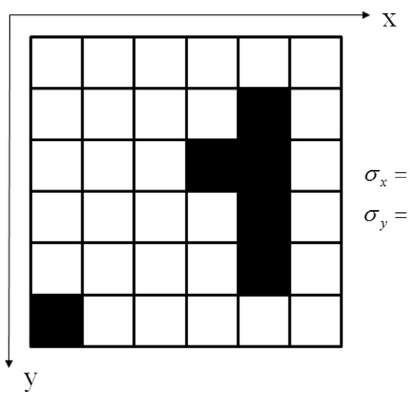

Fig. 1. Drawback of the moment-based decoding method.

3. Proposed decoding method

Dictionaries known as textons or visual codewords are the redundant basis vectors used for sparse linear representation, which has been extensively applied to image denoising, face recognition, texture classification, and inverse halftoning [17–20]. The basis functions of the discrete cosine transform or discrete wavelet transform have been directly used for the dictionaries; however, it has recently been recommended more often that the many natural patches extracted from training image sets be learned for a better dictionary generation [17].

In this paper, dictionaries are used to detect the embedded binary data in clustered halftone dots. The basic idea behind this approach is that the reconstruction errors of the clustered dots in a halftone cell are differentiable according to the dictionaries used. The concept of the proposed method is illustrated in Fig. 2, wherein the learned dictionaries correspond to the basis vectors, which can be linearly combined with the coefficients $\boldsymbol{\alpha}^i$ to represent the input halftone patch. It is assumed based on the statistics of natural images [17] that most coefficients $\boldsymbol{\alpha}^i$ are zero, i.e., ℓ_0-norm $\|\boldsymbol{\alpha}\|_0$ is less than the constant value, *TH*. Given the input halftone patch with vertically clustered dots on the leftmost side, dictionaries with vertically clustered dots can more accurately reconstruct the input halftone patch than can dictionaries with horizontally clustered dots. Therefore, two types of learned dictionaries that optimally represent vertically or horizontally clustered dots will be generated to infer the clustered-dot orientation that indicates the embedded '0' or '1' data.

3.1. Dictionary generation for clustered halftone dots

Assuming that there are two dictionaries, $\{\mathbf{D}^H, \mathbf{D}^V\}$, that optimally represent the horizontally- and vertically-clustered dots, respectively, the shape of the clustered dots in a halftone cell can be more accurately represented by one of the dictionaries. The dictionary that provides better representation can determine the orientation of the clustered dots in a halftone cell, and thus reveal the embedded binary data.

$$\min_{j=\{V,H\}} \|\mathbf{x}^i - \mathbf{D}^j\boldsymbol{\alpha}^i\|_2^2, \quad \|\boldsymbol{\alpha}^i\|_0 \le TH \tag{1}$$

In the preceding equation, the column vector, $\mathbf{x}^i$, contains the values of the *i*th patch that was extracted from an input halftoned image. In this paper, it is assumed that the patch is identical in size to the dithering matrix that was used to generate the clustered halftone dots. $\boldsymbol{\alpha}^i$ is the predicted representation column vector of $\mathbf{x}^i$ resulting from the gradient pursuit algorithm [21], which is the fast

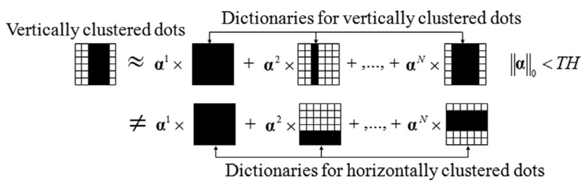

Fig. 2. Concept of the proposed decoding method.