COPYRIGHT LABELING OF PRINTED IMAGES

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ABSTRACT

Digital Watermarking is a labeling technique for digital images which embeds a code into the digital data so the data is marked. Watermarking techniques previously developed deal with on-line digital data and have been developed to withstand digital attacks such as image processing, compression and geometric transformations. In this paper we deal with printed images rather than on-line data. An important issue is to intercept and prevent forgery in printed material such as currency notes and bank checks and to track and validate sensitive and secret printed material. Watermarking in such printed material can also be used for embedding additional informatice information (source, date, type of transaction etc). In this work we propose a method of embedding watermarks in printed images by inherently, exploting the printing process. The method is visually unobtrusive to the printed image, the watermark is easily extracted and is robust under reconstruction errors. The decoding algorithm is automatic given the watermarked image.

1. INTRODUCTION

A method is proposed to embed a watermark in printed images by exploiting the printing process itself. In general, printing of color or gray scale images with a finite number of inks is performed by distributing ink dots in various densities and patterns throughout the print. A correct pattern of ink dots reproduces the original colors of the image. There are many possible ink patterns that produce printed images that appear similar to the human eye. This characteristic is exploited to embed a watermark in printed images. In the proposed method, the embedded code locally varies the pattern of ink dots such that correct distribution is still maintained. The variation in ink pattern is tightly constrained to allow high probability of correct decoding of the watermark, and to reduce visibility of texture artifacts that may arise.

2. WATERMARKS IN DITHERED IMAGES

Very little work has been presented on watermarking of printed images. Concurrent with this work, a similar approach to embedding watermarks in dithered images is described in [1]. In [2, 3] a method is proposed for embedding a watermark in a dithered image which is the typical representation of a printed image. The authors also suggested watermarking techniques for predictive coding and run-length coding which are used to represent fax data. Their methods are based on embedding the watermark by having it resemble quantization noise. In this paper, a novel method is presented that embeds the watermark in the dithering threshold during the halftoning process.

3. ENCODING

Encoding of the watermark in the printed image is based on halftoning the image using the Dithering technique [5, 6]. The watermark is embedded in the print by using a number of different dither cells to create a threshold pattern in the halftoning process. The pattern of the dither cells used for dithering is determined by the watermark code. A schematic diagram of the proposed method is shown in Figure 1. Given a binary sequence as the watermark code, rearrange the code as a binary array. This array is used to select dither cells from a set of predefined dither cells. A single dither cell is selected for each entry in the watermark array. The selected dither cells are tiled in correspondence to the watermark array to form a thresholding pattern. This pattern is repetitively used to threshold the original image pixel; values and obtain the watermarked halftoned image.

An example is shown in Figure 2 where an original 128×128 monochrome image (Figure 2a) is watermarked with a binary sequence of 64 bits. Figure 2b shows the watermark reordered as an 8×8 array (black and white pixels denote '0' and '1' respectively). The

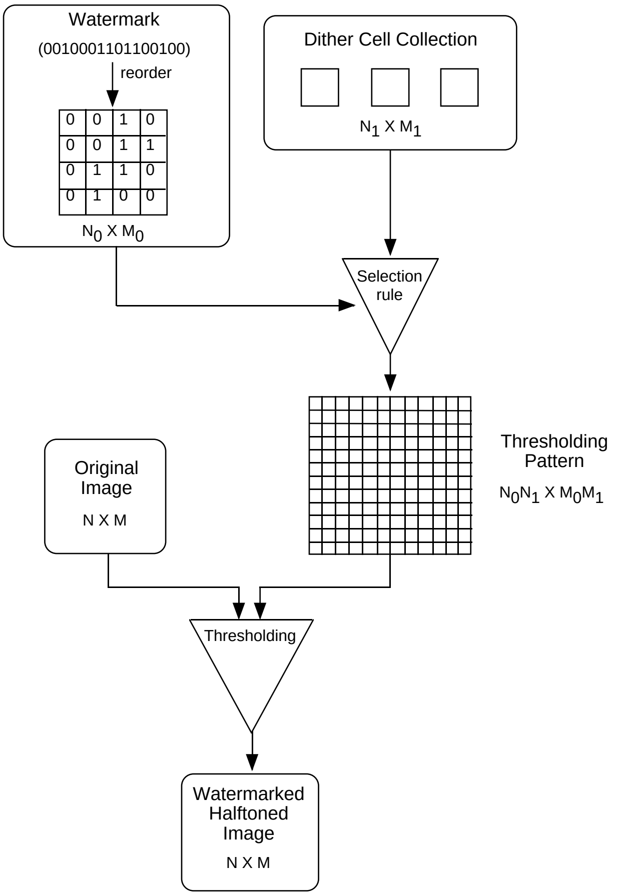

Fig. 1. Schematic diagram of the watermarking technique for printed images.

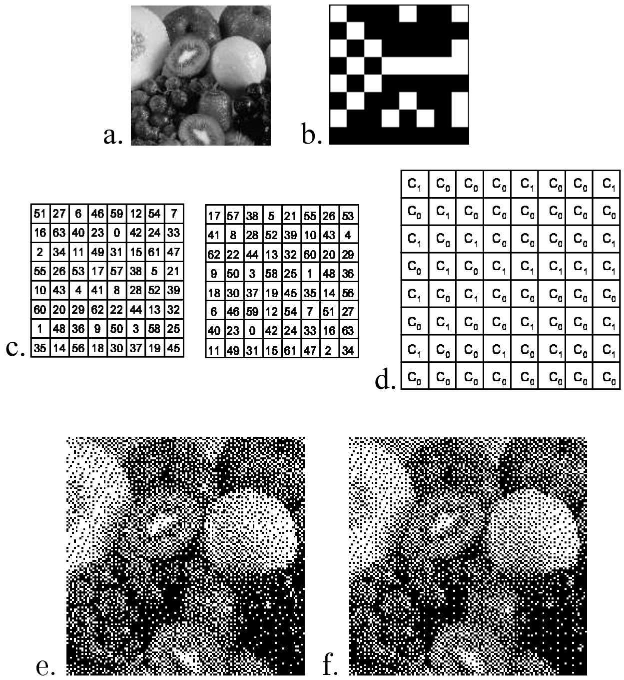

Fig. 2. Watermarking a printed image - Example a) Original 128×128 monochrome image. b) The watermark is a binary sequence of 64 bits which is reordered as an 8×8 array. Black pixels represent '0', white pixels represent '1'. c) The set of available dither cells consisting of two 8×8 arrays. The threshold values have been normalized to the range 0..63. d) The 64×64 threshold pattern produced by the watermarking algorithm. e) The watermarked halftone image. f) The original image halftoned for comparison.

set of available dither cells consists of the two 8×8 arrays shown in Figure 2c and denoted C_0 and C_1 (threshold values have been normalized to the range 0..63 for convenience). A single dither cell is selected for each entry in the watermark. The rule for selection of the dither cell is to select C_0 for bit '0' and C_1 for bit '1'. The selected dither cells are tiled in correspondence to the watermark array to form a thresholding pattern of size 64×64, shown in Figure 2d. This pattern is tiled in the image plane (2×2) to produce the threshold values that are used to halftone the original 128×128 image. The watermarked halftoned image is shown in Figure 2e. For comparison, the original image halftoned using only dither cell C_0 is shown in Figure 2f.

4. DECODING

Decoding of the watermark is performed by scanning the halftoned image and determining the sequence of dither cells used to create the halftone pattern. Assuming the size of the watermark array ($N_0 \times M_0$) and the size of each dither cell ($N_1 \times M_1$) are known, the decoding reduces to the following problem: Given an appropriate $N_1 \times M_1$ region of the halftoned image, decide which of the dither cells in the available set was used. In the above example, given an 8×8 region, decide whether C_0 or C_1 was used. This decision is non-trivial since, the underlying grayscale image, used to create the halftone pattern is unknown. To make this decision, the halftoning process is again exploited. The halftoning process is based on the HVS characteristic of limited spatial resolution [7]. Reproduction of a color using halftoning is obtained by producing a pattern of available printer inks such that the local average of the pattern is of similar color. Decoding of the watermark is performed based on this rule. Given a region of the halftoned image, decode by calculating the region's average color and simulating the halftoning of a constant colored region having this average

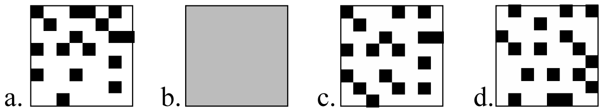

Fig. 3. Decoding a bit of the watermark - Example
a) An 8×8 region of the watermarked halftoned image. The average gray level is 0.734 (in the range $0 \ldots 1$). b) A constant 8×8 patch of gray value 0.734. c) The halftone pattern obtained by thresholding constant patch b) with dither cell C_0. d) The halftone pattern obtained by thresholding constant patch b) with dither cell C_1.
It can be seen that the original halftone is more similar to that produced by dither cell C_0. Thus the watermark bit is deduced to be '0'.

color. Each of the available dither cells is used in turn in this Halftoning process, resulting in a set of halftoning results. The dither cell creating the pattern most similar to the original halftone region, is selected as the decoding dither cell (and the decoded watermark bit).

For example consider the 8×8 region of the halftoned image of Figure 2e shown in Figure 3a. The average gray level of the region is 0.734 (in the range $0 \ldots 1$). An 8×8 image of constant gray level 0.734 (Figure 2b) is halftoned using dither cells C_0 and C_1 producing the halftoned images in Figure 3c and 3d respectively. A Hebb-metric is used to decide that C_0 produces a more similar result to the original halftoned region, than C_1 (34 pixels are inconsistent with C_1 while only 4 are inconsistent with C_0). Thus the appropriate bit of the watermark binary sequence is deduced to be '0'.

The decoding algorithm applied to the example of Figure 2 is shown in Figure 4. The watermark was decoded with no errors (compare Figure 4b and Figure 2b).

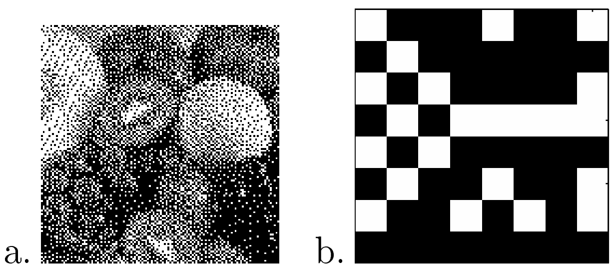

Fig. 4. Decoding a watermark
a) The watermarked halftoned image. b) The watermark is decoded with no errors (compare with Figure 2b).

5. ISSUES TO CONSIDER

On implementing, the watermarking technique for printed images suggested above, one must decide on the set of available dither cells to be used in the encoding and on the selection rule which chooses cells from this set according to the value of the watermark bit. When choosing the set of dither cells, the following issues and criteria must be considered (see [8] for details):

- The dither cells should produce different halftone patterns for all colors or gray levels.
- The dither cells should be visually continuous, i.e. false contours and edges should not appear due to tiling of different dither cells. For example artifacts are visible when a single C_0 dither cell is used in an array of C_1 cells to halftone a constant colored region (Figure 5).
- The dither cells should have corresponding threshold values. Threshold values in the set of dither cells should be similar, i.e. the position of a given threshold value in one dither cell should not be distant from its position in other dithercells.

For the example case given above, C_0 and C_1 were chosen to fulfill these constraints to the extent possible, as follows: To satisfy the first constraint, C_0 and C_1 were chosen from a class of dither cells known as Stochastic dither cells [6]. To satisfy the third constraint we chose to select C_0 and C_1 from among a set of cyclically rotated versions of a single Stochastic dither cell. The stochastic pattern of threshold values and the cyclic rotatiion produce correlated cells as required by the third constraint. To satisfy the second constraint, we tested pairs from the set of cyclically rotated dither cells, by halftoning a constant valued image with a threshold pattern produced from a mixture of the dither cell pair. We chose as C_0 and C_1, the pair of cells which produced a halftone with minimal distortion (distortion was evaluated visually).

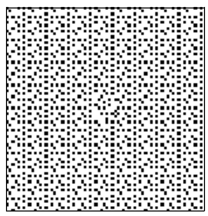

Fig. 5. Artifacts are visible when a constant colored image is halftoned using a threshold pattern obtained using a single C_0 dither cell in an array of C_1 cells.

In addition to the example shown in Figure 2, the printed watermarking technique was applied to over 2000 images of size 128×128. The embeded watermark was of size 8×8 thus 4 multiple embeddings were performed in each image. The watermark was perfectly decoded in over 99% of the trials.

6. CONCLUSION

A watermarking technique was presented which embeds a binary code in a printed image. The method produces a watermark which is inherently part of the printed image and is thus visually unobtrusive. The decoding algorithm is automatic following scanning of the image and was developed to be robust to errors. It is still left to verify that the method is not susceptible to forgery and that decoding is not possible without apriori knowledge which includes, the set of possible dither cells. Variants of the method can be developed to increase security of the watermark: the bits of the watermark should be ordered with a random number generator and the selected dither cell should be used in randomly selected positions of the image. The seed for the generator must then be provided as a key for decoding the watermark.

7. REFERENCES

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