WATERMARKING IN HALFTONE IMAGES WITH PARITY-MATCHED ERROR DIFFUSION

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Abstract

A halftone watermarking technique of high capacity, robustness, and capacity flexibility is presented in this paper. This Parity-Matched Error Diffusion (PMEDF) method is capable of achieving an embedded capacity as high as 6.25% to 25% with good image quality and without the original image as the reference to decode the watermark. As the experimental results demonstrated, this technique is able to guard against degradation due to cropping, tampering, and printed-and-scanned process in error-diffused halftone images.

Key Words
halftone, ordered dithering, error diffusion, least-squares

1. Introduction

Digital halftoning [2] produces two-tone texture pattern that, through the human low-passed visual system, approximate the original multi-tone images, preserving a significant level of the original information content. The technique is widely used in computer printer-outs, printed books, newspapers, and magazines, because these printing processes are limited to the black-and-white format. There are many halftone methods, and the most popular ones are the ordered dithering [2], error diffusion [3], and least-squares [4]. Among these, error diffusion produces good visual quality and reasonable computational complexity.

Watermarking and data hiding have many usages, including: protecting ownership rights of an image, protecting against the use of an image without permission, and authenticating an image to prove that it has not been altered. Generally speaking, watermarking should take the robustness issue into consideration. Currently, numerous methods using halftones to embed watermarks have been studied. These techniques can be used for printing security documents such as ID card, currency as well as confidential documents, and prevent from illegal duplication and forgery by further scanning these documents to digital forms. In general, these methods can be divided into two categories.

Techniques of the first category embed invisible digital data into halftone images, which can be retrieved by applying some extraction algorithms on the scanned images. These methods are in general based on the concept of vector quantization (VQ) to embed watermarks into the most or least significant bit (MSB/LSB) of error diffusion images [5], or modified data hiding error diffusion (MDHED) to embed data into error diffusion images [6]

Methods in the second category embed hidden visual patterns into two or more halftone images. The hidden visual patterns can be perceived directly when the halftone images are overlaid each other. These techniques include using stochastic screen patterns [7], hybrid pixel-based data hiding and block-based watermarking [1]. In [1], a noise-balanced error diffusion (NBEDF) is proposed for data hiding, and a robust watermarking decoder is also proposed with 2-D FFT and Lookup Table (LUT). However, the 2-D FFT is time-consuming and LUT involves more memory requirement. In addition, the watermarking and data hiding in [1] are two distinct and unrelated techniques. This often results in an increase in hardware complexity. In this paper, we present a low complexity Parity-Matched Error Diffusion (PMEDF) watermarking method. With the objective quality evaluation, the performance of this technique is superior to [1]. In addition, it is capable of achieving the capacity as high as 6.25% to 25%, and robust to cropping, tampering, and printed-and-scanned degradation processes.

2. Quality evaluation

For an image with size $P \times Q$, the quality evaluation of halftone images is defined as,

$$PSNR = \frac{P \times Q \times 255^2}{\sum_{i=1}^{P}\sum_{j=1}^{Q}[x_{i,j} - \sum_{m,n\in R}\sum w_{m,n} b_{i+m,j+n}]^2} \tag{1}$$

where $w_{m,n}$ is the human visual system coefficient at position (m,n), and R is the support region of the human visual system coefficients. In this paper we fixed R at size 15×15. The human visual system w can be obtained by psychophysical experiments [8]. The other way to derive w can use a training set of both pairs of gray level images and good halftone results of them, such as using error diffusion or ordered dithering to produce the set. Here we use Least-Mean-Square (LMS) to derive w as described as follows.

$$e_{i,j}^2 = (x_{i,j} - \sum_{m,n\in R}\sum w_{m,n} b_{i+m,j+n})^2 \,, \tag{2}$$

$$w_{m,n}^{(k+1)} = w_{m,n}^k + \mu e_{i,j} b_{i+m,j+n} \,, \tag{3}$$

where $w_{i,j,opt}$ is the optimum LMS coefficient; $e_{i,j}^2$ is the MSE between $x_{i,j}$ and $\hat{x}_{i,j}$; μ is the adjusting parameter used to control the convergent speed of the LMS optimum procedure, which is set to be 10^{-5} in our experiments.

There are 8 images used in our training process: Lena, Mandrill, Yosemite, Paris, Airplane, Peppers, Milk, and Lake images The Floyd error diffusion [3] and Bayer-5 dispersed-dot halftone screen [2] are used to produce the corresponding halftone training results. The trained human visual filter is shown in Fig. 1. Notice that this filter has the basic human visual system characteristics, which includes (1) the diagonal has less sensitivity than the vertical and horizontal directions and (2) the center portion has the highest sensitivity and it decreases while moving away from the center.

3. Error diffusion

Error diffusion is a major key step in watermarking. In this section, we provide a brief overview of error diffusion. The standard EDF can be described as Eqs. (4) and (5).

$$v_{i,j} = x_{i,j} + x'_{i,j}\text{, where } x'_{i,j} = \sum_{m=0}^{2}\sum_{n=-2}^{2} e_{i+m,j+n} \times h_{m,n} \quad (4)$$

$$e_{i,j} = v_{i,j} - b_{i,j}\text{, where } b_{i,j} = \begin{cases} 0 & if \quad v_{i,j} < 128 \\ 255 & if \quad v_{i,j} \geq 128 \end{cases} \quad (5)$$

where the variable $b_{i,j}$ means binary output in position (i, j), and the Floyd error diffusion kernel $h_{m,n}$ [3] is used here. The variable $v_{i,j}$ is the modified gray output and $e_{i,j}$ is the difference between the modified gray output $v_{i,j}$ and binary output $b_{i,j}$.

We numerically define 0 as a black pixel and 255 as a white pixel. Figure 2(a) is the original gray level image, and Figure 2(b) is its corresponding Floyd error-diffused halftone image with PSNR of 35.29dB.

4. Watermarking with parity-matched noise-balanced error diffusion

Suppose the size of the original gray level image $x_{i,j}$ is $P \times Q$, and divides into several cells of each with size $M \times N$. The size of watermark $w_{i,j}$ is supposed to be $\frac{P}{M} \times \frac{Q}{N}$. We set the initial binary output $b_{i,j}$ and its surrounding pixels to be black. Since the error diffusion is a causal processing, we can pre-define a region in $b_{i,j}$ includes the preprocessed points $(i - x, j - y)$. For the examples in this paper, the intervals of *x* and *y* are $0 \leq x < 11$ and $0 \leq y < 11$, respectively. Then the parity sum is evaluated over this region. The parity sum is defined as:

$$P_{i,j} = [(\sum_{x,y \in PDR} b_{i-x,j-y}) / 255 \ ] \bmod 2$$

where PDR stands for the pre-defined region. Note that, before the process reaches to the binary output at the location (i, j), $b_{i,j}$ remains a black pixel. Here, let's define w_W as the set of locations corresponding to all the white pixels in the watermark and w_B for the black pixels. When the following two conditions satisfy simultaneously, we can switch from Eqs. (4) and (5) to Eqs. (6) and (7).

1. $x_{i,j} + x'_{i,j} \geq 128$.
2. $\{[(\left\lfloor \frac{i}{M} \right\rfloor, \left\lfloor \frac{j}{N} \right\rfloor) \in w_B]\ AND\ (P_{i,j} = 0)\} OR \{[(\left\lfloor \frac{i}{M} \right\rfloor, \left\lfloor \frac{j}{N} \right\rfloor) \in w_W]\ AND\ (P_{i,j} = 1)\}$.

$$v_{i,j} = x_{i,j} + x'_{i,j} - N_A, \quad (6)$$

$$e_{i,j} = v_{i,j} - b_{i,j} + N_A, \quad (7)$$

where the notations AND and OR stand for the logic operations, and the variable N_A is the additive error term that we use to force the current binary output to the parity sum desired. The objective is that we hope to match the parity sum to the corresponding watermark value. The value of the additive noise N_A determines the quality of the embedded halftone image, robustness, as well as correct-decoding rate in the decoder. However, the quality of the embedded halftone image will be degraded. The following section, objective criterions will be used to determine the trade-off value of additive noise N_A. With the noise-balanced strategy, even for high N_A values, it is still feasible of producing good embedded halftone images. To illustrate the process, the flow chart of the Parity-Matched Error Diffusion (PMEDF) method is shown as Fig. 3.

In the same manner, when the following two conditions satisfy simultaneously, we switch from Eqs. (4) and (5) to Eqs. (8) and (9).

1. $x_{i,j} + x'_{i,j} < 128$.
2. $\{[(\left\lfloor \frac{i}{M} \right\rfloor, \left\lfloor \frac{j}{N} \right\rfloor) \in w_B]\ AND\ (P_{i,j} = 1)\} OR \{[(\left\lfloor \frac{i}{M} \right\rfloor, \left\lfloor \frac{j}{N} \right\rfloor) \in w_W]\ AND\ (P_{i,j} = 0)\}$.

$$v_{i,j} = x_{i,j} + x'_{i,j} + N_A \quad (8)$$

$$e_{i,j} = v_{i,j} - b_{i,j} - N_A \quad (9)$$

The original watermark or the halftone image is not needed during decoding. The watermark can be decoded directly by the following criterion.

$$w'_{m,n} = \begin{cases} 255, & if \displaystyle\sum_{\left\lfloor \frac{i}{M} \right\rfloor = m, \left\lfloor \frac{j}{N} \right\rfloor = n} [(\sum_{x,y \in PDR} b_{i-x,j-y} / 255) \bmod 2] / (M \times N) \geq 0.5 \\ 0, & otherwise \end{cases}$$

In simple terms, this can be described as the majority voting. In other words, when most of the parity-sum values are 1, it suggests that the white pixel in the watermark was embedded into its corresponding cell of the halftone image, and vice versa. Two criterions are used for judging if there is a watermark embedded in the halftone image. The first is the correct decoding rate (DR), which is given as,

$$DR = \frac{\sum_{\substack{0 \leq i \leq M-1 \\ 0 \leq j \leq N-1}} w_{i,j} \ \Theta \ w'_{i,j}}{M \times N} \times 100 \ \%, \quad (10)$$

where $w_{i,j}$ and $w'_{i,j}$ stand for the original watermark and the decoded watermark, and the notation Θ stands for the NXOR (Not exclusive OR) operation. The higher the DR is, the more certainty we can claim the decoded watermark is what we want.

The second one is measured with a correlation detector given as

$$\gamma(w') = \frac{< w, w' >}{\sqrt{< w', w' >}}, \quad (11)$$

where $< \bullet >$ means inner product. Generally speaking, the value of γ greater than 6 is taken as a positive detection.

5. Experimental results

In this section we apply the watermarking technique for quantitative performance evaluation. Fig. 4 shows the decoded watermark correlation, embedded halftone image qualities, and correct-decoding rates under nine different levels of additive noise. These data are the average values of the eight tested images as described in Section 2. The capacity of this experiment is at 1.5% corresponding to a watermark of size 64×64 embedded into a 512×512 halftone image. We should point out that the additive-noise level of 25 is a good experimental value. For that, we can simultaneously achieve good quality embedded halftone images at PSNR=32.5dB and high correct decoding rate of 99.43%.

Fig. 5 shows the correct decoding rates under four different capacity levels. Four levels of additive noise, 10, 20, 30, and 40, are applied to the tests. For the most critical situation of N_A=10 and 25% capacity, the algorithm produces correct-decoding rate of 66.16%, where the correction detector is 85.19.

Figure 6 shows the qualities of embedded halftone images under 4 different capacities. Four different additive noises are also used for testing. Usually watermarking technique with high capacity will have serious quality degradation. However, with the proposed technique, it is clear that with the same additive noise, even the capacity is increased, the quality will not degrade a lot. Here we reach a conclusion that with the proposed watermarking, the quality of the embedded image is mainly dominated by the additive noise.

The quality (PSNR) value of the watermarking result with the kernels-alternated error diffusion method [1] is 31.26dB and the capacity is 0.39%, with watermark of the size 32×32 embedded into a 512×512 halftone image. At the same capacity level, the PMEDF method can achieve better quality of 33.69 PSNR with the Lena image. The computational complexity is also significantly lower than the conventional approaches [1], where 2-D FFT or LUT are involved, and the correct decoding rate of PMEDF is as high as 100% at the same capacity level.

Figs. 7(a) and 7(b) show the original watermark of the size 64×64 and 256×256, printed at 150 and 300 dpi, respectively. Figs. 7(e) and 7(f) are the embedded halftone images of PSNR=32.6 and 32.08 dB, with the watermarks shown as 7(a) and 7(b), and printed at 300 dpi. Figs. 7(c) and 7(d) are the decoded watermarks from Figs. 7(e) and 7(f) with correct-decoding rate of 99.29% and 80.03%, respectively. The additive noise level N_A used here is 25.

Next, we perform experiments to demonstrate the robustness of this proposed technique. Fig. 8(a) shows one quarter cropping with Fig. 7(f), and the decoded watermark is shown in Fig. 8(c). The correct decoding rate is 74.71%, and the correlation detector is 126.49. Fig. 8(b) shows the tampering attack with Fig. 7(f), and the decoded watermark is shown in Fig. 8(d). The correct decoding rate is 64.64%, and the correlation detector is 74.98. The experiments indicate that this new watermarking technique can perform well under the cropping and tampering attack, when the capacity is as high as 25%.

In the most common applications of halftoning in printed books, newspapers, and magazines, the original embedded watermarked image is often damaged by the printed-and-scanned process, e.g., zooming, rotation, and dot gain. Extracting the original watermarks perfectly is very challenging. So during the extraction process, we put auxiliary synchronized black pixels in four corners of the embedded halftone image. The printed-and-scanned embedded image is first re-rotated by Adobe Photoshop7.0. Because the size of printed-and-scanned image is usually larger than the expected (when the same DPI of printing and scanning are applied), the printed-and-scanned embedded image should be geometrically transformed into size of 512×512 before the decoding process. To overcome the problem, the printed-and-scanned image is divided into 262144 square blocks, under the assumption that the original image is 512×512, and the average of the pixels within a block is thresholded to recover the original halftone image pixel. Since the laser printer often introduces dot gain, the threshold was lowered from 128 to 100 to overcome the dot gain effect. For the experiments, the HP LaserJet 4050 printer and HP OfficeJet 7100 scanner were utilized. Before the embedded halftone image is printed, the format is saved in bitmap and sent directly to the printer. For that, the printer driver does not involve any further halftone process with the image.

Table 1 shows the printed-and-scanned average correlation of eight embedded tested halftone images as described above. The capacities are at the same level of 6.25%, with watermark of the size 128×128 embedded into 512×512 halftone image. Note that, in this experiment, the capacity level of 25% makes it extremely vulnerable to the printed-and-scanned distortion.The embedded images are printed at 150 dpi and scanned at 150, 300, and 600 dpi for variation in resolution. The corresponding average correct decoding rates are 63.18%, 72.58%, and 76.66%, respectively. In summary, the experiments well demonstrated the PMEDF technique's tolerance for printed-and-scanned distortion.

6. Conclusion

In this paper we propose a parity-matched error diffusion (PMEDF) watermarking method, which offers good embedded error-diffused halftone image by noise-balanced strategy, achieve the capacity as high as 6.25% to 25%, and are robust to cropping, tampering, and printed-and-scanned distortions.

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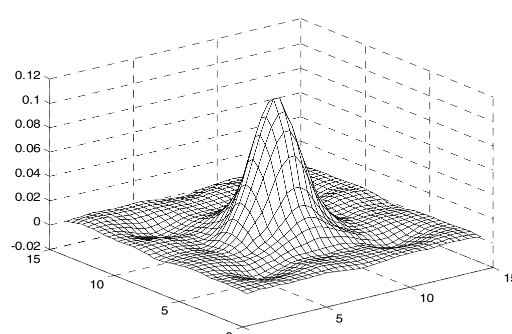

Fig. 1. LMS-trained human visual filter (15×15)

(a) (b)

Fig. 2. (a) Original 512×512 gray level Lena image. (b) Floyd error-diffused Lena image (PSNR=35.29dB).

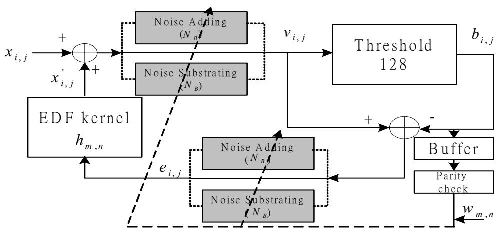

Fig. 3. Flow chart of parity-matched error diffusion.

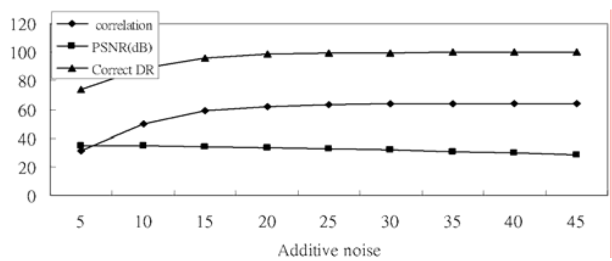

Fig. 4. Decoded watermark correlations, PSNR of embedded halftone image, and correct-decoding rates under different additive noises.

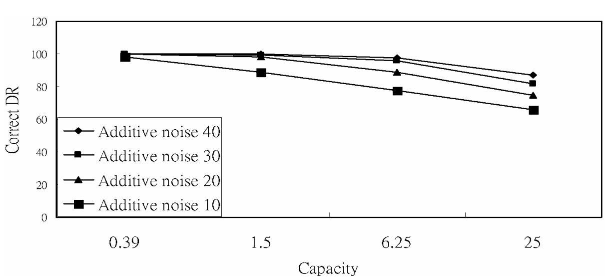

Fig. 5. Correct decoding rates under different capacities and additive noises.

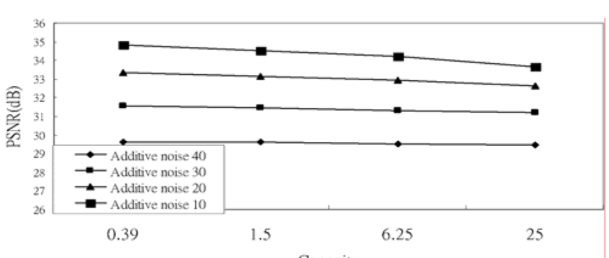

Fig. 6. PSNR of embedded halftone images under different capacities and additive noise.

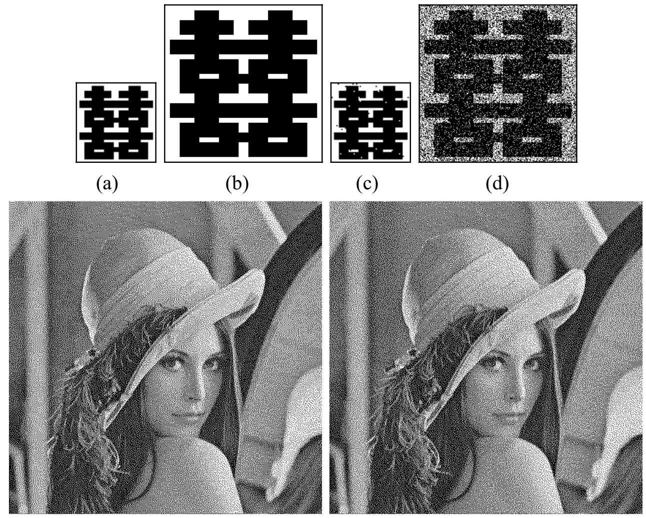

Fig. 7. (a)-(b) Original watermarks with 64 × 64 and 256 × 256, respectively. (Printed at 150 and 300 dpi, respectively) (c)-(d) Decoded watermarks from Fig. 7(c) and 7(d) with decoded rate of 99.29 and 80.03, respectively. (e)-(f) Embedded halftone images with PSNR=32.6 and 32.08 dB, respectively. (Printed at 300 dpi) Fig. 7(c) embedded with 7(a), and 7(d) embedded with 7(b).

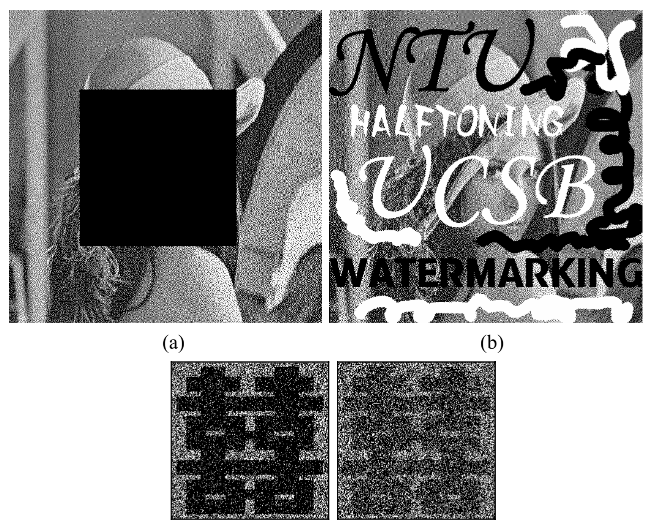

Fig. 8. Robustness testing under cropping and tampering attacks. (a) One quarter cropping with Fig. 7(f). (b) Tampering with Fig. 7(f). (c) The decoded watermark of Fig. 8(a). The correct-decoding rate is 74.71. (d) The decoded watermark of Fig. 8(b). The correct-decoding rate is 64.64.

TABLE. I. AVERAGE CORRECT DECODING RATES OF 8 TESTED EMBEDDED HALFTONE IMAGES AFTER PRINTED-AND-SCANNED WITH PMEDF (N_B =35).

Scanned density	Average correct-decoding rate
600 dpi	81.66%
300 dpi	77.58%
150 dpi	68.18%