A Robust Public Watermark for Halftone Images

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ABSTRACT

In many printer and publishing applications, it is desirable to embed data in halftone images for copyright control and authentication purposes. While intentional attacks on printed matters may not be likely, unintentional attacks such as cropping and distortion due to dirt or human writing/marking are likely. In this paper, we proposed a novel halftone image watermarking method called Watermarking Error Diffusion (WED) to embed a robust, invisible, public watermark in the parity domain of halftone images during halftoning while introducing minimal distortion. Since WED uses the local stochastic properties of the halftone image to embed the watermark throughout the whole image, WED is robust to cropping and distortion due to dirt or human writing/marking. Experimental results suggest that WED can give halftone images with good visual quality and the watermark is robust to crop and human marking.

1. INTRODUCTION

Nowadays, digital images are extremely common. It is often desirable to embed data into the images as value-added content, or for copyright control and authentication purposes. Such embedded data are commonly called watermarks and the method of watermark embedding is called watermarking [1]. Most watermarks of interest are invisible. Some watermarks are fragile and some are robust. Fragile watermarks are designed to be broken easily by common image processing operations and are good for tampering detection and authentication. Robust watermarks are designed to survive hostile and/or un-intentional attack and are good for copyright control. Watermarks can also be classified as private and public watermarks. A private watermark uses the original image in the watermark decoding while a public one does not.

In this paper, we are concerned about watermarking for halftone images [2]. Halftone images are binary images appearing routinely in massively distributed printed matters such as books, magazines, newspapers, as well as printouts and fax documents. It is often desirable to hide invisible watermark within the halftone images for copyright protection.

There are some existing techniques for watermarking in halftone images. Some use two different dithering matrices for the halftone generation [3] such that the different statistical properties due to the two dithering matrices can be detected. Some use stochastic screen patterns [4] and conjugate halftone screens [5]. In these methods, the embedded pattern cannot be

recovered with only one halftone image. It can be viewed only when two halftone images are overlaid. Some hide invisible data in halftone images by forcing pixels at pseudo-random locations to toggle and use various methods to minimize the visual degradation [6].

All these methods have their own limitations. While intentional attacks on halftone images on printed matters may not be likely due to their relatively low commercial values and less convenient distribution channels, unintentional attacks such as cropping and distortion due to dirt or human writing/marking are likely. Most, if not all, of the existing watermarking methods are less than robust to cropping.

In this paper, we propose a novel public watermarking method called watermarking error diffusion for halftone image that is robust to cropping, and human markings.

2. ERROR DIFFUSION

Error Diffusion is a halftoning technique, which can generate high quality halftone image. Error Diffusion is a causal single-pass sequential algorithm. The 2-D multi tone image is halftoned line-by-line sequentially. In this algorithm, the past error is diffused back to the current pixel. Figure 7 is the block diagram of error diffusion. The relationship between input and output of error diffusion can be described by the following equations (1) – (3):

$$u_{m,n} = x_{m,n} - \sum h_{k,l} e_{m-k,n-l} \quad (1)$$

$$b_{m,n} = Q(u_{m,n}) \quad (2)$$

$$e_{m,n} = \beta b_{m,n} - u_{m,n} \quad (3)$$

$$Q(u_{m,n}) = \begin{cases} 1, & u_{m,n} \geq T_0 \\ 0, & u_{m,n} < T_0 \end{cases}$$

$x_{m,n}$ = original gray-scale image

$b_{m,n}$ = binary halftone image

$e_{m,n}$ = quantization error

$u_{m,n}$ = state variable

β = dynamic range of the image, usually 255

$h_{k,l}$ = error diffusion kernel

$Q(.)$ 1-bit quantization, $T_0 = 128$ used

The error diffusion kernel controls the feedback weighting of past errors. In this paper, a typical kernel, the Jarvis[2] kernel, is used.

3. WATERMARKING ERROR DIFFUSION

The proposed Watermarking error diffusion (WED) embeds watermark in the local and global parity domain

of the halftone image.

Consider an arbitrary 2-dimensional shape S with a corresponding “origin”. When origin of the shape is placed at location (i, j) of the halftone image, it defines a neighborhood $S(i, j)$. The local parity $P_{i,j}^S$ at location (i, j)

$$P_{i,j}^S = \left[\sum_{(k,l) \in S(i,j)} b_{k,l} \right] \bmod 2$$

is the parity of the sum of all the halftone pixels within the neighborhood $S(i, j)$. The global parity

$$P^S = \text{average}\{P_{i,j}^S, \forall i, j\}$$

is the average of all the local parity with respect to the shape S . The watermark will be embedded in the global parity.

In this paper, for the sake of simplicity, the shape S is chosen to be an $N \times N$ block of pixels with its origin at the lower right corner pixel. Thus, the local parity is

$$P_{i,j}^N = \left(\sum_{(0 \leq k, l \leq N-1)} b_{i-k, j-l} \right) \bmod 2 \quad (4)$$

for an $N \times N$ block of pixels at location (i, j) and is defined for any $i \geq N$ and $j \geq N$. It is a causal function. The global parity is

$$P^N = \text{Average}\{P_{i,j}^N : i \geq N, j \geq N\} \quad (5)$$

with respect to the shape of an $N \times N$ block.

In normal error diffusion an image, the local parity tends to be quite random, equally likely to be 0 or 1. The local parity behaves like a binary random variable, with a mean of 0.5 and variance of 0.25, which will be verified later. The global parity, or the sample mean, tends to have a binomial distribution. According to the Central Limit Theorem, the global parity tends to have a Gaussian distribution with a mean of 0.5 and a variance of $0.25/M$, where M is the total number of shapes (possibly overlapping) that can fit into the image and is usually a very large number. For a 256×256 image with $N=4$, M is equal to $253 \times 253 = 64009$. Thus, the global parity tends to be very close to 0.5 for most images.

Our method, WED, works by altering the global parity to be significantly different from 0.5 to indicate the presence of a watermark. When the global parity is significantly larger or smaller than 0.5, it can represent the presence of a “1” or “0” respectively, or vice versa.

For example, we can define the relationship between the global parity and watermark W as

If $P^N \leq T_1$, then $W = 0$.

If $T_1 < P^N < T_2$, watermark undefined. (6)

If $T_2 \leq P^N$, then $W = 1$.

An example is $T_1 = 0.4$ and $T_2 = 0.6$. One strong attribute of WED is that when an image without watermark is subject to watermark detection, it would

declare the watermark as undefined.

Figure 8 is the block diagram of watermarking error diffusion. The structure of WED is similar to the normal error diffusion. The major difference is the Noisy Function block $N(\cdot)$ in which the binary output is adaptively toggled.

In Figure 8, $b_{m,n}$ is the “normal” output without WED according to error diffusion. With $b_{m,n}$, the local parity $P_{m,n}^N$ is computed using Eqn. (4). If the local parity indicates the correct watermark according to (6), no change is applied. And if it gives the wrong watermark, $b_{m,n}$ should be toggled to give the correct watermark. However, this can introduce a huge distortion causing undesirable visual artifacts. As a result, the change would be performed only if the change is acceptable.

The change can be controlled by realizing that forced toggling of $b_{m,n}$ is equivalent to adding a distortion to the original image pixel $x_{m,n}$ in Eqn. (2) to distort $u_{m,n}$ such that the quantized output in Eqn. (3) is reverted.

$$\begin{aligned} x'_{m,n} &= x_{m,n} + \Delta x_{m,n} \\ u'_{m,n} &= x'_{m,n} + \sum h_{k,l} e_{m-k, n-l} = u_{m,n} + \Delta x_{m,n} \\ b'_{m,n} &= Q(u'_{m,n}) = Q(u_{m,n} + \Delta x_{m,n}) \end{aligned}$$

If $u_{m,n} \geq 128$, the minimal distortion $\Delta x_{m,n}$ required is $128 - u_{m,n} - 1 < 0$. Otherwise, the minimal $\Delta x_{m,n}$ required is $128 - u_{m,n} > 0$.

In WED, if $|\Delta x_{m,n}| < T_3$ for some appropriate threshold T_3 , the pixel-wise distortion associated with the forced toggling is considered to be acceptable and thus the toggling would be performed. Otherwise, it would not be performed. Apart from the $N(\cdot)$ block, WED is the same as regular error diffusion.

The Noisy Function is equivalent to adding noise of bounded magnitude to the input image to alter the local parity. The parameter T_3 provides the trade-off between visual quality and the deviation amount of the global parity. A large T_3 allows more local parity to be the correct watermark bit and thus the global parity, being the sample average, would deviate more from the normal value of 0.5 towards the correct watermark bit. But a large T_3 means that the magnitude of the additive noise is large which would translate to large image degradation or lower visual quality.

The noisy multi-tone image x' is a good estimator to quantify the quality of halftone image by PSNR.

4. SIMULATION RESULTS

The proposed WED is simulated on the 512×512

8-bit test image 'Lena', shown in Figure 1. The halftoned Lena using regular error diffusion with Jarvis kernel (without WED) is shown in Figure 2. The WED-watermarked halftoned Lena is shown in Figure 3. The embedded watermark bit is 1. The equivalent noise-added gray-scale image is shown in Figure 4, with a PSNR of 32.4dB. Its subjective visual quality is quite good. One type of unintentional attack, human marking, is simulated in Figure 5. The human marking covers a significant area of the image. Another type, cropping, is shown in Figure 6. The cropping is done on all four sides of the image. The global parity for different block size N and different situations are shown in Table 1.

In row (a) of Table 1, the simulation results verify that the normal global parity without WED is very close to 0.5 regardless of the block size N, as expected. In row (b), after WED is applied with N=4, the global parity at N=4 becomes 0.78, significantly larger than 0.5 indicating effectively the presence of the watermark bit of 1. The global parities of other N's are basically unaffected, except for N=8. A 8x8 block contains four 4x4 blocks and would have an expected global parity of $4(0.78)(0.22)^3 + 4(0.78)^3(0.22) = 0.45$ as verified in Table 1. In row (c), the global parity at N=4 tends toward 0.5, because the 4x4 local parity is randomized with expected value of 0.5 in the corrupted area. But the watermark can still be detected. The global parities of other N are not affected by corruption. In row (d), the global parity of the cropped image is basically unaffected. These suggest that the proposed WED is indeed robust to human marking and to cropping.

5. CONCLUSION

The proposed Watermarking Error Diffusion (WED) provides an effective way to embed robust public watermark in the halftone image. It embeds watermark in the local parity domain throughout the whole image while maintains the visual quality of halftone image. The stochastic property is robust to cropping and distortion due to dirt or human writing/marking.

6. ACKNOWLEDGEMENT

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7. REFERENCE

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Block Size, N	1	2	3	4	5	6	7	8
(a) Lena without watermark	0.49	0.48	0.50	0.50	0.50	0.49	0.50	0.50
(b) Watermarked Lena	0.49	0.50	0.50	0.78	0.50	0.50	0.50	0.45
(c) Corrupted Watermarked Lena	0.43	0.46	0.46	0.70	0.48	0.48	0.50	0.46
(d) Cropped Watermarked Lena	0.49	0.51	0.49	0.76	0.50	0.49	0.49	0.44

Table 1 Global Parity of watermarked LENA, (t = 20, PSNR=32.4dB, W₄ = 1)

Figure 1 512x512 original Lena

Figure 2 Halftoned Lena

Figure 3 Lena by WED ($t=20$, $W_4=1$, PSNR=32.4 dB)

Figure 4 Noisy Lena ($t=20$, $W_4=1$, PSNR=32.4 dB)

Figure 5 Lena by WED after corruption ($t=20$, $W_4=1$, PSNR=32.4 dB)

Figure 6 Lena by WED after cropping ($t=20$, $W_4=1$, PSNR=32.4 dB)

Figure 7 Block Diagram of Error Diffusion

Figure 8 Block Diagram of Watermarking Error Diffusion (WED)