A SYMMETRIC KEY WATERMARK FOR HALFTONE IMAGES

*Oscar C. Au, Ming Sun Fu **

Hong Kong Univ. of Science and Technology, Clear Water Bay, Hong Kong, China.

Tel: +852 2358-7053 Fax: +852 2358-1485 Email: fmsun@ust.hk, eeau@ust.hk*

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 watermark in the parity domain of halftone images with symmetric key during halftoning while introducing minimal distortion.

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]. 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].

In this paper, we propose a novel public watermarking method called watermarking error diffusion (WED) for halftone image. WED embeds the watermarking in the local parity and uses the global parity for the watermark detection. It is free from the problem of falsely declaring an unwatermarked image as containing a watermark.

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. The relationship between input and output of error diffusion can be described by the following equations (1) – (3):

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

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

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

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

$x_{m,n}$ = 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 (WED)

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)

$$P_{i,j}^S = \left[\sum_{(k,l)\in S(i,j)} b_{k,l} \right] \bmod 2 \quad (4)$$

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

$$P^S = average\{P_{i,j}^S, \forall i, j\} \quad (5)$$

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

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In typical error diffused images, 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. 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 e.g. 512x512=262144. Thus, the global parity tends to be very close to 0.5 for most images. Figure 2 shows that even though the occurrence of $b_{m,n}$ is not equal to 0.5 in the bright or dark region, the local parity still behaves with a mean of 0.5 when the size shape *S* is large enough (>8).

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 $P^S \le T_1$, then $W = 0$.

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

If $T_2 \le P^S$, 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 3 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(.)* in which the binary output is adaptively toggled.

In Figure 3, $b_{m,n}$ is the "normal" output without WED according to error diffusion. With $b_{m,n}$, the local parity $P^S_{m,n}$ 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 $\Delta x_{m,n}$ to the original image pixel $x_{m,n}$ in Eqn. (1) to distort $u_{m,n}$ such that the quantized output in Eqn. (2) is reverted.

$$x'_{m,n} = x_{m,n} + \Delta x_{m,n}$$

$$u'_{m,n} = x'_{m,n} + \sum h_{k,l} e_{m-k,n-l} = u_{m,n} + \Delta x_{m,n}$$

$$b'_{m,n} = Q(u'_{m,n}) = Q(u_{m,n} + \Delta x_{m,n})$$

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

In WED, if $\left|\Delta x_{m,n}\right| < T_3$ 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(.)* 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. SYMMETRIC KEY WATERMARKING

In order to embed and detect the watermark, we need to use the same shape *S*. Effectively, the shape *S* functions as the symmetric embedding and detection key.

To avoid two different keys from detecting each other's watermark and guarantee the minimum size of shape *S*, we impose a constraint that there must be two or more locations (or bits) within the neighborhood which must be always present in all allowable shapes (or keys).

To illustrate this constraint, we give a simple example in which we restrict the neighborhood to be a 1x32 area as shown in Fig. 1. Within this area, a "1" in a pixel indicate that point to be in the shape *S*. In this example, we force the first 12 pixels and the last 12 pixels to be always "1" and allow the other 8 locations to be any combination of "0" and "1". This gives rise to 2^8=256 possible 32-bit keys, all with a leading and trailing "1s". Of course, any shape of the neighborhood can be used and any locations can be forced to be permanently "1". When a large-size shape is used, there can be numerous combinations. For example, there can be 2^{128} different keys for a rectangular shape of size 8x16 exclusive leading and trailing.

5. SIMULATION RESULTS

Figure 6 is the 512x512 test image, Lena. Figure 7 is the normal error diffused Lena by Jarvis kernel. Figure 8 is the Lena halftoned by WED with the watermark W=1 embedded in the image using key = 85 = [111111111111]01010101 [111111111111]. The thresholds chosen are $T_1 = 0.4$, $T_2 = 0.6$ and $T_3 = 20$. Figure 8 looks very good with natural texture. Figure 9 is the corresponding noisy multi-tone image x' that can generate the watermarked image using regular error diffusion. The PSNR of x' is 39.6 dB compared with the original image.

Figure 4 is the watermark detection result of the normal halftone image without watermark. All the 256 possible keys are applied and no watermark is detected, as expected. This verifies that the global parity of regular error diffused images tends to be 0.5 with a small variance. All the global parity values stay well within the boundaries of 0.4 and 0.6.

Figure 5 is the watermark detection result of watermarked halftone image. When all the 256 keys are applied, only the correct key (key=85) can detect the watermark signal. The global parity at key=85 is about 0.6754, significantly larger than the global parity of any incorrect keys whose global parity stay well within the 0.4 and 0.6 boundaries.

6. CONCLUSION

In this paper, we propose a novel method called Watermarking Error Diffusion (WED) to embed public watermarks in halftone images. It embeds watermark in the local parity domain throughout the whole image while maintaining high visual quality of the halftone image. For embedding and extracting the watermark, the same key is required. Simulation results show that the proposed WED gives halftone images with good visual quality.

7. ACKNOWLEDGEMENT

This work was supported by Research Grants Council of Hong Kong SAR (HKUST6028/01E).

8. REFERENCES

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P0-7	B8	B9	B10	B11	B12	B13	B14	B15	P16-23

P0-7,P16-23 : Permanently selected Bit (= 1)
B0-B7 : bit 0 to bit 7 of the watermarking key, each can be "0" or "1"

Figure 1 Example of 16-bit shape key definition (a total of 256 different keys allowed)

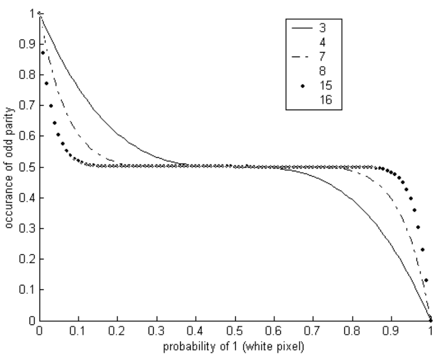

Figure 2 Relationship between intensity and parity

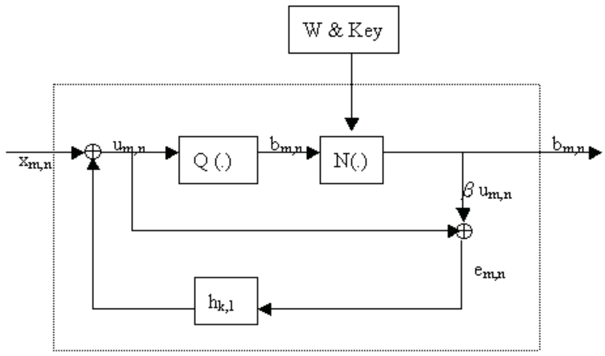

Figure 3 Block diagram of the proposed WED

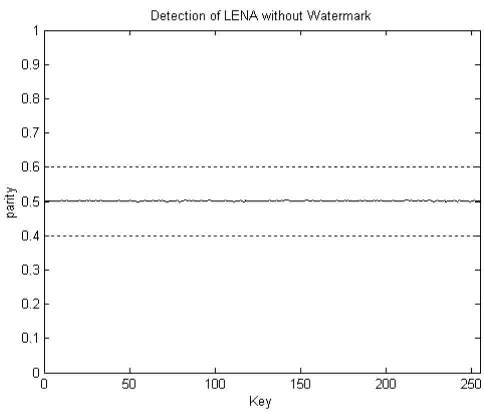

Figure 4 Detection of Image without Watermark (Max=0.5051, min=0.4982, mean=0.5052. std=0.011)

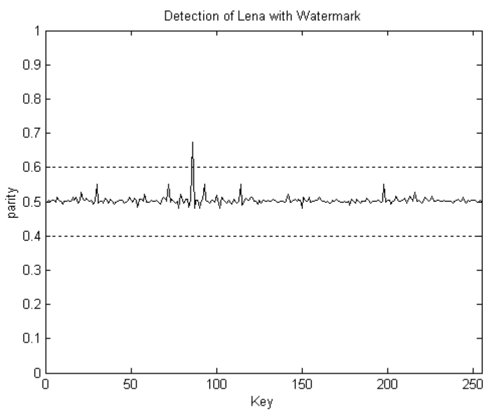

Figure 5 Detection of Image with Watermark (Peak=0.6754)

Figure 6 512x512 original Lena

Figure 7 Normal error diffused Lena

Figure 8 Lena by WED (T_3 =20, W = 1)

Figure 9 Noisy Lena (T_3 =20, W = 1, PSNR=39.6 dB)