Watermarking in dot-diffusion halftones using adaptive class-matrix and error diffusion

Jing-Ming Guo [1] and **Sankarasrinivasan Seshathiri** [2]

ABSTRACT

Digital halftoning deals with transforming a gray or color image into its binary version which is useful in printing applications. Dot diffusion is one of the prominent halftone methods which can yield superior image quality with parallel processing capabilities. In this paper, a rapid watermarking algorithm is proposed for dot-diffusion halftone images using adaptive class-matrix selection and modified error diffusion kernels. To process the image using an adaptive class matrix, the processing order of the class matrix is reversed and transposed, and for error diffusion the coefficients are replaced with different weights. For decoding, an effective strategy is proposed based on a correlation analysis and halftone statistics. The proposed strategy can successfully embed and decode the binary watermark from a single dot-diffused halftone image. From the experimental results, the proposed method is found to be effective in terms of good decoding accuracy, imperceptibility and robustness against various printed distortions.

Keywords: Digital Halftones, Dot Diffusion, Error Diffusion, Watermarking.

1. INTRODUCTION

Digital halftoning [1] is widely adopted for printing multi-media data in journals, newspapers, scientific books and so on. The primary intentions of the digital halftoning techniques are to obtain high quality printing output and are also to support the printer engine design. In practical applications, two types of printer engines are predominantly used (ink-jet and laser mechanisms) [2]. The ink-jet printers utilize dispersed-dot patterns which are comprised of homogeneously distributed black and white pixels, while laser printer deals with clustered dot printing. Among various halftone techniques, the most simplistic approach is ordered dithering (OD) [3], which involves thresholding an original image using dithering mask and the output is assigned with either '0' or '255'. Though the OD method is computationally less demanding, its image quality cannot be improved beyond a certain limit. Further, the error-diffusion (ED) [4] method is proposed which attempts to improve the quality by distributing the error value to the neighbourhood pixels. Several ED methods [1] have been proposed and each method utilizes a specific error diffusion kernel with different sizes and weights to improve the image quality. The main disadvantage of the ED method is its sequential operation. It takes more time than necessary and is not computationally efficient. In order to overcome this issue, dot-diffusion (DD) [5] [6] halftoning is proposed which combines the advantages of both the OD and ED methods. Hence, the technique can achieve parallel operation even with error-diffusion operation. The DD method is popular and it is widely used for the generation of dispersed-dot patterns meant for ink-jet printers.

Watermarking in halftone images deals with hiding secret data in the printed materials to protect the ownership copyrights [7]. This has wide scope in many types of secured document printing such as passports, currencies, legal documents and other confidential files. In general, the watermarking for halftone images is implemented in two ways: In the first approach [8] the secret data is embedded in a single halftone image and then extracted using a specific decoding technique. The second approach [9] involves embedding the secret data in two halftone images and can be extracted when the halftone images are overlaid on each other. On the other hand, the secret data can be of any form such as images, audio, video, web-links and so on.

The present work is formulated based on the first approach and focuses on embedding secret image data in a DD halftone image. An optimal watermarking scheme must meet the following requirements: good embedding capacity, perfect decoding, imperceptibility and robustness [7]. The embedding capacity deals with the number of watermark bits that can be hidden in an original or host image. The decoding accuracy is computed between the original- and extracted- hidden image, and the extraction process is very important for copyright claims. The imperceptibility guarantees that the embedded watermark is visually undetectable, and the robustness deals with algorithm performance in response to various image attacks.

From the comprehensive literature review, it is inferred that the existing watermarking scheme for the DD method is limited to the second approach, that is secret data is hidden in two halftone images. Some

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of the limitations associated with such methods are as follows: The non-linear thresholding method [10] works for the two halftone images which are generated from the same original image. Another approach [11] utilises secret shared DD technique and the decoding can be performed by overlaying the two halftone images or using XNOR operations. But the technique results in generation of strange artifacts termed 'burr' during the overlaid operation and it tends to be worse when computed through XNOR operation. Further, to reduce this issue conjugate dot-diffusion and error-diffusion [12] is carried out, which generates fewer artifacts. Moreover, based on the first approach many of the existing watermarking techniques are meant only for ED techniques. The primary approach is based on the vector quantization [13] which can embed the watermark information in the most or least significant bit. Using the modified error diffusion kernels, another approach is proposed to perform watermarking on ED images [14]. As these techniques embed watermarks only in single halftone images, the watermark data is obtained through scanning and decoding through some mathematical computations [15] - [17]. In summary, it can be inferred that the existing watermarking algorithms require either halftone image pairs and are not suitable for all halftones. Considering the existing issues, this paper focuses on the development of a watermarking scheme that can embed and retrieve data from a single dot-diffused halftone image.

The main contributions of the paper are as follows.

i.) The class matrix of the DD method is exploited and a new approach to embed watermark information is proposed by altering the class matrix values in such a way that the condition of imperceptibility is maintained.

ii.) The error diffusion kernels of the DD method are altered with different weights, that helps to improve the decoding efficiency.

iii.) The watermark decoding strategy is formulated combining the correlation analysis along with the halftone statistical parameters.

As the watermarking is performed only by altering the class matrix and ED kernel coefficients, the proposed method is inherently embedded in the DD process and can achieve joint watermarking and halftoning.

2. DOT DIFFUSION HALFTONE

The dot-diffusion technique is the ideal combination of the ordered dithering and error diffusion methods. In ordered dithering, the image pixel $im(x, y)$ is thresholded using the specific dithering screen $S(x, y)$ and then the output $H(x, y)$ is assigned either '0' or '1' as shown in Fig. 1.

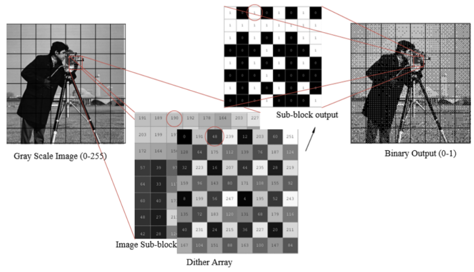

Fig.1: *Ordered dithering technique.*

As stated in Eq. 1, the thresholding is carried out using the dither screen S (x,y) and results in binary output.

$$H(x, y) = \begin{cases} 1 & im(x, y) \geq S(x, y) \\ 0 & otherwise \end{cases} \quad (1)$$

Further, the ED method is proposed which attempts to improve the image quality by distribution the error to the neighbourhood pixels. The ED method operates sequentially in the serpentine scan order and uses specific diffusion kernels to distribute the error with specific weights as shown in Fig. 2.

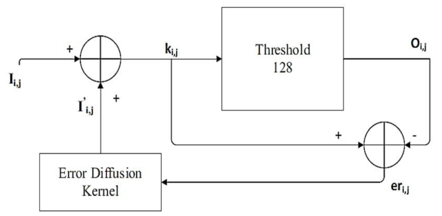

Fig.2: *Error diffusion.*

$$k_{i,j} = I_{i,j} + I'_{i,j} \quad (2)$$

$$I'_{i,j} = \sum_{m=0}^{2} \sum_{n=-2}^{2} er_{i+m,j+n} * h_{m,n} \quad (3)$$

$$e_{i,j} = k_{i,j} - O_{i,j} \quad (4)$$

$$O_{i,j} = \begin{cases} 0 & \text{if } k_{i,j} < 128 \\ 255 & \text{if } k_{i,j} \geq 128 \end{cases} \quad (5)$$

In equations 2 through 5, $e_{i,j}$ refers to the difference between actual input $k_{i,j}$ and output $O_{i,j}$. $h_{m,n}$ refers to the error diffusion filter. $I'_{i,j}$ contains the difference of error that need to be added with the neighborhood pixels.

The DD method is formulated by combining the parallel processing capacity of OD and diffusion strategy of ED to obtain a better image quality. The method utilises the class matrix and error diffusion kernels to perform halftoning.

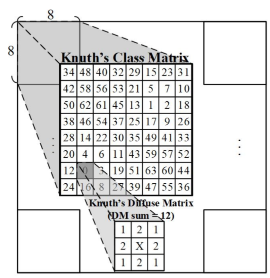

Fig.3: *Class matrix of dot-diffusion.*

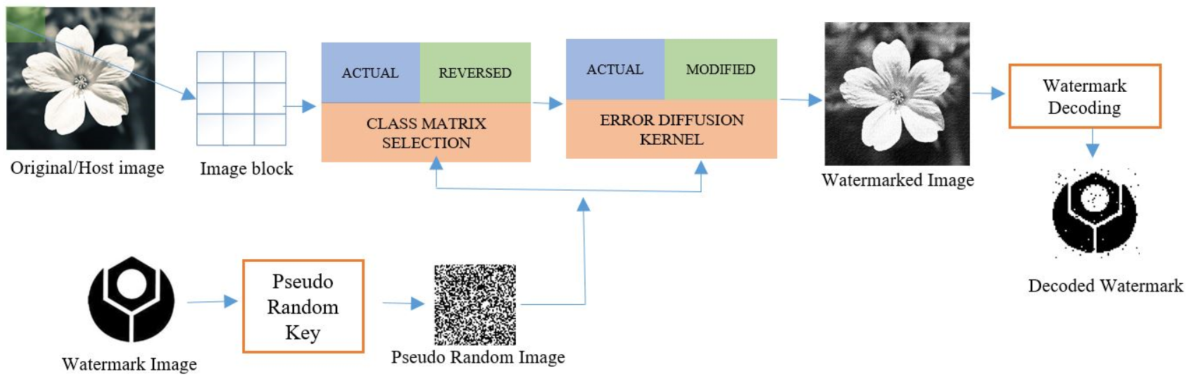

Fig.4: *Proposed Watermarking Strategy.*

A class matrix for the DD method is typically in the block size of 8×8 or 16×16, and it consists of randomly permuted numbers. For instance, the class matrix of size 8×8 is comprised of 0 to 63 distributed in such a way to generated a dispersed dot pattern. To begin with, the pixel indicated in the position '0' of the class matrix is processed and thresholded using the mid-grey level value (=128). After the thresholding, the output bit is assigned either 255 or 0, and difference of the output and actual value is computed. The error is distributed to the neighbouring pixels using some weights as shown in Fig. 5 and subsequent pixels are processed. Two prominent dot-diffusion techniques from Knuth [5] and Mese, et. al. [6] are considered in this paper.

3. PROPOSED WATERMARKING METHOD

The schematic diagram of the proposed watermarking strategy is shown in Fig. 4. The embedding method is formulated based on the adaptive selection of class matrix and error diffusion kernels. The decoding is performed using the correlation analysis and halftone statistics parameters. In this section, the watermark embedding and decoding is elaborated in detail.

3.1 Watermark Embedding

The watermark information is embedded altering the standard dot-diffusion process through changes in class matrix and error diffusion kernels.

A) Class Matrix Selection

The class matrix of the dot-diffusion approach is comprised of a random pseudo-permutation of numbers. In the proposed approach, the initial idea is to embed watermark data by reversing the processing of the pixels. Hence, an alternate class matrix with reversed order is used while embedding the watermark.

Though the process has produced a visually indistinguishable pattern, while decoding, the extraction process becomes very difficult as both of the

34	48	40	32	29	15	23	31
42	58	56	53	21	5	7	10
50	62	61	45	13	1	2	18
38	46	54	37	25	17	9	26
28	14	22	30	35	49	41	33
20	4	6	11	43	59	57	52
12	0	3	19	51	63	60	42
24	16	8	27	39	47	55	36

(a) Actual Class Matrix

29	15	23	31	34	48	40	32
21	5	7	10	42	58	56	53
13	1	2	18	50	62	61	45
25	17	9	26	38	46	54	37
35	49	41	33	28	14	22	30
43	59	57	52	20	4	6	11
51	63	60	44	12	0	3	21
39	47	55	36	24	16	8	27

(b) Reversed Class matrix

Fig.5: *Class matrix selection.*

patterns are very similar. To overcome this issue, an additional strategy of swapping the matrix rows is attempted and is found to be effective. The swapping operation is carried out between two or three rows and its selection is performed randomly to enhance the complexity of the algorithm. The information on random selection of rows also serves as a key in the decoding stage.

B) Error-Diffusion Kernel Selection

The standard kernels utilised in the DD method are shown below

1	2	1
2	0	2
1	2	1

$\times \frac{1}{12}$

(a) Actual ED Kernel (AED)

1	4	1
4	0	4
1	4	1

$\times \frac{1}{20}$

(b) Modified ED Kernel (MED)

Fig.6: *ED Kernel Selection.*

In the proposed approach, the existing kernel is slightly varied and it is useful in improving the decoding rate. The selected kernel also results in slight reduction in image quality but there the watermarked image does not undergo any visual degradations.

The overall steps in the watermark decoding are follows:

i) Let us assume that the original host image is of the size $S_1 \times S_2$ and the processing block size is of $B_1 \times B_2$.
ii) The watermark image that can be embedded is of the size of

$$W_1 = \frac{S_1}{B_1}; W_2 = \frac{S_2}{B_2}; \tag{6}$$

iii) The watermark image undergoes the pseudo random operation and the watermark pixels are rearranged according to the random key. This process is very critical in improving the robustness of the proposed approach and will be detailed in the results section.
iv) The next step is the selection of class matrix according to the watermark tone. In this proposed strategy, two class matrices such as CM and CM_R are utilised for watermark tones of '0' and '1' respectively.
v) The host image is processed in the sequence as described in the selected class matrix, and further the error diffusion kernel is also selected in accordance to the watermark tone.

$$EDK = \begin{cases} AED & \text{if } iw(x,y) = 0 \\ MED & \text{if } iw(x,y) = 1 \end{cases} \tag{7}$$

AED and MED refer to actual and modified error diffusion kernels respectively.

3.2 Watermark Decoding

The extraction of watermark data is very critical as it is the evidence used for any copyright claims. The proposed watermark extraction exploits the pattern statistics and dissimilarities to accurately decode the hidden data.

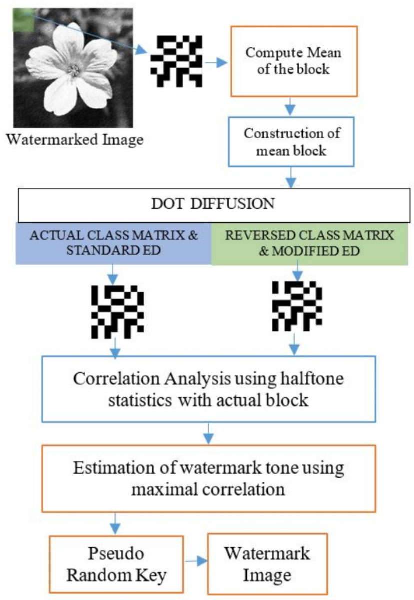

Fig.7: *Watermark Embedding.*

The decoding process begins with processing the watermarked image in a block wise manner. Then the mean of the block is computed and a constant grey block is constructed using the mean values. The mean block undergoes dot diffusion using two different configurations. The first configuration involves the standard class matrix and the error diffusion kernel, and the second configuration utilises the reversed class matrix and modified error diffusion kernel.

The two different versions of the dot-diffused block of the watermark image are compared with the watermarked image block. For the decoding analysis, the inner product is computed between the two dot-diffused blocks

$$I_{wt} = \sum\nolimits_{wt=0}^{1} \langle M_B, WM_B \rangle, \tag{8}$$

I_{wt} refers to the inner product of the watermark tone. As the proposed case deals with binary watermarking the possibilities of the $wt = \{0, 1\}$. M_B and WM_B refer to the mean block and the current watermark image block. Concurrently a stochastic parameters termed radially averaged power spectral density (RAPSD) is computed and its inner product is added with I_{wt} [18]. This helps to accurately differentiate the DD patterns and improvise the decoding accuracy. Ultimately the watermark tone is decided based on the maximum of inner products.

$$WT = \max\{IP_0,\ IP_1\}, \tag{9}$$

WT is the decoded watermark tone (wt) which is selected based on the maximum among the two inner products.

4. RESULTS AND DISCUSSION

For performance evaluation, the 2-tone binary image is embedded in the dot-diffusion image. Two prominent DD techniques from Knuth [5] and Mese. et. al. [6] are considered for analysis. As the dot-diffusion images are meant for printing, they are expected to undergo many potentially damaging transformations such as tampering, cropping and scanned images may also go through compression. The proposed technique is tested against all this degradation to ensure the robustness. The decoding efficiency is estimated using two image quality metrics: correct decoding rate (CDR) and structural similarity index (SSIM).

Table 1: *Halftone image quality and watermark capacity.*

Halftone Types	Class matrix size	Watermark Size
Knuth	8×8	64×64
Mese	8×8	64×64
	16×16	32×32

Table 2: *Image Quality of the Decoded Watermark.*

Halftone Types	Secret Image	Watermarked Image	Decoded Watermark
Knuth (8x8)		 SSIM=0.9856	 CDR=92.5%
Messe (8x8)		 SSIM=0.9753	 CDR=92.47%
Messe (16x16)		 SSIM=0.9788	 CDR=94.21%

The correct decoding rate (CDR) is defined as follows:

$$CDR = \frac{1}{P \times Q}(\sum\nolimits_{i=1}^{P}\sum\nolimits_{j=1}^{Q}(w_{i,j}^{ex} \bigotimes w_{i,j}^{org}))\times 100\%, \quad (10)$$

$w_{i,j}^{ex}$ and $w_{i,j}^{org}$ correspond to the extracted and original watermark, respectively, and $\bigotimes$ denotes the XNOR operation. The structural similarity index (SSIM) is defined as follows:

$$SSIM = \left(\frac{2\mu_x\mu_y + C1}{\mu_x^2\mu_y^2 + C1}\right)\left(\frac{2\sigma_{xy} + C2}{\sigma_x^2\sigma_y^2 + C2}\right) \quad (11)$$

where μ_x, σ_x and μ_y, σ_y indicates the mean and variance of test and reference image respectively. σ_{xy} refers to the correlation coefficient between the test and reference image, and C1 and C2 are constants.

For performance evaluation, 50 host images are considered which are randomly embedded with 10 binary images. The size of the host image is 512×512. The experiments are performed to analyse the decoding accuracy of the proposed strategy with respect to actual case and various degradations.

As the dot-diffusion images are meant for printing, its robustness towards different degradations such as tampering, cropping and compressions are analysed. To begin with, Table 1 provides the data capacity of the proposed method for the considered dot-diffusion types. As the proposed approaches performs in a block wise manner, the class matrix size has the direct impact on the data capacity. For instance, the host images for the testing are of size 512×512 and the processing block size for the Knuth and Mese are of 8×8 and 16×16 respectively.

Table 2 shows of the image quality of the decoded watermarks for the actual cases. The watermarked images do not show any visible artifacts and they satisfy the condition of visual imperceptibility. The image quality of the watermark image in comparison with standard dot-diffusion is also provided to validate the same. From the results, it can be also inferred that the decoding accuracy of the proposed scheme is better for the higher block size. As the decoding accuracy of the watermarking scheme is based on inner product, it tends to increase with block size and hence yield better performance.

Table 3 shows the performance of the proposed method towards the cropping attack. It has been mentioned previously that the watermark undergoes pseudo random distribution which distributes the binary image as homogeneously and randomly as possible. Due to the random distribution, even if the portion or area of the watermark image is damaged or cropped, some meaningful information of the hidden data can still be extracted. This pseudo random key also serves as a security key in the decoding step for the perfect retrieval of hidden data.

Table 3: *Image Quality of Decoded Watermark for Cropping Attack (25%).*

2-Tone Watermark	Extracted Image
	 CDR=82.93%

Table 4 shows the result of the proposed scheme for the tampering effect. The image attacks such as cropping and tampering have a similar effect on the performance as both result in loss of information over some portion of the image. Hence the decoding accuracy with respect to the tampering case is almost the same as with cropping damage. As these attacks are very popular in printed documents, the usage of a pseudo random key is very important in order to make the algorithm robust towards such attacks. The performance of the algorithm also depends on the processing block size. For instance, in case of watermark data embedded in the high block size it offers more robustness as the tampering attack is meant for the particular portions. At the same time, the data embedding capacity is reduced for the higher block size and hence there exists a trade-off between the embedding capacity, decoding rate and processing block size.

For the JPEG compression, different quality factors such as 90%, 75% and 50% are considered and the results are presented in Table 5.

Table 4: *Image Quality of Decoded Watermark for Tampering Attack.*

2-Tone Watermark	Extracted Image
	 CDR=94.7%

Table 5: *Image Quality of Decoded Watermark for Jpeg Compression.*

Quality Factor	Knuth (8×8)	Mese (8×8)	Mese (16×16)
90	0.917	0.894	0.924
75	0.875	0.846	0.906
50	0.712	0.726	0.829

Finally, a comparison table is provided considering some of the error diffusion and dot diffusion watermarking schemes.

Table 6: *Comparison of Proposed Watermarking Scheme with Existing Methods.*

Methods	CDR	Remarks
DDNT [10]	–	The method generates distortions along the boundaries of the hidden pattern and can be implemented only in halftone image pairs.
SSDDF [11]	92.13%	Generation of "Burr artifacts"
DHD-CDD [12]	92.75%	Only feasible for DD halftone pairs
PMEDF [17]	94.62%	Implemented on ED images
Proposed	93.2%	Implementation for single DD halftone

Table 6 shows the comparison results with the existing watermarking methods. Many existing methods are feasible to perform watermarking in either halftone image pairs or error diffusion halftones. Hence the proposed scheme is developed for single DD images and from the results it is evident that it achieved consistent performance compared to the other schemes. Moreover, the proposed method has some critical advantages as it can embed and extract the watermark from a single halftone image source. And as the watermark embedding method is integrated in the dot diffusion process, the computational complexity of the method is significantly less than the existing approaches.

5. CONCLUSION

A new approach to perform watermarking for a dot-diffusion halftone image is proposed. The method exploits the properties of the class matrix and error diffusion kernels to achieve imperceptible watermarking. The robustness of the scheme is achieved with the help of pseudo random distribution and processing block size. The watermark decoding is performed using the halftone pattern correlation and statistics and it is found to be very effective in achieving a good decoding rate. The proposed scheme is validated on the two widely used DD methods from Knuth and Mese. The aspect of the proposed technique to highlight is that the watermarking embedding strategies are inherently embedded in the dot-diffusion process and hence it achieves joint watermarking and halftoning. The comparison analysis showed that the proposed approach achieves was performance consistent with the existing schemes and was found to attain imperceptibility and robustness towards various attacks.

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