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Data Hiding in Halftone Images by Dual Conjugate Error Diffusion

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***Abstract*—In this paper, we propose a new halftone watermarking method named Data Hiding by Dual Conjugate Error Diffusion (DHDCED) based on Data Hiding by Conjugate Error Diffusion (DHCED). Unlike DHCED, The proposed method will embed a binary secret pattern into two or more error diffused halftone images by modifying each of them. When the two halftone images are overlaid, the secret pattern will be revealed. From the results we can observe that the proposed method not only improves the perceptibility of the embedded secret pattern but also improves the contrast of the revealed hidden pattern.**

I. Introduction

Nowadays, with the explosive increasing usage of multimedia contents, the security problem becomes important. Currently, people are willing to protect both electronic and printed contents. To protect printed contents, halftone watermarking is currently widely used in currency printing, copyright protection and etc.

Halftone images [1] contain only two tones and are generated from the multitone images by the halftoning process such as the popular technology error diffusion. In error diffusion, Steinberg kernel [2] and Jarvis kernel [3] are the two most popular error kernels in error diffusion.

There are two major classes of halftone watermarking technologies. The first class of methods will embed a secret bitstream into a halftone image. The secret message can be extracted by applying a decoding algorithm to the stego image. The famous methods [4] and [5] belong to this class.

The second class of methods will embed a secret pattern into two or more halftone images such that when the two or more halftone images are overlaid, the secret pattern will be revealed. In 2001, Fu and Au proposed the first halftone image watermarking method [6] for error diffused halftone images in this class. In 2003, Fu and Au analyzed [6], concluded the weakness of [6] and proposed Data Hiding by Conjugate Error Diffusion (DHCED)[7]. In 2006, Chang, Chan and Tai proposed [8]. Although the detail of the embedded halftone image is preserved, the contrast of the revealed pattern is low and the visual quality of the stego images is quite poor compared to the original multitone images, which leads to poor perceptibiliy. In 2008, Yang, Yang, Chen and Ye found [7] is less secure by applying gradient attack to the stego images. They found that there exists visual boundaries of the watermark in the edge map of the stego images. They proposed [9] to solve the problem. But the contrast of the revealed pattern in [9] is much lower than [7] which makes it harder for readers to distinguish the secret pattern from the backgrounds. Also the second generated image has visually lower quality compared to the first generated image.

To improve [7] while retaining its good properties , we also analyzed [7] and concluded its problems. Here we propose a more advanced method called data hiding by dual conjugate error diffusion (DHDCED). The experiments show that with the proposed method, a secret pattern can still be embedded into two halftone images, thus when the two stego images are overlaid, the secret pattern will be revealed. Also, compared to DHCED, the results shows the proposed method have better perceptibility for the stego image and the contrast of the revealed secret pattern is better.

Here is the outline for this paper. Section II will present the DHCED method. Section III will analyze the problem in DHCED and introduce the proposed method. Results will be introduced in Section IV. Finally, Conclusion will be given in Section V.

II. Data Hiding by Conjugate Error Diffusion

Data Hiding by Conjugate Error Diffusion (DHCED) can embed a binary secret pattern into two or more halftone images, such that when the two halftone images are overlaid, the secret pattern will be revealed.

For convenience, some notations will be given at first. Let X_1 and X_2 be the original multitone images. Let Y_1 and Y_2 be the two halftone images which will be generated. Let W be the binary secret pattern to be embedded. Let W_b and W_w be the collection of the locations of the black and white pixels in W respectively. The sizes of X_1, X_2 Y_1, Y_2 and W are identical.

The first halftone image Y_1 will be generated by applying regular error diffusion referencing to X_1. The regular error diffusion will quantize the summation of the current pixel value and the diffused errors from previous pixels to obtain the halftone value, and then the quantization error will feedback to future pixels according to an error kernel. The regular error diffusion is formulated as shown in (1)-(3),

$$u_1(i,j) = x_1(i,j) + \sum h(k,l) \times e_1(i-k, j-l) \quad (1)$$

$$y_1(i,j) = \begin{cases} 0, & u_1(i,j) < 128 \\ 255, & u_1(i,j) \geq 128 \end{cases} \quad (2)$$

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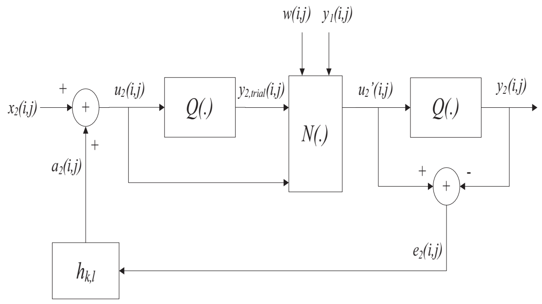


Fig. 1. DHCED system.

$$e_1(i,j) = u_1(i,j) - y_1(i,j) \tag{3}$$

The second halftone image Y_2 will be generated by DHCED process as Fig. 1 shows.

For $(i,j) \in W_b$, $y_2(i,j)$ is 'favored', which will be explained soon, to be conjugate to $y_1(i,j)$. When the current pixel $x_2(i,j)$ enters the system. It will be firstly added to the errors diffused from previous pixels. Then it will be pre-quantized to obtain the trial quantization value $y_{2,trial}(i,j)$. The trial value will be compared to the favored value which will be obtained by $y_2(i,j) = y_1(i,j) \oplus \overline{w(i,j)}$ with respect to Y_1 and W. If the trial value equals to the favored value, then $u_2'(i,j) = u_2(i,j)$. Otherwise, we will toggle the trial value to obtain the favored value unless the distortion caused by toggling is excessive. Toggling will be achieved by $u_2'(i,j) = u_2(i,j) + \Delta u_2(i,j)$. To achieve toggling with minimum distortion, DHCED uses the following mechanism.

When toggling from 0 to 255

$\Delta u_2(i,j) = 128 - u_2(i,j)$ such that $u_2'(i,j) \geq 128$

When toggling from 255 to 0

$\Delta u_2(i,j) = 127 - u_2(i,j)$ such that $u_2'(i,j) < 128$

DHCED uses the threshold T to control the distortion. If $|\Delta u_2(i,j)| < T$, then the favored value will be used and the toggling will be performed. Otherwise, the trial value will still be inherited by the output by $u_2'(i,j) = u_2(i,j)$.

For $(i,j) \in W_w$, if X_1 and X_2 are identical, then $y_2(i,j) = y_1(i,j)$. If X_1 and X_2 are different multitone images, instead of forcing $y_2(i,j) = y_1(i,j)$, $y_2(i,j)$ is favored, which is the same mechanism as $(i,j) \in W_b$, to be identical to $y_1(i,j)$.

III. Data Hiding by Dual Conjugate Error Diffusion

In DHCED, when $X_1 = X_2$, because DHCED will force $y_2(i,j) = y_1(i,j)$ for $(i,j) \in W_w$, boundary artifacts will mainly appear in the flat regions of Y_2 at the bottom and right boundaries of the locations where (i,j) is co-located in W_b. The boundary artifacts will be even more obvious if we obtain the edge map of the stego image by applying Sobel filter to the stego image. Why does these boundary artifacts happen?

Normally, the error diffusion will diffuse the current quantization error to the right and bottom pixels. However, when DHCED process approaches the pixels on the bottom or the right boundaries, the current quantization error can not be fully diffused to future pixels because $y_2(i,j) = y_1(i,j)$ for $(i,j) \in W_w$. Since human eyes are more sensitive to the fluctuations in the flat regions, the boundary artifacts will be more obvious in the flat regions.

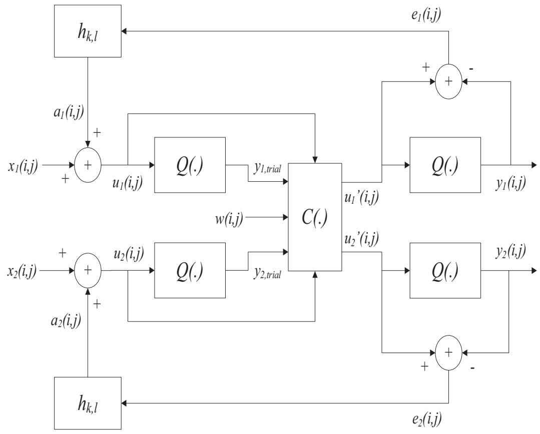


Fig. 2. DHDCED system.

Since DHCED will only embed the secret pattern into Y_2 with respect to Y_1 and W, to solve this boundary artifacts problem and to improve the contrast of the revealed hidden pattern, we propose Data Hiding by Dual Conjugate Error Diffusion (DHDCED) to embed the secret pattern by modifying both Y_1 and Y_2. As such we can not only distribute the distortions to Y_1 and Y_2 to reduce the boundary artifacts, but also increase the chance to make the pixels in Y_1 and Y_2 to be conjugate or identical according to the secret pattern which leads to better contrast of the hidden pattern when revealing.

Recall that X_1 and X_2 are the original multitone images. Y_1 and Y_2 are the two generated halftone images. W is the binary secret pattern to be embedded. W_b and W_w are the collection of the locations of the black pixels and white pixels in W respectively. It is trivial that the size of all these images are identical. Note that the 'favor' mechanism in DHDCED is the same as that in DHCED.

Fig. 2 shows the system diagram of DHDCED. In DHDCED, Y_1 and Y_2 are generated simultaneously with respect to each other and W. For $(i,j) \in W_b$, DHDCED will firstly trial quantize $u_1(i,j)$ and $u_2(i,j)$ into $y_{1,trial}$ and $y_{2,trial}$ respectively. Then the trial quantization value, $u_1(i,j)$, $u_2(i,j)$ and the secret pattern value $w(i,j)$ will enter the computing and comparing block $C(.)$. In $C(.)$, We will firstly compute two strategies.

Strategy 1:

Let $y_2(i,j)$ be favored to be conjugate to $y_1(i,j)$ and obtain the minimum distortion $\Delta u_2(i,j)$.

Strategy 2:

Let $y_1(i,j)$ be favored to be conjugate to $y_2(i,j)$ and obtain the minimum distortion $\Delta u_1(i,j)$.

Then DHDCED will use the following criterions to determine carrying out which strategy.

Criteria 1:

If $0 < |\Delta u_1(i,j)| < T$ and $0 < |\Delta u_2(i,j)| < T$,

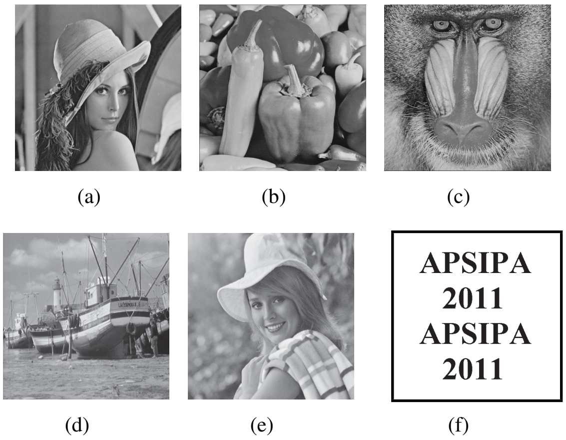


Fig. 3. (a)Original multitone image 'Lena'. (b)Original multitone image 'Pepper'. (c)Original multitone image 'Baboon'. (d)Original multitone image 'Boat'. (e)Original multitone image 'Elaine'. (f)Secret pattern to be embedded.

then the strategy which causes smaller distortion will be carried out.

Criteria 2:

If $0 < |\Delta u_2(i,j)| < T$ and ($|\Delta u_1(i,j)| \geq T$ or $|\Delta u_1(i,j)| = 0$), then strategy 1 will be carried out.

Criteria 3:

If $0 < |\Delta u_1(i,j)| < T$ and ($|\Delta u_2(i,j)| \geq T$ or $|\Delta u_2(i,j)| = 0$), then strategy 2 will be carried out.

Criteria 4:

Otherwise, strategy 1 and 2 will be carried out alternatively.

For $(i,j) \in W_w$, if X_1 and X_2 are not identical, then DHDCED will carry out similar steps as $(i,j) \in W_b$, where DHDCED will favor $y_1(i,j)$ and $y_2(i,j)$ to be identical in the two strategies instead of conjugate. If X_1 and X_2 are identical, then DHDCED will force $y_1(i,j)$ and $y_2(i,j)$ to be identical by copying each other alternatively.

IV. Experimental Results

In the experiments, the test images are all 512×512 and the Steinberg kernel is used. Fig. 3(a)-3(e) are the original multitone images used as test images. Fig. 3(f) is the secret pattern to be embedded.

For Figs. 4(a) - 4(c), we let X_1 and X_2 both be Fig. 3(a), $T = 10$. Fig. 4(a) is obtained by applying Sobel filter to the DHCED stego image Y_2. Fig. 4(b) and Fig. 4(c) are obtained by applying Sobel filter to the DHDCED stego images Y_1 and Y_2. As Figs. 4(a) - 4(c) show, we can observe that some parts of the secret pattern can be visually observed in Fig. 4(a) while in DHDCED's results (Fig. 4(b) and Fig. 4(c)), the secret pattern can hardly be seen.

For Fig. 5(a) and Fig. 5(b), we let X_1 be Fig. 3(a), X_2 be Fig. 3(b), $T = 10$. Fig. 5(a) is obtained by overlaying DHCED Y_1 and DHCED Y_2. Fig. 5(b) is obtained by overlaying DHDCED Y_1 and DHDCED Y_2. As Fig. 5(a) and Fig. 5(b) show, the hidden pattern in Fig. 5(a) is obviously less readable compared to Fig. 5(b).

TABLE I
CDR of the overlaid decoded images ($T = 10$)

Test image	DHCED	DHDCED
Lena	0.5087	0.5119
Pepper	0.5236	0.5266
Baboon	0.5299	0.5332
Boat	0.5269	0.5292
Elaine	0.5498	0.5528

TABLE II
CDR of the XNOR decoded images ($T = 10$)

Test image	DHCED	DHDCED
Lena	0.9519	0.9582
Pepper	0.9557	0.9620
Baboon	0.9507	0.9577
Boat	0.9519	0.9568
Elaine	0.9523	0.9581

For Fig. 6(a) and Fig. 6(b), we let $X_1 = X_2$ and both be Fig. 3(e), $T = 10$. Fig. 6(a) is obtained by XNOR DHCED Y_1 and Y_2. Fig. 6(b) is obtained by XNOR DHDCED Y_1 and Y_2. As Fig. 6(a) and Fig. 6(b) show, the secret pattern in Fig. 6(b) has better contrast than that in Fig. 6(a), especially for the character 'A'.

To quantify the contrast for the revealed hidden pattern, we use Correct Decoding Rate (CDR) as the measurement to measure the similarity between the decoded secret pattern and the original secret pattern. There are two ways to decode the secret pattern. One is overlaying Y_1 and Y_2. The other one is carry out XNOR (not exclusive OR) operation between Y_1 and Y_2. If we let the decoded image be L, black pixel value to be '0', white pixel value to be '1' and the image size to be $p \times q$, then the CDR is defined in (4).

$$\text{CDR} = \sum |w(i,j) \text{ XNOR } l(i,j)|/(p \times q) \tag{4}$$

In this test, All the five test images shown in Fig. 3 are used and we set $X_1 = X_2$ and $T = 10$. The CDR results for the overlaid decoded images are listed in Table I. The CDR results for the XNOR operation decoded images are listed in Table II.

As we can observe from Table I and Table II, the proposed method obtains better contrast of the revealed hidden pattern than the DHCED method.

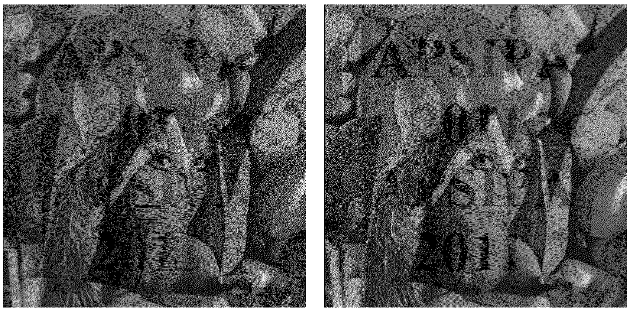
According to our experiments, the perceptibility of DHDCED is better than that of DHCED and the contrast of the revealed hidden pattern of DHDCED is also better than that of DHCED.

V. Conclusions

In this paper, we propose a new method DHDCED based on the existing method DHCED. In the proposed method, by modifying both halftone images, we not only significantly reduce the boundary artifacts which exist in Y_2 in DHCED, but also improve the contrast of the revealed hidden pattern. From the results we can observe that the proposed method outperforms DHCED in both perceptibility and contrast of the revealed secret pattern.

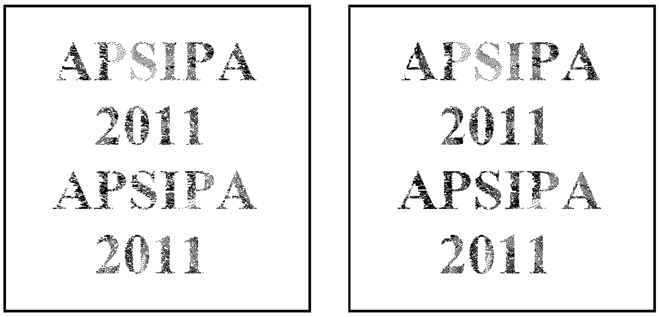
(a) (b) (c)

Fig. 4. Edge maps for DHCED Y_2 and DHDCED Y_1 and Y_2. T=10, Steinberg kernel. (a)DHCED Y_2 (b)DHDCED Y_1 (c)DHDCED Y_2



(a) (b)

Fig. 5. (a)Revealed hidden pattern obtained by overlaying Y_1 and Y_2 in DHCED. T=10, Steinberg kernel. (b)Revealed hidden pattern obtained by overlaying Y_1 and Y_2 in DHDCED. T=10, Steinberg kernel.



(a) (b)

Fig. 6. (a)Revealed hidden pattern obtained by XNOR Y_1 and Y_2 in DHCED. T=10, Steinberg kernel. (b)Revealed hidden pattern obtained by XNOR Y_1 and Y_2 in DHDCED. T=10, Steinberg kernel.

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