Data Hiding in Error Diffused Color Halftone Images

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Abstract— **Halftone image watermarking has been explored and developed rapidly over the past decade. However, there are still issues to be studied. This paper presents a data hiding method called Data Hiding by Dual Color Conjugate Error Diffusion (DHDCCED) to hide a binary secret pattern into two error diffused color halftone images, such that when the two color halftone images are overlaid, the secret pattern will be revealed. The experimental results show that DHDCCED can significantly improve the performances when comparing both the correct decoding rate and the visual quality of the revealed secret pattern to the existing method Color Conjugate Error Diffusion (CCED).**

I. Introduction

Nowadays, with the explosive increasing amount of multimedia content transmission and usage, the security, privacy and protection of multimedia contents during the delivery becomes important. Normally, there are two kinds of technologies which have been used to carry out protection. One is encryption. The other one is digital watermarking. Digital watermarking is the kind of technologies that embed a certain message into cover messages such that when applying certain extracting algorithms, the embedded message can be decoded. Watermarking has been widely applied in copyright protection, authentication, traitor tracing and etc.

Among all the watermarking technologies, halftone image watermarking technologies has been treated specially due to the unique property of halftone images. A halftone image [1] uses only two tones (black and white) to represent a multitone grey-scale image such that when the halftone image is viewed from a certain distance, the halftone image will resemble the original grey-scale image because of the low pass property of human visual system (HVS). The process to generate halftone images such as the famous technique error diffusion [2] is called halftoning process. Since halftone images are 1-bit images, most of the common image watermarking technologies such as Least Significant Bits (LSB) Embedding [**??**] could not directly applied to halftone images.

In halftone image watermarking, the various technologies can be categorized into two classes. The first class of technologies will embed a secret bitstream into the cover halftone images and the secret bitstream can be extracted by applying some computational power with certain decoding algorithms.

The second class of technologies will embed a secret pattern into the cover halftone images such that when the cover images are overlaid, the secret pattern can be revealed. Because of the simple decoding property, this kind of technologies is also called halftone visual cryptography technologies. In 2001, the first halftone visual cryptography method [3] for error diffused halftone images is proposed. In 2003, [4] is proposed to improve [3]. Later in the same year, [5] gives a method to hide the binary secret patterns into color halftone images. But the decoding of the secret patterns can only use the electronic verions of the stego images and seperate the color channels to extract the embedded secret patterns. Later on, Color Conjugate Error Diffusion (CCED) [6] is presented in 2004 which extend [4] from grey-scale images to color images. However, the correct decoding rate and the visual quality of the revealed binary secret pattern is not convincing especially when the distortion allowed for the second halftone image is not large enough. If the two color halftone images are generated from different original multitone color images, the drawback above can be observed more obviously. In 2006, [7] is proposed. However, the obvious drawback of [7] is that the two color halftone images can not be generated from different original multitone color images.

With [8] proposed to improve [4] recently, it is natural to extend the method from grey-scale images to color images. In this paper we propose a halftone visual cryptography method for error diffused color halftone images called Data Hiding by Dual Color Conjugate Error Diffusion (DHDCCED) which aims to improve the performance compared to [6] while maintaining the advantages of [6] which is the simple decoding method and the ability to use different original color images. When comparing both the correct decoding rate (CDR) and the visual quality of the revealed secret pattern, the proposed method DHDCCED performs significantly better than [6].

The paper is organized as follows. Section II reviews Data Hiding by Dual Conjugate Error Diffusion (DHDCED)[8]. Section III presents the proposed method. The experimental results will then be given in Section IV. Finally, conclusion will be presented in Section V.

II. Related Works

In this section, DHDCED will be briefly reviewed. Here some notations will be given firstly.

Let X_1 and X_2 be the input original multitone images. Let Y_1 and Y_2 be the output stego halftone images. Let W be the secret pattern to be embedded. Let $W_b(W_w)$ be the collections of the pixel locations where the pixel value is black(white).

As the Fig. 1 shows, the two stego halftone images Y_1 and Y_2 are generated simutaneously by the DHDCED system.

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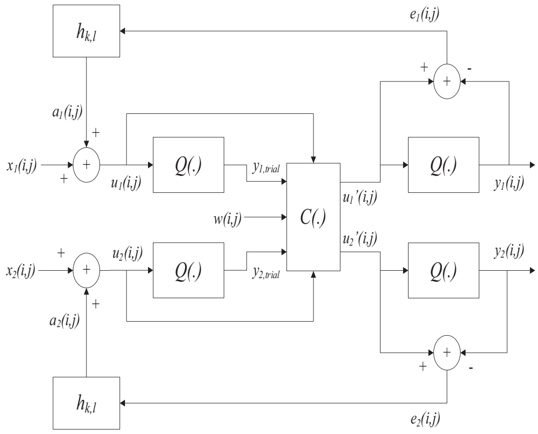


Fig. 1. DHDCED system.

The core of DHDCED is to manipulate the pixel values during the halftoning process and still preserve good visual quality of the generated halftone images. DHDCED will 'favor', where the 'favor' mechanism will be explained soon, $y_1(i,j)$ and $y_2(i,j)$ to be identical when $(i,j) \in W_w$ and $X_1 = X_2$. Note that when $X_1 \neq X_2$ and $(i,j) \in W_w$, DHDCED will force $y_1(i,j) = y_2(i,j)$. When $(i,j) \in W_b$, DHDCED will favor $y_1(i,j)$ and $y_2(i,j)$ to be conjugate to each other. Such that when Y_1 and Y_2 are overlaid, the secret pattern will be revealed due to the contrast differences between $(i,j) \in W_b$ and $(i,j) \in W_w$.

The favor mechanism works as follows. When the current pixel came into the system, it will firstly be added up with the previous errors. Then it will be trial quantized and compared to the favored value. If the trial value equals to the favored value, then the trial value will become the output value. Otherwise, the minimum distortion to toggle the trial value will be computed. The minimum distortion can be calculated as follows. Note that the $u_2(i,j)$, $u_2'(i,j)$ in the expressions below can be replace by $u_1(i,j)$, $u_1'(i,j)$ when needed.

When trying to toggle $255 \rightarrow 0$

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

When trying to toggle $0 \rightarrow 255$

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

If and only if the minimum distortion is under a certain threshold T, the toggling will be performed. The minimum distortion will be set to be zero when there is no toggling performed or the minimum distortion exceeds T. The threshold T controls the tradeoff between the contrast of the revealed secret pattern and the visual quality of the stego halftone images. When T increases, the contrast of the revealed secret pattern will also be increased while the visual quality of the stego halftone images degrades.

For $(i,j) \in W_b$, DHDCED will firstly generate the trial quantized values $y_{1,trial}$ and $y_{2,trial}$ respectively. Then in the computing and comparing block $C(.)$, two strategies will be computed.

Strategy 1:

Obtain the minimum distortion $\Delta u_2(i,j)$ when $y_2(i,j)$ is favored to be conjugate to $y_1(i,j)$.

Strategy 2:

Obtain the minimum distortion $\Delta u_1(i,j)$ when $y_1(i,j)$ is favored to be conjugate to $y_2(i,j)$.

Then the strategy which causes smaller distortion will be carried out. If the two strategy causes equal distortion, then strategy 1 and 2 will be carried out alternatively.

For $(i,j) \in W_w$, similar steps will be carried out where the only difference is that DHDCED will favor $y_1(i,j)$ and $y_2(i,j)$ to be identical instead of conjugate. Note that when $X_1 = X_2$, $y_1(i,j)$ and $y_2(i,j)$ will be forced to be identical by copying each other alternatively.

III. Data Hiding by Dual Color Conjugate Error Diffusion

After DHDCED introduced, the proposed method DHDCCED will be presented.

Recall that we let X_1 and X_2 be the input original multitone images. Still we let Y_1 and Y_2 be the output stego halftone images. Let W be the secret pattern to be embedded. Let $W_b(W_w)$ be the collections of the pixel locations where the pixel value is black(white). Note that in this paper Red-Green-Blue (RGB) color space is used. But the proposed method is not limited to only RGB color images. With proper generalization, the proposed method can be generalized to other types of color spaces.

To extend a method from greyscale halftone images to color halftone images, we firstly need to address the color halftoning process. When generating a color halftone image by error diffusion, the original multitone color image X will be decomposed into three images $[X_R, X_G, X_B]$ firstly. Then for each of the three images, the error diffusion will be carried out. At last, the three error diffused images will be combined together to form the color halftone image which we intended to generate.

Next, we will introduce DHDCCED. The system diagram of DHDCCED is as shown in Fig. 2. The two original color images X_1 and X_2 can be decomposed into three pairs of images $(X_{1,R}, X_{2,R}), (X_{1,G}, X_{2,G}), (X_{1,B}, X_{2,B})$ according to the three channels in RGB color images. As the system diagram shows, for each pair of decomposed images, the system will carry out DHDCED algorithm to generate the stego halftone image pairs $(Y_{1,R}, Y_{2,R}), (Y_{1,G}, Y_{2,G}), (Y_{1,B}, Y_{2,B})$. After the three pairs of images are generated, the stego color halftone images Y_1 and Y_2 can be constructed by combining the three pairs $(Y_{1,R}, Y_{2,R}), (Y_{1,G}, Y_{2,G}), (Y_{1,B}, Y_{2,B})$ together. With Y_1 and Y_2 generated, the secret pattern can be viewed by simply overlaying Y_1 and Y_2 together.

In DHDCCED, the threshold T will still be used to control the tradeoff between the contrast of the revealed secret pattern and the visual quality of the stego halftone images. Similar to DHDCED, when T increases, the contrast of the revealed secret pattern will increase while the visual quality of the stego halftone images will decrease. Also, DHDCCED inherits another advantage of DHDCED that it allows both the stego halftone images to tolerate distortions instead of only letting

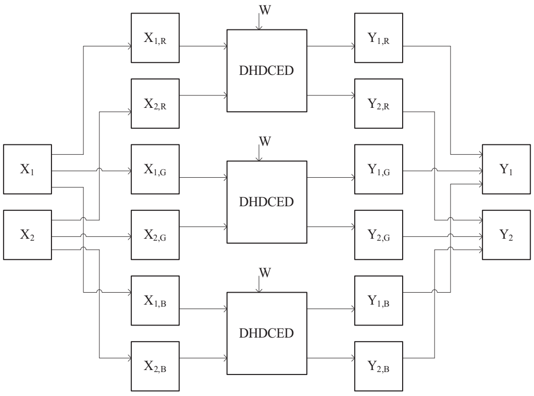
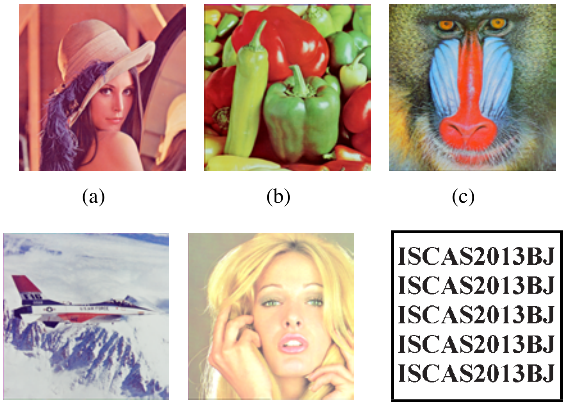


Fig. 2. DHDCCED system.



(a) (b) (c)

(d) (e) (f)

Fig. 3. Original color images and the secret pattern. (a)'Lena'. (b)'Pepper'. (c)'Baboon'. (d)'F16'. (e)'Tiffany'. (f)Secret pattern.

Y_2 suffer in the previous methods such as CCED. Beyond of inheritances, DHDCCED embeds the secret pattern into all three channels. Thus DHDCCED can effectively utilize the usage of the channels and increase the contrast of the secret pattern when revealing.

IV. Experimental Results

In the experiments there are five testing images and one secret pattern as shown in Fig. 3. For consistency, all the experiments here are using the Floyd-Steinberg kernel [2] when carrying out the error feedbacks.

In Fig. 4, the validation of DHDCCED is performed where Fig. 3(b) serves as the original color images $X_1 = X_2$. The threshold T is set to be $T = 10$. As Fig. 4 shows, DHDCCED can successfully embed a binary secret pattern Fig. 3(f) into two color halftone images. Such that not only the stego images show no clues of the secret pattern, but also the secret pattern can be revealed successfully and clearly when the two stego halftone images are overlaid.

In Fig. 5 and 6, the visual quality of the revealed secret pattern obtained by DHDCCED's Y_1 and Y_2 is compared to the one obtained by CCED's Y_1 and Y_2. For Fig. 5, Fig. 3(a) serves as the original color image $X_1 = X_2$ for both DHDCCED and CCED in order to carry out the comparison. Similarly, for Fig. 6, Fig. 3(a) and 3(b) serve as the original color image

TABLE I

CDR of the overlaid decoded images ($X_1 = X_2, T = T_c = 10$)

Test image	CCED	DHDCCED
Lena	0.5135	0.5466
Pepper	0.4803	0.5092
Baboon	0.5110	0.5425
F16	0.6461	0.6732
Tiffany	0.6873	0.7120

TABLE II

CDR of the XNOR decoded images ($X_1 = X_2, T = T_c = 10$)

Test image	CCED	DHDCCED
Lena	0.8395	0.9053
Pepper	0.8380	0.8963
Baboon	0.8391	0.9023
F16	0.8392	0.8916
Tiffany	0.8272	0.8751

X_1 and X_2 respectively. The threshold T for DHDCCED is set to be $T = 10$. The conjugate threshold T_c for CCED is set to be $T_c = 10$ and $T_c = 15$. Note that in CCED the conjugate threshold T_c is used to control the tradeoff between the distortion on the stego image and the contrast of the revealed secret pattern. Based on the observations on Fig. 5 and 6, DHDCCED outperforms CCED not only when $T = T_c = 10$, but also when CCED allowed to tolerate higher distortions (such as $T_c = 15$) than DHDCCED.

After the subjective comparisons, some objective comparison results will be introduced. In this paper the correct decoding rate (CDR) is used as the objective measurement to measure the similarities between the original secret pattern and the revealed secret pattern. There are two decoding methods. One is overlaying Y_1 and Y_2. The other one is perform XNOR (not exclusive OR) operation between Y_1 and Y_2. Let the decoded image be I and the sizes of W and I are both $p \times q$. Then the CDR is defined as follows.

$$\begin{aligned} \text{CDR} = & \sum \frac{1}{3} |i_R(i,j) \text{XNOR} w(i,j)| / (p \times q) \\ & + \sum \frac{1}{3} |i_G(i,j) \text{XNOR} w(i,j)| / (p \times q) \\ & + \sum \frac{1}{3} |i_B(i,j) \text{XNOR} w(i,j)| / (p \times q) \end{aligned} \quad (1)$$

Table I-II show the CDR results of the decoded images where $X_1 = X_2$ and $T = T_c = 10$. From the observations, the CDR results of DHDCCED outperform CCED. Since the secret pattern has only 18.96% black regions, the differences of the CDR results between CCED and DHDCCED indicate significant improvements comparing the proposed DHDCCED to the existing CCED.

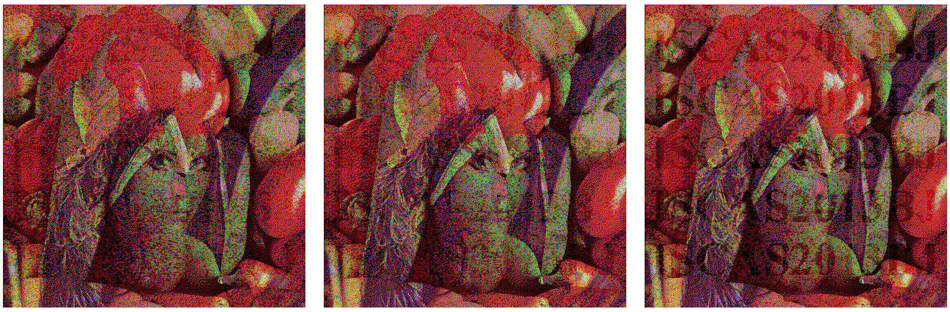
In practice, the stego halftone images may suffer various attacks. The most likely attacks are noise, print-and-scan distortions, cropping and man-marking. Under the cropping or man-marking attacks, the decoded secret pattern will lose the certain part which has been cropped or man-marked. Under the noise attack or print-and-scan distortions, the decoded secret pattern can still preserve a good visual quality with certain preprocessing steps such as resizing, contrast adjustment and 1-bit quantization before the decoding operation.

(a) (b) (c)

Fig. 4. DHDCCED Y_1, Y_2, and the overlaid image with $X_1 = X_2$ and $T = 10$ (a)DHDCCED Y_1 (b)DHDCCED Y_2 (c)The overlaid image of (a) and (b).

(a) (b) (c)

Fig. 5. (a)CCED overlaid image when $X_1 = X_2 = \text{‘}lena'$ and $T_c = 10$ (b)CCED overlaid image when $X_1 = X_2 = \text{‘}lena'$ and $T_c = 15$ (c)DHDCCED overlaid image when $X_1 = X_2 = \text{‘}lena'$ and $T = 10$.



(a) (b) (c)

Fig. 6. (a)CCED overlaid image when $X_1 = \text{‘}lena'$, $X_2 = \text{‘}pepper'$ and $T_c = 10$ (b)CCED overlaid image when $X_1 = \text{‘}lena'$, $X_2 = \text{‘}pepper'$ and $T_c = 15$ (c)DHDCCED overlaid image when $X_1 = \text{‘}lena'$, $X_2 = \text{‘}pepper'$ and $T = 10$.

V. Conclusion

In this paper a new halftone visual cryptography method is proposed. The proposed DHDCCED can effectively embed a binary secret pattern into two color halftone images such that when the two halftone images are overlaid, the secret pattern will be revealed. Although the idea of DHDCCED is simple, it improves the performance significantly compared to the existing method CCED in terms of the correct decoding rate of the revealed secret pattern and the visual quality of the revealed secret pattern.

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