

DATA HIDING IN DOT DIFFUSED HALFTONE IMAGES

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ABSTRACT

In this paper, we propose two halftone image watermarking methods. Data Hiding by Conjugate Dot Diffusion (DHCDD) and Data Hiding by Dual Conjugate Dot Diffusion (DHD-CDD). DHD-CDD is an improved method of DHCDD. Both of these two methods can embed a secret pattern into two halftone images. When the two halftone images are overlaid, the secret pattern will be revealed. Compared to the recent method Noise Balanced Dot Diffusion, the experimental results show that the proposed methods are better in both Correct Decoding Rate and the visual quality of the revealed hidden pattern.

Index Terms— Data hiding, halftone image, watermarking, dot diffusion, visual cryptography

1. INTRODUCTION

In the modern society, computer and internet become a very important aspect of people's life. Although multimedia contents such as images are very widely distributed through internet, printed materials are still playing an important role in daily life. Nowadays, documents, currencies, newspaper and magazines are still being produced with papers.

Currently, with the development of technologies, more and more multimedia materials are being copied or modified illegally. Thus the protection of both electronic and printed multimedia contents become very important. Due to the growing demands, the technologies that can protect the copyright become more and more important. Watermarking is the kind of technology which is being widely used in copyright protection. Watermarking can also be used in steganography, traitor tracing, etc.

Printed images, which are also called halftone images [1], have their unique property. Because of the limitations of the printers, which can only use two color, black and white, to represent the grey-scale images (multitone images). Such that, when viewed from a certain distance, the halftone image

can resemble the original grey-scale image. Nowadays, there are several methods to convert the multitone image to halftone image, where the converting process is called halftoning process. Among those halftoning methods, error diffusion [2] provides good visual quality. Because the error diffusion system cannot be parallel processed, people developed dot diffusion [3] to retain error diffusion's advantage while achieving parallel processing.

Because of the unique property of halftone image, most of the ordinary watermarking techniques such as LSB embedding technology cannot be directly applied to the halftone images. Therefore, halftone image watermarking technologies appear.

In this field, halftone image watermarking has two classes of technologies. The first class of methods will embed a secret bitstream into halftone images and the embedded secret message can be extracted by applying some decoding algorithms. [4] embeds secret bitstreams into random locations in halftone images. [5] uses a feed-forward loop to increase the stego halftone image quality.

The second class of methods will embed a secret pattern into two or more halftone images. When the stego halftone images are overlaid, the secret pattern will be revealed. [6] is the first method for visual cryptography in error diffused halftone images. It manipulates the feedback errors to create a halftone texture phase-shift, such that when the two halftone images are overlaid the secret patterns can be revealed. Then [7] concluded the weakness of [6] and provide a superior method by using conjugate property.

Although there are many techniques in the second class, there are few methods existed for embedding secret patterns into dot diffused halftone images. [8] can only embed a secret pattern into two halftone images which comes from the same original multitone image. [9] will produce some strange artifacts, which we call them the 'burr' artifacts, around the revealed hidden pattern when the stego halftone images are overlaid. If the XNOR operation are carried out on the two stego halftone images, the artifacts will appear to be more obvious.

To solve the previous problems and improve the data hid-

This work has been supported in part by the Innovation and Technology Commission of the Hong Kong Special Administrative Region, China (project no GHP/048/08).

ing performance, we introduce two methods. The first method Data Hiding by Conjugate Dot Diffusion (DHCDD) is an extended method from the previous method Data Hiding by Conjugate Error Diffusion (DHCED) [7]. The second method Data Hiding by Dual Conjugate Dot Diffusion (DHDCDD) is an improved method based on DHCDD.

The rest of the paper is organized as follows. Section 2 introduces the proposed method Data Hiding by Conjugate Dot Diffusion. Section 3 introduces the proposed method Data Hiding by Dual Conjugate Dot Diffusion. The experimental results are given in Section 4. Finally, conclusion is given in Section 5.

2. DATA HIDING BY CONJUGATE DOT DIFFUSION

In this section DHDCDD will be introduced. First we will briefly review DHCED.

Let X_1 and X_2 be the original multitone image. Let Y_1 and Y_2 be the two generated halftone images. Let W_w be the collections of the white pixels in the secret pattern W . Let W_b be the collections of the black pixels in the secret pattern W .

The first halftone image Y_1 is generated by regular error diffusion with respect to X_1 . As shown in Equation 1-3.

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

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

$$e_1(i, j) = u_1(i, j) - y_1(i, j) \quad (3)$$

when the current pixel $x_1(i, j)$ gets into the system, it will firstly add up with the error e obtained from previous pixels according to an error diffusion kernel h . Then it will be quantized. The quantized value $y_1(i, j)$ will be the halftoned value of the current pixel. The quantization error $e_1(i, j)$ will also be calculated and feedback to future pixels.

The second halftone image Y_2 is generated by DHCED system with respect to X_1 , Y_1 and W .

For $(i, j) \in W_b$, DHCED will ‘favor’ Y_2 to be conjugate to Y_1 . The detail of the ‘favor’ mechanism will be explained later.

For $(i, j) \in W_w$, if $X_1 = X_2$, DHCED will simply let $Y_2 = Y_1$. If X_1 and X_2 are not identical, DHCED will favor Y_2 to be identical to Y_1 .

After the two halftone images are generated, the secret pattern can be revealed when the two halftone images are overlaid.

Next, we will introduce DHDCDD.

Still we will let X_1 and X_2 be the original multitone images. Let Y_1 and Y_2 be the two generated halftone images. Let W_w be the collections of the white pixels in the secret

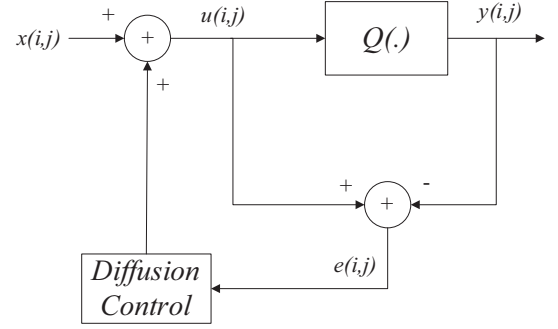


Fig. 1. Regular dot diffusion system.

pattern W . Let W_b be the collections of the black pixels in the secret pattern.

The first halftone image Y_1 is generated by regular dot diffusion from X_1 . Dot diffusion will firstly divide X into 8×8 (16×16) blocks. For each block dot diffusion will process the pixels in the block by a specified order according to a predefined 8×8 (16×16) class matrix. For example, a 8×8 HVS class matrix proposed by Mese [10] is shown as follows.

48	32	52	25	28	46	6	22
38	64	54	12	23	5	2	34
62	1	58	17	27	30	47	9
21	15	10	63	19	42	39	7
18	14	26	16	56	49	53	59
4	8	3	33	31	35	57	61
29	41	37	40	50	44	36	11
55	24	51	13	43	60	45	20

As the system shows in Figure 1, the dot diffusion is processed with a feedback loop. When the current pixel comes into the system, it will firstly be added up with the error diffused from previous processed pixels (if existed). Then it will go through a quantizer as Equation 4,

$$y_1(i, j) = \begin{cases} 0, & u_1(i, j) < 128 \\ 255, & u_1(i, j) \geq 128 \end{cases} \quad (4)$$

After the quantizer, the quantization error will be calculated as Equation 5,

$$e_1(i, j) = u_1(i, j) - y_1(i, j) \quad (5)$$

Then the system will look at the eight neighbors of the current location (i, j) in the class matrix such as the Mese [10] 8×8 HVS class matrix we mentioned before. If the neighbors have a higher class number, then the quantization error will be diffused to them according to the mechanism below.

The system will use a counter w to count how many portions the error needs to be divided into. For each diagonal

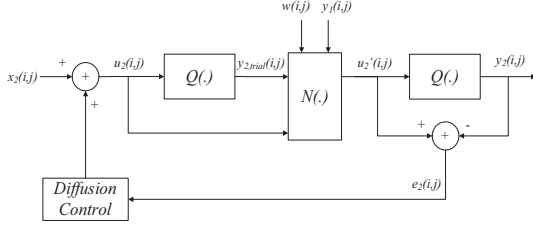


Fig. 2. DHCDD system.

higher class number neighbors, $w = w + 1$. For each horizontal or vertical higher class number neighbors, $w = w + 2$. Then the error will be diffused. $2 \times e(i, j)/w$ will be diffused to each horizontal or vertical higher class number neighbors. $e(i, j)/w$ will be diffused to each diagonal higher class number neighbors. After the quantization error is diffused, the next pixel will enter the system.

The second halftone image Y_2 is generated by DHCDD system as shown in Figure 2.

DHCDD uses the same ‘favor’ mechanism as DHCED. For $(i, j) \in W_w$, if $X_1 = X_2$, DHCDD will force $y_2(i, j) = y_1(i, j)$, else DHCDD will favor $y_2(i, j)$ to be identical to $y_1(i, j)$. For $(i, j) \in W_b$, DHCDD will favor $y_2(i, j)$ to be conjugate to $y_1(i, j)$. The favor mechanism will be explained soon.

As we can see from the DHCDD system, there are a trial quantization block and a noise block $N(\cdot)$ added compared to regular dot diffusion system. When the current pixel enters the system, it will firstly add up with the errors diffused from previous processed pixels (if exists). Then it will be trial quantized to $y_{2,trial}(i, j)$. Then the noise block $N(\cdot)$ will decide whether this trial value is the favored value. If the trial value is exactly the favored value, the trial value will be inherited by the output by $u_2'(i, j) = u_2(i, j)$. If the trial value is not the favored value, then the system will toggle the trial value unless the distortion to toggle is too excessive.

To achieve toggling with minimum distortion, DHCDD uses the following mechanism.

When toggling from 255 to 0

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

When toggling from 0 to 255

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

DHCDD uses the threshold T to control the distortion. If $|\Delta u_2(i, j)| \leq T$, then the favored value will be used and the toggling will be performed. Otherwise, the toggling will not be carried out. The threshold T can be used to tradeoff between visual quality of the stego image and the contrast of the revealed hidden pattern. If T increases, the contrast of the revealed hidden pattern will be higher while the visual quality of the stego image Y_2 will degrade.

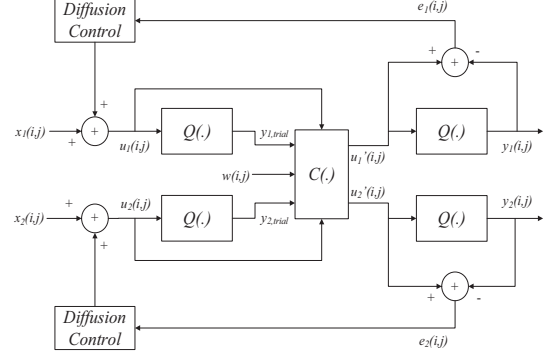


Fig. 3. DHDCDD system.

3. DATA HIDING BY DUAL CONJUGATE DOT DIFFUSION

In DHDCDD, the secret pattern will be embedded only by modifying Y_2 , which sometimes is not very effective to obtain the favored value. Also, DHDCDD will cause some noticeable boundary artifacts in the flat regions of Y_2 when T is reasonably large and $X_1 = X_2$. To solve the boundary artifact problem and improve the contrast of the revealed hidden pattern, DHDCDD is developed.

Recall that X_1 and X_2 are the original multitone images. We let Y_1 and Y_2 be the two generated halftone images. Let W_w be the collections of the white pixels in the secret pattern W . Let W_b be the collections of the black pixels in the secret pattern W .

Unlike DHCDD, DHDCDD will generate Y_1 and Y_2 simultaneously, as shown in Figure 3.

For $(i, j) \in W_b$, DHDCDD will firstly trial quantize $x_1(i, j)$ and $x_2(i, j)$ into $y_{1,trial}$ and $y_{2,trial}$ respectively. Then in the computing and comparing block $C(\cdot)$, DHDCDD will compute two strategies: (1) Let $y_2(i, j)$ be favored to be conjugate to $y_1(i, j)$ and then calculate the minimum distortion $\Delta u_2(i, j)$. (2) Let $y_1(i, j)$ be favored to be conjugate to $y_2(i, j)$ and then calculate the minimum distortion $\Delta u_1(i, j)$. Then the system will use the following criterions to determine which strategy will be carried out.

(1) If $0 < |\Delta u_1(i, j)| \leq T$ and $0 < |\Delta u_2(i, j)| \leq T$, then DHDCDD chooses the strategy which will cause smaller distortion and carry out.

(2) If $0 < |\Delta u_2(i, j)| \leq T$ and $|\Delta u_1(i, j)| > T$ or $|\Delta u_1(i, j)| = 0$, then DHDCDD will carry out strategy 1.

(3) If $0 < |\Delta u_1(i, j)| \leq T$ and $|\Delta u_2(i, j)| > T$ or $|\Delta u_2(i, j)| = 0$, then DHDCDD will carry out strategy 2.

(4) Otherwise DHDCDD will carry out strategy 1 and 2 alternatively.

For $(i, j) \in W_w$, if X_1 and X_2 are not identical, then DHDCDD will carry out similar steps as $(i, j) \in W_b$ except DHDCDD 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 DHDCDD will force $y_1(i, j)$ and $y_2(i, j)$ to be identical by copying each other alternatively.

Similar to DHCDD, DHDCDD also uses the threshold T to control the tradeoff between the visual quality of the stego images and the contrast of the revealed hidden pattern. When the threshold T increases, the contrast of the revealed hidden pattern will increase while the visual quality of the stego images will decrease.

4. EXPERIMENTAL RESULTS

In this section, the results for DHCDD and DHDCDD are presented. For comparison, the most recent method NBDDF is also implemented. In the experiments, the size of all the images are 512×512 . The class matrix for the dot diffusion will use the matrix in Equation 2. Figure 4(a)-4(c) show three test images. Figure 4(d) shows the secret pattern to be embedded.

Figure 5 shows that when we use Figure 4(a) as input multitone images X_1 and X_2 , DHCDD (here we set $T = 10$) will generate two halftone images Y_1 (Figure 5(a)) and Y_2 (Figure 5(b)). Such that when Figure 5(a) and Figure 5(b) are overlaid together, the secret pattern will be revealed in Figure 5(c).

Figure 6 shows that when we use Figure 4(a) as input multitone images X_1 and X_2 , DHDCDD (here we also set $T = 10$) will also generate two halftone images Y_1 (Figure 6(a)) and Y_2 (Figure 6(b)). Such that when Figure 6(a) and Figure 6(b) are overlaid together, the secret pattern will be revealed in Figure 6(c).

Figure 7 shows the XNOR operation decoded images of the three methods. Figure 7(a) is obtained by carrying out XNOR operation to DHCDD generated Figure 5(a) and Figure 5(b). Figure 7(b) is obtained by carrying out XNOR operation to DHDCDD generated Figure 6(a) and Figure 6(b). Figure 7(c) is obtained by carrying out XNOR operation to the NBDDF generated two halftone images with Figure 4(a) as the input multitone image. As we can see, Figure 7(c) shows some strange artifacts around the text 'ICME2011', especially at the right and bottom side. From Figure 7, we can observe that DHDCDD shows the best visual quality of the revealed hidden pattern among all the three methods because there are no artifacts and better contrast of the watermark. Since there is no burr artifacts, DHCDD also appears to have better visual quality of the revealed hidden pattern compared to NBDDF.

To compare DHCDD, DHDCDD and NBDDF objectively, here we use Correct Decoding Rate (CDR) to measure the similarity between the original secret pattern and the revealed hidden pattern.

If we let the overlaid image be O , black to be '0' and white to be '1' and the image size to be $p \times q$, then the CDR is defined in Equation 6.

$$CDR = \sum |w(i, j) \text{ XNOR } o(i, j)| / (p \times q) \quad (6)$$

If we let the XNOR operation decoded image be D , black to be '0' and white to be '1' and the image size to be $p \times q$, then the CDR will become Equation 7

$$CDR = \sum |w(i, j) \text{ XNOR } d(i, j)| / (p \times q) \quad (7)$$

With the CDR measurement, a set of results are provided in Table 1-3 and Table 4-6. In the experiments, the threshold T is set to 5, 10, 15 for DHCDD and DHDCDD, the parameter N is set to 5, 10, 15 for NBDDF. Also, the input image X_1 and X_2 are identical in these experiments. From the table, we can obtain that DHCDD and DHDCDD both have better decoding rate than NBDDF. Moreover, DHDCDD shows better results compared to DHCDD.

5. CONCLUSION

Two halftone image watermarking methods, DHCDD and DHDCDD, are proposed in this paper. DHCDD and DHDCDD can both embed a secret pattern into two halftone images such that when the two halftone images are overlaid, the secret pattern will be revealed. According to the experimental results, the proposed methods not only provide people two new methods for embedding secrets into dot diffused halftone images, but also show their superiority compared to the most recent method NBDDF.

6. REFERENCES

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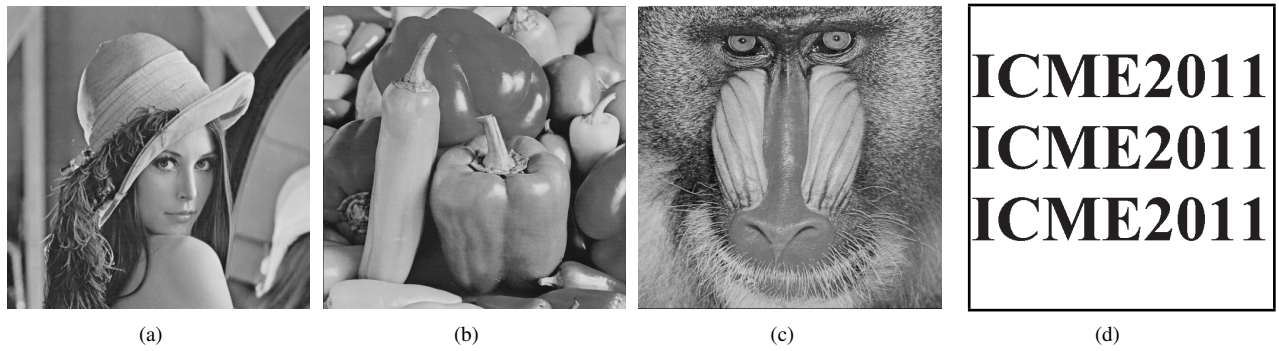


Fig. 4. (a)Original multitone image 'lena'. (b)Original multitone image 'pepper'. (c)Original multitone image 'baboon'. (d)Secret pattern 'icme2011' to be embedded.

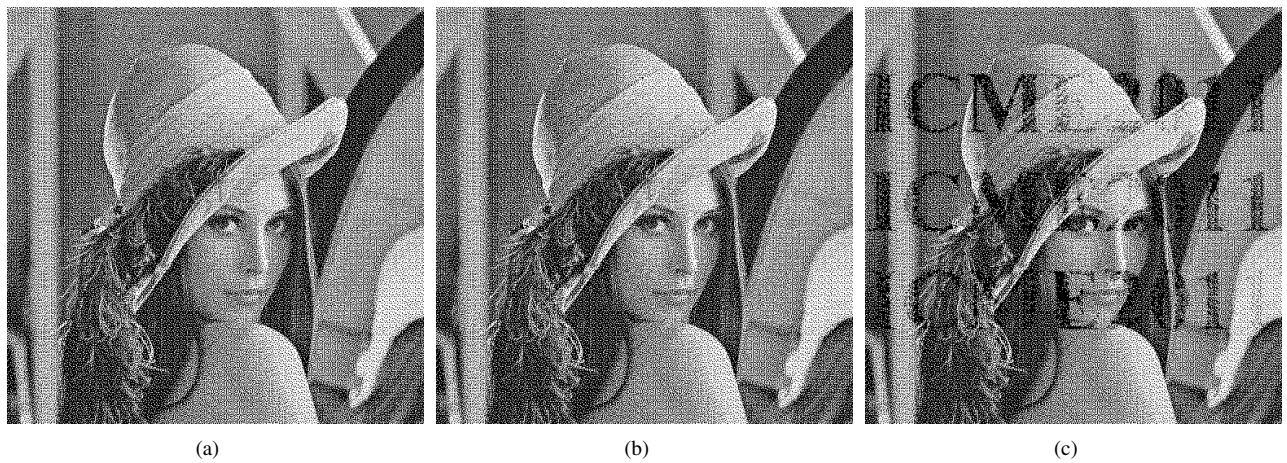


Fig. 5. (a)DHDCDD Y_1 . (b)DHDCDD Y_2 . (c)The overlaid image of (a) and (b).

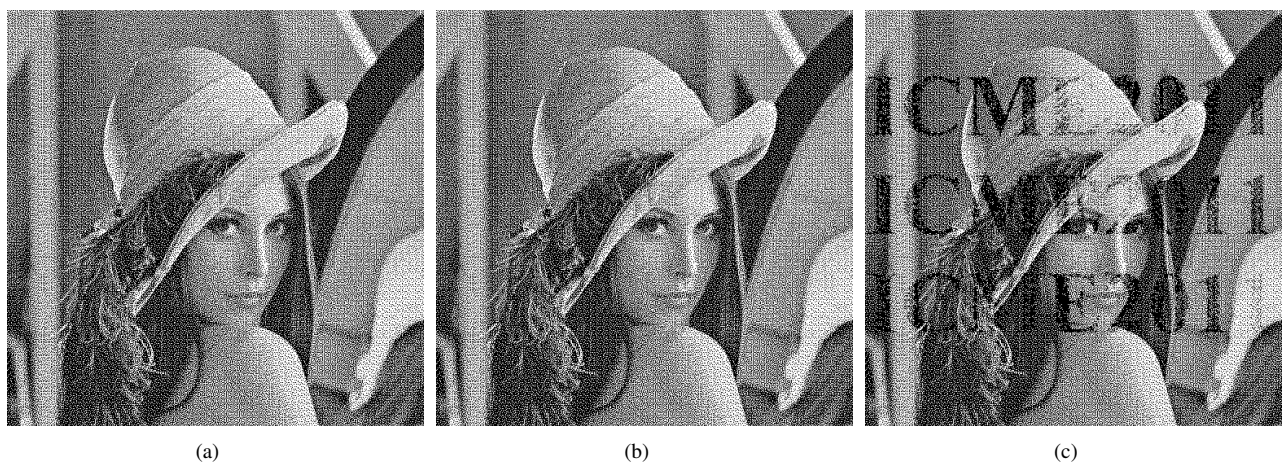


Fig. 6. (a)DHDCDD Y_1 . (b)DHDCDD Y_2 . (c)The overlaid image of (a) and (b).

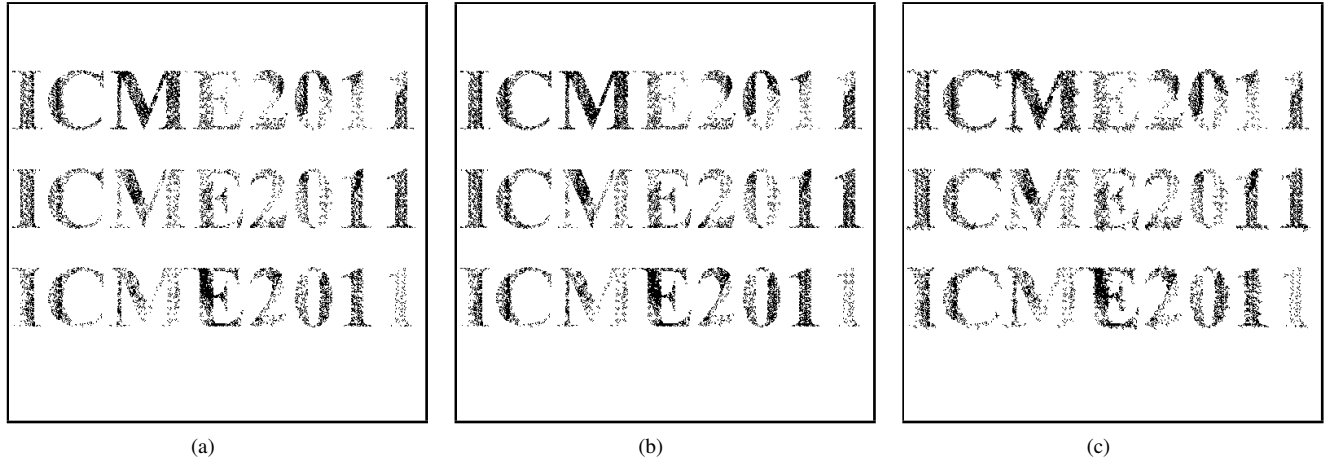


Fig. 7. (a)DHCDD XNOR decoded secret pattern. (b)DHDCDD XNOR decoded secret pattern. (c)NBDDF XNOR decoded secret pattern.

Table 1. CDR of the overlaid images when $T = 5$ and $N = 5$

Test image	DHCDD	DHDCDD	NBDDF
Lena	0.5122	0.5133	0.5112
Pepper	0.5244	0.5257	0.5234
Baboon	0.5219	0.5233	0.5208

Table 2. CDR of the overlaid images when $T = 10$ and $N = 10$

Test image	DHCDD	DHDCDD	NBDDF
Lena	0.5235	0.5263	0.5214
Pepper	0.5361	0.5392	0.5340
Baboon	0.5339	0.5368	0.5317

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Table 3. CDR of the overlaid images when $T = 15$ and $N = 15$

Test image	DHCDD	DHDCDD	NBDDF
Lena	0.5307	0.5344	0.5280
Pepper	0.5435	0.5475	0.5411
Baboon	0.5417	0.5446	0.5386

Table 4. CDR of the XNOR operation decoded images when $T = 5$ and $N = 5$

Test image	DHCDD	DHDCDD	NBDDF
Lena	0.8793	0.8817	0.8772
Pepper	0.8827	0.8854	0.8806
Baboon	0.8813	0.8841	0.8790

Table 5. CDR of the XNOR operation decoded images when $T = 10$ and $N = 10$

Test image	DHCDD	DHDCDD	NBDDF
Lena	0.9017	0.9076	0.8973
Pepper	0.9060	0.9123	0.9017
Baboon	0.9054	0.9115	0.9009

Table 6. CDR of the XNOR operation decoded images when $T = 15$ and $N = 15$

Test image	DHCDD	DHDCDD	NBDDF
Lena	0.9162	0.9235	0.9107
Pepper	0.9209	0.9287	0.9158
Baboon	0.9210	0.9275	0.9152