Hiding a Secret Pattern into Color Halftone Images

Yuanfang Guo(✉), Oscar C. Au, Ketan Tang, and Jiahao Pang

The Hong Kong University of Science and Technology, Hong Kong, China
eeandyguo@ust.hk

Abstract. This paper proposes an effective color halftone image visual cryptography method to embed a binary secret pattern into dot diffused color halftone images, Data Hiding by Dual Color Conjugate Dot Diffusion (DCCDD). DCCDD considers inter-channel correlation in order to restrict the embedding distortions between different channels within an acceptable range. Compared to the previous method, the proposed method can hide a secret pattern into two halftone color images which come from different original multitone images. The experimental results show that DCCDD can embed a binary secret pattern into two color halftone images which can be generated from identical or different original multitone color images. When the two halftone images are overlaid, the secret pattern will be revealed.

1 Introduction

Nowadays, with the explosive increasing amount of usage of digital images, the security problems become more and more important. Currently, watermarking is being widely used as copyright protection, authentication tools and etc.

Halftone image [1] is a special kind of image which only uses two tones (black and white) to represent an image such that when the halftone image is being viewed from a distance, it resembles the original grey-scale image. The process to generate the halftone images is called halftoning process. Among the halftoning processes, dot diffusion [2,3] is developed to achieve parallel processing while generating good visual quality.

Because of the unique property of halftone image (1-bit per pixel), ordinary watermarking techniques can not be directly applied. Thus, the halftone watermarking technologies appear. In recent years, two classes of halftone watermarking technologies have been developed. The first class of technologies such as [4] will embed a secret bitstream into halftone images such that the secret bitstream can be extracted by applying certain decoding algorithm. The second class is the kind of technologies that embed a secret pattern into halftone images such that when the halftone images are overlaid, the secret pattern will be revealed. The second class of technologies is also known as halftone visual cryptography.

In the second class, There are methods such as [5,6] which developed for error diffused gray-scale halftone images. There are methods such as [7,8] which

Y.Q. Shi et al. (Eds.): IWDW 2013, LNCS 8389, pp. 465–474, 2014.
DOI: 10.1007/978-3-662-43886-2_33,

designed for color error diffused halftone images. There are several methods such as [9] which were invented for gray-scale dot diffused halftone images. But to our best knowledge, there is only one method [10] which proposed for color dot diffused halftone images. In [10], although the method can successfully embed a binary secret pattern into two color halftone images and gives reasonable results, the two color halftone images can only be generated from the same original multitone color images.

With the latest methods [9] proposed, it is natural to generalize the most advanced method Data Hiding by Dual Conjugate Dot Diffusion (DHDCDD) from gray-scale images to color images. Here we propose a halftone visual cryptography method for dot diffused color halftone images, Data Hiding by Dual Color Conjugate Dot Diffusion (DCCDD). During the extension, we also consider a unique property, which color images have and grey-scale images don't have, the inter-channel correlation [11] between different color channels. The inter-channel correlation will be used as a constraint to limit the embedding distortions not to be too excessive. The proposed method can effectively embed a binary secret pattern into two color halftone images which can be generated from different original multitone images. Such that when the two color halftone images are overlaid, the secret pattern will be revealed. With our efforts, two simple but effective technologies of halftone image visual cryptography for dot diffused color halftone images has been developed.

The organization of the paper is as follows: Sect. 2 introduces the related works. Section 3 proposes DCCDD. Section 4 gives the experimental results. Finally, conclusion is given in Sect. 5.

2 Related Works

To introduce the proposed method, here we will first introduce the previous methods, Data Hiding by Conjugate Dot Diffusion (DHCDD) and Data Hiding by Dual Conjugate Dot Diffusion (DHDCDD) [9]. Here are some notations to be used later. Let X_1 and X_2 be the two original gray-scale multitone images. Let Y_1 and Y_2 be the two halftone images to be generated. Let W be the secret pattern to be embedded. Let W_w and W_b be the collections of pixel locations where W is white and black respectively.

In DHCDD, the first halftone image Y_1 will be generated from X_1 by regular dot diffusion. The details of dot diffusion can be referred to [3].

The second halftone image Y_2 will be generated by DHCDD system referencing to Y_1, X_2 and W as shown in Fig. 1.

In DHCDD, for $(i, j) \in W_b$, DHCDD will 'favor' $y_2(i, j)$ to be conjugate to $y_1(i, j)$. For $(i, j) \in W_w$, if $X_1 = X_2$, DHCDD will force $y_2(i, j) = y_1(i, j)$, otherwise DHCDD will favor $y_2(i, j)$ to be identical to $y_1(i, j)$. The 'favor' mechanism works as follows. The system will calculate the minimum distortion to toggle the current pixel if $y_2(i, j) \neq y_1(i, j)$ XNOR $w(i, j)$ (XNOR means Not Exclusive OR operation). If the minimum distortion is less than a certain threshold T, the toggling will be performed and the favored value will be achieved.

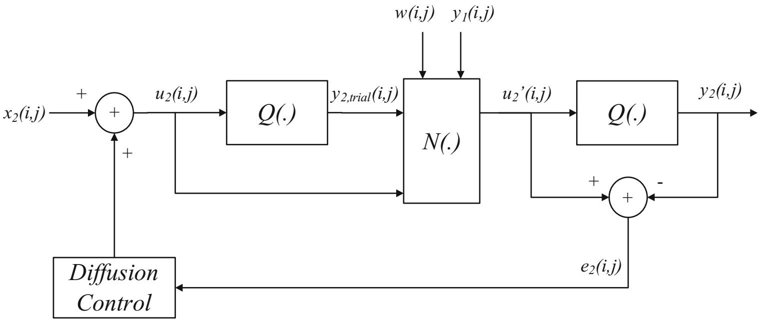


Fig. 1. DHCDD system.

The threshold T controls the tradeoff between visual quality of the stego image and the contrast of the revealed secret pattern. When T decreases, the visual quality of image Y_2 will be improved while the contrast of the revealed secret pattern will decrease.

Next, DHDCDD will be introduced which uses the same favor mechanism as DHCDD. Still we let Y_1 and Y_2 be the two halftone images to be generated. Let W be the secret pattern to be embedded. Let W_w and W_b be the collections of pixel locations where W is white and black respectively.

Unlike DHCDD, DHDCDD will generate the two halftone images simultaneously as the system shows in Fig. 2.

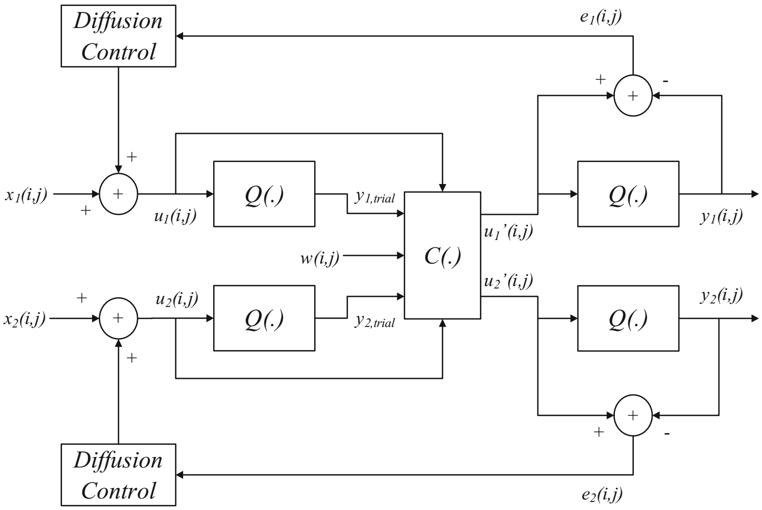


Fig. 2. DHDCDD system.

When the current pixels $x_1(i,j)$ and $x_2(i,j)$ enter the system, it will firstly being quantized to $y_{1,trial}(i,j)$ and $y_{2,trial}(i,j)$ respectively. Then for $(i,j) \in W_b$, DHDCDD will compute two strategies in the computing and comparing block $C(.)$: (1) Let $y_2(i,j)$ be favored to be conjugate to y_1 and 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 calculate the minimum distortion $\Delta u_1(i,j)$. Then the system will select the strategy which derives smaller toggling distortion to be carried out.

For $(i,j) \in W_w$, if $X_1 = X_2$, DHDCDD will force $y_1(i,j)$ and $y_2(i,j)$ to be identical by copying each other alternatively. Otherwise DHDCDD will carry out similar steps as $(i,j) \in W_b$ except that $y_1(i,j)$ and $y_2(i,j)$ are favored to be identical in the two strategies instead of conjugate. The threshold T in DHDCDD will also be used to tradeoff between the visual quality of Y_1 and Y_2 and the contrast of the revealed secret pattern.

3 Proposed Methods

To extend DHDCDD from gray-scale images to color images, firstly, we need to figure out the halftoning process of color images.

For color images, there are many color spaces used. In this paper the color images are all in RGB color space. Then a color image X can be decomposed into $[X_R, X_G, X_B]$ three images. Then the dot diffusion process will be carried out on each of the three images and then it combines them together to form the color halftone image which we intended to obtain.

Next, we will introduce DCCDD system as shown in Fig. 3. We let X_1 and X_2 be the two original color multitone images. Let Y_1 and Y_2 be the two color halftone images to be generated. Let W be the secret pattern to be embedded. Let W_w and W_b be the collections of pixel locations where W is white and black respectively.

In DCCDD, for $(i,j) \in W_b$, we will favor $y_1(i,j)$ and $y_2(i,j)$ to be conjugate to each other i.e. for each pair of $(y_{1,r}(i,j), y_{2,r}(i,j))$, $(y_{1,g}(i,j), y_{2,g}(i,j))$, $(y_{1,b}(i,j), y_{2,b}(i,j))$, the values of each pair are tend not to be the same. For $(i,j) \in W_w$, we will favor $y_1(i,j)$ and $y_2(i,j)$ to be identical to each other. Note that if $X_1 = X_2$, we will force $y_1(i,j) = y_2(i,j)$.

When the current pixels $x_1(i,j)$ and $x_2(i,j)$ enter the system, it will be decomposed to $(x_{1,r}(i,j), x_{2,r}(i,j))$, $(x_{1,g}(i,j), x_{2,g}(i,j))$, $(x_{1,b}(i,j), x_{2,b}(i,j))$. Then for each of them it will go to the trial quantization block to carry out a trial quantization process. Similar to DHDCDD, each pixel channel values will be trial quantized.

After the trial quantization, the trial quantized values, the current pixel channel values added up with previous errors will be sent to the Control Block. The control block will firstly explore that whether the trial values are those values we wanted according to the watermark value $w(i,j)$. Then if some pairs of the trial values are not the values we wanted, the control block will calculate the minimum cost needed for toggle each of the trial values in the pairs. If both of the minimum costs is too excessive, then the toggling won't be performed.

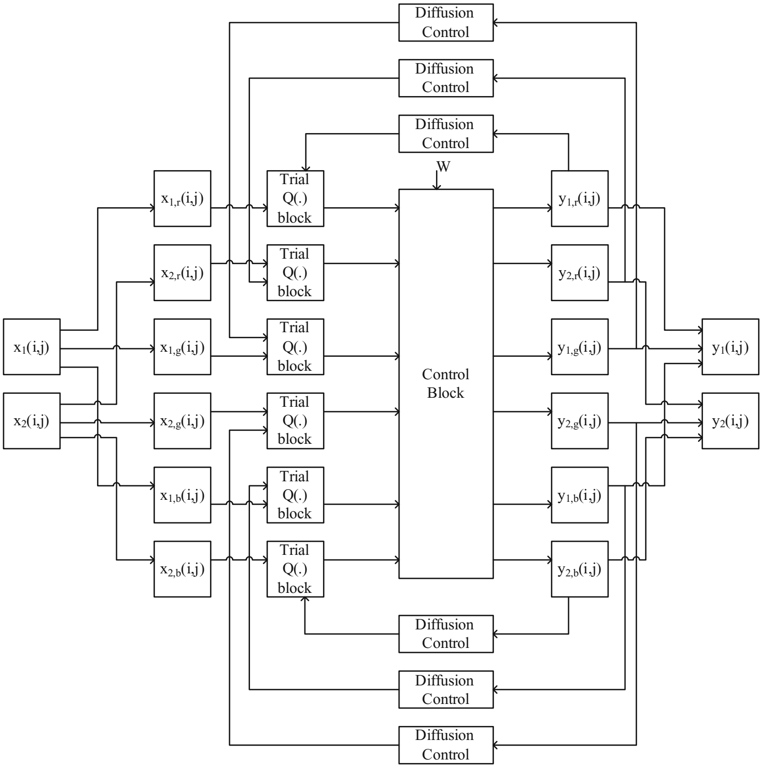


Fig. 3. DCCDD system.

Otherwise the toggling will be performed by toggle the value with lower toggling cost. After the Control Block generate the current halftone pixel values, the quantization errors will be diffused to unprocessed neighboring pixels by using the diffusion control unit.

In DCCDD, two user selected thresholds, T_1 and T_2 are used to control whether the cost is excessive or not. Here T_1 will control the maximum distortions allowed to the current pixel channel value. T_2 will control the maximum distortions allowed to the local inter-channel correlations.

As is known in inter-channel correlation, the absolute channel value differences i.e. $|R-G|$,$|G-B|$,$|R-B|$ tend to be the same in a small local neighborhood. Then if the toggling distortions changes the local inter-channel correlations drastically, attackers may be aware the existence of the watermark by observing the strange behaviors of the local inter-channel correlation. Therefore, the local means of $|R-G|$,$|G-B|$,$|R-B|$ will be calculated respectively and T_2 is used to control the maximum distortions allowed on each of the local means.

People may argue that either T_1 or T_2 is enough to constrain the toggling distortions. However, if only T_1 used, different color channels may be toggling to opposite directions (i.e. the red channel of the $x_1(i,j)$ is toggling from 0 to 1 while the green channel of the $x_1(i, j)$ is toggling from 1 to 0) such that the inter-channel correlations will be changed drastically thus the scheme becomes more crackable. If only T_2 used, then when different color channels toggle to the same direction, the actual allowed distortion may be very large thus it also reduces the security ability of the scheme.

With T_1 and T_2, users can effectively control the tradeoff between the contrast of the revealed secret pattern and the visual quality of the stego color halftone images. When T_1 and T_2 increases, the contrast of the revealed secret pattern will increase while the visual quality of the stego halftone images will decrease.

4 Experimental Results

In the experiments, the sizes of the secret pattern and all the testing images are 512×512. The class matrix uses the 8×8 HVS class matrix proposed in [3]. Figure 4 shows all the five test images and the secret pattern to be embedded. The local neighborhood size used for calculate inter-channel correlation is 3×3.

First, validation of DCCDD is performed in Figs. 5–6 where $T_1 = 10, T_2 = 5$. Figure 5 shows the DCCDD generated Y_1 and Y_2 when $X_1 = X_2 =' Lena'$. Figure 6 shows the decoded result when carry out decoding operation on Fig. 5. As we can observe, Fig. 6(a) is obtained by overlaying (AND operation) Fig. 5(a) and (b) while Fig. 6(b) is obtained by carry out XNOR operation between Fig. 5(a) and (b).

Similarly, validation of DCCDD is also performed in Figs. 7–8 where $T_1 = 15, T_2 = 7$. Figure 7 shows the DCCDD generated Y_1 and Y_2 when $X_1 =' Lena'$ and $X_2 =' Pepper'$. Figure 8 shows the decoded result when carry out decoding operation on Fig. 7. As we can observe, Fig. 8(a) is obtained by overlaying (AND

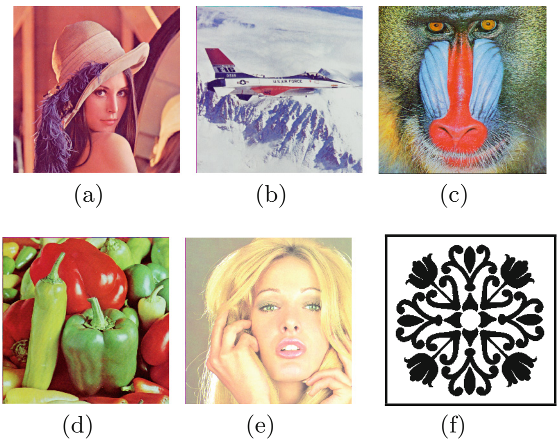


Fig. 4. Original color images and the secret pattern. (a) 'Lena'. (b) 'F16'. (c) 'Baboon'. (d) 'Pepper'. (e) 'Tiffany'. (f) Secret pattern (Color figure online).

(a) (b)

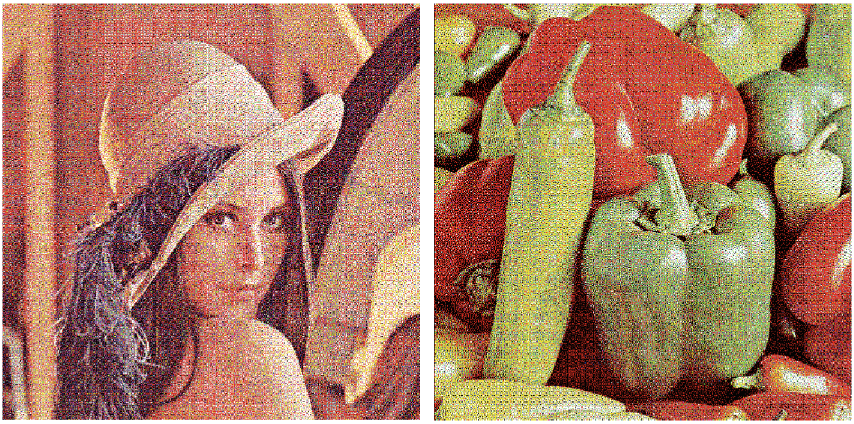
Fig. 5. DCCDD Y_1, Y_2 when $X_1 = X_2$. (a) DCCDD Y_1 (b) DCCDD Y_2.

(a) (b)

Fig. 6. DCCDD AND operation and XNOR operation decoded results when $X_1 = X_2$. (a) DCCDD AND operation decoded result (b) DCCDD XNOR operation decoded result.

operation) Fig. 7(a) and (b) while Fig. 8(b) is obtained by carry out XNOR operation between Fig. 7(a) and (b).

Here the correct decoding rate (CDR) will be used as the objective measurement to measure the similarity between the decoded secret pattern and the original binary secret pattern in order to quantify the contrast of the revealed secret pattern. Currently, there are two simple operations can be applied to decode the secret pattern, Overlaying (AND operation) and XNOR decoding operation.



(a) (b)

Fig. 7. DCCDD Y_1, Y_2 when $X_1 \neq X_2$. (a) DCCDD Y_1 (b) DCCDD Y_2.

(a) (b)

Fig. 8. DCCDD AND operation and XNOR operation decoded results when $X_1 \neq X_2$. (a) DCCDD AND operation decoded result (b) DCCDD XNOR operation decoded result.

Each of them has its own advantage and deficiency. Since the AND operation will provide less contrast while the XNOR operation tend to wrongly decode the pixel value of the secret pattern when $y_1(i,j,k) = y_2(i,j,k) = 0$, we will use both of them to decode the secret pattern and thus measure the CDR.

Let the overlaid/XNOR decoded image be D. The size of D and W are both $p \times q$. For W and each channel of D, the pixel values are binary. Then the CDR is defined as follows.

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

The CDR results are listed in Tables 1–2. Here all the five test images shown in Fig. 4 are used and we set $X_1 = X_2$. From Tables 1–2 we can obtain that the correct decoding rate is increasing when T_1 and T_2 increases i.e. the contrast of the revealed secret pattern of DCCDD is higher when T_1 and T_2 increases.

Although the CDR results numbers looked not very decent especially for the AND operation decoded results, the results are already quite pleasing. Because the secret pattern only has 36.32 % black pixels. The regions where the secret pattern pixels are white will shows the original color stego halftone image pattern when the secret pattern is decoded by AND operation. The XNOR operation tend to wrongly decode the pixel value of the secret pattern when $y_1(i,j,k) = y_2(i,j,k) = 0$. Also, since we are treating the R-G-B channels equally when calculating the CDR, the decoded result will be affected by the original color images. For example, if an original color image has no blue color ($B = 0$), then the final CDR when we are using AND operation to decode will be at most 78.77 %. Even when we are using XNOR operation to decode the secret pattern, the final CDR will be at most 87.89 %.

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

Table 1. DCCDD CDR of the overlaid decoded images

Test image	$T_1 = 5, T_2 = 3$	$T_1 = 10, T_2 = 5$	$T_1 = 15, T_2 = 7$
Lena	0.5471	0.5737	0.5890
Pepper	0.5274	0.5507	0.5647
Baboon	0.5290	0.5534	0.5692
F16	0.5980	0.6190	0.6330
Tiffany	0.5855	0.6013	0.6118

Table 2. DCCDD CDR of the XNOR decoded images

Test image	$T_1 = 5, T_2 = 3$	$T_1 = 10, T_2 = 5$	$T_1 = 15, T_2 = 7$
Lena	0.7257	0.7792	0.8104
Pepper	0.7071	0.7536	0.7820
Baboon	0.7082	0.7574	0.7890
F16	0.6940	0.7357	0.7630
Tiffany	0.6830	0.7140	0.7336

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.

5 Conclusion

In this paper, DCCDD can effectively embed a binary secret pattern into two dot diffused color halftone images such that when the two images are overlaid, the secret pattern will be revealed. By using inter-channel correlation as a constraint when embedding, the security ability of the scheme has been increased. The experimental results validate the proposed method. Also, the observation from the experimental results is consistent with our prediction.

References

1. Bayers, B.E.: An optimum method for two level rendition of continuous tone pictures. In: IEEE International Communication Conference, pp. 2611–2615 (1973)
2. Knuth, D.E.: Digital halftones by dot diffusion. ACM Trans. Graph. **6**, 245–273 (1987)
3. Mese, M., Vaidyanathan, P.P.: Optimized halftoning using dot diffusion and methods for inverse halftoning. IEEE Trans. Image Process. **9**(4), 691–709 (2000)
4. Fu, M.S., Au, O.C.: Data hiding watermarking for halftone images. IEEE Trans. Image Process. **11**, 477–484 (2002)
5. Fu, M.S., Au, O.C.: Data hiding in halftone images by stochastic error diffusion. In: IEEE International Conference on Acoustics, Speech, and Signal Processing, vol. 3, pp. 1965–1968 (2001)
6. Fu, M.S., Au, O.C.: Steganography in halftone images: conjugate error diffusion. Sig. Proc. **83**, 2171–2178 (2003)
7. Pei, S.C., Guo, J.M.: Hybrid pixel-based data hiding and block-based watermarking for error-diffused halftone images. IEEE Trans. Circ. Syst. Video Technol. **13**(8), 867–884 (2003)
8. Fu, M.S., Au, O.C.: Watermarking technique for color halftone images. In: IEEE International Conference on Acoustics Speech and Signal Processing, vol. 3, pp. 381–384 (2004)
9. Guo, Y., Au, O.C., Tang, K., Fang, L. Yu, Z.: Data hiding in dot diffused halftone images. In: IEEE International Conference on Multimedia and Expo, pp. 1–6, 11–15 July (2011)
10. Taheri, O., Attar, A.M., Danesh Panah, M.M.: Hiding data in color halftone images using dot diffusion with nonlinear thresholding. In: IEEE International Conference on Acoustics, Speech, and Signal Processing, vol. 2, pp. II-205–II-208 (2007)
11. Dai, J., Au, O.C., Fang, L., Pang, C., Zou, F., Li, J.: Multichannel non-local means fusion for color image denoising. IEEE Trans. Circ. Syst. Video Technol. **23**(11), 1873–1886 (2013)