Realization and Extension of Data Hiding Methods in Gray-scale Halftone Images

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Abstract. This paper realizes and extends data hiding methods in gray-scale halftone images. Firstly, this paper reviews previous methods of data hiding in gray-scale halftone images. Secondly, this paper realizes and extends these methods. Finally, this paper compares the performance of different methods. According to the experimental results, it can be summarized: the CDRs using dual conjugate property are better than single conjugate property; using Jarvis kernel the reveal pattern has better CDRs than using Floyd-Steinberg kernel; Jarvis kernel the reveal pattern has better CDRs than in dot diffusion halftone images; for gray-scale halftone images, and DHDCED is the best method of previous methods.

Introduction

Halftone image [1] is a special kind of image which only uses two tones (black and white) to represent an image. The process to generate the halftone images is called halftoning process. Many different halftoning methods have been developed, including ordered dithering (OD) [2], error diffusion (ED) [3]–[5], dot diffusion (DD) [6]–[8], direct binary search (DBS) [9]–[10].

Data hiding methods in halftone images is the kind of technologies that embed a secret pattern into two or more halftone images such that when the halftone images are overlaid, the secret pattern will be revealed. In [11], a technique to hide binary visual patterns in two error diffused halftone images is proposed, named Data Hiding by Stochastic Error Diffusion (DHSED). While one halftone image is only a regular error diffused image, stochastic error diffusion is applied to the other image to generate special stochastic characteristics.

In [12], three weaknesses of DHSED [11] are concluded and a novel method called data hiding by conjugate error diffusion (DHCED) is proposed which using conjugate property to hide a visual pattern in two halftone images, and this algorithm is designed to improve the limitations of DHSED, as a result the contrast between the black and white regions of the revealed visual pattern is significantly better than DHSED.

In [13], two halftone image watermarking methods: DHCDD and DHDCDD are proposed. The first method Data Hiding by Conjugate Dot Diffusion (DHCDD) is an extended method from the previous method DHCED [12]. The second method Data Hiding by Dual Conjugate Dot Diffusion (DHDCDD) is an improved method based on DHCDD.

This paper researches the data hiding methods in gray-scale halftone images. Firstly, this paper reviews previous methods of data hiding in gray-scale halftone images. Secondly, this paper realizes and extends these methods. Finally, this paper compares the performance of different methods. According to the experimental results, it can be summarized: the CDRs using dual conjugate property are better than single conjugate property; using Jarvis kernel the reveal pattern has better CDRs than using Floyd-Steinberg kernel; Jarvis kernel the reveal pattern has better CDRs than in dot diffusion halftone images; for gray-scale halftone images, and DHDCED is the best method of previous methods.

The organization of the paper is as follows: Section II introduces the related works. Section III
realizes and extends of data hiding methods. Finally, conclusion is given in Section VI.

Related Works
This paper will review previous methods, include DHCED [12], DHCDD and DHDCDD [13]. In this paper we use $X_1$ and $X_2$ as the original multitone images, and use $Y_1$ and $Y_2$ as the two generated halftone images, and use $W$ as the secret pattern, and use $W_w$ and $W_b$ as the collections of the white pixels and the black pixels in $W$.

DHCED
DHCED [12] hides a secret pattern into gray-scale error diffusion halftone image. The first halftone image $Y_1$ is generated by regular error diffusion with respect to $X_1$. As shown in Equation 1-3.

$$u_i(i, j) = x_i(i, j) + \sum h(k, l) \times e_i(i-k, j-l)$$  \hspace{1cm} (1)

$$y_i(i, j) = \begin{cases} 0, & u_i(i, j) < 128 \\ 255, & u_i(i, j) \geq 128 \end{cases} \hspace{1cm} (2)$$

$$e_i(i, j) = u_i(i, j) - y_i(i, j) \hspace{1cm} (3)$$

When the current pixel $x_i(i, j)$ gets into the system, it will firstly add up with the error $e_i(i,j)$ obtained from previous pixels according to an error diffusion kernel $h$. Then it will be quantized. The quantized value $y_i(i, j)$ will be the halftoned value of the current pixel. The quantization error $e_i(i,j)$ will also be calculated and feedback to future pixels. The second halftone image $Y_2$ is generated by DHDCD 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 in 2.2. 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, DHDEC 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.

DHDCDD
DHCDD [13] is a extend method from DHCED, and DHDCDD hides a secret pattern into gray-scale dot diffusion halftone image. 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 [7]. The second halftone image $Y_2$ will be generated by DHDCDD system referencing to $Y_1, X_2$ and $W$ as shown in Figure 1.

In DHDCDD, for $(i, j) \in W_b$, DHDCDD will ‘favor’ $y_2(i, j)$ to be conjugate to $y_1(i, j)$. For $(i, j) \in W_w$, if $X_1 = X_2$, DHDCDD will force $y_2(i, j) = y_1(i, j)$, otherwise DHDCDD 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 $y_2(i,j) \neq y_1(i,j) \text{XNOR } w(i,j)$ (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.

![Diagram](https://example.com/diagram.png)

Figure 1. DHDCDD system.
The threshold T controls the tradeoff between visual quality of the halftone 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. Dot diffusion effect depends on class matrix, such as $8 \times 8$ HVS class matrix proposed by Mese [7].

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

**DHDCDD**

DHDCDD [20] uses the same favor mechanism as DHCDD. Unlike DHCDD, DHDCDD will generate the two halftone images simultaneously as the system shows in Figure 2.

![Figure 2. DHDCDD system](image)

When the current pixels $x_1(i, j)$ and $x_2(i, j)$ enter the system, it will firstly being quantized to $y_{1,\text{trial}}(i, j)$ and $y_{2,\text{trial}}(i, j)$ 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 $y_1(i, j)$ 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 used.

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.

**Realization and Extension of Data Hiding**

We can extend DHDCDD to error diffusion halftone images, and a method called Data Hiding by Dual Conjugate error Diffusion (DHDCED) can be generated. DHCED, DHCDD, DHDCED, DHDCDD can be realized and compared, and all of these four methods only can be applied in gray-scale halftone images. This paper will analyze experimental results. We will focus on two points: 1) when embedding a secret pattern into two halftone images which are generated from two different original images, which method is the best? 2) Which is better for hiding the secret pattern into error diffusion halftone images and dot diffusion halftone images?

In the experiments, the sizes of the secret pattern and all the testing images are 512×512. Figure 3 shows all the four test images and the secret pattern to be embedded. To compare various methods objectively, here we use Correct Decoding Rate (CDR) to measure the similarity between the
original secret pattern and the revealed hidden pattern, and CDR can also reflect the contrast of the revealed secret pattern, and CDR can be calculated as Equation 4.

\[ CDR = \sum w(i, j) \cdot XNOR \cdot d(i, j) \cdot |p \times q| \]  

(4)

Experimental results of various methods are shown in Table 1. Let \( T_w \) be the threshold of the white pixels in \( W \). Let \( T_b \) be the threshold of the black pixels in \( W \). When \( X_1 \neq X_2 \), for gray-scale halftone images, let \( X_1 = \) ‘Lena’-gray (Figure 5(a)) and \( X_2 = \) ‘Mandrill’-gray (Figure 5(b)), and CDR results are shown in column 5-6. From the results the performance of various methods is mainly reflected in the situation of \( X_1 \neq X_2 \) which means two halftone images generated from two different original multitone images. The results also can be shown in Figure 4.

Table 1. Experimental results of various methods.

<table>
<thead>
<tr>
<th>Name of Algorithm</th>
<th>Halftoning method</th>
<th>Halftone image type</th>
<th>Characteristic of methods</th>
<th>CDR (( X_1 \neq X_2 ), ( T_w=T_b=15 ))</th>
<th>CDR (( X_1 \neq X_2 ), ( T_b=15, T_w=35 ))</th>
</tr>
</thead>
<tbody>
<tr>
<td>DHCED (Jarvis)</td>
<td>error diffusion</td>
<td>gray-scale</td>
<td>conjugate</td>
<td>0.7572</td>
<td>0.7972</td>
</tr>
<tr>
<td>DHCED (floyd-steinberg)</td>
<td>error diffusion</td>
<td>gray-scale</td>
<td>conjugate</td>
<td>0.6433</td>
<td>0.7448</td>
</tr>
<tr>
<td>DHDEC (Jarvis)</td>
<td>error diffusion</td>
<td>gray-scale</td>
<td>dual conjugate</td>
<td>0.7881</td>
<td>0.8300</td>
</tr>
<tr>
<td>DHDEC (floyd-steinberg)</td>
<td>error diffusion</td>
<td>gray-scale</td>
<td>dual conjugate</td>
<td>0.7337</td>
<td>0.7918</td>
</tr>
<tr>
<td>DHCDD</td>
<td>dot diffusion</td>
<td>gray-scale</td>
<td>conjugate</td>
<td>0.6578</td>
<td>0.7470</td>
</tr>
<tr>
<td>DHDCDD</td>
<td>dot diffusion</td>
<td>gray-scale</td>
<td>dual conjugate</td>
<td>0.7283</td>
<td>0.8050</td>
</tr>
</tbody>
</table>

Figure 4. Comparisons of various methods’ CDR.

From the Figure 4 we can summarize: (1) whether in error diffusion halftone images or in dot diffusion halftone images, the CDRs using dual conjugate property are better than single conjugate
property; (2) Using Jarvis kernel the reveal pattern has better CDRs than using Floyd-Steinberg kernel; (3) Using Jarvis kernel the reveal pattern has better CDRs than in dot diffusion halftone images; (4) For gray-scale halftone images, when X₁≠X₂ and using Jarvis kernel, DHDCED is the best method of previous methods.

Conclusion

This paper researches the data hiding methods in Gray-scale Halftone Images. Firstly, this paper reviews previous methods of data hiding in gray-scale halftone images. Secondly, this paper realizes and extends these methods. Finally, this paper compares the performance of different methods. According to the experimental results, it can be summarized: the CDRs using dual conjugate property are better than single conjugate property; using Jarvis kernel the reveal pattern has better CDRs than using Floyd-Steinberg kernel; Jarvis kernel the reveal pattern has better CDRs than in dot diffusion halftone images; for gray-scale halftone images, and DHDCED is the best method of previous methods.

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