A High Visual Quality Embedding Method in Edges Based on Pixel Pair Difference

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ABSTRACT
In this paper, we proposed a new data hiding method based on diamond encoding (DE) and pixel pair difference (PPD). DE proposes a pixel-wise algorithm which flexibly embeds different base digits to maximize payload and image visual quality. During DE embedding, digits embed in sequence without separately consider smooth areas and complex areas. We propose a method based on human visual system in that human eyes are more sensitive to the change of smooth areas where pixel pairs possess less difference. Embedding secret message in complex areas insignificantly affects visual quality of the image, correspondingly makes the stego image less detectable. The proposed method uses PPD to adaptively embed secret message in complex areas and thus improves DE performance. Experimental results illustrate that our algorithm has the same distortion with DE but provides a better visual quality of stego image.

Categories and Subject Descriptors
I.4.9 [Image Process and Computer Vision] : Applications

General Terms

Keywords
Data hiding, Diamond encoding, Pixel pair difference, Human visual system, Switch division algorithm.

1. INTRODUCTION
Data hiding is embedding secret data (text, image, etc.) into digital media to transmit data secretly. The digital media, referred to various types of media, is used to “cover” the secret. After embedding, the cover that contains information is called “stego”. To make secret information as undetectable as possible, the difference between cover and stego should be minimized.

The LSB method is a well-known data hiding method. This method simply replaces the least significant bits (LSB) of cover pixel with secret data via a small amount of calculation. Inspired by essential LSB philosophy, many advanced schemes are derived, such as Optimal Pixel Adjustment Process (OPAP) [1] and LSB Matching (LSBM). Each data hiding scheme contributes a further development since the image distortion is greatly reduced. One remarkable improvement is pair-wise embedding technique [3]. This technique exploits a pair of pixels as a unit for embedding a digit in a specific base. LSB Matching Revisited (LSBMR) [7], Exploiting Modification Direction (EMD) [11] and Diamond Encoding (DE) [2] are representative schemes. In these pair-wise embedding techniques, the produced visual quality of stego images is still limited since the same amount of data bits are embedded into pixels. Recently some methods embed different amounts of data bits into pixels based on human visual system (HVS). Pixel Value Difference (PVD) [9] and its variant, MF-PVD [8], EA-PVD [10], APPM [4] and DE-MBNS [5] are of these types which adaptively embed secret digits in multiple bases which minimize the distortion while maximize the visual quality.

Among the aforementioned methods, DE and PVD scheme are the foundation to increase embedding efficiency because of pair-wise and multiple-base philosophy. This paper exploits the essential idea of PVD and proposes a new method based on DE and PPD. The distortion caused by embedding in the proposed method is less detectable compared with that of the DE method. In the rest of this paper, we first briefly introduce DE method in Section 2. Section 3 is the demonstration of proposed method. We suggest a switch division algorithm (SDA) to find the stego pixel pairs with minimize difference. All the experimental results are presented in Section 4. The end is conclusion section.

2. DIAMOND ENCODING
DE method embeds one digit $S$ into two pixels by using $l$-ary notation system. The parameter $l$ is calculated by

$$l = 2k^2 + 2k + 1,$$  (1)

where $k$ is the embedding parameter. Firstly, the original images generate non-overlapping diamond blocks of two consecutive pixels $(a, b)$. Each diamond characteristic value (DCV) is computed by the following equation:

$$f(a, b) = \text{mod}((2k + 1)a + b, l),$$  (2)

where $f(a, b)$ also defined as extraction function. Suppose each diamond block consists of a neighborhood set $S_k(p_{1,1}, p_{1,2})$. This set represents all the pixel vectors $(p_{1,1}, p_{1,2})$ with the distance to vector $(a, b)$ smaller than $k$. The vectors $(p_{1,1}, p_{1,2})$ can be calculated by

$$S_k(p, q) = \{(a - b) \mid |p_{1,1} - a| + |p_{1,2} - b| \leq k\}.$$  (3)
Secondly, the DE method searches the DCV in set \( S_k(p_{1,1}, p_{1,2}) \) to find a vector \((p_{1,1}', p_{1,2}')\) which the DCV is equal to \(S_k\). Then replace the cover pixel \((a, b)\) by \((p_{1,1}', p_{1,2}')\). The difference between cover pixel and stego pixel is never larger than \(k\) by applying DE scheme which has been determined by the diamond search block.

Secret digit can be simply extracted by employing the extraction function with stego pixel pair \((p_{1,1}', p_{1,2}')\). For clearly explanation of DE, here we use a figure to illustrate diamond block in different \(k\).

Here is a simple example for the DE method. Suppose \(k=2\) and use eq. (1) to get the base \(l=13\). Assume the secret digits 1, 2, and \(S_{13}\) will be embedded into cover pixel pairs (3, 12) and (4, 7), respectively. DCV of (3, 12), which can be computed from eq. (2), is 1. Since the DCV is equal to secret digit 1, the stego pixel pair is the same as cover pixel pair. Likewise, for the second secret digit, the DCV of (4, 7) is 3. Since the DCV is not equal to secret digit 3, replacing the cover pixel pair (4, 7) by (6, 7) of which the DCV is 5. After diamond encoding, the stego pixel are (3, 12) and (6, 7). The procedure is illustrated in figure 2. The embedded digits can be extracted from stego pixel pair (3, 12) and (6, 7) by using the extraction function eq. (2).

The proposed method uses the absolute difference \(d_i = |p_{1,1} - p_{1,2}|\) of pixel pairs, which we named as PPD, to distinguish the smooth areas and complex areas. To minimize the distortion, pixel value in range \([0, 255]\) is divided into two divisions by a threshold parameter \(T\) in figure 3. Pixel pairs with difference smaller than \(T\) are classified into the un-embeddable division, where no secret digit is embedded. Therefore the stego pixels are the same as the cover pixels without any distortion. Contrary to the un-embeddable division, pixel pairs with difference more than \(T\) are divide into the embeddable division, in which efficiently embeds the secret digits by DE scheme.

Since the proposed method embeds secret digits in the pixel pairs with difference larger than a threshold \(T\), our proposed method requires determining a largest \(T\) such that all the secret digits can just be embedded.

Let \(N_d(T)\) be the number of pixel pairs \((p_{1,1}, p_{1,2})\) satisfying \(d_i = |p_{1,1} - p_{1,2}| > T\). To embed \(|S|\) secret digits \(S\), where \(|S|\) is the length of \(S\), we simply find the largest \(T\) satisfying \(N_d(T) \geq |S|\). The threshold \(T\) can be easily solved by calling bisection method or other equation solving method.
the lowest distortion while satisfying \(|p_{1,1}' - p_{1,2}'| < T\). The best \((p_{1,1}', p_{1,2}')\) can be obtained by solving the optimization problem:

\[
\text{Minimize } (p_{1,1} - p_{1,2})^2 + (p_{1,2} - p_{1,2})^2
\]

Subject to: \(|p_{1,1}' - p_{1,2}'| < T\)

Once SDA scheme implemented, it is not hard to conclude the \((p_{1,1}', p_{1,2}')\) always located around the middle of \(p_{1,1}\) and \(p_{1,2}\).

### 3.3 Embedding Procedure

Let \(I\) be the cover image of size \(M_1 \times M_2\), and \(S\) be the secret digits of length \(|S|\). The embedding procedures are listed as following:

**Step 1.** Partition the cover image into non-overlapping pixel pair \(l = \{(p_{1,1}, p_{1,2}), 1 \leq i \leq N\}\), where \(N\) is the total number of pixel pairs. Calculate the threshold \(T\) to define division to which each pixel pair belongs, as described in Section 3.1.

**Step 2.** Process the embedding algorithm. For each pixel pair \((p_{1,1}, p_{1,2})\), if \(d_i \leq T\), the pixel pair is classified in the un-embeddable division. As a result, we skip embedding and set the stego pixel pair \((p_{1,1}', p_{1,2}') = (p_{1,1}, p_{1,2})\); if \(d_i > T\), the pixel pair is in embeddable division, embedding one secret digit by DE method and obtain a stego pixel pair \((p_{1,1}', p_{1,2}')\). Else \(d_i' = |p_{1,1}' - p_{1,2}'| \leq T\), switch \((p_{1,1}, p_{1,2})\) to un-embeddable division using the proposed SDA.

**Step 3.** Take the next cover pixel pair and repeat step 2 until all \(|S|\) secret digits are embedded.

### 3.4 Extraction Procedure

Once obtain the stego image \(I'\), threshold \(T\), \(|S|\), the embedded digits \(S\) can be extracted by eq. (2). The detail steps are listed as following:

**Step 1.** Partition the stego image into non-overlapping pixel pair \((p_{1,1}', p_{1,2}')\), where \(1 \leq i \leq N\).

**Step 2.** Use the same scanning order as in the embedding procedure to obtain the difference \(d_i' = |p_{1,1}' - p_{1,2}'|\). If \(d_i' \leq T\), the pixel pair is in un-embeddable division, and no secret is embedded, move to next stego pixel pair; if \(d_i' > T\), the pixel pair is in embeddable division, extracting one secret digit using eq. (2), \(S = f(p_{1,1}', p_{1,2}')\).

**Step 3.** Take the next stego pixel pair and repeat step 2 until all \(|S|\) secret digits are extracted.

### 3.5 Simple Example

The aforementioned example is referred to explain our procedure. Let cover pixel pairs be \((3, 12)\) and \((4, 7)\). Secret digits are \(1_{13}\) and \(5_{13}\). Supposed \(k = 2\), \(T = 2\), as showed in figure 4.

Since \(d_1 = |3 - 12| = 9 > T\), \((3, 12)\) sits in embeddable division. We have \(DCV = f(3, 12) = 1_{13}\), thus stego pixel pair is the same as cover pixel. As a result, stego pixle pair \((3, 12)\) is still located in embeddable division. For the pixel pair \((4, 7)\), \(d_2 = |4 - 7| = 3 > T\). \((4, 7)\) sits in embeddable division. \(DCV = f(4, 7) = 3 = 5_{13}\). Use DE scheme get \(DE(4, 7) = (6, 7)\). After doing this, stego pixel pair \((6, 7)\) switches into un-embeddable division since \(d_2' \leq T\). Therefore we recalculate stego pixel pair use SDA and obtain SDA(4,7) = (5,6) By only applying DE method, the the difference between cover pixel pair \((4, 7)\) and stego pixle pair \((6, 7)\) is 4. But by applying our proposed algorithm, the difference between cover pixel pair \((4, 7)\) and stego pixle pair \((5,6)\) is only 2.

### 4. EXPERIMENTAL RESULTS

In this section, several experiments are performed to analyze proposed method and compare with the Diamond Encoding method in terms of image quality, PSNR and SSIM [6]. SSIM is employed to measure the similarity of two images. The value of SSIM is within the range \([-1, 1]\). The more SSIM value close to 1, the more two images are similar to each other. Three standard gray images will be referred as cover images, including Lena, Lighthouse and Baboon, as shown in figure 5. All images are \(512 \times 512\) pixels and were obtained from SIPI image databases and internet, respectively.

![Figure 4. Illustration of proposed method](image)

![Figure 5. Three standard images](image)

In figure 6, we show the comparison result of the difference of cover images and stego images by applying proposed method in the order of Lena, Lighthouse and Baboon.
(a) ~ (c) are 10,000 digits payload and (e) ~ (f) are 50,000 digits payload. To obtain these secret digits, we randomly create a secret sequence to embed. We use $k = 2$ in the experiments. DE scheme embeds secret in sequence while proposed scheme embeds adjustably due to PPD. The white spots mean embedded position while black spots do not embed secret, and the embedding location shows that the complexity of cover image influences the embedding location.

Table 1. Comparison result of PSNR and $T$.

<table>
<thead>
<tr>
<th>Image</th>
<th>Payload=10,000 (digits)</th>
<th>Payload=50,000 (digits)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>PSNR(dB)</td>
<td>$T$</td>
</tr>
<tr>
<td>Lena</td>
<td>59.07</td>
<td>13</td>
</tr>
<tr>
<td>Lighthouse</td>
<td>60.70</td>
<td>41</td>
</tr>
<tr>
<td>Baboon</td>
<td>58.94</td>
<td>57</td>
</tr>
</tbody>
</table>

Table 1 summarizes the PSNR and $T$ of three standard images with various payloads by using proposed method. First, we compare the same cover image with different payloads. As expected, the growth of $T$ dose depends on the value of payload. At the same time, the white points increase. Second, we compare the same payload with different cover images. The more complexity of cover image, the larger $T$ generates.

Figure 7. Comparison result of Lighthouse.

(a) Diff. of DE Scheme (b) Diff. of Proposed Method
(c) Stego of DE Scheme (d) Stego of Proposed Method

Figure 7 indicates the comparison result of Lighthouse produced by DE method and proposed scheme. (a) and (b) are differences of cover images and stego images. (c) and (d) are stego images. Let $k = 30$, we embed the same payload with 80,000 secret digits into Lighthouse. The difference between the cover image and stego image indicates that the DE scheme only embed the upper part of cover image in turn. On the other hand, our proposed method adjustably embeds secret digits into the complex pixel pairs. The difference of stego image between DE scheme and proposed scheme is visually different. Meanwhile, the SSIM of DE scheme is smaller than the SSIM of proposed scheme, which means proposed method improves the visual quality greatly.

5. CONCLUSION

This paper proposed a data embedding method with the consideration of human visual system based on DE and PPD scheme. Two pixels are scanned as an embedding unit and conceal digits adaptively according to the absolute difference of pixel pairs. The contributions of the proposed method are summarized as follows. Firstly, our proposed method embeds data in all pixel pairs distinctively among smooth areas and complex areas which improve the image visual quality. Secondly, our proposed method raises a SDA to detect the to-be-destroyed pixel pairs then switch them to un-embeddable division with minimal distortion. The experimental results reveal the improvement which could be discovered visually.

6. REFERENCES