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# A New Reversible Data Hiding Scheme with Improved Capacity Based on Directional Interpolation and Difference Expansion

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**Abstract**

Using reversible data hiding (RDH) we can hide our secret data into a cover image and the receiver can restore both the secret data and the original image. It has wide application in medical imagery, military imagery where no distortion of original cover is allowed. Hong and Chen proposed a RDH scheme based on interpolation and histogram shifting. In their scheme reference pixels are not used for data embedding which leads to low capacity. Huang *et al.* modified this scheme and proposed a high capacity RDH scheme in which prediction errors are used for data embedding. In this paper we propose a further modification to the scheme of Huang *et al.* based on directional interpolation. Directional interpolation yields a better approximation to the original pixel which improves the capacity of embedding. The effectiveness of the proposed scheme is tested using standard test images and the proposed scheme gives better results in terms of embedding capacity and visual quality compared to Huang *et al.* scheme.


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*Keywords:* *Difference expansion; Interpolation; Reversible data hiding; Visual quality*

## 1. Introduction

Protection of data transmitted over the Internet is a challenging research area. Data hiding is an approach that conceals secret data into a cover image. Embedding process will change the original cover image but the distortion is

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imperceptible to the human visual system. Data hiding techniques are commonly classified into two categories namely reversible and irreversible. As the name indicates, in reversible data hiding receiver can restore both the secret data and the original image. So that sometimes this technique is called loss-less data hiding. Images in many applications like medical imagery, military imagery and satellite imagery allow no distortion. Quality of the stego image and the payload capacity are the two parameters deciding the performance of an RDH scheme. When the embedding rate is high then the quality of the stego image will be less and vice versa.

Lately, several RDH schemes have been developed. Most of the schemes are based on difference expansion (DE) and histogram shifting. Tian suggested a data hiding scheme[1] based upon DE. In his method difference between two adjacent pixels are computed and this difference is doubled, so that the secret bit can be embedded in to the even value. Visual quality of Tian scheme is high but capacity is less. Alattar proposed a scheme[2] which is based on integer transform and their capacity is higher than Tian method. In 2011, Liu et al proposed a RDH technique based on bilinear interpolation and difference expansion[3]. In their scheme, in a single cover pixel, two secret bits can be embedded. Histogram modification is another technique used for data hiding. Ni *et al*. proposed a data hiding method[4] based on histogram modification. In their scheme maximum change made to a pixel is 1, so that quality of the stego image is high but the hiding capacity is less. In 2011, Hong and Chen proposed a reversible data hiding based on interpolation and histogram modification[5]. In their scheme, cover image is divided into complex block and smooth block. Smooth block is only used for data embedding so that it produces a high quality stego image. Huang *et al.* modified Hong and Chen method in 2013 and proposed a high capacity RDH scheme based on interpolation and difference expansion[6].

In this paper we propose an enhanced hiding scheme to improve Huang *et al.*'s scheme where prediction errors are utilized for data embedding. Data is embedded in a pixel if the prediction error is less than a predetermined threshold. We use directional interpolation for a more accurate prediction reducing the prediction error and thereby finding more embeddable number of pixels. Hence, the capacity of the proposed scheme is high. To test the effectiveness of the proposed scheme, we used some standard test images like Lena, Boats *etc* and the proposed scheme gives better results compared to Huang *et al.*'s scheme.

The rest of the paper is structured as follows. Section 2 discusses our proposed data hiding scheme. Experimental results are stated and analyzed in section 3. Concluding remarks are given in section 4.

## 2. Proposed RDH scheme

In the proposed scheme, the pixels in a cover image $C$ sized $N \times N$ are classified into two types namely reference pixels and embeddable pixels. Prediction value of all embeddable pixels is computed from its neighboring reference pixels. Data is embedded in a pixel if the prediction error is less than a predetermined threshold. Otherwise, the scheme performs a histogram shift operation. In order to increase the payload capacity, the proposed scheme embeds secret bits into the reference pixels too.

The proposed scheme has two phases- the data embedding phase and the secret extraction and image recovery phase, which have been explained in the following subsection.

### *2.1. Data embedding phase*

In this scheme, the pixels in a cover image are classified into two categories namely reference pixels (*RP*), and embeddable pixels *(EP)* as shown in Fig.1. The following pseudo-code is used for the classification of pixels into *EP*s and *RP*s.

| | | | |
|---|---|---|---|
| $RP_1$ | $EP_1$ | $RP_2$ | $EP_2$ |
| $EP_3$ | $EP_4$ | $EP_5$ | $EP_6$ |
| $RP_3$ | $EP_7$ | $RP_4$ | $EP_8$ |
| $EP_9$ | $EP_{10}$ | $EP_{11}$ | $EP_{12}$ |

Fig.1. Classification

```
for   i = 1 : N  do
      if  i  is even then  select all pixels in the ith row of C as embeddable pixel (EP)
      if  i  is odd then
              for   j = 1 : N  do
                      if  j  is even then  select C(i,j) as embeddable pixel (EP)
                      else select C(i,j) as reference pixel (RP)
              end
end
```

After determining the *RP*s and *EP*s, perform the interpolation operation and compute the interpolated values (*IP*s). Prediction value of all embeddable pixels is computed from its neighboring reference pixels in a 3 × 3 block as shown in Fig.2.

| | | |
|---|---|---|
| $RP_1$ | $EP_1$ | $RP_2$ |
| $EP_2$ | $EP_3$ | $EP_4$ |
| $RP_3$ | $EP_5$ | $RP_4$ |

⇨

| | | |
|---|---|---|
| $RP_1$ | $IP_1$ | $RP_2$ |
| $IP_2$ | $IP_3$ | $IP_4$ |
| $RP_3$ | $IP_5$ | $RP_4$ |

$$IP_1 = (RP_1 + RP_2) / 2$$
$$IP_2 = (RP_1 + RP_3) / 2$$
$$IP_4 = (RP_2 + RP_4) / 2$$
$$IP_5 = (RP_3 + RP_4) / 2$$

Fig.2. Interpolation

For interpolating $EP_3$ we use the directional interpolation[7] proposed by Luo *et al.* In this method the prediction value is calculated as a weighted sum of two directional interpolation values along $45^0$ diagonal and $135^0$ diagonal as shown in Fig.3. The weights are determined to minimize the mean squared error between the original pixel and its interpolated value.

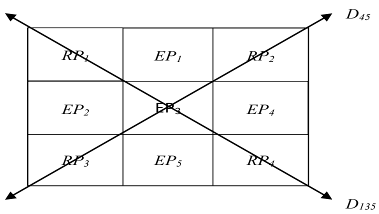


Fig.3. Directional Interpolation

$$IP_3 = w_{45} \times D_{45} + w_{135} \times D_{135} \tag{1}$$

$D_{45}$ , $D_{135}$ are the directional interpolation values and $w_{45}$ and $w_{135}$ are the corresponding weights, which are computed as follows.

$$D_{45} = \frac{(RP_2 + RP_3)}{2} \tag{2}$$

$$D_{135} = \frac{(RP_1 + RP_4)}{2} \tag{3}$$

$$w_{45} = \frac{\sigma(e_{135})}{\sigma(e_{45}) + \sigma(e_{135})} \tag{4}$$

$$w_{135} = \frac{\sigma(e_{45})}{\sigma(e_{45}) + \sigma(e_{135})} \tag{5}$$

where $e_{45}$ and $e_{135}$ represent the interpolation error along these two directions and $\sigma(e_{45})$ and $\sigma(e_{135})$ represent the variance estimations of $e_{45}$ and $e_{135}$ respectively, which are calculated as follows.

$$e_{45} = D_{45} - EP_3 \tag{6}$$

$$e_{135} = D_{135} - EP_3 \tag{7}$$

$$\sigma(e_{45}) = \frac{1}{3}\sum_{k=1}^{3}(S_{45}(k) - \mu)^2 \tag{8}$$

where $S_{45}(k) = RP_2, D_{45}, RP_3$ *for* k=1, 2, 3 and $\mu$ denotes the Mean value of $EP_3$ which is calculated as

$$\mu = (RP_1 + RP_2 + RP_3 + RP_4)/4 \tag{9}$$

$$\sigma(e_{135}) = \frac{1}{3}\sum_{k=1}^{3}(S_{135}(k) - \mu)^2 \tag{10}$$

where $S_{135}(k) = RP_1, D_{135}, RP_4$ *for* k=1, 2, 3 and $\mu$ denotes the Mean value of $EP_3$

It can be seen that the weights $w_{45}$ and $w_{135}$ are calculated in such a way that the direction having higher variance is given less weightage and direction having lower variance is given more weightage, so it gives a better prediction than simple average.

After finding all interpolated pixels, calculates the difference $d_l$ which gives the prediction error between each embeddable pixel value $EP_l$ and its corresponding interpolated value $IP_l$. The value of difference $d_l$ ranged in [-T, T] is used for data embedding, where T is a threshold shared by both the sender and the receiver. Chang *et al.*'s method[8] is used to set the threshold. If the absolute value of $d_l$ is smaller than or equal to T, the scheme embed one bit of the secret data '*s*' using the following equation.

$$EP_l' = IP_l + 2 \times d_l + s \tag{11}$$

where $EP_l'$ represents the stego pixel and $s \in \{0,1\}$.

From Eq.11 it is clear that $2 \times d_l$ produces an even number whether the difference $d_l$ is odd or even, so that we have space to conceal one bit of binary information '*s*' after expanding the difference by a factor 2.

The absolute value of $d_l$ larger than T, indicates that the pixel is non-embeddable. If the pixel is non-embeddable then perform a histogram shift using Eq.12.

$$EP_l' = \begin{cases} EP_l + (T+1) & d_l \geq 0 \\ EP_l - (T+1) & d_l < 0 \end{cases} \quad (12)$$

After embedding the secret bits into the embeddable pixels, this scheme embeds secret data into the reference pixels $RP_k$ also and the embedding method is as follows.

- Calculate the difference $d_k$ between $RP_k$ and its right pixel $EP_k'$
- If the absolute value of $d_k$ is smaller than T, we can embed one bit of the secret data *'s'* using Eq.13.

$$RP_k' = EP_k' + 2 \times d_k + s \quad (13)$$

- If the absolute value of $d_k$ is larger than T, then $RP_k$ *i*s shifted using Eq.14

$$RP_k' = \begin{cases} RP_k + (T+1) & d_k \geq 0 \\ RP_k - (T+1) & d_k < 0 \end{cases} \quad (14)$$

After all the secret bits have been embedded the resulting stego image can be transmitted to the receiver.

*2.2. Data extraction and image recovery*

To perform successful extraction, threshold T must be available to the receiver. When receiver receives the stego image, the stego pixels are classified as the reference pixels and embeddable pixels in the same way as done in the data embedding phase. Receiver first extract secret data from the reference pixels and the procedure is listed below.

- Calculate the difference $d_k'$ between the stego reference pixel $RP_k'$ and its right pixel $EP_k'$.
- If $|d_k'| \leq 2 \times T + 1$, which indicates the pixel $RP_k'$ carries a secret data. We can extract the secret bit '*s*' using Eq.15 and recover the original $RP_k$ using Eq.16.

$$s = mod(d_k', 2) \quad (15)$$

$$RP_k = \begin{cases} EP_k' + \left\lfloor \frac{|d_k'|}{2} \right\rfloor & if\ RP_k' \geq EP_k' \\ EP_k' - \left| \left\lfloor \frac{d_k'}{2} \right\rfloor \right| & otherwise \end{cases} \quad (16)$$

- If $|d_k'| > 2 \times T + 1$, the reference pixel does not carry a secret data. The original pixel $RP_k$ is recovered by reversing the histogram shift using Eq.17

$$RP_k = \begin{cases} RP_k' - (T+1) & if\ RP_k' \geq EP_k' \\ RP_k' + (T+1) & otherwise \end{cases} \quad (17)$$

In the first pass this scheme recovers all the reference pixels using Eq.16 and 17. Using these reference pixels the receiver also performs the same interpolation operation and obtains the interpolation pixels $IP_l'$. Then this scheme computes the difference $d_l'$ between $EP_l'$ and $IP_l'$. If $|d_l'| \leq 2 \times T + 1$, then the secret bit is extracted from embeddable pixel using Eq.18 and original pixel is restored using Eq.19.

$$s = mod(d_l', 2) \quad (18)$$

$$EP_l = \begin{cases} IP_l' + \left\lfloor \frac{|d_l'|}{2} \right\rfloor & if\ EP_l' \geq IP_l' \\ IP_l' - \left| \left\lfloor \frac{d_l'}{2} \right\rfloor \right| & otherwise \end{cases} \tag{19}$$

If $|d_l'| > 2 \times T + 1$, then $EP_l'$ does not carry a secret bit and we can restore the original pixel by reversing the histogram shift using Eq.20.

$$EP_l = \begin{cases} EP_l' - (T+1) & if\ EP_l' \geq IP_l' \\ EP_l' + (T+1) & otherwise \end{cases} \tag{20}$$

*2.3. Extra data for underflow/overflow*

Original pixels having grayscale values in the range [0, T] and [255-T, 255] may generate an overflow or underflow. To avoid an underflow original pixels less than T+1 is modified as T+1 and to avoid overflow original pixel is larger than 255- (T+1) is modified as 255- (T+1). We need to record the position (location) information of these modified pixels and the last $\lceil log_2 T + 2 \rceil$ bits of the original pixel. This extra information is also embedded into the cover image.

## 3. Experimental results

Four standard grayscale images (Lena, sailboat, airplane, boat) of size $512 \times 512$ are used to test the effectiveness of the proposed scheme. Secret data composed of bits '0' and '1' are randomly generated by MATLAB function. The Peak Signal-to-noise ratio (PSNR) and the structural similarity index (SSIM) are the two metrics used to assess the stego image quality. Table 1 shows the comparison result and it shows the pure hiding capacity (bits), PSNR and SSIM of these test images for different values of threshold T. It can be observed that the proposed method provides a higher embedding capacity for all cases and it can also be noted that PSNR and SSIM values are improved slightly. Fig.4. shows the original cover images and its stego images (Lena and Boat), their PSNR values are higher than 30 dB. Normally the image degradation between the cover and stego images cannot be observed by the human eye when the PSNR value crosses 30 dB.

(a) (b) (c) (d)

Fig.4. (a) cover image (b) stego image with capacity 250,343 bits and PSNR 34.096 dB (c) cover image (d) stego image with capacity 233,918 bits and PSNR 31.604 dB

Table 1. Comparison of the proposed scheme with RDH scheme[6]

| Image | Scheme | T= 4 | | | T= 6 | | | T= 10 | | | T= 14 | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Capacity | PSNR | SSIM | Capacity | PSNR | SSIM | Capacity | PSNR | SSIM | Capacity | PSNR | SSIM |
| Lena | Huang *et al* | 201,660 | 38.529 | 0.9923 | 223,224 | 36.963 | 0.9908 | 241,598 | 35.108 | 0.9892 | 249,763 | 33.923 | 0.9884 |
| | Proposed | **202,780** | **38.567** | **0.9923** | **224,306** | **37.023** | **0.9909** | **242,437** | **35.201** | **0.9893** | **250,343** | **34.096** | **0.9885** |
| Sailboat | Huang *et al* | 133,942 | 36.312 | 0.9922 | 166,577 | 34.215 | 0.9891 | 206,628 | 31.782 | 0.9847 | 227,687 | 30.373 | 0.9818 |
| | Proposed | **134,744** | **36.341** | **0.9922** | **167,368** | **34.273** | **0.9892** | **207,168** | **31.803** | **0.9848** | **228,096** | **30.419** | **0.9820** |
| Airplane | Huang *et al* | 201,917 | 38.692 | 0.9942 | 221,022 | 37.022 | 0.9931 | 238,422 | 34.961 | 0.9915 | 246,811 | 33.614 | 0.9905 |
| | Proposed | **202,878** | **38.715** | **0.9943** | **221,959** | **37.068** | **0.9931** | **239,180** | **35.038** | **0.9916** | **247,297** | **33.768** | **0.9906** |
| Boat | Huang *et al* | 169,271 | 37.303 | 0.9939 | 194,232 | 35.387 | 0.9923 | 220,409 | 33.024 | 0.9898 | 233,479 | 31.534 | 0.9882 |
| | Proposed | **169,902** | **37.321** | **0.9939** | **194,802** | **35.406** | **0.9924** | **220,869** | **33.168** | **0.9899** | **233,918** | **31.604** | **0.9883** |

The proposed scheme is completely reversible as shown in Fig.5. We are taking the difference of original cover image and its recovered image, Fig.5(c) shows a complete black image which means both the images are same.

(a) (b) (c)

Fig.5. (a) Cover image (b) Recovered image (c) Difference between the original and recovered image

## 4. Conclusion

This paper proposes a new RDH technique based on directional interpolation and difference expansion. Directional interpolation reduces the prediction error so that number of embeddable pixels is increased. Hence the embedding capacity of the proposed scheme is very high. After extracting the secret data restoration of the original image is done without any distortion. As shown in Table.1, with respect to the embedding capacity and visual quality our method gives better results than Huang *et al*.'s scheme[6].

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