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Reversible Data Hiding Based on Multi-Dimension Difference-Histogram and Bilinear Interpolation

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Abstract: This study proposes a new difference-histogram modification Reversible Data Hiding (RDH) scheme. bilinear interpolation prediction has been used for this purpose. First, the proposed method considers each neighboring pixels x and y to predict z by bilinear interpolation on four pixels which are near to pixel-pairs x and y. Then, according to $d_1 = x - y, d_2 = y - z_y$, and $d_3 = z - z_x$, a new coordinate system (d_1, d_2, d_3) is generated. In this three-dimensional coordinate, the proposed method uses six quadrants to embed secret information: points on the specified surface are used for embedding and the extending space surrounded the embedded surfaces are used for shifting. Finally, a new multi-dimension difference-pair-mapping is used to implement the reversible data embedding. Therefore, more embedding conditions are obtained, thereby increase the number of embedded pixels and get more embedding capacity. Based on the reversible nature of the difference histogram displacement method, the method proposed in this paper can completely restore the original image after taking out confidential information, achieving the effect of no distortion. In terms of application, it can provide a mechanism that needs to save the original pixel value of the image. For example, medical, military, legal, and artistic institutions.

Keywords: *RDH, Histogram Shifting (HS), multi-dimension*

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I. INTRODUCTION

In recent years, due to the development of information technology, network transmission has replaced the way of information dissemination by entities.

However, the convenience has also made the it easy for the information to be intercepted and tampered by sharp-tongued parties. The issue of information security has been noticed and the demand for security protection is increasing. Data hiding technology is receiving more and more attention.

The existing data hiding schemes are mainly divided into two types: RDH and irreversible data hiding [1, 2]. These are based on whether the receiver can recover the stego image back to the original pixel after extracting the secret. In practical applications, irreversible data hiding can hide a large amount of secret information and is relatively easy to implement, but the image cannot be recover after the secret is extracted out [3]. RDH hides less secret information, but it can recover the image after extracting out the secret. Therefore, it is more preferred in most circumstances, such as military institutions, art, and medical images, etc. [4, 5, 6]. The scheme allows the traces of encryption to be completely wiped out, thereby recovering the cover image, which will not be damaged or affected by being used as a hidden secret message [7].

RDH technology is divided into three parts. The first one is Differential Expansion (DE) [8], which was proposed by [8], and then [9] proposed HS in 2006 [9], the last and latest one is Pixel Value Ordering (P.V.O.), proposed by [10]

HS uses the statistical method to record the pixel values of the cover image as a histogram, defining the maxi-

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*Correspondence concerning this article should be addressed to Yi-Chun Lin, National Taichung University of Science and Technology, Taichung, Taiwan. E-mail: kendoumei017@gmail.com mum pixel and the minimum pixel. The maximum point is the peak point, and the minimum point is the zero point. To hide a secret in an image by HS, a value of 0 or 1 can be changed in each pixel value. In order to increase the amount of embedded data, [11] calculated the difference of neighboring pixels and proposed difference-histogram [11]. [12] also improved the HS scheme by proposed prediction-error-histogram, which uses the relationship prediction between neighboring pixels to achieve even higher embedding capacity.

In this paper, based on two-dimensional difference-histogram and the concept of bilinear interpolation prediction, a new RDH scheme is proposed. Proposed method performs bilinear interpolation prediction with four pixel values around the pixel pairs x and y, and then uses the difference between the obtained prediction value z and the neighboring pixels to generate a three-dimensional coordinate system to obtain more embedding conditions and gets more embedding capacity.

II. RELATED WORKS

This chapter introduces three information hiding techniques, all based on histogram displacement. Section A. introduces the earliest histogram displacement method published by [9] scholars, section B. introduces [11] scholars' methods to improve the difference histogram, and section C. introduces the two-dimensional Li Difference histogram architecture. Finally, the bilinear interpolation method is introduced in section III. This paper uses related techniques of this method.

Reversible information hiding is to calculate and change the pixel values in general images to embed binary confidential information, so that the original image becomes a camouflage image with confidential information. Because the pixel values of the pixels that are changed in the camouflage image are usually close to the original pixel values, the original image and the camouflage image are almost indistinguishable from the naked eye, so that the camouflage image can be safely transmitted on the Internet, avoiding Interception and alteration by the three parties. After the receiver successfully obtains this camouflage image, the string of confidential information is taken from the image, and the pixel values of the original image are completely restored to be used again [13]. The following will introduce the basic concept of HS in this paper.

A. HS

[9] published the histogram displacement method, which is a breakthrough for reversible information hiding. The first step of this method is to select the original image to be used as a hidden secret and calculate the appearance of each pixel value in the image Times, draw a statistical histogram. In the second step, find the pixels that appear the most times in this statistical histogram, called peak points, and the pixels that appear zero times, called zero points.

If the original image has multiple zero-value points, in order to maintain a high image quality, the one closest to the peak point is selected, because the pixels between the peak point and the zero-value point will be hidden during the information hiding process. The pixel values are shifted and modified. If there are more pixels between the peak point and the zero value point, the more pixels need to be modified, which will increase the difference between the camouflage image and the original image, resulting in lower image quality.

Next, first determine the positional relationship between the peak point and the zero point. If the peak point is to the right of the zero point, the value of the pixel that appears most often is greater than the value of the pixel that appears zero times. Between the peak point and the zero point 2. Each pixel value to the left of the peak point must be shifted one bit to the left. Conversely, if the peak point is to the left of the zero value point, that is, the value of the most frequently occurring pixel is less than the value of the zero occurring pixel, then The pixel value between the peak point and the zero value point, and to the right of the peak point, must be shifted to the right by one step-this step is the HS method.

The embedded part is to hide the confidential information in the pixels of the peak point. The confidential information is first converted into a binary string, which is composed of 0 and 1. When the value of the hidden confidential information is When the value is 0, the pixel value remains unchanged. When the value of the confidential information is 1, the pixel value is increased or decreased by 1 depending on the positional relationship between the peak value and the zero value point. 1. When the peak point is to the left of the zero point, the pixel is increased by 1, that is, the pixel at the peak point is shifted to the peak point z'.

[9] histogram displacement, because there are not many pixels displaced, retains excellent image quality, but the storage is also unsatisfactory. Therefore, many scholars have proposed improvements based on the concept of histograms in order to obtain a higher level of confidential information. For example, the difference histogram published by Lin et al. [14] is to use the adjacent pixels of the original image as a pair, and change the number of occurrences of a single pixel value counted by the histogram displacement. Create a histogram of the

differences and embed the confidential information.

The reduction method of the histogram displacement method is that the receiver needs to know the position of the original peak point in advance, and then scans the entire image in the same way as when embedding, and the original peak point and its left or right (depending on the peak point and zero point (Depending on the positional relationship) The first pixel value position corresponds to a confidential message of 0 or 1, respectively, and the pixels displaced between the peak point and the zero value point are pushed back to recover, and the confidential information can be taken out and the camouflage completely restored. The image returns to the original image, achieving reversible information hiding without traces and distortions.

B. *Lee et als method*

[11] proposed a method to improve the difference-histogram. First, the pixel values of neighboring pairs pixels in the cover image are recorded as two-dimensional coordinating, assuming neighboring pixels (x,y), and $x=1, y=5$, this pixel pair is recorded in the two-dimensional coordinates $(x,y)=(1,5)$. And a two-dimensional coordinate map is finished.

Secondly, a non-moving axis $(y-x=0)$ is defined in the two-dimensional coordinates, and the left and right sides $(y-x=1 and y-x=-1)$ are used as axis for embedding, and secrets of 0 or 1 are hidden, showing in the black dot in figure below. Then, the area outside the axis that is hidden is used to shift. According to the area of the image to which they belong, it is divided into $y-1$ or $y+1$, as shown in the red dot in Fig. 1 below.

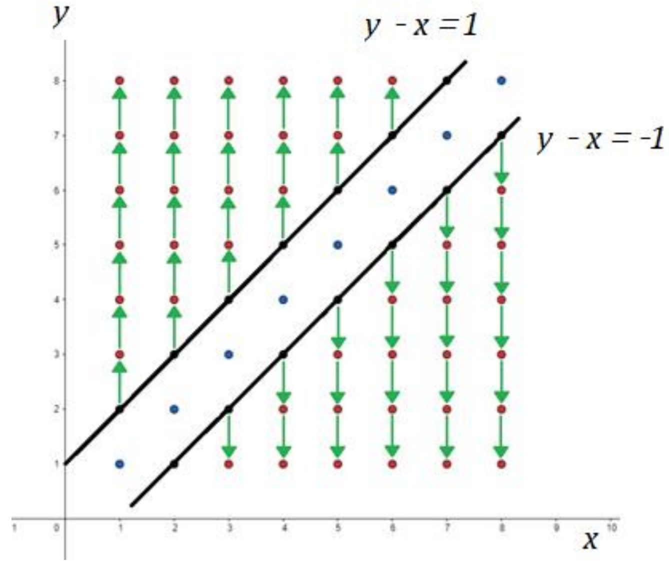


Fig. 1. Blue dots do not move, black dots are used to embed secrets, red dots are for shifting

When $(x,y)=(1,5)$ is moved, after $y+1$, it becomes (1,6), as shown in the following Fig. 2 on the stego image:

1	6			

Fig. 2. The stego image in this example, where y has been embedded within the secret

C. *Li et als method*

[15] proposed a HS scheme based on two-dimensional histogram modification. This method is modified based on Differential Pair Mapping (DPM).

For each (x,y), [15] computed two values $d_1=x-y$ and $d_2=y-z$, where z is a prediction of y of based on the context of for an accurate estimation. Here, to further improve the maximum amount and marked image quality, [15] use Gradient-Adjusted-Prediction (GAP) to calculate the horizontal and vertical gradients for each pixel pair. The vertical gradient is higher than the horizontal gradient. The closer the value of z is to V_1, the smaller the vertical gradient is than the horizontal gradient, the closer the value of z is to V_4, and the gradient adjustment predictor rule is defined as follows:

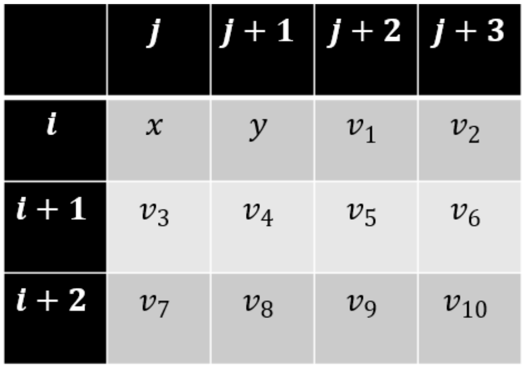
$$z=\begin{cases} v_1, & \text{if } d_v-d_h>80 \\ \frac{(v_1+u)}{2}, & \text{if } d_v-d_h\in(32,80] \\ \frac{(v_1+3u)}{4}, & \text{if } d_v-d_h\in[8,32] \\ u, & \text{if } d_v-d_h\in[-8,8) \\ \frac{(v_4+3u)}{2}, & \text{if } d_v-d_h\in[-32,-8) \\ \frac{(v_4+u)}{2}, & \text{if } d_v-d_h\in[-80,-32) \\ v_4, & \text{if } d_v-d_h<-80 \end{cases} \quad (1)$$

where $\{v_1 : v_8\}$ are neighboring pixels (x,y) (see in Fig. 3) and the calculation methods of d_v, d_h, and u are as follows Equations 2 to 4:

$$d_v = |v_1 - v_5| + |v_3 - v_7| + |v_4 - v_8| \tag{2}$$

$$d_h = |v_1 - v_2| + |v_3 - v_4| + |v_4 - v_5| \tag{3}$$

$$u = \frac{(v_1 + v_4)}{2} + \frac{(v_3 - v_5)}{4} \tag{4}$$



	j	$j+1$	$j+2$	$j+3$
i	x	y	v_1	v_2
$i+1$	v_3	v_4	v_5	v_6
$i+2$	v_7	v_8	v_9	v_{10}

Fig. 3. Neighboring pixels used by the [15], where the location of pixel x is (i,j)

[15] use these two difference values (d_1, d_2) in the two-dimensional coordinates. In the two-dimensional coordinates, because new PPM, [15] modify either x or y by 1. In this situation, since (x,y) has four modification directions, the difference-pair (d_1, d_2) also has four modification directions, as shown in Fig. 4. The specified axis (such as the black coordinate point in Fig. 4) is hidden in the secret and the area outside the axis (as in the blue coordinate point in Fig. 4) is used as the shifting.

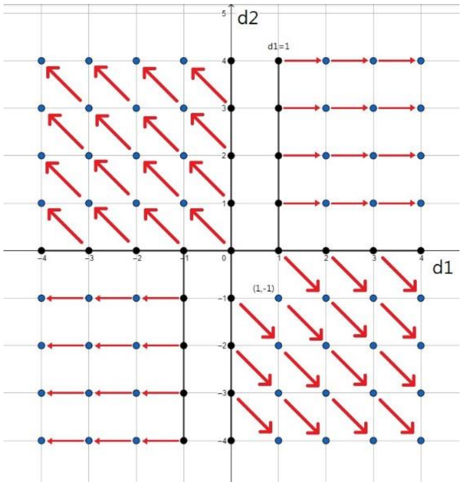


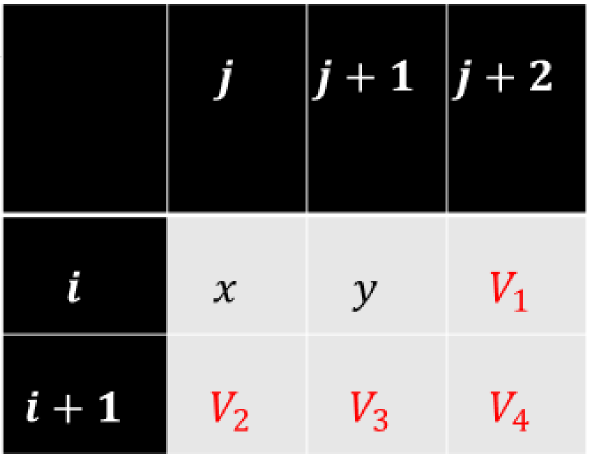
Fig. 4. The black dots are used to hide secret data, and the blue dots are used to shifting

The proposed method will be further improved according to the method of [15] which will be presented in detail in the third section.

III. PROPOSED METHOD

First, the proposed method considers each neighboring pixels x and y to predict z by bilinear interpolation on four pixels which are near to pixel-pairs x and y.

As the following examples:



	j	$j+1$	$j+2$
i	x	y	V_1
$i+1$	V_2	V_3	V_4

Fig. 5. The coordinates of the neighboring pixel pair (x,y) in the example image are (i,j), and the proposed method uses the nearby pixels $V_1,V_2,V_3,$ andV_4 to calculate the value z

Assuming that the neighboring pairs of pixels are x and y, the calculation of bilinear interop-lation is calculated with V_1, V_2, V_3, and V_4, and the interpolated value is obtained as z. The bilinear interpolation method is calculated by the hyperparameters a_x, b_x, a_y and b_y.

The distance ratio between z_x and V_2, V_3 is about 1:2, then $a_x = \frac{1}{(1+2)} = 0.33$

The distance ratio between z_x, V_2, V_3 and V_1, V_4 is about 1:3, then $b_x = \frac{1}{(1+3)} = 0.25$. Therefore, for$x : a_x = 0.33, b_x = 0.25$.

The distance ratio between z_y and V_2, V_3 is about 2:1, then $a_y = \frac{2}{(1+2)} = 0.66$

The distance ratio between z_y, V_2, V_3 and V_1, V_4 is about 1:1, then $b_y = \frac{1}{(1+1)} = 0.5$.

Therefore, for $y : a_y = 0.66, b_y = 0.5$.

Because of the distances between V_1, V_2, V_3 and V_4, bilinear interpolation is like (5) (6), and put a_x, b_x, a_y, b_y and the pixel value of V_1, V_2, V_3 and V_4 into (5)(6) to calculate z_x, z_y:

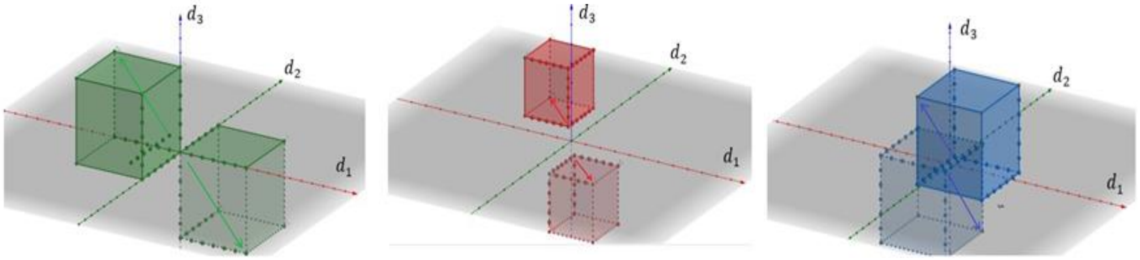
$$\begin{aligned} z_x = {} & (1-a_x)\,b_x V_1 + (1-a_x)(1-b_x)\,V_2 \\ & + a_x(1-b_x)\,V_3 + a_x b_x V_4 \end{aligned} \tag{5}$$

$$\begin{aligned} z_y = {} & (1-a_y)\,b_y V_1 + (1-a_y)(1-b_y)\,V_2 \\ & + a_y(1-b_y)\,V_3 + a_y b_y V_4 \end{aligned} \tag{6}$$

For the pixel pair (x,y), we calculate three differences $d_1 = x - y, d_2 = y - z_y, d_3 = z_x - x$ to form a three-dimensional difference histogram (d_1, d_2, d_3).

Our new Pixel Pair Mapping will change x and y one by one, that the result has six shifting directions $(x+1,y),(x-1,y),(x,y+1),(x,y-1),(x+1,y+1)$, and $(x-1,y-1)$, then (d_1,d_2,d_3) has six directions of shifting: $(d_1+1,d_2,d_3-1),(d_1-1,d_2,d_3+1),(d_1-1,d_2+1,d_3),(d_1+1,d_2-1,d_3)$ and (d_1,d_2+1,d_3-1) (Fig. 6).

For example, y is unchanged, x is changed to $x+1$, the modified direction (x,y) is "to the right", and the corresponding shifting direction (d_1,d_2,d_3), because d_1 is changed to $(d_1+1), d_2$ is unchanged and d_3 is changed to (d_3-1), the direction of the change is the "to the lower right" of the space in the lower right corner of the green one. Based on these six conditions, we will embed the secret by designing the difference-pair-mapping.



(a) Shifting directions: $(x+b,y),(x-b,y)$ (b) Shifting directions: $(x,y+b),(x,y-b)$ (c) Shifting directions: $(x+b,y+b),(x-b,y-b)$

Fig. 6. Three-dimensional coordinate

TABLE 1
EMBEDDING RULE

Conditions on (d_1,d_2,d_3)	Embedding or Shifting	Marked Value
$d_1 \geq 0$ and $d_2 \geq 0$ and $d_3 = 0$	Embedding	$(x+b,y)$
$d_1 = 0$ and $d_2 \geq 0$ and $d_3 < 0$		
$d_1 \leq 0$ and $d_2 \geq 0$ and $d_3 < 0$	Embedding	$(x-b,y)$
$d_1 \leq 0$ and $d_2 \leq 0$ and $d_3 = 0$ and not $(d_1 = 0$ and $d_2 = 0$ and $d_3 = 0)$		
$d_1 = 0$ and $d_2 \leq 0$ and $d_3 > 0$		
$d_1 = -1$ and $d_2 = 0$ and $d_3 = 1$		
$d_1 = -1$ and $d_2 \geq 1$ and $d_3 \geq 0$	Embedding	$(x+b,y)$
$d_1 < -1$ and $d_2 = 1$ and $d_3 \geq 0$		
$d_1 = 1$ and $d_2 \leq -1$ and $d_3 \leq 0$	Embedding	$(x-b,y)$
$d_1 > 1$ and $d_2 = -1$ and $d_3 \leq 0$		
$d_1 \leq -1$ and $d_2 = 0$ and $d_3 \leq -1$	Embedding	$(x+b,y+b)$
$d_1 \leq -1$ and $d_2 > 0$ and $d_3 = -1$		
$d_1 \geq 1$ and $d_2 = 0$ and $d_3 \geq 1$	Embedding	$(x-b,y-b)$
$d_1 \geq 1$ and $d_2 < 0$ and $d_3 = 1$		
$d_1 > 0$ and $d_2 \geq 0$ and $d_3 < 0$	Shifting	$(x+1,y)$
$d_1 < 0$ and $d_2 \leq 0$ and $d_3 > 0$ and not $(d_1 = -1$ and $d_2 = 0$ and $d_3 = 1)$	Shifting	$(x-1,y)$
$d_1 < -1$ and $d_2 > 1$ and $d_3 \geq 0$	Shifting	(x, y+1)
$d_1 > 1$ and $d_2 < -1$ and $d_3 \leq 0$	Shifting	(x, y-1)
$d_1 \leq -1$ and $d_2 > 0$ and $d_3 < -1$	Shifting	$(x+1,y+1)$
$d_1 \geq 1$ and $d_2 < 0$ and $d_3 > 1$	Shifting	$(x-1,y-1)$

TABLE 2
EXTRACT RULE

Conditions on (d_1, d_2, d_3)	Extracted data bit b	Recovered Value
$(d_1 \geq 0$ and $d_2 \geq 0$ and $d_3 = 0)$ or $(d_1 > 0$ and $d_2 \geq 0$ and $d_3 = -1)$	$-d_3$	$(x-b, y)$
$(d_1 = 0$ and $d_2 \geq 0$ and $d_3 < 0)$ or $(d_1 = 1$ and $d_2 \geq 0$ and $d_3 < -1)$	d_1	
$((d_1 \leq 0$ and $d_2 \leq 0$ and $d_3 = 0)$ or $(d_1 < 0$ and $d_2 \leq 0$ and $d_3 = 1))$ and not $((d_1 = 0$ and $d_2 = 0$ and $d_3 = 0)$ and not $(d_1 = -1,$ and $d_2 = 0,$ and $d_3 = 1)$	d_3	$(x+b, y)$
$(d_1 = 0$ and $d_2 \leq 0$ and $d_3 > 0)$ or $(d_1 = -1$ and $d_2 \leq 0$ and $d_3 > 1)$	$-d_1$	
$(d_1 = -1$ and $d_2 = 0$ and $d_3 = 1)$ or $(d_1 = -2$ and $d_2 = 0$ and $d_3 = 2)$	$d_3 - 1$	
$d_1 = -1$ and $d_2 \geq 1$ and $d_3 \geq 0$ or $d_1 = -2$ and $d_2 > 1$ and $d_3 \geq 0$	$-d_1 - 1$	$(x, y-b)$
$d_1 < -1$ and $d_2 = 1$ and $d_3 \geq 0$ or $d_1 < -2$ and $d_2 = 2$ and $d_3 \geq 0$	$d_2 - 1$	
$d_1 = 1$ and $d_2 \leq -1$ and $d_3 \leq 0$ or $d_1 = 2$ and $d_2 < -1$ and $d_3 \leq 0$	$d_1 - 1$	$(x, y+b)$
$d_1 > 1$ and $d_2 = -1$ and $d_3 \leq 0$ or $d_1 > 2$ and $d_2 = -2$ and $d_3 \leq 0$	$-d_2 - 1$	
$d_1 \leq -1$ and $d_2 = 0$ and $d_3 \leq -1$ or $a_1 \leq -1$ and $d_2 = 1$ and $d_3 < -1$	d_2	$(x-b, y-b)$
$d_1 \leq -1$ and $d_2 > 0$ and $d_3 = -1$ or $d_1 \leq -1$ and $d_2 > 1$ and $d_3 = -2$	$-d_3 - 1$	
$d_1 \geq 1$ and $d_2 = 0$ and $d_3 \geq 1$ or $d_1 \geq 1$ and $d_2 = -1$ and $d_3 > 1$	$-d_2$	$(x+b, y+b)$
$d_1 \geq 1$ and $d_2 < 0$ and $d_3 = 1$ or $d_1 \geq 1$ and $d_2 < -1$ and $d_3 = 2$	$d_3 - 1$	
$d_1 > 1$ and $d_2 \geq 0$ and $d_3 < -1$	No embedding data	$(x-1, y)$
$(d_1 < -1$ and $d_2 \leq 0$ and $d_3 > 1)$ and not $(d_1 = -1$ and $d_2 = 0$ and $d_3 = 1)$	No embedding data	$(x+1, y)$
$d_1 < -2$ and $d_2 > 2$ and $d_3 \geq 0$	No embedding data	$(x, y-1)$
$d_1 > 2$ and $d_2 < -2$ and $d_3 \leq 0$	No embedding data	$(x, y+1)$
$d_1 \leq -1$ and $d_2 > 1$ and $d_3 < -2$	No embedding data	$(x-1, y-1)$
$d_1 \geq 1$ and $d_2 < -1$ and $d_3 > 2$	No embedding data	$(x+1, y+1)$

For example: neighboring pixel pair $(x, y) = (144, 144)$, calculate z as Formula (5), get $z_x = 143, z_y = 144$, we can obtain (d_1, d_2, d_3) are $d_1 = 0, d_2 = 0, d_3 = -1$, which corre-sponds to the point in the right green space in the figure, in this case, this pixel pairs will be used to embed the secret,

If $b = 0$, the pixel pair will be $(x, y) = (144, 144)$.

If $b = 1$, the pixel pair will be $(x+1, y) = (145, 144)$.

Another example: $(x, y) = (144, 143)$, calculate $z_x = 142, z_y = 143$, and $d_1 = 1, d_2 = 0, d_3 = -1$, which corresponds to the the green space on the right in the figure, in this case, this pixel pair will be shifted, then the pixel pair will be $(x-1, y) = (145, 143)$.

The order for the pixel pairs in our extraction process is opposite to the order for embedding. In this way, when the pixel pair is processed into the extract, the surrounding pixels of the used and calculated z have been restored. Therefore, the decoder can obtain the same prediction z used by the encoder. This guarantees our reversibility. The corresponding extract rules are listed in Table 2.

IV. EXPERIMENTAL RESULTS

This chapter introduces the experimental results of the method in this paper. In the experiment, six 512×512 images such as Lena, Baboon, Barbara, Airplane (also known as F-16), Peppers, and Fishing boat were compared with other scholars' methods. The maximum information hiding capacity (EC) is introduced in Section A., the Peak Signal-to-Noise Ratio (PSNR) is introduced in Section B., and the experimental results are discussed in Section V.

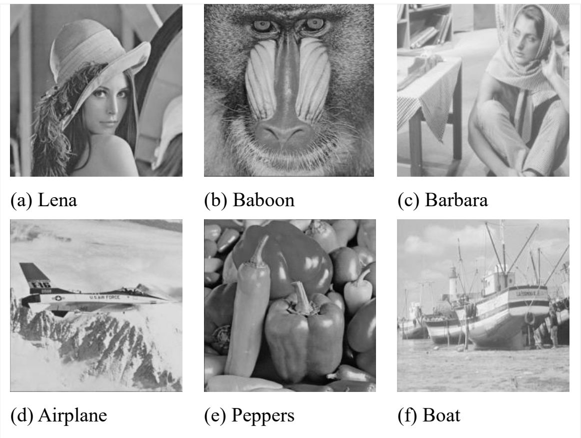

(a) Lena (b) Baboon (c) Barbara
(d) Airplane (e) Peppers (f) Boat

Fig. 7. Our test images

A. *Maximum Embedding Capacity*

The Maximum embedding capacity refers to the number of confidential information that can be hidden in an image. The higher the Maximum embedding capacity, the better the performance of this method. The following will compare the method of this thesis with the method of [9] scholar, the method of [11] scholar, and the method of [15] scholar for the Maximum embedding capacity of the same six images.

TABLE 3
MAXIMUM EMBEDDING CAPACITY RESULTS FOR 6 TEST IMAGES

	[9]	[11]	[15]	Proposed Method
Lena	5363	30766	36859	47474
Baboon	5398	10657	11846	17551
Barbara	4046	21586	25169	32247
Airplane	8768	32624	37083	48565
Peppers	3687	18655	19015	30236
Boat	11473	20359	23800	32601

B. *PSNR*

PSNR is a very important and commonly used basis for evaluating the quality of camouflage images. When the PSNR is higher, it means that the camouflage image is closer to the original Images are less likely to be detected by unlawful third parties during the transmission process on the Internet, so that they are subject to interception, tampering, theft, etc.

The calculation method of the peak signal to noise ratio is as follows (6):

$$PSNR = 10 \times log_{10}(\frac{255}{MSE})^2 (dB) \tag{7}$$

The Mean Square Error (MSE) in the formula (6) refers to the MSE of the pixels of the original image and the disguised image. Assuming that the pixel value at the (i, j) position of the original image is $P_{i,j}$, the length of the camouflage image is H and the width is W. This MSE is calculated as shown in the following Equation 8:

$$MSE = \frac{1}{(H \times W)} \sum_{(i=1)}^{H} \sum_{(i=1)}^{W} (P_{(i,j)} - P'_{(i,j)})^2 \tag{8}$$

Tables 4 to 7 compare this paper with [9] method, [16] method, and [15]. method. When the reservoirs are set to 2500, 5000, or 7000, respectively, for the same Results of experiments on six images:

TABLE 4
PSNR RESULTS FOR 6 TEST IMAGES FOR AN EC OF 5,000 BITS

	[9]	[11]	[15]	Proposed Method
Lena	53.9	62.3	61.9	61.8
Baboon	50.5	54.9	55.0	55.2
Barbara	–	57.6	58.0	58.9
Airplane	54.0	61.4	61.2	61.8
Peppers	–	57.7	57.4	58.3
Boat	52.0	58.7	58.9	60.0
Avg.	52.6	58.8	58.7	59.3

TABLE 5
PSNR RESULTS FOR 6 TEST IMAGES FOR AN EC OF 10,000 BITS

	[11]	[15]	Proposed Method
Lena	56.6	57.4	58.1
Baboon	51.9	52.6	53.3
Barbara	55.8	55.6	55.7
Airplane	58.0	57.7	58.6
Peppers	54.8	54.5	55.9
Boat	55.6	55.7	56.7
Avg.	55.5	55.6	56.4

TABLE 6
PSNR RESULTS FOR 6 TEST IMAGES FOR AN EC OF 15,000 BITS

	[11]	[15]	Proposed Method
Lena	54.9	54.8	55.3
Baboon	–	–	51.4
Barbara	54.8	54.7	54.7
Airplane	55.8	55.6	56.6
Peppers	52.7	52.5	54.2
Boat	53.7	53.9	54.7
Avg.	54.4	54.3	54.5

TABLE 7
PSNR RESULTS FOR 6 TEST IMAGES FOR AN EC OF 20,000 BITS

	[11]	[15]	Proposed Method
Lena	54.1	53.9	54.0
Barbara	52.5	53.3	54.0
Airplane	54.3	54.0	55.1
Peppers	–	51.5	52.9
Boat	52.1	52.5	53.3
Avg.	53.3	53.0	53.9

V. RESULTS AND DISCUSSION

In terms of maximum reserves, the methods in this paper have higher maximum reserves than those of [9], [11] and [15] However, the reserves are set to be the same. The value of PSNR is slightly lower than the method of [15].

A feature was found from the experimental results. The method proposed in this thesis improved the storage more in images with more dark areas; in the case of images with more light areas, such as Airplane, the situation of increasing reserves was not ideal. To verify the relationship between the color depth and the ability to increase the storage, the color depth of the image is also used in this study. The experimental results are Lena average 127, Baboon average 126, Barbara average 174, Airplane average 181, Pepper average 110, Boat average 184. It can be seen from the above data that there is no correlation with the ability to increase reserves.

VI. CONCLUSION AND RECOMMENDATIONS

In this section, the conclusion of this paper is in Section A. This paper contains the advantages and disadvantages of the method proposed in this paper and the application of the method in this paper, and proposes future work in Section B.

A. *Conclusion*

The method proposed in this paper is based on a two-dimensional difference histogram structure. The existing two-dimensional coordinates are changed to three-dimensional coordinates. The unit that was originally embedded with the axis is changed to the unit that is embedded with the surface. The area is replaced with the unit of displacement. With the unit of space displacement, multiple conditions for embedding confidential information have been added, so that more confidential information can be hidden in the original image. In addition, the bilinear interpolation prediction method is added to replace the original gradient adjustment prediction method, and the concept of interpolation method prediction is incorporated, and a new RDH structure is modified to obtain the ratio of the largest amount of information hidden. Existing methods have greater reserves. Although in terms of image quality, most of the image PSNR results are slightly lower than the method proposed by [15], but when it is necessary to use a large amount of confidential information instead of pursuing high-quality images, it can be seen as transmission. The current use and needs of the recipient or recipient, choose to use this paper to embed confidential information.

Based on the reversible nature of the difference histogram displacement method, the method proposed in this paper can completely restore the original image after taking out confidential information, achieving the effect of no distortion. In terms of application, it can provide a mechanism that needs to save the original pixel value of the image. For example, medical, military, legal, and artistic institutions.

B. *Future Outlook*

According to the experimental results, it is shown that the method proposed in this paper has better results than existing methods in improving the storage of embedded confidential information. However, in terms of PSNR, most cases are lower than those of [15]. The calculation method of the value is adjusted, for example, the coefficients used in the interpolation method are adjusted, or machine learning or other interpolation methods are used to obtain the optimal z to improve the PSNR.

In addition, this paper continues the existing method to perform displacement in 2D, but has already used the concept of 3D stereo coordinates. In future research, we can further try 3D stereo displacement or use the concept of 4D and higher dimensions.

Declaration of Conflicting Interests

No known financial as well as non-financial conflicts are identified for this work.

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