A Novel Reversible Data Hiding Scheme in Dual Stego-Image

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ABSTRACT

The dual stego-image reversible data embedding methods have been developed rapidly, such as exploiting modification direction, magic matrix, and center folding strategy. However, the maximum secret digit once occurs in these strategies. It seriously decreases the visual quality of the stego-image. To overcome this problem, this paper proposes a novel encoding method to reduce the secret digits and decrease the occurrence frequency of the maximum digits by the joint neighboring pixel similarity and frequency-based encoding method. Experimental results show that the proposed method can achieve a greater PSNR value than previous methods under the same embedding rate, thereby confirming that the proposed method is effective.

Keywords: Data Hiding; Center folding strategy; Frequency-based encoding

一種新穎的可逆式雙影像藏密策略

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摘　　要

近幾年，雙影像資料藏密法有著飛躍式的發展，諸如利用方向改變法、魔術方陣以及中央對折策略等均屬此類研究範疇。然而前述機制有著當最大機密位元頻繁地出現，被藏密後的影像品質會急速的崩壞的問題。本文提出了一種新穎的編碼方式來解決此種問題。藉由整合鄰近像素相似性與考量頻率的編碼方式，有效的減低大數值機密位元頻繁出現的問題。實驗結果證明所提出的方式相較於前述機制在相同的藏密率之下，有效的提升藏密圖像的 PSNR 值。

關鍵詞：資料隱藏，中央對折策略，頻率編碼

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Ⅰ. INTRODUCTION

The reversible data hiding method can prevent attacks from hackers through embedding secret messages into multimedia, e.g., images [1,3, 4, 6, 7, 9–13, 15– 18, 22–24], videos [5], DNA sequences [2, 8], and compression codes[19–21]. After embedding the secret data, the stego-media is still similar to the original media, thus the method is very suitable for some applications, e.g., steganography, watermarking, and annotation [14].

The previous reported methods are mainly classified into four types, i.e., difference expansion [24], prediction error expansion [6, 10, 13, 22, 23], histogram shifting [18], and dual stego- images[8–16]. In 2003, Tian [15] proposed a difference expansion method that doubles the difference between two adjacent pixels and embeds one secret bit into this difference. Fig.1 shows a diagram about the method. However, difference expansion may distort the stego-image seriously.

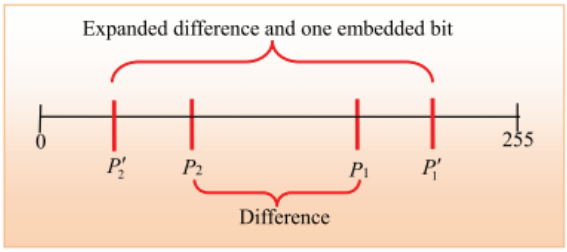

Fig.1 Difference expansion method

In order to avoid this problem, Thodi and Rodriguez [22] proposed a prediction-based method which derived by relationship between adjacent cover pixels to generate an exact prediction value. As a result, the prediction error is significantly smaller than the difference between adjacent pixels, and causes a slight distortion.

Ni *et al.* [18] proposed a histogram shifting method. After counting the frequency of occurrence of cover pixels, they only modified the cover pixel between the peak point and the zero point to embed messages and control the distortion to maintain an acceptable image quality. The peak point means the cover pixel with most occurrence frequency, and the zero point means the cover pixel with lowest occurrence frequency. Fig.2 shows a histogram example of cover pixels. The pixels between the peak and the zero points were shifted for creating an embedding space. Afterwards, the cover pixels that were equal to the peak point are used to embed messages. The method can control the distortion of each pixel within 1, but only embed a few secret bits.

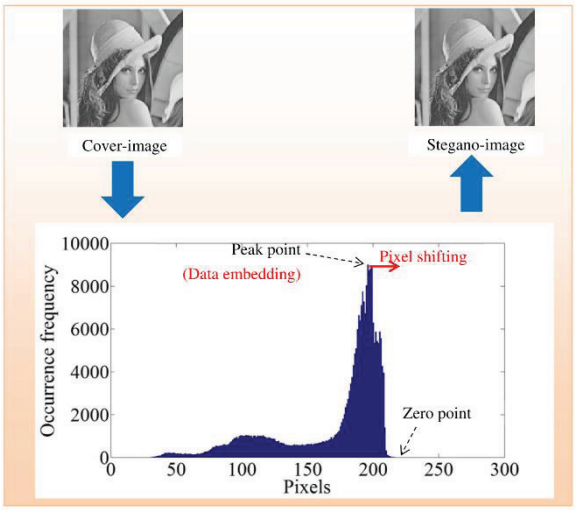

Fig.2 Histogram shifting method

Different from the previous methods, Chang *et al.* [1] embedded a large amount of secret data into two identical images by using the exploiting modification direction (EMD) [18] skillfully. This type of method is called dual-image hiding scheme. Obviously, the method needs more spaces to storage two stego-images, but no illegal person can extract secret data and recover the cover image without both stego-images. This approach provides greater security and be regarded as a special case for secret sharing.

Unlike a single-image hiding scheme, the dual-image hiding scheme generates two stego-images to share a secret message. In this scheme, two images are duplicated from a cover image, and the secret message is then averagely concealed into the generated images. An authorized person who can extract secret data and recover the cover image must have all the stego-images. Fig.3 shows the difference between the single-image and the dual-image hiding scheme.

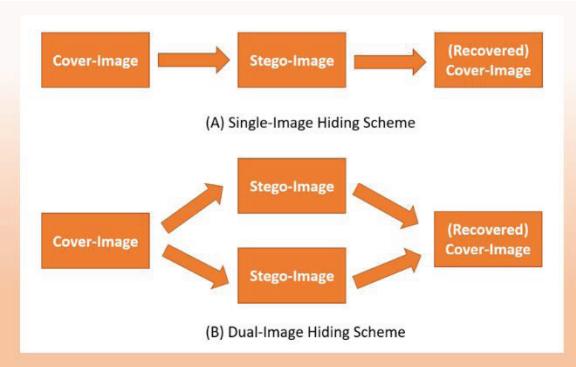

Fig.3 Diagrams of the image hiding schemes

Lee *et al.* [10] proposed a high image quality data hiding technique with a direction-based technique, as shown in Fig.4. However, the method only can embed about 50 % probability exists that four bits are embedded.

In 2013, Lee and Huang [11] enhanced the modification rules from four directions to five directions, and embedded base-5 digits into two stego-images, as shown in Fig.5. The method is redesigned for increasing the hiding capacity, and controls the modification level of pixel within 1, thereby maintaining good image quality. Nevertheless, the method still can't embed large number digits effectively.

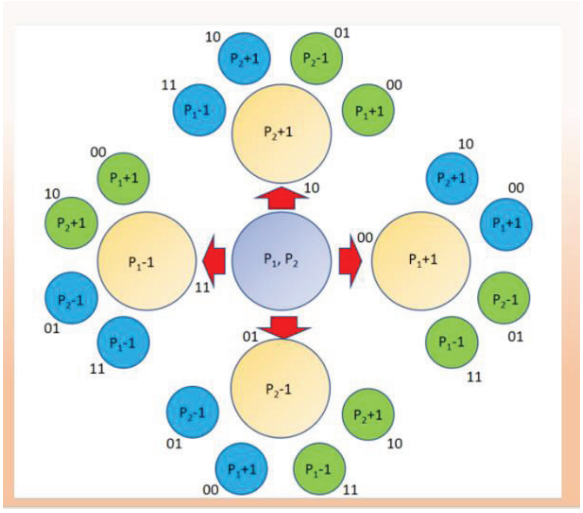

Fig.4 Direction-based embedding rules

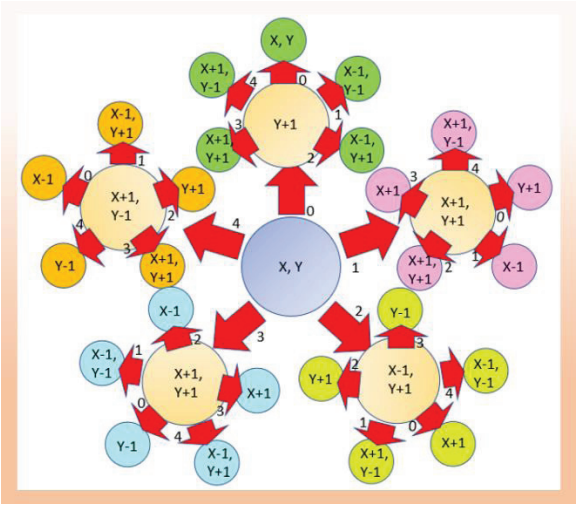

Fig.5 Embedding method base on 5 directions

Unlike in the direction-based hiding method, Chang *et al*. [4] embedded base-9 secret digits into two stego-images with a magic matrix, thus the method increased the hiding capacity successfully. The magic matrix is generated by

$$M(P_{x,y}, P_{x,y}) = (P_{x,y} + 3 \times P_{x,y}) mod\ 9. \quad (1)$$

$M(P_{x,y},P_{x,y})$ represents the value of the magic matrix, and $P_{x,y}$ represents the cover pixel. Fig.6 shows the magic matrix.

Although the method can enhance embedding capacity effectively, the modification level of pixel is large, leading to the serious distortion of the image quality.

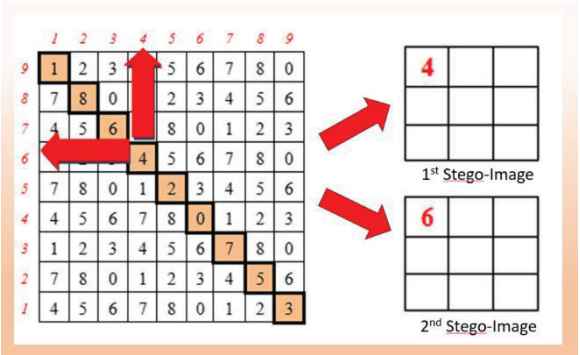

Fig.6 Magic matrix based hiding method

Lu *et al.* [15] adopted least significant bit (LSB) matching to embed one bit into the pixel. For embedding more bits and maintaining better quality of the stego-image, Lu *et al.* [16] proposed a center folding strategy (CFS) that

adaptively transformed K secret binary bits into smaller decimal digits and reduced the distortion problem.

However, CFS still cannot decrease the frequency of occurrence of the largest value. In this paper, we propose a novel encoding strategy to reduce the frequency of occurrence of the largest value. Thus, we can decrease distortion of the image in the data embedding phase.

The rest of the paper is organized as follows. Sections 2 and 3 present the CFS hiding method and the proposed method, respectively. Section 4 compares the proposed method and the five related methods in terms of the embedding rate and the quality of the stego-image. The conclusions are presented in Section 5.

II. RELATED WORKS

For enhancing the quality of payload and reducing the distortion, a center-folding strategy proposed by Lu *et al*. [16] transformed each decimal digit to a smaller digit, thus reduced the modification level of the stego-image. Fig.7 shows the flowchart of the center-folding strategy.

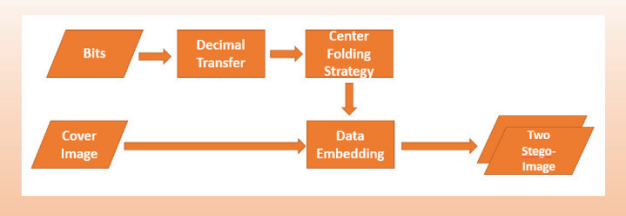

Fig.7 Flowchart of Center folding strategy

The strategy transferred the secret data from $R=\{0,1,,\ldots,2^{N-1}\}$ to $R'=\{-2^{N-1}, -2^{N-1}+1,\ldots,-1,0,1,\ldots,2^{N-1}-2,2^{N-1}-1\}$ with follow formula:

$$R' = R - 2^{N-1}. \qquad (2)$$

The R' is folded with 0 from original data R . Obviously, the strategy is effective and easy to implemented, but cannot decrease the frequency of occurrence of the largest value. Fig.8 shows the problem, some images transformed with the CFS method with K=2 still have a lot of digits with largest value which will cause serious distortion after hiding to cover media, so that the CFS method cannot diminish the number of the largest embedded value effectively.

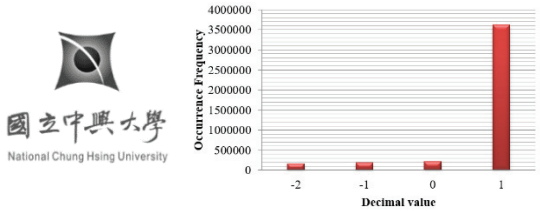

Fig.8 The occurrence distribution of digits in the CFS encoded image with K = 2

Because the center-folding strategy cannot reduce the frequency of the maximum absolute value's occurrence, and this disadvantage diminishes the visual quality of the resulting stego-image. Consequently, Lu *et al*. [17] used a frequency-based encoding strategy to reduce the distortion of the frequency of occurrence of the maximum absolute value in 2016. As shown as Fig.9, after using CFS reduced the digit stream, the frequency-based encoding strategy further re-encoded the digit with the rank of occurrence frequency and exhibits better embedding performance.

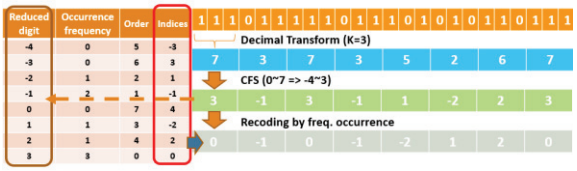

Fig.9 Example of the frequency-based method

Although the frequency-based encoding method can solve the problem about the distortion of the frequency of occurrence of the maximum absolute value, it still does not consider the relationship between adjacent digits so that the method still can be enhanced further.

III. PROPOSED METHOD

In the Section, we exploited the relationship between adjacent digits to reduce the number of the largest values.

3.1 Encoding and data embedding

Since most pixels in general images have

the local similarity, we use a codebook to "cache" the value transformed from the pixels and, replace its original value with the cache index of the codebook for decreasing the number of the largest values while the cached value occurs again. Fig. 10 shows the diagram of our encoding and data embedding procedures.

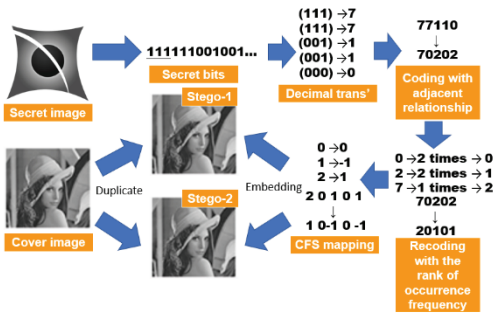

Fig.10 Diagram of the proposed method

The proposed procedures can be elucidated further by the following algorithm.

Step 1: Transform a set of K secret bits into a decimal value, i.e., $d_i = \sum_{j=1}^{K} S_j \times 2^{j-1}$, and $0 \le d_i \le 2^K - 1$. The notation i denotes the ID number of the decimal value.

Step 2: Generate the codebook which consists of 2^K codewords, and the indices are set sequentially from 0 to $2^K - 1$.

Step 3: Replace decimal value d_i by the index I_i in the codebook, where its codeword is equal to the decimal value d_i, and the index is replaced by $\acute{d}_i$.

Step 4: Update the index of the codeword, i.e., modifying the index of the selected codeword from I_i to 0 and increasing the index of the other codewords by 1.

Step 5: Perform the Steps 1 through 4 mentioned above until all secret bits d_i have been transformed to $\acute{d}_t$.

Step 6: Compile the occurrence frequencies of the transformed digits, sort them in descending order, and the index of sorted results is denoted as O_i.

Step 7: All of the relationship between the transformed digits and indices mentioned above must be recorded for use in the reference information of image recovery phase.

Step 8: Classify the pixel in cover-image into the embeddable pixels and non-embeddable pixels to avoid the underflow and overflow problems. The pixels between 2^{K-1} and $256 - 2^{K-1}$ are labeled as the embeddable pixels. Otherwise, other pixels are the non-embeddable pixels. Fig. 11 illustrates the mentioned range.

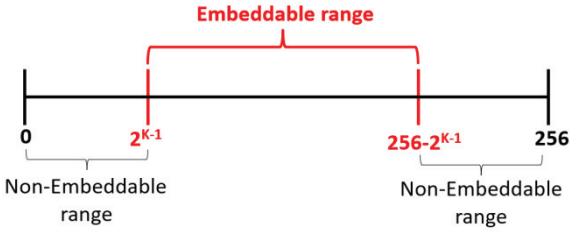

Fig.11 Solution for the overflow and underflow problems by pixel classification

Step 9: Reduce the index O_i to O'_i by Eq. (3), and according to the pre-determined random value r, embed the reduced index O'_i into two stego pixels by Eq. (4). The random value r is generated by the pre-determined random seed.

$$O'_i = \begin{cases} \dfrac{O_i}{2} & \text{, if } I_i \text{ is even.} \\ -\dfrac{O_i + 1}{2} & \text{, otherwise.} \end{cases} \tag{3}$$

$$P_{x,y,1} = \begin{cases} P_{x,y} + \left\lfloor \dfrac{O'_i}{2} \right\rfloor & \text{, if } r = 0. \\ P_{x,y} - \left\lceil \dfrac{O'_i}{2} \right\rceil & \text{, if } r = 1. \end{cases}$$

and

$$P_{x,y,2} = \begin{cases} P_{x,y} - \left\lceil \dfrac{O'_i}{2} \right\rceil & \text{, if } r = 0. \\ P_{x,y} + \left\lfloor \dfrac{O'_i}{2} \right\rfloor & \text{, if } r = 1. \end{cases} \tag{4}$$

Step 10: Perform the step 8 and step 9 until all O'_i have been embedded into two stego-image.

All of the procedures are illustrated in Fig. 12. There are 15 secret bits and set K = 3, thus the codebook with size 2^K=8 is built and all indices are initialized sequentially from 0 to 7.

The first trio of secret bits "$111_{(2)}$" are transformed into $7_{(10)}$. Other bits are performed by the same procedures until all of bits are transformed into decimal digits.

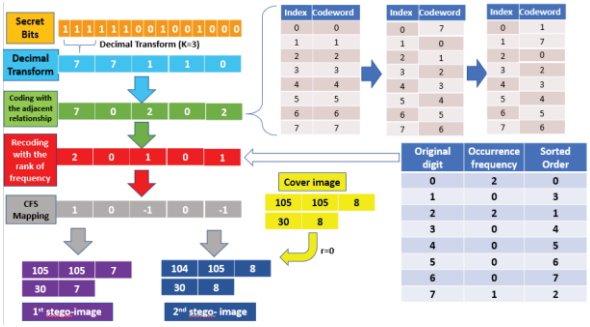

Fig.12 A coding and embedding example of the proposed method

Furthermore, the first decimal digit $7_{(10)}$ is matched with the index of codebook, and replaced by the index value of the matched codeword. Then, the index of the codeword is updated from 7 to 0 for enhancing the matching possibility.

Following, the second decimal digit is still $7_{(10)}$. Because the digit matches the first index value of renew codebook, and the value of the index "0" is used to represent the second decimal digit. Since the matched index is first one, the codebook remains unchanged. The procedure is continued until all the decimal digits accomplish the codebook matching for coding.

After the procedure of coding, these encoded indices $\acute{d}_i$={7, 0, 2, 0, 2} are encoded further by their occurrence frequency, thereby decreasing the absolute digit. As showing in Fig.12, the digits of $\acute{d}_i$ occurs the most frequently are '0' and '2'; therefore, their value are recoded as '0' and '1'. The last digit $\acute{d}_i$ is '7' and recoded as '2'.

Before being embedded, all of the digits are folded with '0' as Eq. (3) for decreasing the distortion as more as possible.

After all the procedure mentioned are done, the origin stream of decimal digits d_i={7, 7, 1, 1, 0} is reduced to O'_i={1, 0, -1, 0, -1}. Apparently, the proposed method effectively changes the digit from a larger value to a smaller one.

3.2 Decoding and image recovery

In this section, we make a dissection about the encoded digits are extracted from the stego-image as well as the process of cover image recovery.

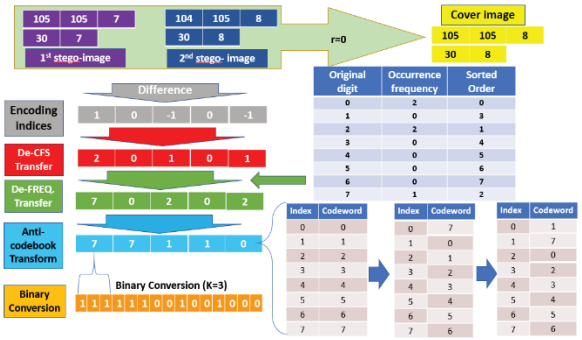

Fig.13 The extraction and recovery example of the proposed method

Fig. 13 shows the example of image recovery and secret extraction and decoding of the proposed method. First, the average value between the first pixels in two stego image is calculated to obtain the first cover pixel, i.e.

$$P_{x,y} = \left\lceil \frac{P_{x,y,1} + P_{x,y,2}}{2} \right\rceil = \left\lceil \frac{105 + 104}{2} \right\rceil = 105$$

Moreover, the embedded index can be derived through the difference between pixels in two stego-images, i.e.,

$$O'_i = \begin{cases} P_{x,y,1} - P_{x,y,2} & \text{, if } r = 0. \\ P_{x,y,2} - P_{x,y,1} & \text{, if } r = 1. \end{cases} \quad (5)$$

According to Eq. (5), the difference between the first pixels in two stego image is calculated by $O'_i = P_{1,1,1} - P_{1,1,2} = 105 - 104 = 1$, thereby obtaining the first embedded value.

Next, the original index O_i is decoded by, i.e.

$$O_i = \begin{cases} 2O'_i & \text{, if } O'_i \geqq 0. \\ 2 \times |O'_i| - 1 & \text{, otherwise.} \end{cases} \quad (6)$$

By the Eq. (6), the embedded value "1" is double to obtain the sorted index. By passed

information about relationship of frequency mapping and codebook, the recoded indices $\acute{d}_i$ and the original indices d_i are seriatim obtained. Finally, each secret digit is transformed into *K* secret bits by the binary conversion.

The sorted index is mapped by the codebook to obtain the secret value "7". Since K = 3, the secret digit "7" is transformed into the trio of secret bits {1, 1, 1}. In addition, the codebook is updated, where the first codeword is replaced by the current secret digit "7", and the indices of other codewords are increased by 1. The above procedures are repeated until all secret data are recovered and all of cover pixels are recovered without any distortion.

IV. EXPERIMENTAL RESULTS

In this section, we implement the proposed method and five related methods (the orientation combinations [11], the CFS hiding method [16], the frequency encoding based hiding method [17] , the magic matrix [4], *K-N* [7]) to confirm the effectiveness of the proposed method. We measured the embedding rate and the visual quality of the stego-image where the embedding rate ***R*** was computed by

$$\boldsymbol{R} = \frac{C - E}{2 \times H \times W} (\text{bpp}). \qquad (7)$$

where *C* represents the total secret bits embedded in the dual stego-images, *E* is the size of the extra bits for recovering processes, i.e. the mapping table and codebook, and the $H \times W$ means the number of cover pixels. Because there are two duplicating images for secret embedding, the "$H \times W$" should multiple for '2'. A higher embedding rate indicates more excellent hiding ability.

The peak signal-to-noise ratio (PSNR) is taken for indicating the visual similarity between the stego-image and the cover-image, which was computed by

$$\text{PSNR} = 10 \times \log_{10} \frac{255^2}{MSE} \ (dB). \qquad (8)$$

The *MSE* is mean square error between the cover image and the stego-image, i.e.,

$$\text{MSE} = \frac{1}{x \times y} \sum_{i=1}^{x} \sum_{j=1}^{y} \left(P_{x,y,z} - P_{x,y}\right)^2. \qquad (9)$$

A higher PSNR value means that the stego-image is more similar to the cover image. Generally, if the PSNR value is greater than 30 dB, the unauthorized person can't detect the difference between the cover image and the stego-image. [14]

Fig.14 shows the cover images and secret image, where the former includes Lena, Peppers, Lake, and the latter includes Brain, Dolphin, IM , NCHU , Google, Baboon and Barbara.

Fig.14 The pictures for experiment

Fig.15 to Fig.21 show the comparison results among related methods [4,7,11,16,17] and the proposed method with all seven secret images. Table 1 shows the detail data of embedding different secret images into each cover-image.

Both our proposed method and [17] take the maximum digits having the occurrence frequency as the smaller value. This advantage implies better PSNR than other methods. The conclusion can be obtained from Table 1 easily. Even with complex textures like brain, baboon and barbara, our proposed method and [17] still achieve about 51.4 dB, which is greater than [4] (41.73dB), [7] (47.42 dB), [11] (49.89 dB) and [16] (51.38 dB).

In addition, our proposed method used the relationship between adjacent digits to encode secret data so that the proposed method can achieve higher PSNR value than [17] in most conditions. Especially, for the two secret images Dolphin and NCHU, the PSNR value of the proposed method is at least 1.43 dB more than

[17]. This finding proves that the proper processing of the relationship between adjacent digits and the maximum digits having the occurrence can achieve better stego-image quality and reduce the degree of modification.

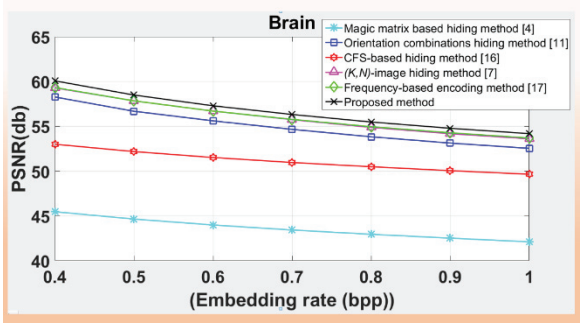

Fig.15 The result for the secret image “Brain”

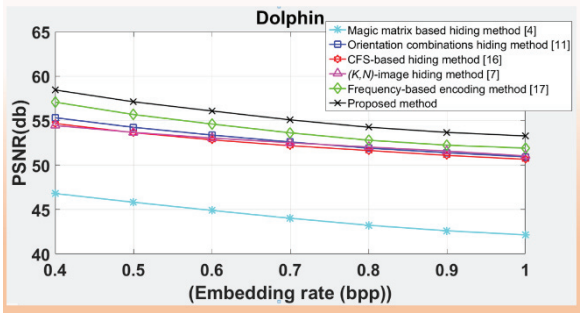

Fig.16 The result for the secret image “Dolphin”

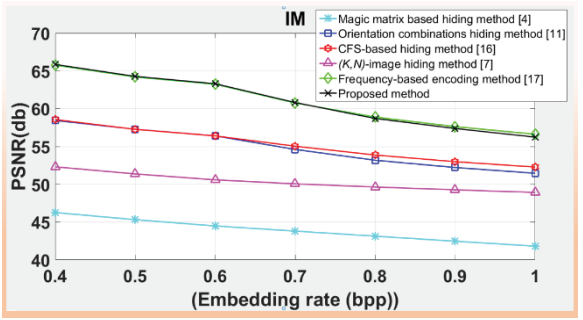

Fig.17 The result for the secret image “IM”

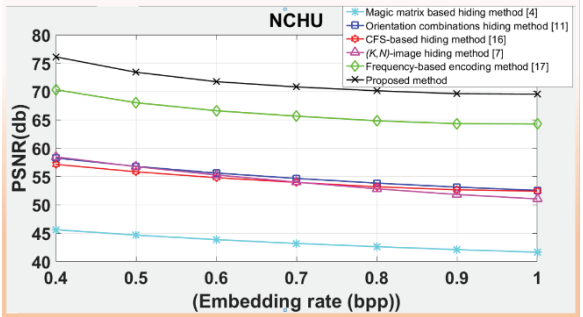

Fig.18 The result for the secret image “NCHU”

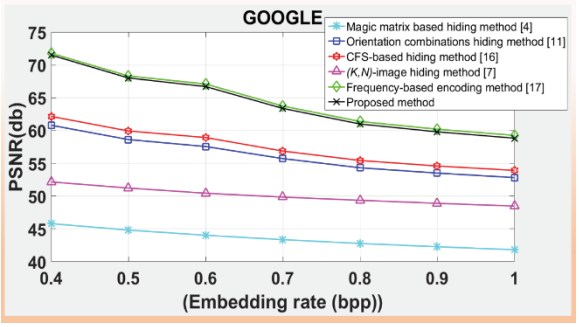

Fig.19 The result for the secret image “Google”

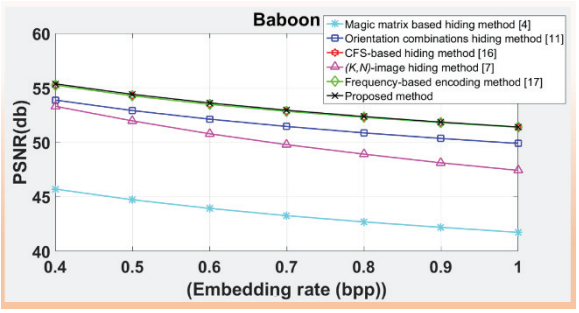

Fig.20 The result for the secret image “Baboon”

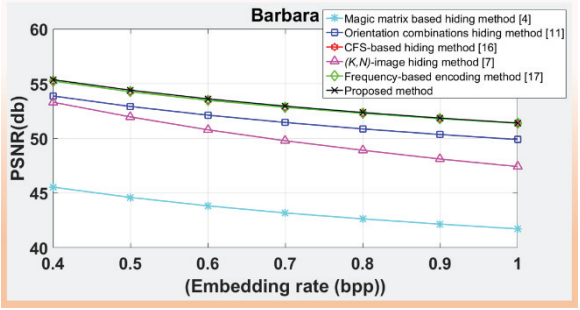

Fig.21 The result for the secret image “Barbara”

Table.3 Experimental results

Secret Image	**Brain**						
R	0.4	0.5	0.6	0.7	0.8	0.9	1.0
Proposed method	60.07	58.49	57.29	56.32	55.48	54.78	54.18
Frequency-based encoding method [17]	59.32	57.84	56.70	55.77	54.95	54.27	53.69
(*K,N*)-image hiding method [7]	59.28	57.84	56.70	55.74	54.88	54.18	53.61
CFS-based hiding method [16]	53.00	52.18	51.52	50.96	50.49	50.05	49.65
Orientation combinaitons hiding method [11]	58.27	56.68	55.61	54.66	53.83	53.13	52.54
Magic matrix based hiding method [4]	45.47	44.65	43.99	43.43	42.95	42.52	42.11
	Dolphin						
R	0.4	0.5	0.6	0.7	0.8	0.9	1.0
Proposed method	58.45	57.12	56.09	55.09	54.26	53.68	53.28
Frequency-based encoding method [17]	57.08	55.69	54.62	53.63	52.80	52.24	51.91
(K,N)-image hiding method [7]	54.45	53.68	53.04	52.52	52.03	51.58	51.03
CFS-based hiding method [16]	54.68	53.65	52.84	52.18	51.64	51.09	50.65
Orientation combinaitons hiding method [11]	55.33	54.25	53.38	52.60	51.91	51.39	50.93
Magic matrix based hiding method [4]	46.80	45.82	44.90	44.02	43.23	42.61	42.15
	IM						
R	0.4	0.5	0.6	0.7	0.8	0.9	1.0
Proposed method	65.84	64.26	63.29	60.80	58.70	57.37	56.23
Frequency-based encoding method [17]	65.75	64.19	63.23	60.75	58.88	57.62	56.61
(K,N)-image hiding method [7]	52.30	51.36	50.58	50.05	49.63	49.26	48.91
CFS-based hiding method [16]	58.55	57.26	56.39	55.03	53.86	52.98	52.27
Orientation combinaitons hiding method [11]	58.44	57.27	56.40	54.60	53.17	52.21	51.45
Magic matrix based hiding method [4]	46.25	45.31	44.48	43.80	43.13	42.46	41.81
	NCHU						
R	0.4	0.5	0.6	0.7	0.8	0.9	1.0
Proposed method	76.10	73.39	71.73	70.80	70.12	69.61	69.54
Frequency-based encoding method [17]	70.31	68.02	66.60	65.65	64.83	64.32	64.26
(K,N)-image hiding method [7]	58.45	56.74	55.27	54.00	52.83	51.82	51.05
CFS-based hiding method [16]	57.14	55.83	54.79	53.96	53.18	52.65	52.42
Orientation combinaitons hiding method [11]	58.27	56.78	55.61	54.66	53.83	53.13	52.54
Magic matrix based hiding method [4]	45.61	44.66	43.86	43.19	42.62	42.10	41.64
	Google						
R	0.4	0.5	0.6	0.7	0.8	0.9	1.0
Proposed method	71.50	68.01	66.70	63.37	60.99	59.80	58.83
Frequency-based encoding method [17]	71.77	68.32	67.09	63.73	61.38	60.20	59.26
(K,N)-image hiding method [7]	52.16	51.23	50.44	49.85	49.36	48.90	48.48
CFS-based hiding method [16]	62.15	59.93	58.93	56.87	55.43	54.59	53.92
Orientation combinaitons hiding method [11]	60.80	58.62	57.56	55.72	54.32	53.51	52.82
Magic matrix based hiding method [4]	45.80	44.82	44.03	43.36	42.78	42.28	41.82
	Boboon						
R	0.4	0.5	0.6	0.7	0.8	0.9	1.0
Proposed method	55.36	54.40	53.61	52.94	52.36	51.85	51.40
Frequency-based encoding method [17]	55.24	54.26	53.48	52.84	52.29	51.80	51.39
(K,N)-image hiding method [7]	53.30	51.96	50.78	49.78	48.91	48.11	47.42
CFS-based hiding method [16]	55.24	54.26	53.48	52.83	52.28	51.80	51.38
Orientation combinaitons hiding method [11]	53.87	52.91	52.12	51.45	50.86	50.35	49.89
Magic matrix based hiding method [4]	45.70	44.72	43.93	43.26	42.69	42.19	41.73
	Barbara						
R	0.4	0.5	0.6	0.7	0.8	0.9	1.0
Proposed method	55.63	54.65	53.84	53.16	52.58	52.06	51.61
Frequency-based encoding method [17]	55.60	54.64	53.86	53.22	52.66	52.17	51.71
(K,N)-image hiding method [7]	53.15	51.79	50.53	49.52	48.63	47.77	47.10
CFS-based hiding method [16]	55.50	54.54	53.74	53.08	52.52	52.03	51.56
Orientation combinaitons hiding method [11]	53.90	52.93	52.14	51.47	50.89	50.37	49.91
Magic matrix based hiding method [4]	45.74	44.77	43.98	43.30	42.73	42.22	41.76

V. CONCLUSION

In this paper, we propose a novel encoding method that can effectively encode the secret digit to reduce the frequency of occurrence of the largest value and take the relationship occurrence frequency of digits, thereby decreasing the modification level obviously in the data embedding stage.

Experimental results show that the PSNR value of the proposed method is greater than that of the related methods [4,7,11,16]. However, for the image "Google", the PSNR value of the proposed method is smaller than that of the frequency-based encoding method [17] with the same embedding rate. This is because the difference between two adjacent sets of secret bits presents the uniform distribution, decreasing the encoding effectiveness of the codebook. However, in other images, the PSNR value of the proposed method is significantly higher than that of the frequency-based encoding method. Consequently, the proposed method has high practicability in the application of data hiding.

In the future, we will attempt to improve the codebook to enhance the possibility of matching the first several patterns, thereby achieving better PSNR.

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