Improved Lossless Data Hiding Mechanisms based on Block-based Hiding Algorithm, Double Hiding Strategy and Variable Control Technique

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Abstract. The lossless information hiding technique is to embed secret message into multi-media to generate stego multi-media. Due to the stego media is very similar to the cover media, it is difficult for illegal users to detect that there are some secret message concealed on the cover media. Jin et al. proposed a lossless information hiding technique in 2007. Their method is simple and the quality of the stego image is nice. However, the hiding capacity of their method is low. Therefore, we apply three mechanisms to improve Jin et al.'s scheme. The mechanisms include block-based hiding algorithm, double hiding strategy, and variable control technique. Six systems are implemented to test the performances of the mechanisms. The experimental results show that the hiding capacities of the proposed schemes are better than that of Jin et al.'s scheme. In addition, the performance of the proposed scheme is better than that of Coltuc et al.'s RCM-based scheme. We also compare Ni et al.'s histogram-based method with the proposed schemes. Although the image quality of Ni et al.'s scheme is better than that of the proposed scheme, the hiding capacity of the proposed scheme is several times of that of Ni et al.'s scheme.

Keywords: lossless information hiding technique, sort technique, block-based hiding technique, double hiding technique, variable

1 Introduction

Information hiding technique is to conceal data into multi-media to generate stego multi-media. Due to the stego multi-media is similar to the original multi-media, the hacker can not detect that there are some secret message concealed on the multi-media. Nevertheless, this kinds of technique will destroy the original multi-media. The damaged multi-media are not suitable for the delicate fields of military and medicine [1]. In order to solve the problems, experts proposed lossless information hiding techniques.

Lossless information hiding technique is to embed message into multi-media without been detected by hacker. When the receiver receives the stego multi-media, they can use extraction and recovering algorithm to extract the secret data and restore the host multi-media.

In 2003, Tian [2] proposed a lossless information hiding by using difference expansion method. The technique uses two pixels to embed one secret data. Assumed that a pixel pair is $(A, B) = (150, 160)$ and secret data is $s = (1)_2$. First, the scheme calculates its absolute difference value and integer average value, $d = |A - B| = 150 - 160 = 10$ and $\ell = \left\lfloor \frac{A+B}{2} \right\rfloor = \left\lfloor \frac{150+160}{2} \right\rfloor = 155$. Second, the scheme embeds the secret data into the difference to generate a new absolute difference value, $d' = 2 \times d + s = 2 \times 10 + 1 = 21$. Finally, they use the integer average value and the new absolute difference value to generate two stego pixels,

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$A' = \ell + \left\lfloor \frac{d'+1}{2} \right\rfloor = 155 + 11 = 166$ and $B' = \ell - \left\lfloor \frac{d'}{2} \right\rfloor = 155 - 10 = 145$. The distortion of the above technique is pretty low and the hiding capacity is nice. However, this technique has overflow or underflow problems. In order to solve this problem, a location map is used to identify if the pair is embeddable or not. Next, they use compression technique to compress the location map to increase the pure hiding capacity. However, the compression technique is complex [3].

In 2007, Jin et al. proposed a lossless information hiding technique to improve Tian's method [4]. In their scheme, a best threshold is predefined to avoid underflow or overflow problems. Therefore, Jin et al.'s scheme does not need location map and compression technique. However, the hiding capacity of their scheme is pretty low. Hence, in this paper, we shall propose an efficient block-based lossless information hiding technique to improve Jin et al.'s scheme. In addition, we also apply double hiding strategy and variable control technique to enhance hiding capacity.

2 Related Works

In this section, we describe Jin et al.'s lossless information hiding scheme [4]. The hiding and extraction procedures of their scheme are described as follows.

2.1 Hiding Phase

First, they divide a *h*-bit grayscale image sized $M \times M$ into several overlap blocks. Let P be the center pixel of a block. The structure of the block is shown in Fig. 1. The pixels $N_1, N_2, \ldots, N_8$ are the neighboring pixels of P. Second, the scheme calculates the integer average value $\overline{N}$ of P's neighboring pixels by the following equation:

$$\overline{N} = \left\lfloor \frac{\sum_{j=1}^{8} N_j}{8} \right\rfloor. \tag{1}$$

N_1	N_2	N_3
N_4	P	N_5
N_6	N_7	N_8

Fig. 1. The structure of a block in Jin et al.'s scheme

Third, the scheme calculates the difference d between the center pixel and the integer average value, $d = P - \overline{N}$. The scheme figure out the distance by the following:

$$\Delta = \begin{cases} N_{\max} - \overline{N}, d \geq 0, \\ N_{\min} - \overline{N}, d < 0, \end{cases} \tag{2}$$

where $N_{\max}$ is the maximum neighboring pixel, $N_{\max} = \underset{j=1}{\overset{8}{Max}}\{N_j\}$, and $N_{\min}$ is the minimum neighboring pixel, $N_{\min} = \underset{j=1}{\overset{8}{Min}}\{N_j\}$. Δ and t are used to calculate the threshold of the block, where t is judged by

$$t = \begin{cases} |\Delta|, \overline{N} + 2 \times d < 0 \text{ or } \overline{N} + 2 \times d > 2^h - 2, \\ \infty, \text{others}. \end{cases} \tag{3}$$

Finally, the scheme chooses the minimum t from the blocks as the final threshold, T . In Jin et al.'s scheme, if the block satisfies the condition $|\Delta| < T$, then the block is embeddable, which can be used to embed the secret message. Otherwise, the block is non-embeddable.

The scheme embeds the secret data by the following equation:

$$P' = \begin{cases} \overline{N} + 2 \times d + s, \text{ if the block is embeddable}, \\ P \qquad\qquad\qquad , \text{others}, \end{cases} \tag{4}$$

where P' represents the stego pixel.

2.2 Extraction and Recovery Phase

When the receiver gets the stego image and the threshold T , the scheme divides the stego image into several overlap blocks sized 3×3. The scheme then calculates the integer average value $\overline{N}'$ of the neighboring pixels and figure out the difference d' between the center pixel P' and the integer average value $\overline{N}'$, where $d' = P' - \overline{N}'$.

Next, the scheme calculates the distance by following equation:

$$\Delta' = \begin{cases} N'_{\max} - \overline{N}', d' \geq 0, \\ N'_{\min} - \overline{N}', d' < 0. \end{cases} \tag{5}$$

If $|\Delta'| < T$, then the secret data s is extracted by

$$s = d' \bmod 2 . \tag{6}$$

Finally, the original pixels can be reconstructed by

$$P = \begin{cases} \dfrac{P' + \overline{N}' - s}{2}, |\Delta'| < T, \\ P' \qquad\qquad\quad , \text{others}. \end{cases} \tag{7}$$

3 The Proposed Scheme

Jin et al.'s scheme is simple and the stego image quality is nice. However, the ideal hiding capacity of Jin et al.'s scheme is $C = \left\lfloor \dfrac{M-1}{2} \right\rfloor \times \left\lfloor \dfrac{M-1}{2} \right\rfloor$. Therefore, we apply three mechanisms to increase the hiding capacity. In following section, three mechanisms are described.

3.1 Block-based Hiding Algorithm

The proposed scheme divides a cover image sized $M \times M$ into several non-overlap blocks sized 3×3. The structure of the block is shown in Fig. 2. Let $P = \{P_1, P_2, \ldots, P_5\}$ be a set of the candidate pixels, which can be used to conceal secret data, $N = \{N_1, N_2, N_3, N_4\}$ be a set of the neighboring pixel and $s = \{s_1, s_2, \ldots, s_5\}$ be a set of the secret bits.

Next, the scheme computes the integer average value $\overline{N} = \left\lfloor \dfrac{\sum_{j=1}^{4} N_j}{4} \right\rfloor$ of the neighboring pixels and calculates the differences d_i between each candidate pixel P_i and $\overline{N}$, where $d_i = P_i - \overline{N}$.

The proposed scheme figure out the distance by

$$\Delta = \begin{cases} N_{max} - \overline{N}, d_{max} \geq 0, \\ N_{min} - \overline{N}, d_{max} < 0, \end{cases} \quad (8)$$

where N_{max} is the maximum neighboring pixel, $N_{max} = \underset{j=1}{\overset{4}{Max}}\{N_j\}$, N_{min} is the minimum neighboring pixel, $N_{min} = \underset{j=1}{\overset{4}{Min}}\{N_j\}$, and d_{max} is the maximum difference of the differences, where $d_{max} = sig(d_i)\underset{i=1}{\overset{5}{Max}}\{|d_i|\}$ and $sig(d_i)$ is the signal of d_i. The scheme also uses Δ and t to calculate the threshold of the block, where t is judged by

$$t = \begin{cases} |\Delta|, \overline{N} + 2 \times d_{max} < 0 \text{ or } \overline{N} + 2 \times d_{max} > 2^h - 2, \\ \infty, \text{others}. \end{cases} \quad (9)$$

The minimum t is set as the final threshold, T.

P_1	N_1	P_2
N_2	P_3	N_3
P_4	N_4	P_5

Fig. 2. The structure of the block in the proposed scheme

Let us take Fig. 3 as an example to demonstrate how to define the final threshold. The scheme divides the image into four blocks and computes the integer average values for each block. The average values are 16, 46, 250, and 250, respectively. Next, we calculate the differences between the candidate pixels and the average values and figure out the maximum differences for each block. The maximum differences of each block are 3, 4, 5, and 1. Then, the distance between the maximum (or minimum) neighboring pixel and the integer average value is obtained using Equation 8. The distance Δ of each block are 1, 2, 5, and 5, respectively. The scheme then uses the distances to judge the thresholds. The thresholds are ∞, ∞, 5, and 5. Hence, the minimum threshold is T = 5.

16	15	14	50	48	50
15	13	17	47	46	45
15	17	15	44	44	43
250	255	250	250	255	250
250	255	250	249	250	249
250	245	250	249	249	249

Fig. 3. An example image

If the block satisfies the condition $|\Delta| < T$, then the block is embeddable, which can be used to embed the secret message. Otherwise, the block is non-embeddable. The scheme embeds one secret bit to each candidate pixel of the embeddable block by

$$P_i' = \begin{cases} \overline{N} + 2 \times d_i + s_i, \text{if the block is embeddable}, \\ P_i \qquad\qquad\quad, \text{others}, \end{cases} \quad (10)$$

where P_i' is the stego pixel.

In Fig. 3, the distances of the first block and the second blocks are less than T. Hence, the two blocks are embeddable which can be used to conceal the secret message. Suppose that the secret message is $s = \{0111010001\}$. The first stego pixel of the first block is 16, since $P_1' = \overline{N} + 2 \times d_1 + s_1 = 16 + 2 \times 0 + 0 = 16$. The second stego pixel is 13, since $P_2' = \overline{N} + 2 \times d_2 + s_2 = 16 + 2 \times (-2) + 1 = 13$. The final stego pixels are shown in Fig. 4.

16	15	13	55	48	54
15	11	17	47	46	45
15	17	14	42	44	41
250	255	250	250	255	250
250	255	250	249	250	249
250	245	250	249	249	249

Fig. 4. The stego image of Fig. 3

When the receiver gets the stego image and threshold T , the scheme divides the stego image into several non-overlap blocks sized 3×3 and further calculates the integer average value $\overline{N}'$ and the differences $d_i' = P_i' - \overline{N}'$. After that, the scheme uses

$$\Delta' = \begin{cases} N'_{\max} - \overline{N}', d'_{\max} \geq 0, \\ N'_{\min} - \overline{N}', d'_{\max} < 0. \end{cases} \quad (\mathbf{11})$$

to figure out the distance, where $d'_{\max}$ is the maximum difference of the differences, where $d_{\max} = sig(d_i') \underset{i=1}{\overset{5}{Max}} \{|d_i'|\}$. If $|\Delta'| < T$, the secret bits is extracted by

$$s_i = (P_i' - \overline{N}') \bmod 2. \quad (\mathbf{12})$$

Finally, restore the pixels by the following:

$$P_i = \begin{cases} \dfrac{P_i' + \overline{N}' - s_i}{2}, |\Delta'| < T, \\ P_i', \qquad , \text{others}. \end{cases} \quad (\mathbf{13})$$

For example, when the receiver received the stego image as shown in Fig. 4. The scheme divides the image into four blocks and further calculates the integer average values and the differences for each block. The average values are 16, 46, 250, and 250, respectively. The maximum differences of each block are 5, 9, 5, and 1. Then, the distance between the maximum (or minimum) neighboring pixel and the integer average value is obtained using Equation 11. The distance Δ' of each block are 1, 2, 5, and 5, respectively. Because the distances of the first and the second blocks are smaller than the final threshold, $|\Delta'| < T$, the secret bits is extracted by Equation 12. The extracted secret bits are $s = \{0111010001\}$. Then, the scheme uses Equation 13 to restore the original pixel. For example, the first pixel of the first block is restored by $P_1 = \frac{P_1' + \overline{N}' - s_1}{2} = \frac{16+16-0}{2} = 16$. The second pixel is restored by $P_2 = \frac{P_2' + \overline{N}' - s_2}{2} = \frac{13+16-1}{2} = 14$.

3.2 Double Hiding Strategy

The double hiding strategy is applied to Jin et al.'s scheme and the proposed scheme for increasing the hiding capacity. The strategy is described as following. Let P be a set of the candidate pixels, for example, in Jin et al.'s scheme P has one element which is the center pixel of the block, in the proposed scheme P is the set of the candidate pixels $P = \{P_1, P_2, \ldots, P_5\}$. Let $\overline{N}$ be the integer average value of the neighboring pixels, and s be the secret data, where $s_i \in [0, 3]$. The scheme calculates the difference d_i between P and $\overline{N}$, $d_i = P_i - \overline{N}$. Afterward, the scheme use

$$\Delta = \begin{cases} N_{\max} - \overline{N}, d_{\max} \geq 0, \\ N_{\min} - \overline{N}, d_{\max} < 0, \end{cases} \text{ and}$$

$$t = \begin{cases} |\Delta|, \overline{N} + 4 \times d_{\max} < 0 \text{ or } \overline{N} + 4 \times d_{\max} > 2^h - 1 - S_{\max}, \\ \infty, \text{ others}, \end{cases} \quad (\mathbf{14})$$

to figure out the distance and to calculate the threshold of each block, respectively. In the equation, $d_{\max} = sig(d_i)Max\{|d_i|\}$ and $S_{\max}$ is maximum value of the secret data, $S_{\max} = Max\{s_i\}$. Finally, the scheme chooses the minimum threshold t as the threshold, T.

If the block satisfies the condition $|\Delta| < T$, then the block is embeddable. Otherwise, the block is non-embeddable. The scheme embeds two secret bits to each candidate pixel of the embeddable block by

$$P_i' = \begin{cases} \overline{N} + 4 \times d_i + s_i, \text{the block is embeddable}, \\ P_i, \quad \text{, others}, \end{cases} \quad (15)$$

where P_i' is stego pixel.

When the receiver receives the stego image and threshold T, the scheme calculates the integer average value $\overline{N}'$ of the neighboring pixels P_i', and further figure out the difference between P_i' and $\overline{N}'$, where $d_i' = P_i' - \overline{N}'$. Afterward, the scheme calculate the distance by

$$\Delta' = \begin{cases} N'_{\max} - \overline{N}', d'_{\max} \geq 0, \\ N'_{\min} - \overline{N}', d'_{\max} < 0. \end{cases} \quad (16)$$

If $|\Delta'| < T$, the secret message is extracted by

$$s_i = (P_i' - \overline{N}')\bmod(S_{\max} + 1). \quad (17)$$

Finally, the scheme use

$$P_i = \begin{cases} \dfrac{P_i' + \overline{N}' - s_i - \dfrac{\left\lfloor \dfrac{P_i' - \overline{N}'}{4} \right\rfloor \times 4}{2}}{2}, |\Delta| < T, \\ P_i', \quad \text{, others}, \end{cases} \quad (18)$$

to restore original pixels.

3.3 Variable Control Technique

Both Jin et al.'s scheme and the proposed scheme use Δ to determine whether the block is embeddable. If $|\Delta| < T$, then the block is embeddable. However, some blocks does not satisfy the condition $|\Delta| < T$ but is embeddable. For example, the distance Δ of the fourth block in Fig. 3 is 5 that is equal to the final threshold. Hence, the block is be judged as a non-embeddable block. Nevertheless, the block is embeddable in fact. Because the embedding process will let the stego pixels have overflow or underflow problem. In order to prevent this kind of problems, the proposed scheme applies variable control technique as an auxiliary mechanism to judge the embeddable blocks. The variable control technique is applied to Jin et al.'s scheme and the proposed scheme for increasing the hiding capacity.

After finding the threshold T, the scheme computes the variable for each block. Let $N = \{N_1, N_2, \ldots, N_R\}$ be the set of the neighboring pixels. The scheme uses

$$v = \frac{1}{R-1}\sum_{j=1}^{R}(N_j - \overline{N})^2. \quad (19)$$

to get the variable of the block. Then, we choose the maximum v from the non-embeddable blocks as the variable threshold, ℓ. If the block satisfies the conditions $|\Delta| \geq T$ and $v \geq \ell$, then the block is non-embeddable. Otherwise, the block is embeddable.

For example, the variables of the blocks in Fig. 3 are 1.33, 3,33, 16.67, and 9. The maximum variable of the non-embeddable blocks is 16.67. Hence, the variable threshold is ℓ = 16.67. In this case, only the third block is non-embeddable. Other blocks are embeddable.

When the receiver receives the thresholds and the stego image, he uses Equation 11 to get the distance and Equation 19 to get the variable for each block. If the distance is lower than T and the variable is lower than ℓ, it means there are some secret bits embedded in the block. The scheme uses the extraction and recovering algorithm to extract the secret data and to restore the original image.

4 Experimental Results and Performance Evaluation

Eight difference systems are implemented to test the performances of the proposed mechanisms. The systems are described as follows.

- Jin et al.'s system: The system applies Jin et al.'s scheme.
- JV system: The system applies Jin et al.'s scheme with variable control technique.
- JDV system: The system applies Jin et al.'s scheme with double hiding strategy and variable control technique.
- LH system: The system applies the proposed block-based hiding algorithm.
- LHD system: The system applies the proposed block-based hiding algorithm with double hiding strategy.
- LHDV system: The system applies the proposed block-based hiding algorithm with double hiding strategy and variable control technique.
- Coltuc et al.'s system: The system applies Coltuc and Chassery's scheme [3].
- Ni et al.'s system: The system applies Ni et al.'s scheme [5].

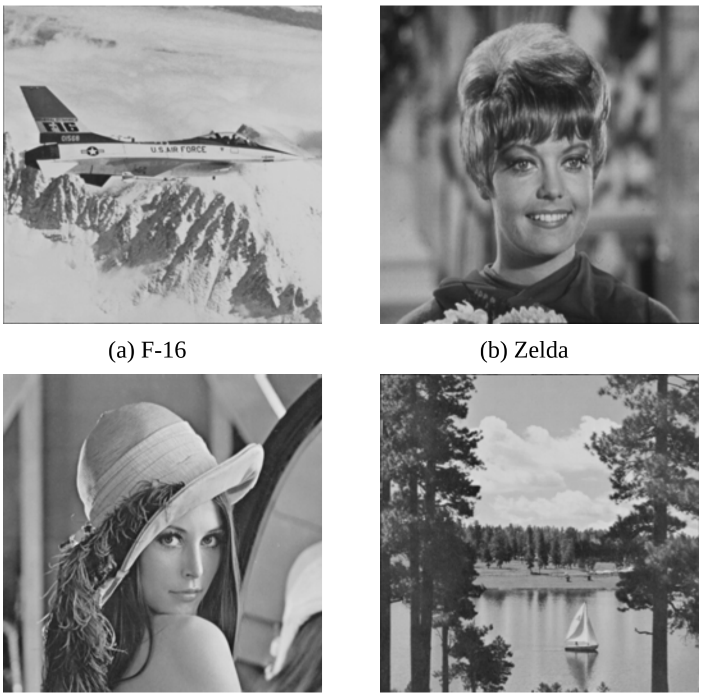
Four test images sized 512×512 are shown in Fig. 5. We use a random number generator to generate the secret message. The peak signal-to-noise ratio (PSNR) is used to evaluate the performance of the proposed scheme. The equation of PSNR is as the following:

$$\text{PSNR} = 10 \times \log_{10} \frac{255^2}{\text{MSE}} \text{ (Decibel, dB).} \quad \textbf{(20)}$$

In the equation, MSE is mean square error between the cover image and stego image. MSE is defined as follows,

$$\text{MSE} = \frac{1}{M \times M} \sum_{k=1}^{M} \sum_{q=1}^{M} (P_{k,q} - P'_{k,q})^2. \quad \textbf{(21)}$$

where (k, q) is the location of the pixel and $M \times M$ is total number of pixels in the image.



(a) F-16 (b) Zelda

(c) Lena (d) Sailboat

Fig. 5. Four test images

The system with double hiding strategy needs to record the minimum threshold T and the variable threshold ℓ. If all candidate pixels do not have underflow or overflow problem, then the threshold will be set to a limitless value. The experimental results are shown in Table 1. The results of Jin et al.'s system, JV, and JDV are shown in Table 1 (a), (b) and (c), respectively. We can see that the hiding capacity and PSNR of JV are better than that of Jin et al.'s system. Although PSNR of JDV is lower than that of Jin et al.'s system, the hiding capacity of JDV is high.

The results of LH, LHD, and LHDV systems are shown in Table 1 (d), (e) and (f), respectively. The hiding capacity of the proposed scheme is almost twice as large as that of Jin et al.'s system. In addition, the quality of the stego image is accepted.

We can see that the hiding capacity of the system with high threshold T is higher than that of the system with low threshold. For example, the threshold T of F16 is higher than that of Lena, and the hiding capacity of F16 is better than that of Lena.

Table 1. Experimental results

(a) Experimental results of Jin et al.'s system

Image	Bits	PSNR (dB)	Threshold (T)
F16	63,889	39.289	45
Zelda	65025	43.4703	∞
Lena	62,325	40.204	31
Sailboat	64,851	36.029	67

(b) Experimental results of JV system

Image	Bits	PSNR (dB)	Variable Threshold (ℓ)
F16	64,340	39.3886	2.0951e+003
Zelda	65,025	43.4703	∞
Lena	62,963	39.9466	787.6964
Sailboat	64,843	36.1692	2.8534e+003

(c) Experimental results of JDV system

Image	Bits	PSNR (dB)	Thresholds (ℓ, T)
F16	109,492	36.5957	(25.3571, 45)
Zelda	127,643	35.3372	(240.9821, ∞)
Lena	63,216	40.1278	(1.0714, 31)
Sailboat	78,427	35.1633	(8, 67)

(d) Experimental results of LH system

Image	Bits	PSNR (dB)	Thresholds (T)
F16	131,361	35.8113	19
Zelda	143,678	35.3272	32
Lena	119,348	37.3634	11
Sailboat	122,472	33.3735	18

(e) Experimental results of LHD system

Image	Bits	PSNR (dB)	Thresholds (T_1, T_2)
F16	199,734	33.9563	(3, 19)
Zelda	145,769	35.2732	(1, 32)
Lena	119,348	37.3634	(0, 11)
Sailboat	124,465	33.2886	(1, 18)

(f) Experimental results of LHDV system

Image	Bits	PSNR (dB)	Thresholds (ℓ, T)
F16	209,646	33.5480	(6.9167, 19)
Zelda	185,483	33.8519	(4, 32)
Lena	124,258	36.9887	(0.9167, 11)
Sailboat	135,502	32.7812	(1.6667, 18)

Next, we compare the proposed scheme with Ni et al.'s system and Coltuc et al.'s system. The comparison results are shown in Table 2. From Table 2, it is noted that the hiding capacity and image quality of LH are better than that of Coltuc et al.'s system. Meanwhile, two thresholds are used in Ni et al.'s system and LHD. Table 2 shows that the image quality of Ni et al.'s system is nice. However, its hiding capacity is pretty low.

Table 2. Comparison results

(a) Comparison results of F-16

Method	Bits	PSNR(dB)	Threshold
LH system	131,361	35.8113	19
Coltuc et al.'s system	119,726	35.1776	23
LHD system	199,734	33.9563	(3, 19)
Ni et al.'s system	9,002	53.2454	(195, 216)

(b) Comparison results of Zelda

Method	Bits	PSNR(dB)	Threshold
LH system	143,678	35.3272	32
Coltuc et al.'s system	127,344	35.0562	23
LHD system	145,769	35.2732	(1, 32)
Ni et al.'s system	2,565	53.3138	(137, 207)

(c) Comparison results of Lena

Method	Bits	PSNR(dB)	Threshold
LH system	119,348	37.3634	11
Coltuc et al.'s system	117,932	33.0146	23
LHD system	119,348	37.3634	(0, 11)
Ni et al.'s system	2,748	53.7346	(155, 237)

(d) Comparison results of Sailboat

Method	Bits	PSNR(dB)	Threshold
LH system	122,472	33.3735	18
Coltuc et al.'s system	113,468	31.7470	23
LHD system	124,465	33.2886	(1, 18)
Ni et al.'s system	4,263	53.6258	(173, 222)

5 Conclusions

In this paper, we proposed three mechanisms, block-based hiding algorithm, double hiding strategy, and variable control technique, to increase hiding capacity. Block-based hiding algorithm is allowed to embed five bits in a block. The experimental results show that the hiding capacity of this technique is better than that of Jin et al.'s scheme. In addition, the double hiding strategy is allowed to embed two secret bits for each candidate pixel. Also the variable control technique is used to increase the hiding capacity. The experimental results demonstrate that the techniques are very suitable for smooth image.

In the future, we will work on the worth related issues which are described as following:

(1) Use logarithm method to reduce the length of variable.
(2) Embed more secret bit into complex image.
(3) Embed private message into color image.

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