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Distortion reduction for histogram modification-based reversible data hiding

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ABSTRACT

The histogram modification (HM) method proposed by Ni et al. is very efficient for reversible data hiding (RDH). Besides the excellent execution-time performance, Ni et al.'s HM-based RDH (HMRDH) method has a high PSNR lower bound of marked images. In this short communication, an observation on Ni et al.'s HM-based RDH (HMRDH) method is pointed out that the distortion of the marked image from Ni et al.'s method is dependent on the number of 1's in the watermark. From this observation, we first present a watermark complement scheme to reduce the distortion occurred in Ni et al.'s HMRDH method. Later, combinatorial analysis for average distortion ratio of the proposed scheme is provided. This analysis motivates us to present a block-based complement scheme to improve the distortion reduction further. The tradeoff between the distortion and the number of partitioned blocks is also investigated. Taking nine well-known trademarks as the test watermarks and two cover images with different types of content, experimental results demonstrated the distortion reduction and higher PSNR lower bound advantages of the proposed block-based watermark complement scheme.

1. Introduction

Reversible data hiding (RDH) has received intense attention in recent years. In practical applications, some cover images, e.g. medical images, are very sensitive to the distortion caused by embedding the watermark into the cover image, so besides the high embedding capacity requirement, RDH also has two other requirements-(1) after embedding the watermark into the cover image, the marked image should be distorted as least as possible and (2) after extracting the watermark, the cover image can be restored completely.

In the literature, there are many RDH methods that have been developed. These methods include the JPEG domain-based invertible watermark scheme [8], the difference expansion technique [1,9–11,19–22,27], the integer-to-integer wavelet/DCT transform-based technique [2,13,29], the vector map approach [24], the LSB-based technique [4], the vector quantization-based technique [3,28], the Hamming code-based technique [14], the histogram mapping around a circle [25], the difference image histogram approach [15], and the histogram modification-based scheme [5,6,12,16–18,23,26].

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Since this research focuses on reducing the distortion for histogram modification-based RDH (HMRDH), the relevant previous works are introduced in more detail. Ni et al. [18] first utilized the peak–valley pair in the histogram to hide the watermark by modifying the gray values between the peak value and the valley value; the embedding capacity is equal to the frequency of the peak point. Their method can be extended to multiple peak–valley pairs. Varsaki et al. [26] also presented a peak–valley pair concept to embed the watermark. Chung et al. [7] presented a dynamic programming approach to find the peak–valley pairs with higher embedding capacity. Based on block-based difference subimages, Lin et al. [17] presented an efficient multilevel histogram modification method to embed the watermark. Tai et al. [23] presented a binary tree structure to solve the problem of communicating pairs of peak points to the recipients. Kim et al. [12] exploited the spatial correlation between sub-sampled images to achieve high capacity and imperceptible embedding. Some variants of HMRDH techniques have been applied to several applications, such as authentication [16], intra-frame error concealment in H.264/AVC video sequences [5], and multilevel RDH for video sequences [6]. For some secret and sensitive cover images, such as medical images, aerial images and military images, it is more important to reduce the distortion rather than to increase the embedding capacity. The motivation of this research is to present a novel approach to reduce the distortion for HMRDH method significantly, but to have a little capacity degradation.

In this short communication, an observation on Ni et al.'s HMRDH method is first given to explain why the number of 1's in the embedding watermark will affect the distortion degree of the marked image. From this observation, we present a simple watermark complement scheme to reduce the distortion occurred in Ni et al.'s HMRDH method. The number of 1's and the number of 0's in the watermark are counted in advance and a complement process is performed if the embedding watermark contains more 1's than 0's. The proposed scheme leads to a distortion reduction effect since it guarantees that the number of 0's in the embedding watermark is larger than the number of 1's. Later, a combinatorial analysis is provided to show the average distortion ratio. This analysis motivates us to design a block-based watermark complement scheme to improve the distortion reduction further. In additional, since each block needs one bit overhead to record that this block has been complemented or not, the tradeoff between the number of partitioned blocks and the distortion is investigated. Our experiments consider two cover images and the first one is the natural image with small embedding capacity and the second one is the guide_map image with much higher embedding capacity. Nine well-known trademarks are used as test watermarks and each watermark has two different sized version, one is 66×66 and the other is 420×420. These nine 66×66 and nine 420×420 watermarks are used to be embedded into first and second cover images, respectively. Experimental results showed the distortion reduction and higher Peak-Signal-to-Noise-Ratio (PSNR) lower bound when compared to Ni et al.'s method.

The rest of this short communication is organized as follows. In Section 2, an observation on the HMRDH method is given first. Based on this observation, our proposed watermark complement scheme is presented. In the same section, a combinational analysis is provided. Further, a block-based distortion reduction scheme is presented and the tradeoff between the number of partitioned blocks and the distortion is described. In Section 3, some experimental results are carried out to demonstrate the distortion reduction effect and higher PSNR lower bound of our proposed method. Finally, some concluding remarks are addressed in Section 4.

2. Proposed block-based watermark complement scheme for reducing distortion

2.1. Observation on Ni et al.'s HMRDH

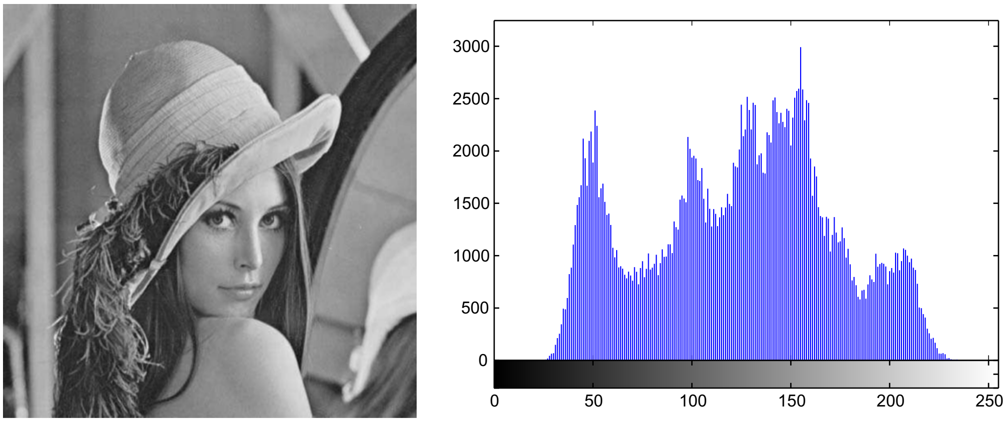
We are given a 512×512 Lena image I as shown in Fig. 1(a). The histogram of Fig. 1(a) is shown in Fig. 1(b) where the highest peak value is $P = 154$ and its frequency is 2787; it yields $f_P(154) = 2787$. From Fig. 1(b), the valley value V is 235 and its frequency is zero. Suppose we have an n-bits watermark denoted by $W = w_1w_2 \ldots w_n$ where $w_i \in \{0,1\}$ and $n = 2787$, and it meets the frequency of the peak value.

Based on Ni et al.'s HMRDH method, for Fig. 1(b), we first modify those pixel values in the range $(P,V)(=(154,235))$ by performing shift operations: $I(x,y) = I(x,y) + 1$ for $P < I(x,y) < V$, where $I(x,y)$ denotes the gray value at location (x,y). Note that if the valley value whose frequency is not zero, we must record the relevant positions for the valley value before performing the above shift operations. After completing the shift operations, for embedding the watermark W, the peak value P with frequency 2787 is modified by the following rule:

$$I'(x,y) = \begin{cases} I(x,y) + w_i & \text{if } I(x,y) = P, \\ I(x,y) & \text{otherwise} \end{cases} \tag{1}$$

for $0 \leqslant x, y \leqslant 511$ where $w_i \in \{0,1\}$ denotes the currently embedded bit in W.

Observation 1. Suppose the number of 1's in the watermark W is k, $0 \leqslant k \leqslant n-1$. After performing the histogram modification-based watermarking process in Eq. (1), the frequency of the gray value $P+1$ (=155) in the marked image I' becomes k and the frequency of the gray value P (=154) in I' becomes $n-k$, where P denotes the peak value.



(a) Input Lenaimage. (b) Histogram of the Lena image.

Fig. 1. Histogram of the Lena image.

Reconsidering Fig. 1(b), it is known that $n = 2787$. From Observation 1, for example, assume $k = 2000$; after performing the above histogram modification-based watermarking, in these 2787 peak values for $P = 154$, there are 2000 peak values being changed from 154 (=P) to 155 (=$P + 1$) and 787 (=2787 − 2000) peak values retain the same. This example reveals that using the HMRDH process, the number of distorted peak values is equal to the number of 1's in the watermark W, i.e. the parameter k. To relax the distortion problem, a simple watermark complement scheme is presented in next subsection. An improved version will be presented in SubSection 2.3.

2.2. Proposed watermark complement scheme and the average analysis of distortion ratio

Let the numbers of 1's and 0's in the watermark W be denoted by $|W_1|$ and $|W_0|$, respectively, and it satisfies $|W| = |W_1| + |W_0|$ where $|S|$ denotes the length of the binary string $S \in \{W, W_1, W_0\}$; let the complement of W be denoted by $\overline{W}$. For example, assume the watermark is given by $W = 110111011101$, then we have $|W| = 12$, $|W_1| = 9$, $|W_0| = 3$, and $\overline{W} = 001000100010$. The proposed watermark complement scheme obeys the following rule:

$$W' = \begin{cases} \overline{W} & \text{if } |W_1| > |W_0|, \\ W & \text{otherwise} \end{cases} \tag{2}$$

Returning to the above example again, since $|W_1|$(=9) is much larger than $|W_0|$(=3), by Eq. (2), the original watermark W(=110111011101) is changed to $\overline{W}(= 001000100010)$ as a new watermark; after performing Eq. (1), only three peak values are added to one instead of nine peak values. On the other hand, instead of nine gray values, only three gray values, 154's, are changed to 155's. We have the following average distortion ratio for the peak values by using the above watermark complement scheme.

Theorem 1. *Given a watermark W with $|W| = n$, the proposed watermark complement scheme yields the average distortion ratio $R_d = 1/2 - \binom{n-1}{n/2}/2^n$ for $n = 2m$; $R_d = 1/2 - \binom{n-1}{(n-1)/2}/2^n$ for $n = 2m + 1$.*

Proof. We first consider the even case, i.e. $n = 2m$. Because of $|W| = n$, there are 2^n different watermarks in total and each one has n bits. Therefore, the original outcome space has $n2^n$ bits totally. If the condition $|W_0| \geqslant |W_1|$ is held, the outcome space has $\sum_{k=0}^{m} k\binom{n}{k}$ 1's in total; otherwise, we have $|W_1| > |W_0|$ and after performing the proposed watermark complement operation, the outcome space has $\sum_{k=m+1}^{2m}(n-k)\binom{n}{k}$ 1's in total. Combining the above two conditions, the number of total 1's in the new outcome space is equal to

$$\begin{aligned}
&\sum_{k=0}^{m} k\binom{n}{k} + \sum_{k=m+1}^{2m}(n-k)\binom{n}{k}\\
&= \sum_{k=0}^{m} k\binom{n}{k} + \sum_{k=m+1}^{2m}(n-k)\binom{n}{n-k}\\
&= \sum_{k=0}^{m} k\binom{n}{k} + \sum_{j=0}^{m-1} j\binom{n}{j}\\
&= \sum_{k=0}^{m} k\binom{n}{k} + \sum_{k=0}^{m-1} k\binom{n}{k}\\
&= \sum_{k=1}^{m} n\binom{n-1}{k-1} + \sum_{k=1}^{m-1} n\binom{n-1}{k-1}\\
&= n\left[\sum_{k=1}^{m}\binom{n-1}{k-1} + \sum_{k=1}^{m-1}\binom{n-1}{k-1}\right]\\
&= n\left[\sum_{k=1}^{m}\binom{n-1}{k-1} + \sum_{k=1}^{m-1}\binom{n-1}{n-k}\right]\\
&= n\left[\sum_{k=0}^{m-1}\binom{n-1}{k} + \sum_{k=m+1}^{2m-1}\binom{n-1}{k}\right]\\
&= n\left[2^{n-1} - \binom{n-1}{m}\right]\\
&= n\left[2^{n-1} - \binom{n-1}{n/2}\right].
\end{aligned}$$

Therefore, for $n = 2m$, the ratio of the number of total 1's in the new outcome space using the proposed watermark complement scheme over that in the original outcome space is equal to $R_d = n\left[2^{n-1} - \binom{n-1}{n/2}\right]/(n\cdot 2^n) = 1/2 - \binom{n-1}{n/2}/2^n$.

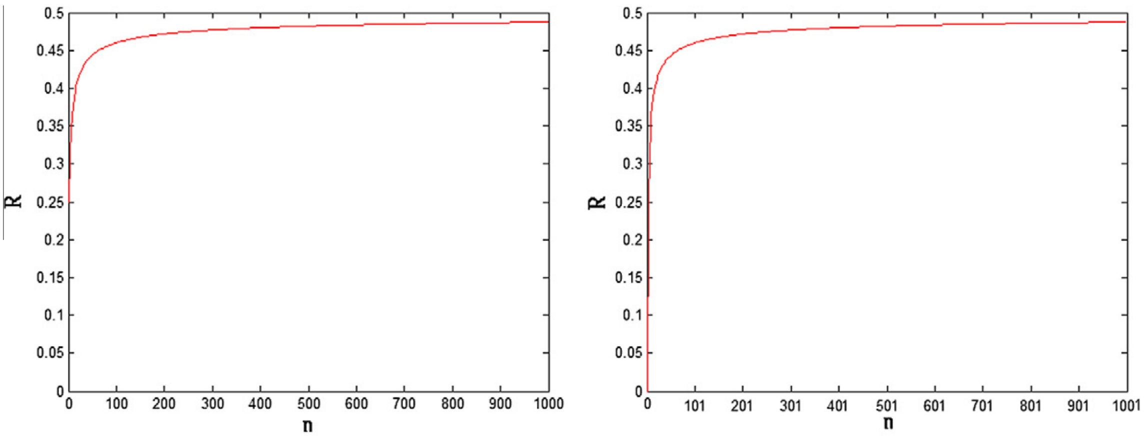
We further consider the odd case, i.e. $n = 2m + 1$. Similar to the above derivation, we have

$$\begin{aligned}
&\sum_{k=0}^{m} k\binom{n}{k} + \sum_{k=m+1}^{2m+1}(n-k)\binom{n}{k}\\
&= \sum_{k=0}^{m} k\binom{n}{k} + \sum_{k=m+1}^{2m+1}(n-k)\binom{n}{n-k}\\
&= \sum_{k=0}^{m} k\binom{n}{k} + \sum_{k=0}^{m} k\binom{n}{k}\\
&= \sum_{k=1}^{m} n\binom{n-1}{k-1} + \sum_{k=1}^{m} n\binom{n-1}{k-1}\\
&= n\left[\sum_{k=1}^{m}\binom{n-1}{k-1} + \sum_{k=1}^{m}\binom{n-1}{k-1}\right]\\
&= n\left[\sum_{k=0}^{m-1}\binom{n-1}{k} + \sum_{k=m+1}^{n}\binom{n-1}{k}\right]\\
&= n\left[2^{n-1} - \binom{n-1}{m}\right]\\
&= n\left[2^{n-1} - \binom{n-1}{(n-1)/2}\right]
\end{aligned}$$

Therefore, for $n = 2m + 1$, we have $R_d = n\left[2^{n-1} - \binom{n-1}{(n-1)/2}\right]/(n\cdot 2^n) = 1/2 - \binom{n-1}{(n-1)/2}/2^n$. We complete the proof. □

By Theorem 1, for $n = 2$, the distortion ratio is $R_d = 1/4$ (=1/2 − 1/4). For this case, we have four (=2^2) possible watermarks in total and each watermark contains two bits. These four watermarks form the original outcome space {00,01,10,11} and based on the proposed watermark complement scheme, we have a new outcome space {00,01,10,00} since the watermark 11 is changed to 00. That is, the number of total 1's in the outcome space can be reduced from 4 to 2 by using the proposed scheme. The distortion ratio is thus changed from 1/2 to 1/4. For $n = 3$, the original eight possible watermarks {000,001,010,011,100,100,101,110,111} are changed to the new set {000,001,010,100,100,100,010,001,000} by using the proposed watermark complement scheme; the distortion ratio is reduced from 1/2 to 7/24. In general, the distortion ratios for even n and odd n are depicted in Fig. 2(a) and (b), respectively.

If the distribution of all possible watermarks is uniform, the distortion ratio should be 1/4. However, from Fig. 2, it is observed that the distortion ratio approaches 1/2 when the value of n is large enough. The main reason is that for fixed n,



(a) For even n (b) For odd n

Fig. 2. The depiction of distortion ratios.

the distribution of $\binom{n}{k}$ for $0 \leqslant k \leqslant n$ is not a uniform distribution, but is a normal distribution and $\binom{n}{2/n}$ has the highest probability in the distribution. It means that the larger the number of 1's in the possible watermark is, the larger the corresponding probability is.

Fig. 2 also indicates that the smaller the value of $n(=|W|)$ is, the better the distortion reduction effect of the proposed watermark complement scheme is. Naturally, this indication motivates us to partition the watermark into a set of blocks. However, it is a tradeoff between the block size and the overhead for recording whether the watermark complement scheme is used for each block or not. The proposed block-based watermark complement scheme is presented in next subsection.

2.3. Proposed block-based watermark complement scheme

In this subsection, a block-based watermark complement scheme is presented to improve the distortion reduction effect further. The given watermark W is first partitioned into b blocks evenly and these b blocks are denoted by $W_1 = W_{11}W_{12}\ldots W_{1(n/b)}$, $W_2 = W_{21}W_{22}\ldots W_{2(n/b)},\ldots$, and $W_b = W_{b1}W_{b2}\ldots W_{b(n/b)}$. Here we assume n/b is an integer for convenience. After modifying the proposed watermark complement scheme mentioned in Eq. (2) slightly, the proposed block-based watermark complement scheme is given by

$$W'_i = \begin{cases} \overline{W_i} & \text{if } f_{n_1}(W_i) > f_{n_0}(W_i), \\ W_i & \text{otherwise} \end{cases} \tag{3}$$

for $1 \leqslant i \leqslant b$ where $f_{n_1}(W_i)$ and $f_{n_0}(W_i)$ denote the number of 1's and the number of 0's in the ith block of W, respectively; $\overline{W_i}$ denotes the complement of the ith block of W. Then, we cascade these b blocks, i.e. $W' = W'_1W'_2\ldots W'_b$, as a new watermark to be fed into the HMRDH method. The overhead of the above block-based watermark scheme in Eq. (3) is $b + \lceil \log_2 b \rceil$ bits where $\lceil \log_2 b \rceil$ bits are used to denote the size of each block and each bit of these b bits is used to specify whether the relevant block has been complemented or not.

For example, let the original watermark be W = 0010111010110111 and the number of partitioned blocks be $b = 4$, then by Eq. (3), we have $W'_1 = 0010, W'_2 = 0001, W'_3 = 0100$, and $W'_4 = 1000$. We further cascade $W' = W'_1W'_2W'_3W'_4 =$ 0010000101001000 as a new watermark. The overhead needs seven bits, three bits for representing $b = 4(=100_2)$ and four bits $(=0111_2)$ for specifying the complement status of each block in the four blocks. For this example, there are four 1's in the new watermark W' and due to *overhead* = 1000111, there are four 1's in the overhead. Consequently, instead of ten peak values distorted for the original watermark W, eight peak values are distorted for the new watermark W'. The distortion reduction improvement ratio is 0.2 $(=(10-8)/10)$.

Based on the same watermark W = 0010111010110111, let the number of partitioned blocks be $b = 16$, then by Eq. (3), we have $W'_1 = 0, W'_2 = 0,\ldots$, and $W'_{16} = 0$. The cascaded watermark $W' = W'_1W'_2\ldots W'_{16} =$ 0000000000000000 is used as the new watermark. The overhead needs twenty-one bits, five bits for representing $b = 16$, i.e. $b = (10000_2)$, and 16 bits $(=0010111010110111_2)$ for specifying the complement status of each block in the sixteen blocks. For this example, there are zero 1's in the new watermark W', but eleven 1's in the overhead. Therefore, eleven peak values are distorted for W' and it has one more distorted peak value when compared to that for W.

From the above two examples, it is a tradeoff between the number of partitioned blocks and the overhead for recording whether the watermark complement scheme is used for each block or not. Thus, the best choice for the number of partitioned blocks, say b^*, can be determined by

$$b^* = \arg\min_b \left[f_{n_1}(W') + f_{n_1}(h_b)\right] \quad (4)$$

where $h_b = b + \lceil \log_2 b \rceil$ denotes the overhead associated with the number of partitioned blocks, say $b; f_{n_1}(h_b)$ denotes the number of 1's in $h_b; f_{n_1}(W')$ denotes the number of 1's in the new watermark W'. Note that W' and b must satisfy the following condition:

$$|W'| + b + \lceil \log_2 b \rceil \leqslant C \quad (5)$$

where C denotes the embedding capacity of the cover image,

After embedding the overhead with $b^* + \lceil \log_2 b^* \rceil$ bits and the new watermark W' into the cover image, it is not hard to extract the overhead and W' from the marked image completely. According to the first b^* bits of the overhead, W' is thus partitioned into b^* blocks, and then from the last $\lceil \log_2 b^* \rceil$ bits of the overhead, each partitioned block can be recovered to the original one. Finally, these cascaded recovered blocks constitute the original watermark W.

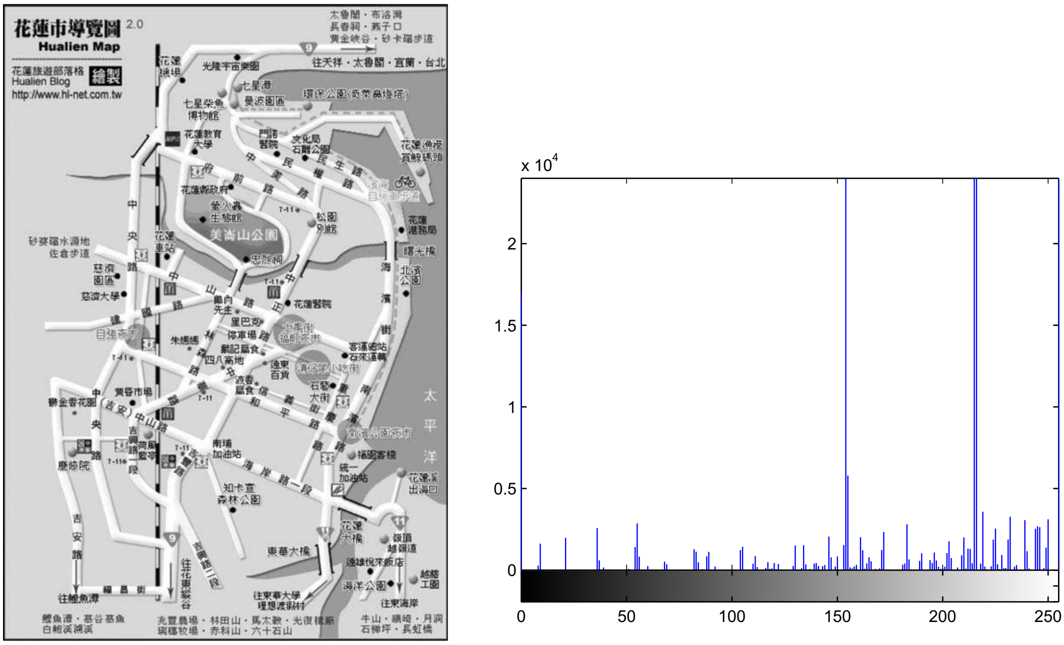
3. Experimental results

In this section, nine well-known trademarks are taken as the test watermarks to demonstrate the distortion reduction effect of our proposed block-based watermark complement method when compared to Ni et al.'s HMRDH method. These test watermarks are shown in Fig. 3 where each test watermark has two different sizes, one being 66×66 and the other being 420×420. Two cover images are used in our experiments, the first cover image as shown in Fig. 1(a) is the Lena image with size 512×512 and its histogram is shown in Fig. 1(b). In the Lena image, two maximal peak–valley pairs are utilized and the total embedding capacity is 5589. As shown in Fig. 4 (a), the second cover image is the guide_map image with size 517×741 and Fig. 4(b) illustrates its histogram. From Fig. 4(b), we can observe that guide_map image contains more peak–valley pairs than the Lena image, so it can provide higher embedding capacity. In the guide_map image, 30 peak–valley pairs are utilized and the total embedding capacity is 183972. In what follows, two experiments are provided to demonstrate the quality advantage of our proposed block-based watermark complement scheme. All the concerned experiments are performed on the Intel Core 2 Duo CPU with 2.8 GHz and 2 GB RAM. The operating system is MS-Windows XP and the program developing environment is Borland C++ Builder 6.0.

In the first experiment, we run Ni et al.'s method and our proposed method to embed nine 66×66 watermarks into the Lena image and the experimental results are shown in Table 1. In Table 1, five fields are listed for performance evaluation. In the five fields, the PSNR is defined by $PSNR = 10\log_{10}\frac{255^2}{\frac{1}{XY}\sum_{i=0}^{X-1}\sum_{j=0}^{Y-1}[I(i,j)-I'(i,j)]^2}$ where I and I' denote the cover image and the marked image, respectively; X and Y are the width and the height of the cover image and the marked image. The distortion ratio R_d has been mentioned in SubSection 2.2. The parameter b^* has been defined in Eq. (4). The distortion reduction ratio R_r is calculated by $R_r = \frac{R_d^{Ni} - R_d^{Our}}{R_d^{Ni}}$ where R_d^{Ni} and R_d^{Our} denote the distortion ratios of Ni et al.'s method and our proposed method, respectively. The overhead bits required in our method is defined by $h_{b^*} = b^* + \lceil \log_2 b^* \rceil$. From Table 1, it indicates that when compared to Ni et al.'s method, the proposed method has 0.71 average distortion reduction ratio. The quality of the marked image obtained by our proposed method is 48.21 which is higher than 48.18 obtained by Ni et al.'s method.

In the second experiment, the guide_map image provides much higher embedding capacity, 183972 bits totally. By running Ni et al.'s method and our proposed method to embed nine 420×420 watermarks into the guide_map image, experimental results are shown in Table 2. It indicates that the proposed method has 0.83 average distortion reduction ratio. The

Fig. 3. Nine test watermarks.



(a) Input guide_map image.
(b) Histogram of the guide_map image.

Fig. 4. Histogram of the guide_map image.

Table 1
Comparison between Ni et al.'s HMRDH method and our proposed method when embedding nine 66 × 66 test watermarks into Lena image.

Watermarks	Ni et al.'method		Our proposed method				
	R_d	PSNE	b^*	R_d	PSNR	R_r	h^{b^*}
(a)	0.59	48.18	545	0.18	48.20	0.69	555
(b)	0.41	48.19	1089	0.14	48.21	0.66	1100
(c)	0.40	48.19	1089	0.14	48.21	0.65	1100
(d)	0.67	48.17	26	0.23	48.20	0.66	31
(e)	0.61	48.17	872	0.17	48.20	0.72	882
(f)	0.58	48.18	623	0.18	48.20	0.69	633
(g)	0.70	48.17	257	0.11	48.21	0.84	266
(h)	0.45	48.19	1089	0.14	48.21	0.69	1100
(i)	0.55	48.18	726	0.16	48.21	0.71	736
Average	0.55	48.18	702	0.16	48.21	0.71	711

Table 2
Comparison between Ni et al.'s HMRDH method and our proposed method when embedding nine 420 × 420 test watermarks into guide_map image.

Watermarks	Ni et al.'method		Our proposed method				
	R_d	PSNE	b^*	R_d	PSNR	R_r	h^{b^*}
(a)	0.57	53.02	7350	0.11	57.55	0.81	7363
(b)	0.35	54.62	7350	0.09	57.90	0.74	7363
(c)	0.37	54.43	7350	0.10	57.76	0.73	7363
(d)	0.68	52.36	6300	0.12	57.44	0.82	6313
(e)	0.57	53.04	7350	0.08	58.05	0.86	7363
(f)	0.57	53.00	7350	0.09	57.99	0.84	7363
(g)	0.69	52.33	6785	0.05	58.82	0.93	6799
(h)	0.44	53.90	7350	0.08	58.16	0.82	7363
(i)	0.53	53.29	7350	0.08	58.13	0.85	7363
Average	0.53	53.33	7171	0.09	57.98	0.83	7184

quality of the marked image obtained by our proposed method is 57.98 and it has 4.65 (=57.98 − 53.33) dBs PSNR improvement when compared to Ni et al.'s method.

4. Conclusions

We have presented the proposed block-based watermark complement method to reduce the distortion occurred in Ni et al.'s HMRDH method. First a simple watermark complement approach is presented. Then an analysis is given to show the average bound for distortion ratio of the proposed simple approach. This analysis motivates us to present an improved block-based watermark complement approach. Further, a tradeoff between the number of partitioned blocks and the distortion is provided to determine the best partition way for the watermark. Some experimental results are carried out to demonstrate the distortion reduction effect and higher PSNR lower bound advantages of our proposed method when compared to Ni et al.'s HMRDH method. It is an interesting research issue to apply the proposed approach to the other RDH methods, such as the difference expansion-based RDH.

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