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A parameter memorization-free lossless data hiding method with flexible payload size

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Abstract: This paper proposes a lossless data hiding method which accepts various payload sizes. A lossless data hiding method once distorts an image to embed data into the image. From the distorted image, the method extracts the inserted payload data and restores the original image. The proposed method does not have to memorize any parameter for data extraction and image recovery. By simple modification to the conventional method having the above mentioned features, the proposed method becomes free from fixing payload size and from iterative parameter estimation.

Keywords: reversible watermarking, invertible information embedding, location map-free, spatial domain, prediction-based, capacity

Classification: Science and engineering for electronics

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1 Introduction

A data hiding method imperceptibly distorts an image to embed *payload* data into the image, and it extracts the payload from a distorted *stego* image [1]. A *lossless* data hiding method further restores the original image from the stego image, thus it is applicable to medical and military images [2].

A conventional lossless data hiding method extracts payload and restores an original image without memorizing any image-dependent parameter [3]. That is, this method is free not only from managing a parameter database but from identifying the stego image among all possible images to retrieve the parameter. The method, however, must fix the payload size as a system-wide setting, and it requires iterative parameter estimation for payload extraction.

This paper proposes an extended method based on the conventional method [3]. By a simple modification which sophisticates the criterion for guaranteeing lossless data hiding, the proposed method provides improved features; the method accepts payload of various sizes. It is further free from an iterative parameter estimation, because it uses no parameter. These features make the proposed method more practical.

2 Conventional method

This section mentions the conventional method [3]. The method divides a $X \times Y$-sized image into B of 3×3-sized overlapping blocks, as shown in Fig. 1 (a), where $B = \lfloor (X-1)/2 \rfloor \lfloor (Y-1)/2 \rfloor$. A payload bit, w_n, is hidden to t_b that is the central pixel of the b-th block, as shown in Fig. 1 (b), where $n = 0, 1, \ldots, N-1$ and $b = 0, 1, \ldots, B-1$.

First of all, the following steps are applied to all blocks to derive parameter τ that is used in both the embedding and extraction algorithms.

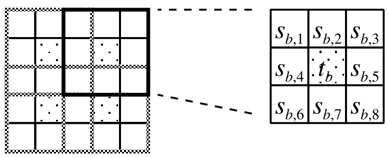
1. For center pixel t_b, predicted value p_b and prediction error e_b are obtained as

$$p_b = \frac{1}{8} \left\lfloor \sum_{j=0}^{7} s_{b,j} \right\rfloor, \quad (1)$$

$$e_b = t_b - p_b, \quad (2)$$

respectively.

2. According to the hiding equation mentioned later and the dynamic



(a) Block placement (b) b-th block

Fig. 1. Block division.

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range of a pixel, the usability of the b-th block is checked as

$$u_b = \begin{cases} 1, & 0 \leq p_b + 2e_b \leq 2^Q - 2 \\ 0, & \text{others} \end{cases}, \tag{3}$$

where Q represents the quantization bits for pixel values. When $u_b = 1$, the b-th block is usable, i.e., the block meets the criterion for guaranteeing lossless data hiding.

3. For deriving τ, the maximum absolute deviation-like value d_b is obtained from $s_{b,j}$'s as

$$d_b = \begin{cases} s_{b,\max} - p_b, & e_b \geq 0 \\ s_{b,\min} - p_b, & e_b < 0 \end{cases}, \tag{4}$$

where $s_{b,\max} = \max_j s_{b,j}$ and $s_{b,\min} = \min_j s_{b,j}$.

4. Parameter candidate τ_b is derived based on u_b and $|d_b|$ as

$$\tau_b = \begin{cases} 2^Q, & u_b = 1 \\ |d_b|, & u_b = 0 \end{cases}. \tag{5}$$

From all τ_b's, image-dependent parameter τ that distinguishes usable blocks from the unusable is determined as $\tau = \min_b \tau_b$. Moreover, this method decreases τ so that the method estimates τ at a payload extraction process. Parameter τ becomes the smallest positive integer satisfying that *capacity* M is greater than or equal to payload size N, where M is the number of blocks in which $|d_b| < \tau$. Thus, $N \leq M \leq B$.

Then, by using τ, the method hides payload to only blocks satisfying $|d_b| < \tau$, as

$$\hat{t}_b = \begin{cases} p_b + 2e_b + w_n, & |d_b| < \tau \\ t_b, & \text{others} \end{cases}. \tag{6}$$

In a payload extraction and image recovery process, the method estimates τ to identify watermarked (usable) blocks. First, the method obtains d_b for each block as

$$d_b = \begin{cases} s_{b,\max} - p_b, & \hat{t}_b - p_b \geq 0 \\ s_{b,\min} - p_b, & \hat{t}_b - p_b < 0 \end{cases}. \tag{7}$$

Then, this method determines τ as the smallest positive integer satisfying $M \geq N$. It requires iterative estimation of τ which begins with $\tau = 1$ towards $\tau = \infty$. Finally, using estimated τ, the method extracts the payload and restores the original image.

This method has to fix the payload size, N, as a system-wide setting so that the method can estimate τ. Thus, no user can hide various sized payloads. In the next section, an extended method that accepts payload of various sizes is proposed.

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3 Proposed method

This section proposes a parameter memorization-free lossless data hiding method which allows various sized payload. A modification based on the fact that the conventional method [3] results in hiding payload to only blocks with small $|d_b|$, the proposed method is free from fixing the payload size and from iterative parameter estimation.

3.1 Algorithms

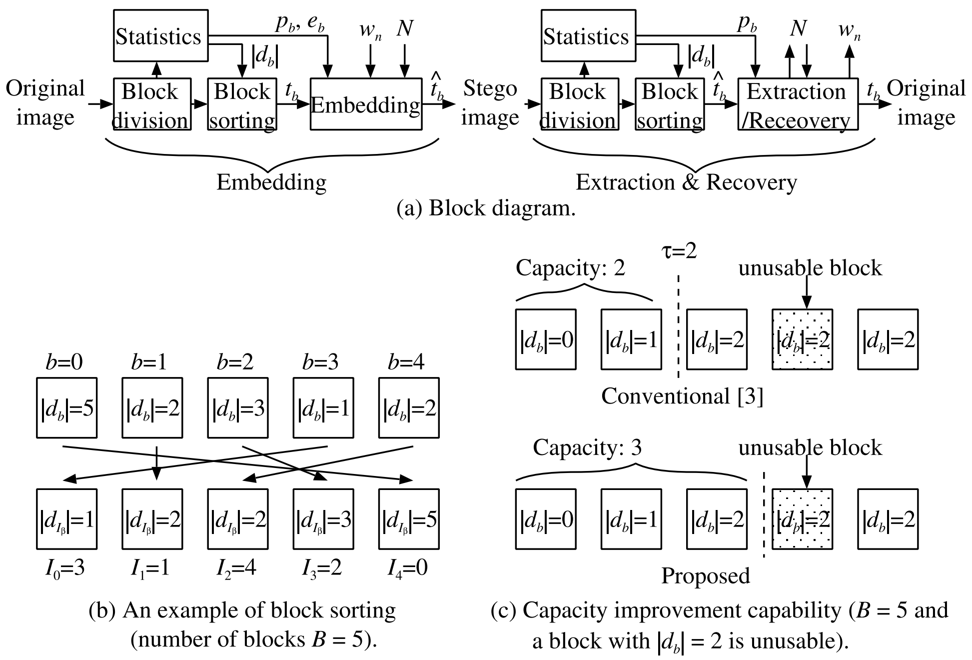
The block diagram of the proposed method is shown as Fig. 2 (a). This method divides an image as the same as the conventional method does, c.f., Sect. 2.

3.1.1 Embedding

First, the following steps are applied to all blocks for deriving a statistic and for the usability check. The statistic, $|d_b|$, will be used as the sort key for arranging blocks before the actual data hiding process.

1. For center pixel t_b, predict value p_b and prediction error e_b are derived by Eqs. (1) and (2), respectively.
2. The usability of the block is checked as Eq. (3).
3. The maximum absolute deviation-like value d_b that will be uses as a sort key is given by Eq. (4).

Then, this embedding algorithm arranges the blocks in ascending order of $|d_b|$ as shown in Fig. 2 (b) in which the indexes for sorted blocks are I_β's and $\beta = 0, 1, \ldots, B-1$.



(a) Block diagram.

(b) An example of block sorting (number of blocks $B = 5$).

(c) Capacity improvement capability ($B = 5$ and a block with $|d_b| = 2$ is unusable).

Fig. 2. The proposed method.

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Finally, this algorithm hides the payload size information represented with L bits as well as the N-bits payload itself to the original image by the following steps.

1. Encode N as L-bits string $\mathbf{h}$.
2. $l := 0$.
3. If $u_{I_l} = 1$, the l-th payload size information bit is hidden to pixel t_{I_l} by
$$\hat{t}_{I_l} = p_{I_l} + 2e_{I_l} + h_l, \tag{8}$$
where $\hat{t}_{I_l}$ is the stego pixel. Otherwise, terminate this algorithm.
4. $l := l + 1$. Continue to Step 3 unless $l = L$.
5. $n := 0$.
6. If $u_{I_{(n+L)}} = 1$, stego pixel $\hat{t}_{I_{(n+L)}}$ is generated by embedding the n-th payload bit w_n to pixel $t_{I_{(n+L)}}$ by
$$\hat{t}_{I_{(n+L)}} = p_{I_{(n+L)}} + 2e_{I_{(n+L)}} + w_n. \tag{9}$$
Otherwise, this algorithm is terminated.
7. $n := n + 1$. Continue to Step 6 unless $n = N$.

If a unusable block in which $u_{I_\beta} = 0$ appears, the above mentioned algorithm stops. For an image in which the number of consecutive usable blocks is smaller than $L + N$, a user can employ a technique such as the reversible pre-modification of pixels [4] to increase the total capacity, $L + M$.

3.1.2 Payload extraction and image recovery

First, this algorithm derives $|d_b|$ from the b-th block of a stego image by the following steps, where $b = 0, 1, \ldots, B - 1$.

1. Prediction p_b is derived by Eq. (1).
2. Sort key $|d_b|$ is obtained by Eq. (7).

By using above obtained $|d_b|$, the blocks are arranged in ascending order of $|d_b|$ as well as in the embedding algorithm.

Then, this algorithm extracts the L-bits information for the payload size and N-bits payload from the arranged blocks. It also restores the original image blocks to recover the original image.

1. $l := 0$.
2. The l-th payload size information bit, h_l, is extracted by
$$h_l = \left(\hat{t}_{I_l} - p_{I_l}\right) \bmod 2, \tag{10}$$
and the center pixel of the I_l-th block is recovered by
$$t_{I_l} = \frac{\hat{t}_{I_l} + p_{I_l} - h_l}{2}. \tag{11}$$

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3. $l := l + 1$. Continue to Step 2 unless $l = L$.

4. Decode $\mathbf{h}$ to obtain payload size N.

5. $n := 0$.

6. The n-th payload bit, i.e., w_n, is extracted by

$$w_n = \left(\hat{t}_{I_{(n+L)}} - p_{I_{(n+L)}}\right) \bmod 2, \tag{12}$$

and the original pixel is restored by

$$t_{I_{(n+L)}} = \frac{\hat{t}_{I_{(n+L)}} + p_{I_{(n+L)}} - w_n}{2}. \tag{13}$$

7. $n := n + 1$. Continue to Step 6 unless $n + N$.

Finally, the N-bits payload and the original image are obtained.

3.2 Features

Besides parameter memorization-free, the proposed method is free from iterative parameter estimation and accepts various sized payload.

The embedding algorithm in the proposed method utilizes the fact that usable blocks tend to have small $|d_b|$. That is, the method hides the payload to consecutive usable blocks in ascending order of $|d_b|$ so that it does not have to identify watermarked blocks in a payload extraction process. So, the proposed method is free from iterative parameter estimation.

The proposed method does not have to estimate parameter as mentioned above, so this method is free from fixing the payload size. To determine the payload size in a payload extraction process, the proposed method hides the payload size information, $\mathbf{h}$, as well as the payload itself to an image.

4 Experimental results

The performance evaluated with eight 512×512-sized 8-bits grayscale images is given in Table I, in which the size of information for payload size, L, is 32. Payload consists of equiprobable zeros and ones.

Table I (a) shows that the total capacity for payload and overhead information in the proposed method, $L + M$, is superior to that in the conventional method [3]. As shown in Fig. 2 (c), the proposed method always achieves $L + M_\mathrm{p} \geq M_\mathrm{c}$, where M_p and M_c are the capacity for payload in the proposed and conventional methods, respectively. That is, the proposed method increases the capacity.

Table I (b) compares the PSNR of stego images between the proposed and conventional methods under the condition that the payload sizes are the same for both methods. This table shows that stego images generated by the proposed and conventional methods are with the almost same quality, even the proposed method further embeds L-bits overhead information.

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Table I. Performance comparisons.

(a) Capacity.

Image	Capacity for payload M [bits]		$L+M$ [bits]
	Conventional [3]	Proposed	
Airplane	63889	63900	63932
Baboon	38734	39257	39289
Barbara	32776	33773	33805
Cameraman	10270	10321	10353
Lena	62333	62341	62373
Peppers	61600	61776	61808
Sailboat	64851	64826	64858
Tiffany	60950	61286	61318

(b) PSNR.

Image	Payload N [bits]	PSNR [dB]	
		Conventional [3]	Proposed
Airplane	63889	39.44	39.41
Baboon	38734	37.45	37.42
Barbara	32776	46.82	46.79
Cameraman	10270	54.38	54.19
Lena	62333	40.38	40.26
Peppers	61600	41.85	41.84
Sailboat	64826	36.10	36.08
Tiffany	60950	42.80	42.79

5 Conclusions

This paper has proposed a parameter memorization-free lossless data hiding method accepting various sized payload. Addition to features of the conventional method [3], the proposed method is free from fixing the payload size and from iterative parameter estimation.

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