PE Expansion-Based Reversible Data Hiding without Location Maps

Masaaki FUJIYOSHI and Hitoshi KIYA
Tokyo Metropolitan University, Hino, Tokyo 191–0065, Japan
E-mail: mfujiyoshi@m.ieice.org, kiya@sd.tmu.ac.jp Tel: +81–42–585–8454

***Abstract*—This paper proposes a prediction error expansion-based reversible data hiding method using no location map. Though a reversible data hiding method once distorts an image to hide data into the image, the distorted image is completely separated to the original image and the hidden data. The proposed method uses only one parameter to extract data; this method extracts data without any location map, whereas conventional prediction error expansion-based reversible data hiding method requires a location map. Experimental results show the effectiveness of the proposed method.**

I. Introduction

Data hiding technology has been diligently studied for not only security-related problems [1], [2], in particular, intellectual property rights protection of digital contents [3], but also non security-oriented issues [1], [4] such as broadcast monitoring [5]. A data hiding technique embeds data referred to as a *payload* into a target signal that is called as the *original* signal. It, then, generates a slightly distorted signal carrying the payload, and this distorted signal is referred to as a *stego* signal. Many of data hiding techniques extract hidden data but leave a stego signal as it is [6].

In military and medical applications, restoration of the original image as well as extraction of hidden payload are desired [7], so *reversible* data hiding (RDH) methods that restore the original image have been proposed [7]–[15]. Among several RDH methods, difference expansion-based RDH (DE-RDH) [8], [9] is one major class in which a payload bit is hidden to an image by expanding the difference between two pixels. Some integer transformation-based RDH [10], [11] are also categorized to this class.

A prediction error is also expanded to increase the conveyable payload size, the *capacity*, in RDH [12]–[14], and this paper focuses prediction error expansion-based RDH (PEE-RDH) methods. PEE-RDH methods have a drawback as well as DE-RDH methods have [15]; an image-dependent *location map* which distinguishes two different pixel groups is required when the hidden payload is extracted from a stego image. Though studies to deal with the location map exist [14], [15], an image still requires its corresponding location map in an expansion-based RDH method.

This paper proposes one approach to make a PEE-RDH method free from location maps. The proposed approach uses one simple parameter for an image which is based on block statistics, rather than a binary location map with the number of pixel pairs. By utilizing the introduced parameter, the proposed method is able to control the capacity.

II. Preliminary

This section briefly describes the fundamental of DE-RDH and PEE-RDH, and the necessity of a location map is also described.

A. DE-RDH

The most basic and simplest DE-RDH method [8] is mentioned here. It, however, is generalized in which D-bits payload is hidden to a pixel pair of a 2^Q-bits quantized image, where $D < Q$.

This method firstly divides an original image consisting of $2K$ pixels to two pixel groups in which a group is compound of K pixels; K pixel pairs are in the image. From a pixel pair, namely x and y where $x, y \in \left[0, 2^Q - 1\right]$, average l and difference h are derived as

$$l = \left\lfloor \frac{x+y}{2} \right\rfloor \quad \text{and} \quad h = x - y. \tag{1}$$

D-bits payload $\mathbf{w} = \{w_d | w_d \in \{0,1\}, d = 0, 1, \ldots, D-1\}$ is hidden to h as

$$\hat{h} = 2^D h + \mathbf{w} \tag{2}$$

as long as h is *expandable*, that is,

$$\left|2^D h + \mathbf{w}\right| \in \left[0, \min\left(2\left(2^Q - 1 - l\right), 2l + 1\right)\right], \quad \forall \mathbf{w}, \tag{3}$$

where $\hat{h}$ is watermarked difference. Watermarked pixels are obtained by

$$\hat{x} = l + \left\lfloor \frac{\hat{h}+1}{2} \right\rfloor, \qquad \hat{y} = l - \left\lfloor \frac{\hat{h}}{2} \right\rfloor, \tag{4}$$

where $\hat{x}$ and $\hat{y}$ are watermarked pixels and $\lfloor r \rfloor$ rounds real-value r to the nearest integer towards negative infinity.

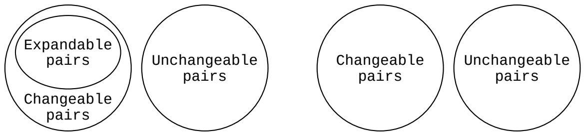
Furthermore, $\mathbf{w}$ is hidden to unwatermarked pairs by replacing least significant bits (LSBs) of h with $\mathbf{w}$ as

$$\hat{h} = 2^D \left\lfloor \frac{h}{2^D} \right\rfloor + \mathbf{w} \tag{5}$$

as long as h is *changeable*, i.e.,

$$\left|2^D \left\lfloor \frac{h}{2^D} \right\rfloor + \mathbf{w}\right| \in \left[0, \min\left(2\left(2^Q - 1 - l\right), 2l + 1\right)\right], \quad \forall \mathbf{w}. \tag{6}$$

For changeable pairs, $\hat{x}$ and $\hat{y}$ are derived by Eq. (4) as well as for expandable pairs. It is noted that the original state of LSBs of h is required for changeable pairs to recover original h.



(a) Original image. (b) Stego image.

Fig. 1. Pixel pair classification in difference expansion- and prediction error expansion-based reversible data hiding.

B. PEE-RDH

As the previous section, the most basic and simplest PEE-RDH method [14] is mentioned here. It is also generalized to hide D-bits payload to a pair consisting of a pixel and its predicted pixel.

This method firstly divides a 2^Q-bits quantized original image to two pixel groups; one is used for prediction. From a pixel pair consisting of pixel $t \in \left[0, 2^Q - 1\right]$ and its predicted value p, prediction error e is derived as

$$e = t - p. \tag{7}$$

Then, payload $\mathbf{w}$ is hidden to e as

$$\hat{e} = 2^D e + \mathbf{w} \tag{8}$$

as long as e is expandable;

$$2^D e + \mathbf{w} \in \left[-p, 2^Q - 1 - p\right], \quad \forall \mathbf{w}. \tag{9}$$

This method also hides $\mathbf{w}$ to unwatermarked e as

$$\hat{e} = 2^D \left\lfloor \frac{e}{2^D} \right\rfloor + \mathbf{w} \tag{10}$$

as long as e is changeable,

$$2^D \left\lfloor \frac{e}{2^D} \right\rfloor + \mathbf{w} \in \left[-p, 2^Q - 1 - p\right], \quad \forall \mathbf{w}. \tag{11}$$

Finally, watermarked pixel $\hat{t}$ is obtained as

$$\hat{t} = p + \hat{e}. \tag{12}$$

It is assumed hereafter that the pixel group for prediction is not modified by data hiding.

C. Location Map

In DE-RDH and PEE-RDH, a method can distinguishes watermarked pixel pairs from unwatermarked pixel pairs in a stego image by checking whether a pair is changeable, because all watermarked pairs become changeable [8] as shown in Fig. 1 where

- Expandable pairs $\subseteq$ Changeable pairs,
- Changeable pairs $\cap$ Unchangeable pairs $= \emptyset$,
- Changeable pairs $\cup$ Unchangeable pairs $=$ All pairs.

The method, however, cannot distinguish expandable pairs from changeable pairs; since embedding equations are different as Eqs. (2) and (5), and Eqs. (8) and (10), the hidden payload cannot be correctly extracted without identifying whether a pair is expandable or changeable. This fact requires a location map to correctly extract the hidden payload in DE-RDH and PEE-RDH which the map indicates the original state of pairs; expandable or changeable.

D. Location Map-Free

As mentioned in the previous section, a location map is required to make a distinction between expandable pairs and changeable pairs. Since all expandable pairs are changeable [8], one simple and straightforward way to throw location maps away can be easily conceived; hiding a payload to an image by using the embedding equation for changeable pairs, Eqs. (5) and (10) for DE-RDH and PEE-RDH, respectively, even to expandable pairs. Similar approach has been proposed [14]; the method rounds all predicted values to even integers to guarantee that all pairs are changeable. It, however, has to keep the original state of the least significant D-bits information of h or e for all pairs to recover the original image, as mentioned in Sect. II-A.

Another way is projecting a location map onto another item such as a thresholding parameter. By comparing the parameter with a statistic of pixels, a method can discriminate between two different groups of pixel pairs in a stego image. To enable this approach, the following two conditions should be satisfied:

COND 1. The method hides a payload to an original image by taking accounts into the parameter and the statistic of the original image.

COND 2. The statistic has to be identical in the original and stego images.

To guarantee that the statistic is stationary, PEE-RDH introduces this approach more easily than DE-RDH.

In the next section, an implementation of the latter approach to make PEE-RDH free from location maps is proposed.

III. Proposed Method

This section proposed a PEE-RDH method which becomes free from location maps by introducing the second way mentioned in Sect. II-D. The proposed method uses a block-based statistic, and it sets a thresholding parameter by taking accounts into a location map and the statistic. This method hides a payload to expandable pairs based on PEE, and the parameter is used to distinguish watermarked pairs from unwatermarked pairs of a stego image.

A. Algorithms

The proposed method divides an image to B of blocks in which a block consists of a target pixel and J pixels for prediction. With statistics from blocks and a location map indicating expandable blocks, thresholding parameter τ which will be used to hide and extract a payload is decided.

1) Parameter Decision:

Step 1. $b := 0$.

Step 2. In the b-th block where $b = 0, 1, \ldots, B-1$, prediction p_b is derived from the other pixels for prediction, $s_{b,j}$'s, as

$$p_b = \left\lfloor \mathrm{MED}_j \left(s_{b,j}\right) \right\rfloor, \tag{13}$$

where MED returns the median value of $s_{b,j}$'s. Prediction error e_b is given by

$$e_b = t_b - p_b, \tag{14}$$

where t_b is the target pixel and $t_b \in \left[0, 2^Q - 1\right]$.

Step 3. Check the b-th block is expandable by

$$2^D e_b + \mathbf{w} \in \left[-p, 2^Q - 1 - p\right], \qquad \forall \mathbf{w}, \tag{15}$$

and set parameter candidate τ_b as

$$\tau_b = \begin{cases} 2^Q, & \text{expandable} \\ |a_b|, & \text{others} \end{cases}, \tag{16}$$

where a_b is a maximum absolute deviation-like value, for describing the smoothness of the block, obtained from $s_{b,j}$'s:

$$a_b = \max\left(\left|s_{b,\max} - p_b\right|, \left|s_{b,\min - p_b}\right|\right), \tag{17}$$

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

Step 4. $b := b + 1$. Continue to Step 2 unless $b = B$.

Step 5. Parameter τ is decided from candidates τ_b as

$$\tau = \min_b \tau_b. \tag{18}$$

A location map is projected onto τ by Steps 3 and 5 in this parameter derivation algorithm, based on that blocks having small a_b tend to be expandable. In contrast, a conventional PEE-RDH method classifies all blocks to expandable, changeable, or unchangeable instead of Step 3 of the proposed method and generates a location map indicating exapndable blocks instead of Step 5 of the proposed method.

2) Data Hiding: By using τ derived in the previous section, a payload is hidden to an image based on PEE.

Step 1. $b := 0$. $n := 0$.

Step 2. n-th D-bits payload portion $\mathbf{w}_n$ is hidden to the b-th block, if $|a_b| < \tau$:

$$\hat{t}_b = \begin{cases} p_b + \hat{e}_b, & |a_b| < \tau \\ t_b, & |a_b| \geq \tau \end{cases}, \tag{19}$$

where $\hat{e}_b$ is the watermarked (expanded) prediction error given by

$$\hat{e}_b = 2^D e_b + \mathbf{w}_n \tag{20}$$

and $\hat{t}_b$ is the watermarked target pixel, respectively. $n := n + 1$, if $|a_b| < \tau$.

Step 3. $b := b + 1$. Continue to Step 2 unless $b = B$.

Step 4. $N := n$.

A payload which is up to $N \log_2 D$-bits is hidden to the image by this embedding algorithm, where $N \leq M$ and M is the number of expandable blocks. In addition, the capacity can be controlled by decreasing τ in the proposed method.

Instead of Step 2 of the proposed method, a conventional PEE-RDH method uses Eq. (20) and another equation to hide data based on whether the block is expandable or changeable, and it memorizes LSBs of e_b for changeable blocks to recover the original value.

3) Hidden Payload Extraction and Original Image Recovery: With τ, watermarked blocks are identified to extract the hidden payload and to restore the original image.

Step 1. $b := 0$. $n := 0$.

Step 2. Maximum absolute deviation-like value a_b is obtained by

$$a_b = \begin{cases} s_{b,\max} - p_b, & \hat{t}_b - p_b \geq 0 \\ s_{b,\min} - p_b, & \hat{t}_b - p_b < 0 \end{cases}. \tag{21}$$

Step 3. If $|a_b| < \tau$, payload portion $\mathbf{w}_n$ is extracted as

$$\mathbf{w}_n = \hat{e}_b - 2^D e_b = \hat{t}_b - p_b - 2^D e_b \tag{22}$$

and $n := n + 1$, where original prediction error e_b is given as

$$e_b = \left\lfloor \frac{\hat{e}_b}{2^D} \right\rfloor = \left\lfloor \frac{\hat{t}_b - p_b}{2^D} \right\rfloor. \tag{23}$$

In addition, original target pixel t_b is recovered as

$$t_b = \begin{cases} p_b + e_b, & |a_b| < \tau \\ \hat{t}_b, & |a_b| \geq \tau \end{cases}. \tag{24}$$

Step 4. $b := b + 1$. Continue to Step 2 unless $b = B$.

Though statistics a_b's are derived by Eq. (21) which differs from Eq. (17) used in the embedding algorithm, a_b's are identical for an original image and a stego image as described in the next section. Instead of Step 2 of the proposed method, a conventional PEE-RDH method checks the changeability of the blocks based on Eq. (11).

In contrast to Step 3 of the proposed method, a conventional PEE-RDH method uses Eq. (22) and another equation to extract hidden data and uses Eq. (23) and another equation to recover the original pixel, based on the location map.

B. Features

This section summarizes the features of the proposed method, namely, location map-free and applicable to other PEE-RDH methods.

1) Location Map-Free: The proposed method projects a location map onto thresholding parameter τ based on block-based statistics $|a_b|$'s as described in Sect. III-A1, whereas conventional PEE-RDH methods maintain a location map as is even the map is reversibly compressed. The proposed method selects expandable blocks by comparing τ and $|a_b|$ as described in Sect. III-A2. This satisfies the COND. 1 mentioned in Sect. II-D.

For the hidden payload extraction and the original image recovery, $|a_b|$ and τ are also used to identify watermarked blocks, whereas conventional PEE-RDH methods have to identify changeable pairs, and they further have to distinguish the expandable from the changeable. Though Eqs. (17) and (21) are different, a_b's are identical between original and stego images if the positive and negative sign of e_b and $\hat{t}_b - p_b$ are the same. From Eqs. (14), (19), and (20),

$$\hat{t}_b - p_b = \begin{cases} \hat{e}_b = 2^D e_b + \mathbf{w}_n, & |a_b| < \tau \\ t_b - p_b = e_b, & |a_b| \geq \tau \end{cases}. \tag{25}$$

Under the condition that $\mathbf{w}_n \in \left\{0, 1, \ldots, 2^D - 1\right\}$ and e_b is an integer,

$$\begin{cases} 2^D e_b + \mathbf{w}_n \geq 0, & e_b \geq 0 \\ 2^D e_b + \mathbf{w}_n < 0, & e_b < 0 \end{cases}. \tag{26}$$

(a) Block division. (b) b-th block.

Fig. 2. The block condition for performance evaluation.

TABLE I

THE CAPACITY, THE NUMBER OF EXPANDABLE BLOCKS, AND THE AVERAGE STEGO IMAGE QUALITY (50 DIFFERENT WATERMARKS) OF THE PROPOSED METHOD UNDER THE CONDITIONS THAT AN IMAGE IS DIVIDED AS SHOWN IN FIG. 2.

Image	Expandable M	Capacity N [bits]	PSNR [dB]
Airplane	65025	65025	40.08
Baboon	64927	42238	36.04
Barbara	64206	34004	46.40
Lena	65022	62351	40.67
Peppers	65015	61712	41.86
Sailboat	65021	63721	36.79
Tiffany	64988	61582	42.28

From Eqs. (25) and (26),

$$\begin{cases} \hat{t}_b - p_b \geq 0, & e_b \geq 0 \\ \hat{t}_b - p_b < 0, & e_b < 0 \end{cases}, \tag{27}$$

thus, a_b given by Eqs. (17) and (21) are identical. This satisfies COND. 2.

2) Applicable to Other PEE-RDH Methods: The concept that projecting a location map onto a parameter is not dedicated to the proposed implementation, so it is applicable to other PEE-RDH methods. That is, an existing PEE-RDH method can become location map-free.

IV. EXPERIMENTAL RESULTS

The proposed method is implemented under the conditions that an image is divided to 3×3-sized overlapping blocks as shown in Fig. 2 (a). The number of blocks, B, is 65025. Pixels in the b-th block are shown in Fig. 2 (b) where the center pixel is target pixel t_b and the surrounding eight pixels are used for prediction, i.e., $J = 8$. Moreover, D is set to two for its simplicity, i.e., binary data sequence is hidden to images.

Table I shows the number of expandable blocks, M, capacity N, and the average stego image quality by using seven natural images with 512×512-pixels from CIPR-RPI [16]. From the table, it is found that the proposed method do not utilize all expandable blocks, and sophisticating of the statistic and the parameter dependently on the predictor is desired.

Figure 3 shows the relation between capacity N and parameter τ. As mentioned in Sect. III-A2, the capacity is controllable by decreasing τ.

V. CONCLUSIONS

This paper has proposed a PEE-RDH method which is free from a location map. By projecting a location map onto a thresholding parameter instead of treating pairs as changeable even they are expandable, The proposed method is free from location maps. The approach which the proposed method takes can be applicable to other PEE-RDH method.

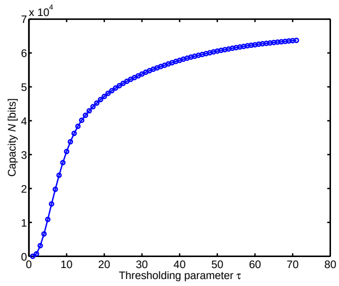


Fig. 3. Capacity N versus parameter τ for image "Sailboat."

Further works include the sophistication of the proposed algorithms, in particular, the statistic which is compared to the parameter should be selected more carefully based on the used predictor.

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