A Reversible Data Hiding Method Free from Location Map and Parameter Memorization

Masaaki FUJIYOSHI, Takahiro TSUNEYOSHI, and Hitoshi KIYA
Tokyo Metropolitan University, Japan
E-mail: mfujiyoshi@ieee.org, kiya@sd.tmu.ac.jp
Tel: +81–42–585–8454, +81–42–585–8419

***Abstract*—This paper proposes a reversible data hiding method in which hidden data are extracted without using either any image-dependent parameter or any image-dependent location map indicating watermarked positions. Using an image-dependent parameter and/or an image-dependent location map at an extraction process requires to identify the image among possible images for retrieving its corresponding parameter and/or location map from the database. In contrast, the proposed method is free from such costly operations and storage. Furthermore, the proposed method having flexibility in the payload length, whereas the conventional parameter memorization- and location map-free method has to fix the payload length as a system-wide setting. 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 hidden payload are desired [7]–[9], so *reversible* data hiding methods that restore the original image have been proposed [7]–[17]. Some reversible data hiding methods have to embed partial image data for image restoration to an image as well as they embed the payload itself to the image [8]–[12]. Another methods hide no data for image recovery, but memorizing [7], [13] or hiding [14] an image-dependent *location map*, that indicates where data are embedded, is required for hidden data extraction.

A reversible method free from both hiding data for restoration and location map-memorization requires to memorize an image-dependent parameter [15]. Methods memorizing a parameter or a location map need an identification of the image among possible images to retrieve its corresponding parameter. It costs highly, and it also prevents a real time data extraction for video sequences [16]. An improved method that is free from parameter memorization as well has been proposed, but it has to fix the payload length as a system-wide setting [16].

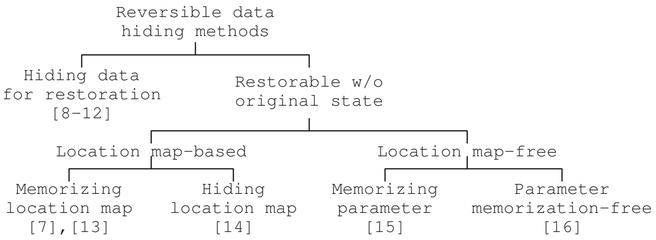


Fig. 1. Classification of reversible data hiding methods.

This paper proposes an improved location map- and parameter memorization-free reversible data hiding method for practical use. By hiding a payload to image blocks in ascending order of a block-based statistic, the proposed method becomes free from using a parameter. Moreover, this method simply embeds the payload length information to an image prior to hiding the payload itself so that the method offers the flexible payload length, whereas the conventional location map- and parameter memorization-free method has to fix the payload length [16]. In addition to the above mentioned advantages, the capacity and the quality of stego images in the proposed method are equal or superior to that in the conventional method [16].

The organization of this paper is as follows. Section II mentions location map- and parameter memorization-free properties, and it also briefly describes the conventional location map- and parameter memorization-free method [16]. Section III presents the proposed location map- and parameter memorization-free method serving a flexible payload size. Experimental results are shown in Section IV, and conclusions are drawn in Section V.

II. CONVENTIONAL LOCATION MAP- AND PARAMETER MEMORIZATION-FREE METHOD

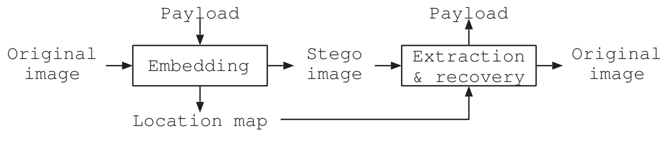
This section briefly describes two properties, namely, location map-free and parameter memorization-free. It, then, describes the conventional location map- and parameter memorization-free reversible data hiding method [16].

A. Location Map-Free

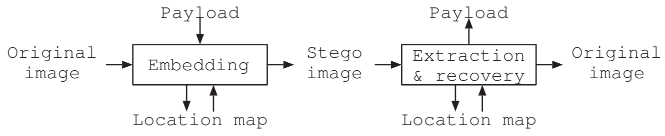
As shown in Fig. 1, reversible data hiding methods free from hiding data for restoration [7], [13]–[16] are classified

---

The second author is currently with Nara Institute of Science and Technology, Japan.

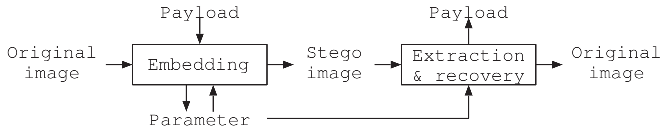


(a) Memorizing a location map [7], [13].

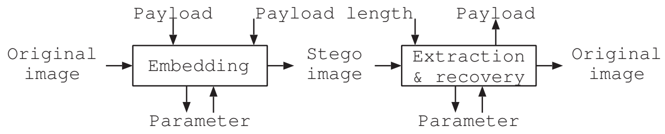


(b) Hiding a location map [14].

Fig. 2. Conventional location map-based methods.



(a) Parameter-based method [15].



(b) Parameter memorization-free method [16].

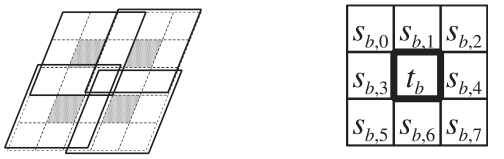
Fig. 3. Conventional location map-free methods.

into location map-free methods and the others. For hidden data extraction, location map-free reversible data hiding methods distinguish watermarked positions from the unwatermarked positions in a stego image without a location map that indicates watermarked positions [15], [16], whereas location map-based methods require to memorize [7], [13] or embed [14] an image-dependent location map as shown in Fig. 2.

B. Parameter Memorization-Free

Focusing location map-free methods [15], [16], one uses an image-dependent parameter for both data hiding and extraction processes which the parameter is obtained in a data hiding process [15], as shown in Fig. 3 (a). Memorizing an image-dependent parameter or an image-dependent location map not only consumes a parameter or location map storage but also introduces a computational cost for identifying the image among possible images and retrieving its corresponding parameter or location map from the database. These operations cost highly, in particular, for huge image database or video database, and they prevent real time data extraction for video sequences [16].

On the other hand, the other location map-free method does not memorize any parameter for hidden data extraction [16], i.e., it is a location map- and parameter memorization-free method. This method, however, has to fix the payload length as a system-wide regulation, as shown in Fig. 3 (b), so that it can estimate the parameter at the extraction side by using the system-wide payload length. This payload length limitation only suits specific applications.



(a) Placement of blocks. (b) b-th block.

Fig. 4. Overlapping block division.

The next section further mentions the conventional location map- and parameter memorization-free method.

C. Conventional Location Map- and Parameter Memorization-Free Method

This section briefly describes the conventional location map- and parameter memorization-free method [16].

This method divides a $X \times Y$-sized original image into B of 3×3-sized overlapping blocks (Fig. 4 (a)) for data hiding, data extraction, and image restoration, where

$$B = \left\lfloor \frac{X-1}{2} \right\rfloor \left\lfloor \frac{Y-1}{2} \right\rfloor \tag{1}$$

and $\lfloor q \rfloor$ rounds real-value q to the nearest integer towards minus infinity. Though any other sized and shaped blocks can be used [15], this paper uses 3×3-sized square block for its simplicity.

It hides data bit w_n, the n-th element of N-length payload $\mathbf{w} = \left\{ w_n \middle| n = 0, 1, \ldots, N-1 \right\}$, to t_b that is the central pixel of the b-th block as shown in Fig. 4 (b), where $b = 0, 1, \ldots, B-1$ and $N \leq B$.

Firstly, this method applies the following step to all blocks to derive an image-dependent threshold parameter τ:

1) For target pixel t_b, predicted value p_b and prediction error e_b are obtained as

$$p_b = \frac{1}{8} \left\lfloor \sum_{j=0}^{7} s_{b,j} \right\rfloor, \tag{2}$$

$$e_b = t_b - p_b, \tag{3}$$

respectively.

2) The maximum absolute deviation-like parameter d_b is obtained from $s_{b,j}$'s as

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

where

$$s_{\max,b} = \max_j s_{b,j}, \tag{5}$$

$$s_{\min,b} = \min_j s_{b,j}, \tag{6}$$

respectively.

3) According to the embedding equation appeared later and the dynamic range of a pixel, the usability of the b-th block is checked as

$$r_b = \begin{cases} 1, & 0 \leq p_b + 2e_b \leq 2^K - 2 \\ 0, & \text{others} \end{cases}, \tag{7}$$

where K represents the quantization bits for pixel values, i.e., $K = 8$ for eight-bits quantized grayscale images. When $r_b = 1$, the b-th block is usable which a *usable* block satisfies the criterion for guaranteeing the reversibility.

4) Parameter candidate τ_b is derived by

$$\tau_b = \begin{cases} 2^K, & r_b = 1 \\ |d_b|, & r_b = 0 \end{cases}. \tag{8}$$

From all τ_b's, image-dependent threshold parameter τ is determined as

$$\tau = \min_b \tau_b. \tag{9}$$

Furthermore, this method decreases τ unless the number of blocks in which $|d_b| < \tau$ is less than payload length, i.e., the *capacity* is less than N.

The method, then, embeds data to the image by

$$\hat{t}_b = \begin{cases} p_b + 2e_b + w_n, & |d_b| < \tau \\ t_b, & \text{others} \end{cases}, \tag{10}$$

where w_n is the n-th bit of the payload and $n = 0, 1, \ldots, N-1$. $\hat{t}_b$ is the stego pixel that is equal to the original pixel in unusable blocks. That is, this method has to distinguishes the watermarked blocks from the unwatermarked blocks in a stego image.

In a hidden data extraction and the original image recovery process, this method firstly estimates τ rather than memorizing it. The method obtains d_b for each block as

$$d_b = \begin{cases} s_{\max,b} - p_b, & \hat{t}_b - p_b \geq 0 \\ s_{\min,b} - p_b, & \hat{t}_b - p_b < 0 \end{cases}. \tag{11}$$

This method determines τ as the smallest positive integer satisfying that the number of blocks in which $|d_b| < \tau$ is greater than or equal to N.

By using estimated τ, this method can tell the difference between the watermarked blocks and the unwatermarked blocks. This method extracts hidden data as

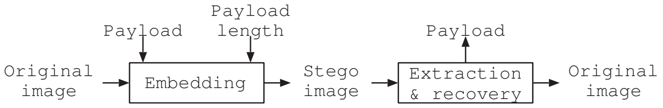
$$w_n = (\hat{t}_b - p_b) \bmod 2, \tag{12}$$

if $|d_b| < \tau$. This method further restores the original image as

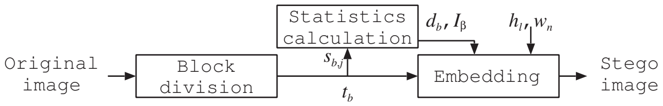
$$t_b = \begin{cases} (\hat{t}_b + p_b - w_n)/2, & |d_b| < \tau \\ \hat{t}_b, & \text{others} \end{cases}. \tag{13}$$

As described above, this method require neither a location map nor any image-dependent parameter to extract the hidden data and to restore the original image. Payload length N, however, is fixed system-widely in the method. This limitation only suits specific applications.

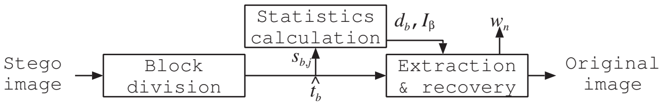
In the next section, an improved location map- and parameter memorization-free reversible data hiding method that overcomes the above mentioned problem is proposed.



(a) System.



(b) Data hiding.



(c) Data extraction and image recovery.

Fig. 5. Proposed method.

III. PROPOSED METHOD

This section proposes an improved location map- and parameter memorization-free reversible data hiding method.

The block diagram of the proposed method is shown in Fig. 5. As well as the conventional method [16] described in Section II-C, this method divides a $X \times Y$-sized original image to B of 3×3-sized blocks and it hides data bits w_n to t_b, the central pixel of the b-th block.

It is noted that this method hides information on payload length N which information is represented by L-bits string $\mathbf{h}$ as an overhead information where $\mathbf{h} = \{h_l \mid h_l \in \{0,1\}, l = 0, 1, \ldots, L-1\}$. So, the capacity is up to M bits satisfying $0 \leq L + M \leq B$, and payload length N should be $0 \leq N \leq M$. This M, referred to as the *actual capacity* hereafter, varies with the original image.

A. Algorithms

Firstly, the proposed method derives a block-based statistic. The method, then, arranges the blocks in ascending order of the derived statistic, and it embeds payload length information $\mathbf{h}$ and payload $\mathbf{w}$ to the blocks without using any parameter. The extraction of hidden data and the restoration of the original image do not require either an image-dependent location map or any image-dependent parameter. The data hiding (Fig. 5 (b)) and extraction & restoration (Fig. 5 (c)) algorithms are subsequently described from the next section.

1) Embedding Algorithm: At the beginning of the embedding algorithm, the following three steps are applied to all overlapping blocks for deriving a statistic and for the usability check. The statistic, $|d_b|$, will be used as the sort key for arranging the blocks before the actual data hiding process.

1) In the b-th block, predict value p_b and prediction error e_b are derived by Eqs. (2) and (3), respectively.
2) The maximum absolute deviation-like parameter d_b that will be used as a sort key is given by Eq. (4).
3) The usability of the b-th block is checked by Eq. (7).

Then, this embedding algorithm arranges the blocks in ascending order of $|d_b|$ by mapping block indices b's to

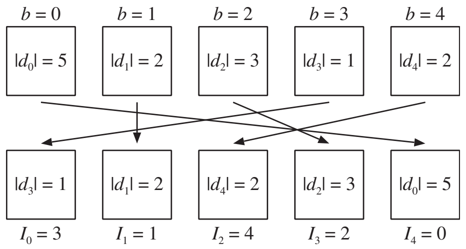


Fig. 6. An example of block sorting (the number of blocks $B = 5$).

embedding indices I_β's as shown in Fig. 6, where $\left|d_{I_\beta}\right|$ is the β-th smallest $|d_b|$ and $\beta = 0, 1, \ldots, B-1$.

Finally, this algorithm hides the L-bits payload length information and the N-bits payload to the original image to generate a stego image by the following seven steps.

1) Encode N as L-bits string $\mathbf{h}$.
2) $l := 0$.
3) The l-th bits from the payload length information is hidden to pixel t_{I_l} by
$$\hat{t}_{I_l} = p_{I_l} + 2e_{I_l} + h_l, \tag{14}$$
where $\hat{t}_{I_l}$ is the stego pixel.
4) $l := l + 1$. Continue to Step 3 unless $l = L$.
5) $n := 0$.
6) 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
$$\hat{t}_{I_{(n+L)}} = p_{I_{(n+L)}} + 2e_{I_{(n+L)}} + w_n. \tag{15}$$
7) $n := n + 1$. Continue to Step 6 unless $n = N$.

If a block in which $r_b = 0$ appears, the proposed method stops the above mentioned data hiding steps. For an image in which the number of consecutive usable blocks is smaller than $N + L$, a user can employ a technique such as the reversible pre-modification of pixels [18] to increase actual capacity M.

2) Hidden Data Extraction and Image Recovery Algorithm: First of all, this algorithm derives $|d_b|$ from the b-th block of the stego image by the following steps, where $b = 0, 1, \ldots, B-1$.

1) In the b-th block, prediction p_b is derived by Eq. (2).
2) Sort key $|d_b|$ is obtained by Eq. (11).

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 payload length information and N-bits payload from the arranged blocks, and it also restores the original image blocks to recover the original image. The following steps are applied to the arranged blocks.

1) $l := 0$.
2) The l-th bit of the payload length information, h_l, is extracted by
$$h_l = \left(\hat{t}_{I_l} - p_{I_l}\right) \bmod 2, \tag{16}$$
and the center pixel of the I_l-th block is recovered by
$$t_{I_l} = \frac{\hat{t}_{I_l} + p_{I_l} - h_l}{2}. \tag{17}$$
3) $l := l + 1$. Continue to Step 2 unless $l = L$.
4) Decode $\mathbf{h}$ to obtain payload length N.
5) $n := 0$.
6) The n-th payload bit, i.e., w_n, is extracted by
$$w_n = \left(\hat{t}_{I_{(n+L)}} - p_{I_{(n+L)}}\right) \bmod 2, \tag{18}$$
and the original pixel is restored by
$$t_{I_{(n+L)}} = \frac{\hat{t}_{I_{(n+L)}} + p_{I_{(n+L)}} - w_n}{2}. \tag{19}$$
7) $n := n + 1$. Continue to Step 6 unless $n = N$.

At the end of this algorithm, the N-bits payload and the original image are obtained.

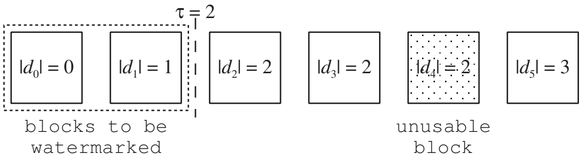
B. Features of the Proposed Method

Besides the location map-free as well as the conventional location map-free methods [15], [16], the proposed method has four features. This section describes these four features.

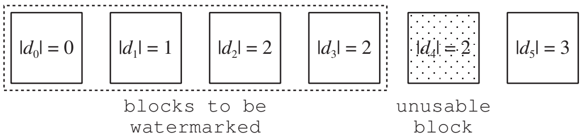
1) Parameter Memorization-Free: The proposed method does not use any parameter to extract hidden data. The conventional methods [15], [16] represents the usability of blocks by an image-dependent single parameter rather than by an image-dependent location map. They, thus, need to memorize or estimate the parameter to distinguish the watermarked blocks from the unwatermarked blocks in a data extraction process. On the other hand, the proposed method only hides payload bits to the *consecutive* usable blocks in ascending order of statistic $|d_b|$, as described in Section III-A1. Since $|d_b|$ can be reproduced from a stego image, the proposed method can easily identify the watermarked blocks as the head blocks of the reordered blocks. This feature makes the proposed method parameter memorization-free.

2) Flexible Payload Length: The proposed method does not have to fix the payload length as a system-wide regulation. Though conventional method [16] does not memorize any parameter as described in Section II, it has to fix the payload length as a system-wide setting to enabling the parameter estimation in a data extraction process. The proposed method simply embeds payload length information $\mathbf{h}$ to an image in prior to the payload itself, so payload length N can vary as long as $0 \leq N \leq M$ in the proposed method.

3) Equaling or Surpassing Capacity: The hidden data capacity of the proposed method is equal or superior to that of the conventional methods [16]. For discussing the total amount of hidden data, the capacity of the proposed method is $M + L$ in this section. The conventional methods hide data to blocks in which statistic $|d_b|$ is smaller than parameter τ as mentioned in Section II-C, whereas the proposed method hides data to consecutive usable blocks in ascending order of $|d_b|$ as described in Section III-A1. The proposed method, therefore, can embed data bits to the blocks in which $|d_b|$ is equal to parameter τ of the conventional methods, i.e., the blocks to which the conventional methods do not embed data, as shown in Fig. 7. Moreover, since the usability criterion, Eq. (7), are the common among the conventional and proposed methods, the capacity of the proposed method is at least equal to that of the conventional methods.



(a) Conventional method [16] (data are hidden to blocks satisfying $|d_b| < \tau = 2$ and the capacity is two bits).



(b) Proposed (data are hidden to consecutive usable blocks and the capacity is four bits).

Fig. 7. An example capacity (the number of blocks $B = 6$ and the smallest $|d_b|$ among unusable blocks is two).

4) Quality Improvement of Stego Images: The proposed method is expected to generate stego images with superior quality to that generated by the conventional methods [16]. The proposed method hides data to the blocks in ascending order of $|d_b|$ that is the difference between the predicted value, p_b, and the maximum (or minimum pixel value) in the surrounding pixels as shown in Eq. (4). The block in which surrounding pixels $s_{b,j}$ are similar each other gives small $|d_b|$. In natural images, center pixel t_b also has a similar value in such blocks, so the difference between the original and stego pixels given by

$$\hat{t}_b - t_b = p_b + 2e_b + \varepsilon - t_b = t_b - p_b + \varepsilon \qquad (20)$$

is determined to be small, where ε is h_l or w_n and $\varepsilon \in \{0, 1\}$. So the image degradation by data hiding in the proposed method in which data are hidden to blocks in ascending order of $|d_b|$ is expected to be smaller than that by the conventional methods in which data are hidden to blocks independently of $|d_b|$.

IV. EXPERIMENTAL RESULTS

By using nine of 512×512-sized grayscale images shown in Fig. 8, the proposed method is compared with the conventional location map- and parameter memorization-free method [16]. Payload $\mathbf{w}$ consists of equiprobable zeros and ones, and the payload length information $\mathbf{h}$ is 32-bits long, i.e., $L = 32$. Conditions are summarized in Table I. It is noted that the conventional method embeds data to the first N blocks among M usable blocks from the top to the bottom and the left to the right of images, and they leave $(M - N)$ usable blocks as the original.

Table II shows actual capacity M of images in the conventional [16] and proposed methods. It was confirmed that the capacity in the proposed method is equal or superior to the conventional method as described in Section III-B3, though the proposed method does not use any image-dependent parameter in its embedding and extraction processes. It is noteworthy that the total capacity of the proposed method is $(L + M)$ [bits] in fact as shown in the rightmost column of Table II, whereas the conventional method has to limit the payload length to zero for these nine images. As Table II shows, the proposed and conventional methods are capable of embedding little data to images such as “Texmos3b” shown in Fig. 8 (h). For such images, a user can employ a technique such as the reversible pre-modification of pixels [18] to increase actual capacity M,

(a) Airplane. (b) Baboon. (c) Barbara.

(d) Cameraman. (e) Lena. (f) Peppers.

(g) Sailboat. (h) Texmos3b. (i) Tiffany.

Fig. 8. Images for evaluation from CIPR-RPI [19] and USI-SIPI [20].

TABLE I
CONDITIONS.

Image	Airplane, Baboon, Barbara, Cameraman, Lena, Peppers, Sailboat, Texmos3b, Tiffany ($X = Y = 512$, $K = 8$, $B = 65025$)
Payload $\mathbf{w}$	N of equiprobable zeros and ones
Payload length information $\mathbf{h}$	$L = 32$

TABLE II
ACTUAL CAPACITY M (THE PROPOSED METHOD FURTHER HIDES L-BITS INFORMATION).

Image	Actual Capacity M [bits]		$L + M$ [bits]
	Conventional [16]	Proposed	
Airplane	63889	63900	63932
Baboon	38734	39257	39289
Barbara	32776	32948	32980
Cameraman	10270	10321	10353
Lena	62333	62334	62366
Peppers	61600	61776	61808
Sailboat	64851	64826	64858
Texmos3b	0	0	0
Tiffany	60950	61286	61318

TABLE III
THE PSNR OF STEGO IMAGES (THE PROPOSED METHOD FURTHER HIDES L-BITS INFORMATION).

Image	Payload length N [bits]	PSNR [dB]	
		Conventional [16]	Proposed
Airplane	63889	39.3	39.3
Baboon	38734	37.4	37.4
Barbara	32776	47.2	47.2
Cameraman	10270	54.4	54.4
Lena	62333	40.2	40.2
Peppers	61600	41.6	41.6
Sailboat	64826	36.0	36.0
Texmos3b	—	—	—
Tiffany	60950	42.5	42.5

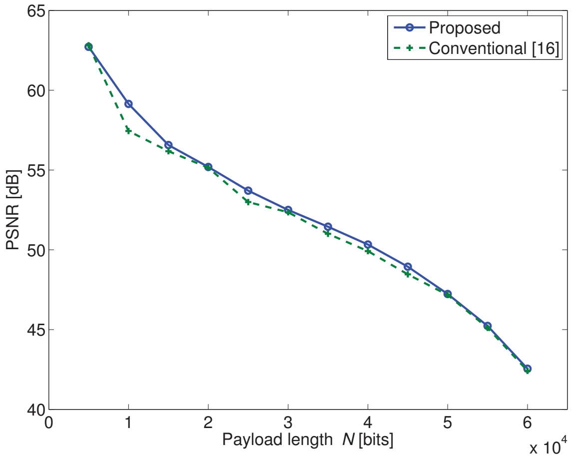


Fig. 9. The PSNR versus payload length N for image "Airplane."

as mentioned in Section III-A1.

Table III lists the PSNR's of stego images when the same payload is used in both methods, where the proposed method further embeds L-bits data. In addition, Fig. 9 shows the PSNR versus payload length N for image "Airplane." It was found that the image quality of stego images in the proposed method are equal or superior to that in the conventional methods as described in Section III-B4. Similar results are obtained for other images.

V. CONCLUSIONS

This paper has proposed a reversible data hiding method that does not require to memorize either an image-dependent location map or any image-dependent parameter. This feature require no cost for identifying the image among possible images to retrieve the corresponding location map or parameter from a storage in a hidden data extraction process. Furthermore, the proposed method does not has to fix the payload length as a system-wide regulation, whereas the conventional location map- and parameter-free method must fix it [16]. It was confirmed that the hidden data capacity in the proposed method is equal or superior to that in the conventional methods [16] and that the proposed method generates stego images with higher quality than the conventional methods, though the proposed method has the above mentioned features.

REFERENCES

[1] G.C. Langelaar, I. Setyawan, and R.L. Lagendijk, "Watermarking digital image and video data," *IEEE Signal Process. Mag.*, vol.17, no.5, pp.20–46, Sep. 2000.

[2] M. Barni, "What is the future for watermarking? (Part I)," *IEEE Signal Process. Mag.*, vol.20, no.5, pp.55–59, Sep. 2003.

[3] C.-C.J. Kuo, T. Kalker, and W. Zhou, eds., "Digital rights management," *IEEE Signal Process. Mag.*, vol.21, no.2, pp.11–117, Mar. 2004.

[4] M. Barni, "What is the future for watermarking? (Part II)," *IEEE Signal Process. Mag.*, vol.20, no.6, pp.53–59, Nov. 2003.

[5] T. Tachibana, M. Fujiyoshi, and H. Kiya, "A removable watermarking scheme retaining the desired image quality," in *Proc. IEEE ISPACS*, 2003, pp.538–542.

[6] M. Fujiyoshi, Y. Seki, H. Kobayashi, and H. Kiya, "Modulo arithmetic-based image watermarking and its theoretical analysis of image-quality," in *Proc. IEEE ICIP*, 2005, pp.969–972.

[7] C. De Vleeschouwer, J.-F. Delaigle, and B. Macq, "Circular interpretation of bijective transformations in lossless watermarking for media asset management," *IEEE Trans. Multimedia*, vol.5, pp.97–105, Mar. 2003.

[8] M.U. Celik, G. Sharma, A.M. Tekalp, and E. Saber, "Lossless generalized-LSB data embedding," *IEEE Trans. Image Process.*, vol.14, pp.253–266, Feb. 2005.

[9] M. Fallahpour, D. Megias, and M. Ghanbari, "High capacity, reversible data hiding in medical images," in *Proc. IEEE ICIP*, 2009, pp.4241–4244.

[10] J. Fridrich, M. Goljan, and R. Du, "Lossless data embedding — New paradigm in digital watermarking," *EURASIP J. Applied Signal Process.*, vol.2002, pp.185–196, Feb. 2002.

[11] J. Tian, "Reversible data embedding using a difference expansion," *IEEE Trans. Circuits Syst. Video Technol.*, vol.13, pp.890–896, Aug. 2003.

[12] Z. Ni, Y.-Q. Shi, N. Ansari, and W. Su, "Reversible data hiding," *IEEE Trans. Circuits Syst. Video Technol.*, vol.16, pp.354–362, Mar. 2006.

[13] D. Coltuc, "Improved capacity reversible watermarking," in *Proc. IEEE ICIP*, 2007, pp.249–252.

[14] P. Tsai, Y.-C. Hu, and H.-L. Yeh, "Reversible image hiding scheme using predictive coding and histogram shifting," *Signal Processing*, vol.89, pp.1129–1143, Jun. 2009.

[15] M. Fujiyoshi, S. Sato, H.L. Jin, and H. Kiya, "A location-map free reversible data hiding method using block-based single parameter," in *Proc. IEEE ICIP*, 2007, pp.257–260.

[16] S. Han, M. Fujiyoshi, and H. Kiya, "A reversible image authentication method without memorization of hiding parameters," *IEICE Trans. Fundamentals*, vol.E92-A, pp.2572–2579, Oct. 2009.

[17] R. Caldelli, F. Filippini, and R. Becarelli, "Reversible watermarking techniques: An overview and a classification," *EURASIP J. Inf. Security*, vol.2010, 2010.

[18] H.L. Jin, Y. Choe, and H. Kiya, "Reversible data hiding based on adaptive modulation of statistics invertibility," *IEICE Trans. Fundamentals*, vol.E93-A, pp.565–569, Feb. 2010.

[19] "Still images and sequences," Center for Image Processing, Renesselaer Polytechnic Insititute. [Online]. Available: http://www.cipr.rpi.edu/

[20] "Image database," Signal & Image Processing Institute, University of Southern California. [Online]. Available: http://sipi.usc.edu/database/