Blind Scheme with Histogram Peak Estimation for Histogram Modification-Based Lossless Information Embedding

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ABSTRACT

In this paper, a simple scheme for histogram modification-based lossless information embedding (HM-LIE) is proposed. The proposed scheme is free from memorizing side information, i.e., blind. A HM-LIE scheme modifies particular pixel values in an image in order to embed information in it on the basis of its histogram, i.e., tonal distribution. The scheme recovers the original image as well as extracts embedded information from a distorted image conveying embedded information. Most HM-LIE schemes should memorize a set of image-dependent side information per image. The proposed scheme does not have to memorize such information to avoid costly identification of the distorted image carrying embedded information because of the introduction of two mechanisms. One is estimating side information on the basis of a simple statistic, and the other is concealing not only main information but also a part of the side information in the image. These approaches make the proposed scheme superior to the conventional blind schemes in terms of the quality of images conveying embedded information.

Keywords: Watermarking, Fingerprinting, Steganography, Data Hiding, Histogram Shifting, Parameter Memorization Free

1. INTRODUCTION

Information embedding technology has been diligently studied [1–3] for not only security-related problems [4, 5], in particular, intellectual property rights protection of digital content [6], but also non security-oriented issues [4, 7] like broadcast monitoring [8]. An information embedding technique hides information called a *payload* in a target signal referred to as the *original* or host signal. The technique then produces a slightly degraded signal that conveys the payload in the signal itself, and this signal is termed a *stego* signal. Many information embedding techniques take out the concealed payload from the stego signal, but the stego signal is left as it is [9].

Not only extracting the embedded payload but also recovering the original signal are desired in military and medical applications [10], *so lossless* information embedding (LIE) schemes that recover the original signal have been proposed [10–23]. In LIE for images, *histogram modification*-based LIE (HM-LIE) [17–23] is one major category due to its less degraded stego images. In HM-LIE, an original image is modified in order to embed a payload into the image itself on the basis of its tonal distribution [17–20] or that of a pre-processed image [21–23].

HM-LIE schemes have the same drawback [18] that different expansion-based [11] and prediction error expansion-based [12–14] LIE schemes have [14]; side information should be memorized per image for extracting the embedded payload and also for recovering the original image. In addition, parameter memorization-based LIE first has to identify the stego image to retrieve its corresponding parameters from a parameter database. This is a costly task in practice, where a lot of images are managed by an LIE scheme [16]. As for prediction error expansion-based LIE [15, 16], schemes free from memorizing side information have been proposed for HM-LIE [18, 19], but these schemes degrade stego images excessively.

This paper proposes a simple blind scheme for HM-LIE where the proposed scheme is free from side information memorization. The proposed scheme becomes blind by involving two strategies; one is estimating the histogram peak on the basis of a simple statistic, and the other is concealing side information in an image as well as hiding the payload in the image [13–15, 18, 19]. The former is the main key for being blind, which is based on the fact that a HM-LIE scheme embeds the payload in the *peak* of the histogram of the original image. The latter supports the proposed scheme by distinguishing the true peak from possible false peaks.

The rest of this paper is organized as follows. In section 2, the original HM-LIE scheme [17] and the conventional blind schemes for HM-LIE [18, 19] are reviewed to point out the problem that this paper tackles. A new blind HM-LIE scheme is proposed in Sect. 3. Experimental results and conclusions are drawn in Sects. 4 and 5, respectively.

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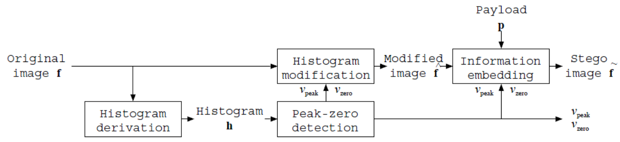
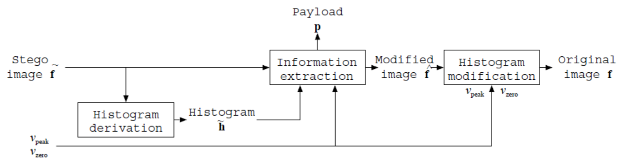
2. PRELIMINARIES

This section mentions the original [17] and conventional blind schemes [18, 19] for HM-LIE to explain the inconvenience on which this paper is focused.



(a) Information Embedding.

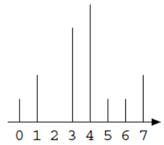


(b) Embedded payload extraction and original image recovery.

Fig.1: *Histogram modification-based lossless information embedding scheme [17]. Side information v_{peak} and v_{zero} should be memorized for each image.*

1	3	4	7
0	1	7	3
3	4	4	5
4	4	3	6

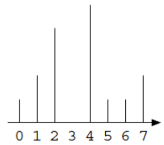
(a) Original image $\mathbf{f}$.



(b) Original histogram $\mathbf{h}$.

1	2	4	7
0	1	7	2
2	4	4	5
4	4	2	6

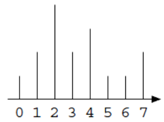
(c) Modified image $\hat{\mathbf{f}}$.



(d) Modified histogram $\hat{\mathbf{h}}$.

1	2	4	7
0	1	7	2
2	3	4	5
4	3	2	6

(e) Stego image $\tilde{\mathbf{f}}$.



(f) Stego histogram $\tilde{\mathbf{h}}$.

Fig.2: *Example of information embedding with the histogram modification-based lossless information embedding scheme [17]. Five-bits payload '10110' is embedded to a 4×4-sized image with 3-bit pixels, with the left-to-right and top-to-bottom pixel scanning order.*

2.1 Histogram Modification-Based Lossless Information Embedding

This section briefly describes the essence of the original HM-LIE scheme [17] of which Fig.1 shows a block diagram. It is assumed here that the payload to be embedded to an image is a L-bit binary sequence $\mathbf{p} = \{p(l)\}$, where $p(l) \in \{0, 1\}$ and $l = 0, 1, \ldots, L-1$. It is also assumed that $\mathbf{p}$ is concealed in $X \times Y$-sized grayscale image $\mathbf{f} = \{f(x, y)\}$ with Q-bit pixels, where $f(x, y) \in \{0, 1, \ldots, 2^Q - 1\}$, $x = 0, 1, \ldots, X-1$, and $y = 0, 1, \ldots, Y-1$.

As depicted in Fig. 1 (a), this scheme first derives the tonal distribution

$$\mathbf{h} = \{h(v)\} \tag{1}$$

of original image $\mathbf{f}$, where $h(v)$ is the number of pixels with pixel value v in $\mathbf{f}$ and $v = 0, 1, \ldots, 2^Q - 1$. Therefore,

$$h(v) \geq 0, \qquad \forall v, \tag{2}$$

$$XY = \sum_{v=0}^{2^Q-1} h(v). \tag{3}$$

This scheme then finds pixel values v_{peak} and v_{zero}, where

$$h\left(v_{\mathrm{peak}}\right) = \max h(v), \tag{4}$$

$$h\left(v_{\mathrm{zero}}\right) = 0, \tag{5}$$

viz., pixels with pixel value v_{peak} significantly appear in $\mathbf{f}$, and no pixel with pixel value v_{zero} exists in $\mathbf{f}$.

For ease of explanation, another assumption is introduced here that

$$L \leq h\left(v_{\mathrm{peak}}\right), \tag{6}$$

$$v_{\mathrm{zero}} < v_{\mathrm{peak}}, \tag{7}$$

and, it is also assumed that only one pixel value satisfying Eq. (4) appears in $\mathbf{f}$ as well as only one pixel value satisfying Eq. (5) exists in $\mathbf{f}$.

The scheme prepares room in original image $\mathbf{f}$ for payload $\mathbf{p}$ to hide by subtracting one from all pixels that have pixel values between $(v_{\mathrm{zero}} + 1)$ and $(v_{\mathrm{peak}} - 1)$;

$$\hat{f}(x, y) = \begin{cases} f(x, y) - 1, & v_{\mathrm{zero}} < f(x, y) < v_{\mathrm{peak}} \\ f(x, y), & \text{otherwise} \end{cases}, \tag{8}$$

where $\hat{f}(x, y)$'s are pixels in histogram-modified image $\hat{\mathbf{f}} = \left\{\hat{f}(x, y)\right\}$ and $\hat{f}(x, y) \in \left\{0, 1, \ldots, 2^Q - 1\right\}$.

This scheme now conceals $\mathbf{p}$ in $\hat{\mathbf{f}}$. In accordance with payload bit $p(l)$, the pixel that has pixel value v_{peak} is decreased by one or is left as is;

$$\tilde{f}(x, y) = \begin{cases} \hat{f}(x, y) - 1, & \hat{f}(x, y) = v_{\mathrm{peak}} \text{ and } p(l) = 0 \\ \hat{f}(x, y), & \text{otherwise} \end{cases}, \tag{9}$$

where the stego image that hides the payload in it is $\tilde{\mathbf{f}} = \left\{\tilde{f}(x,y)\right\}$ and $\tilde{f}(x,y) \in \left\{0,1,\ldots,2^Q-1\right\}$. Therefore, pixels satisfying $\tilde{f}(x,y) = (v_{\text{peak}}-1)$ convey bit '0' and those having v_{peak} carry bit '1.' Information embedding capacity C, which is the maximum amount of conveyable payload, is $h\left(v_{\text{peak}}\right)$, i.e.,

$$C = h\left(v_{\text{peak}}\right), \tag{10}$$

in this scheme.

Figure 2 shows an example of the scheme, where $v_{\text{peak}} = 4$, $C = h\left(v_{\text{peak}}\right) = 5$, and $v_{\text{zero}} = 2$. In this example, the 5-bit binary sequence '10110' is embedded in a 4×4-sized original image with 3-bit pixels, that is, $X = Y = 4$, $L = 5$, and $Q = 3$. By using Eq. (1), histogram $\mathbf{h}$ shown in Fig. 2(b) is derived from original image $\mathbf{f}$ shown in Fig. 2(a). Equation (8) is then applied to $\mathbf{f}$ in order to obtain histogram modified image $\hat{\mathbf{f}}$ shown in Fig. 2(d). As shown in Fig. 2(d), histogram $\hat{\mathbf{h}}$ of $\hat{\mathbf{f}}$ has an empty bin next to the peak. Pixels with value '4' in $\hat{\mathbf{f}}$ are picked up in the left-right and top-bottom pixel scanning order, and each payload bit $p(l)$ is assigned to a selected pixel. Finally, Eq. (9) embeds $p(l)$ in the corresponding pixel, and stego image $\tilde{\mathbf{f}}$ shown in Fig. 2(e) is generated.

To take out concealed payload $\mathbf{p}$ from stego image $\tilde{\mathbf{f}}$, this scheme requires side information v_{peak} and v_{zero}, as shown in Fig. 1(b). The scheme first compares v_{peak} and v_{zero} to estimate the direction of histogram shifting. This scheme easily determines that the histogram of $\mathbf{f}$ was moved toward minus infinity[1].

On the basis of this determination, it becomes clear that pixel $\tilde{f}(x,y)$ with pixel value $(v_{\text{peak}}-1)$ conveys bit '0' and that with v_{peak} carrys bit '1,' as mentioned above.

Then, embedded payload $\mathbf{p}$ is easily extracted along with pixels having pixel values $(v_{\text{peak}}-1)$ and v_{peak} as

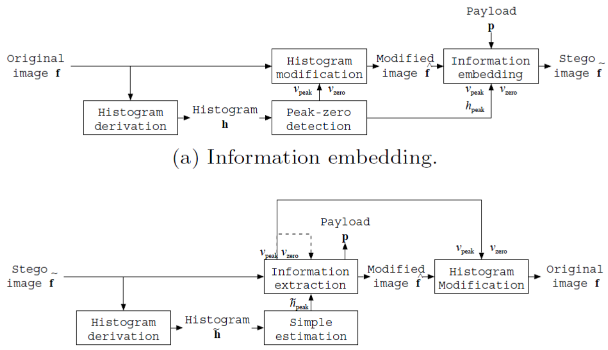
$$p(l) = \begin{cases} 0, & \tilde{f}(x,y) = v_{\text{peak}}-1 \\ 1, & \tilde{f}(x,y) = v_{\text{peak}} \end{cases}. \tag{11}$$

By applying

$$\hat{f}(x,y) = \begin{cases} \tilde{f}(x,y)+1, & \tilde{f}(x,y) = v_{\text{peak}}-1 \\ \tilde{f}(x,y), & \text{otherwise} \end{cases} \tag{12}$$

to stego image $\tilde{\mathbf{f}}$, histogram-modified image $\hat{\mathbf{f}}$ is regenerated. The scheme already knows that the embedding process used Eq. (8); it inversely moves the modified histogram of $\hat{\mathbf{f}}$ to recover original image $\mathbf{f}$ by using

[1]It is assumed here that original image $\mathbf{f}$ satisfies Eq. (7) and that the embedding process used Eq. (8)



(b) Embedded payload extraction and original image recovery.

Fig.3: *Conventional blind histogram modification-based lossless information embedding schemes [18, 19].*

$$f(x,y) = \begin{cases} \hat{f}(x,y)+1, & v_{\text{zero}} \le \hat{f}(x,y) < v_{\text{peak}}-1 \\ \hat{f}(x,y), & \text{otherwise} \end{cases}. \tag{13}$$

Now, original image $\mathbf{f}$ and payload $\mathbf{p}$ are yielded.

It is noted that if original image$\mathbf{f}$ does not satisfy Eq. (7) or

$$v_{\text{zero}} > v_{\text{peak}} \tag{14}$$

holds in $\mathbf{f}$, Eqs. (8), (9), (11), (12), and (13) become

$$\hat{f}(x,y) = \begin{cases} f(x,y)+1, & v_{\text{peak}} < f(x,y) < v_{\text{zero}} \\ f(x,y), & \text{otherwise} \end{cases}, \tag{15}$$

$$\tilde{f}(x,y) = \begin{cases} \hat{f}(x,y)+1, & \hat{f}(x,y) = v_{\text{peak}} \text{ and } p(l) = 1 \\ \hat{f}(x,y), & \text{otherwise} \end{cases}, \tag{16}$$

$$p(l) = \begin{cases} 0, & \tilde{f}(x,y) = v_{\text{peak}} \\ 1, & \tilde{f}(x,y) = v_{\text{peak}}+1 \end{cases}, \tag{17}$$

$$\hat{f}(x,y) = \begin{cases} \tilde{f}(x,y)-1, & \tilde{f}(x,y) = v_{\text{peak}}+1 \\ \tilde{f}(x,y), & \text{otherwise} \end{cases}, \tag{18}$$

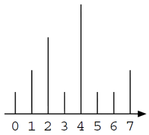
and

$$f(x,y) = \begin{cases} \hat{f}(x,y)-1, & v_{\text{peak}}+1 < \hat{f}(x,y) \le v_{\text{zero}} \\ \hat{f}(x,y), & \text{otherwise} \end{cases}, \tag{19}$$

respectively. It is noted that it is quite difficult in general to determine whether Eq. (7) or (14) is held in original image $\mathbf{f}$ only from stego image $\tilde{\mathbf{f}}$. It is evident by the fact that steganalysis techniques that reveal whether a suspected image is a stego image have been currently under development for HM- LIE

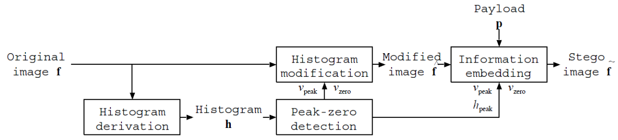
1	2	4	7
0	1	7	3
2	4	4	5
4	4	2	6

(a) Stego image $\tilde{\mathbf{f}}$.

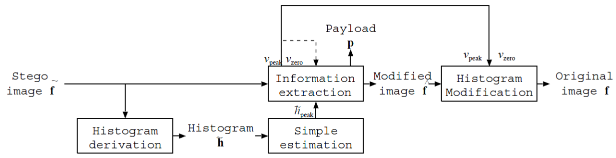


(b) Stego histogram $\tilde{\mathbf{h}}$.

Fig.4: *The essence of the conventional blind histogram modified-based lossless information embedding schemes [18, 19]. Side information v_{zero} represented by 3 -bits and one bit payload '0' is concealed in the image with 3-bit pixels shown in Fig. 2(a).*



(a) Information embedding.



(b) Embedded payload extraction and original image recovery.

Fig.5: *Proposed scheme.*

schemes [24–27]. Therefore, it is not easy to make this scheme free from memorizing not only v_{peak} but also v_{zero}.

2.2 Conventional Blind Schemes for Histogram Modification-Based Lossless Information Embedding

To overcome the disadvantage defined above, i.e., a set of side information should be memorized per image in HM-LIE schemes [18], blind schemes free from side information memorization, shown in Fig. 3, have been proposed for HM-LIE [18, 19]. The essence of these blind schemes [18, 19] are identical; the schemes leave the histogram peak as it is to determine the peak, even from stego image $\tilde{\mathbf{f}}$.

It is assumed here again that $\mathbf{f}$ satisfies Eq. (7). These blind schemes generate histogram-modified image $\hat{\mathbf{f}}$ with Eq. (8), but the hidingformula in these schemes is different from Eq. (9):

$$\tilde{f}(x,y) = \begin{cases} \hat{f}(x,y)+1, & \hat{f}(x,y) = v_{\text{peak}} - 2 \\ & \text{and } d(k) = 1 \\ \hat{f}(x,y), & \text{otherwise} \end{cases}, \quad (20)$$

where $d(k)$ is the k-th bit of K-bit binary sequence $\mathbf{d}$, which consists of two pieces of information. One is v_{zero}, which is represented by Q-bit binary sequence $\mathbf{s} = \{s(q)\}$, and the other is payload $\mathbf{p}$. It is noted that $s(q) \in \{0,1\}$, $q = 0,1,\ldots,Q-1$, $k = 0,1,\ldots,K-1$, and $K = Q+L$.

Figure 4 shows an example of conventional blind schemes, where 3-bit side information $\mathbf{s} = \{0,1,0\}$, which represents $v_{\text{zero}} = 2$, and one bit payload '0' are embedded in image $\mathbf{f}$ with 3-bit pixels, shown in Fig. 2(a). As the original scheme [17], histogram $\mathbf{h}$ shown in Fig. 2(b) is derived from original image $\mathbf{f}$ by using Eq. (1). Equation (8) is applied to $\mathbf{f}$ to obtain histogram modified image $\hat{\mathbf{f}}$ as well. Instead of Eq. (9) in the original scheme, these schemes involve Eq. (20) to conceal side information $\mathbf{s}$ and payload $\mathbf{p}$ in the image. By using Eq. (20), v_{peak} is obviously found in these schemes, as shown in Fig. 4(b), and then v_{zero} and payload $\mathbf{p}$ are easily taken out from pixels with pixel value $(v_{\text{peak}}-2)$ and $(v_{\text{peak}}-1)$. However, the schemes still need to know in advance that a part of the histogram in $\mathbf{f}$ was shifted toward minus infinity.

These schemes [18, 19] further pinpoint v_{zero}, which satisfies $v_{\text{zero}} > v_{\text{peak}}$ to embed another payload in the image. The process described above is applied to pixels whose value are between v_{peak} and v_{zero}, which is larger than v_{peak}. With this second process, pixels with $(v_{\text{peak}}+1)$ and $(v_{\text{peak}}+2)$ carry '0' and '1,' respectively. Consequently, a stego image in these schemes carries '0' in pixels with pixel value $(v_{\text{peak}}-2)$ and $(v_{\text{peak}}+1)$ and '1' in pixels with $(v_{\text{peak}}-1)$ and $(v_{\text{peak}}+2)$, respectively.

This strategy of these blind schemes simultaneously solves two problems: estimating the histogram shifting direction and the information embedding capacity decreasing. As mentioned in the previous section, HM-LIE should estimate the histogram shifting direction for determining whether $(v_{\text{peak}}-1)$ or $(v_{\text{peak}}+1)$ carries a part of the concealed payload, whereas these blind schemes easily determine that four pixel values $(v_{\text{peak}}-2)$, $(v_{\text{peak}}-1)$, $(v_{\text{peak}}+1)$, and $(v_{\text{peak}}+2)$ convey the payload. Therefore, these schemes are free from estimating the histogram shifting direction.

It is obvious that $h(v_{\text{peak}}-1) < h(v_{\text{peak}})$ from Eq. (4), i.e., these blind schemes decrease the information embedding capacity from that of the original scheme [17]. These blind schemes, however, use two pixel bins for information embedding, so the capacity becomes $h(v_{\text{peak}}-1) + h(v_{\text{peak}}+1)$. Therefore, these blind schemes roughly double the information embedding capacity compared with that of the original scheme.

On the one hand, these schemes become blind, but on the other hand, they increase the number of modified pixels, i.e., the image quality of stego images gets worse. The next section proposes a simple blind HM-LIE scheme based on different approaches to improve the image quality of stego images.

3. PROPOSED SCHEME

The algorithms in the proposed scheme are described for information embedding and for the embedded payload extraction and original image recovery. Then, the features of the proposed scheme are summarized.

3.1 Algorithms

A block diagram of the proposed scheme is shown in Fig. 5. The consecutive sections describe the two algorithms in the proposed scheme.

3.1.1 Information Embedding

The following algorithm conceals L length binary payload $\mathbf{p} = \{p(l)\}$ in original image $\mathbf{f} = \{f(x,y)\}$, which is comprised of the $X \times Y$ of Q-bit pixels, where $f(x,y) \in \{0,1,\ldots,2^Q-1\}$, $x = 0,1,\ldots,X-1$, $y = 0,1,\ldots,Y-1$, $p(l) \in \{0,1\}$, and $l = 0,1,\ldots,L-1$. For simplicity, it is assumed here again that $\mathbf{f}$ satisfied Eq. (7), i.e., $v_{\text{zero}} < v_{\text{peak}}$.

Step 1. Derive tonal distribution $\mathbf{h} = \{h(v)\}$ from $\mathbf{f}$, where $v = 0,1,\ldots,2^Q-1$.

Step 2. From derived $\mathbf{h}$, pinpoint pixel values v_{peak} and v_{zero}, which are given by Eqs. (4) and (5), respectively.

Step 3. Represent v_{zero} with a Q-bit binary sequence, $\mathbf{s} = \{s(q)\}$, where $s(q) \in \{0,1\}$ and $q = 0,1,\ldots,Q-1$. Furthermore, $C = h(v_{\text{peak}})$ is represented by N-length binary sequence $\mathbf{t} = \{t(n)\}$, where $t(n) \in \{0,1\}$, $n = 0,1,\ldots,N-1$, and $N = \lceil \log_2 XY \rceil$. Here, $\lceil r \rceil$ is the ceiling function that inputs real value r and outputs the nearest integer greater than or equal to r.

Step 4. Histogram modified image $\hat{\mathbf{f}} = \left\{\hat{f}(x,y)\right\}$ is generated by Eq. (8), where $\hat{f}(x,y) \in \left\{0,1,\ldots,2^Q-1\right\}$.

Step 5. Side information $\mathbf{t}$ represented as a N-bit binary sequence, L-bit binary payload $\mathbf{p}$, and side information $\mathbf{s}$ with Q-bits are embedded into $\hat{\mathbf{f}}$ by

$$\tilde{f}(x,y) = \begin{cases} \hat{f}(x,y) - 1, & \hat{f}(x,y) = v_{\text{peak}} \\ & \text{and } u(m) = 0 \\ \hat{f}(x,y), & \text{otherwise} \end{cases}, \tag{21}$$

and stego image $\bar{\mathbf{f}} = \left\{\bar{f}(x,y)\right\}$ is produced, where $u(m)$ is the m-th bit of $\mathbf{u}$ that is comprised of $\mathbf{t}$, $\mathbf{p}$, and $\mathbf{s}$, i.e., $\mathbf{u} = \{\mathbf{t},\mathbf{p},\mathbf{s}\}$. It is noted that $m = 0,1,\ldots,M-1$, $M = N + L + Q$, and $\bar{f}(x,y) \in \left\{0,1,\ldots,2^Q-1\right\}$.

This algorithm embeds two pieces of side information C and v_{zero} with N- and Q-bits binary representation, respectively, into pixels with pixel value v_{peak}, so the proposed scheme does not have to memorize any side information. It is noted that capacity formula Eq. (10) holds in this proposed scheme as well as the original HM-LIE because embedding formula Eq. (21) is essentially the same as Eq. (9) in the original HM-LIE. It is noteworthy that capacity C is less than or equal to XY from Eqs. (2), (3), and (4). Therefore, C is represented by a N-bit binary sequence, where $N = \lceil \log_2 XY \rceil$.

When $\mathbf{f}$ satisfies Eq. (14) instead of Eq. (7), Step 4 involves Eq. (15) instead of Eq. (8) in histogram modification. Step 5 is also alternated for meeting the condition; it uses

$$\tilde{f}(x,y) = \begin{cases} \hat{f}(x,y) + 1, & \hat{f}(x,y) = v_{\text{peak}} \\ & \text{and } u(m) = 1 \\ \hat{f}(x,y), & \text{otherwise} \end{cases}. \tag{22}$$

3.1.2 Embedded Payload Extraction and Original Image Restoration

For $X \times Y$ sized stego image $\tilde{\mathbf{f}}$ consisting of Q-bit pixels, the following algorithm is used to extract embedded payload $\mathbf{p}$ and to recover original image $\mathbf{f}$. It is still assumed here that $\mathbf{f}$ satisfies Eq. (7).

Step 1. Derive tonal distribution $\tilde{\mathbf{h}} = \left\{\tilde{h}(v)\right\}$ from stego image $\tilde{\mathbf{f}}$, where $v = 0,1,\ldots,2^Q-1$.

Step 2. Initialize parameter for estimating v_{peak}; $w := 0$, where w represents a pixel value.

Step 3. Calculate the summation of two successive histogram bins whose pixel values are w and $(w+1)$ as

$$\tilde{C} = \tilde{h}(w) + \tilde{h}(w+1). \tag{23}$$

When

$$\tilde{C} = \eta, \tag{24}$$

where

$$\eta = \max_{z=0,1,\ldots,2^Q-1, z \neq w, z \neq (w+1)} \left(\tilde{C}, \tilde{h}(z)\right), \tag{25}$$

is satisfied, proceed to Step 5. Otherwise, continue to Step 4.

Step 4. Increase parameter value as $w := w + 1$. Return to Step 3 unless $w = 2^Q - 1$. When w reaches $2^Q - 1$, exit from this algorithm.

Step 5. Tentatively extract an N-length binary sequence as side information $\mathbf{t}$ with

$$t(n) = \begin{cases} 0, & \tilde{f}(x,y) = w \\ 1, & \tilde{f}(x,y) = w + 1 \end{cases}, \tag{26}$$

from the first N pixel whose pixel value is either w or $(w+1)$, where $N = \lceil \log_2 XY \rceil$. Positive integer C is obtained by decoding $\mathbf{t}$. If obtained C satisfies

$$C = \tilde{C}, \tag{27}$$

proceed to Step 6. Otherwise, w is obviously different from $v_{\rm peak}$. Therefore, return to Step 4 to find another candidate for $v_{\rm peak}$.

Step 6. A candidate of $v_{\rm peak}$ is set as $v_{\rm can} = w$, where $v_{\rm can}$ is the candidate of $v_{\rm peak}$. From the next L pixel whose pixel value is either $v_{\rm can}$ or $(v_{\rm can}+1)$, L-bits payload $\mathbf{p}$ is uncovered as

$$p(l) = \begin{cases} 0, & \tilde{f}(x,y) = v_{\rm can} \\ 1, & \tilde{f}(x,y) = v_{\rm can}+1 \end{cases}. \tag{28}$$

Step 7. Q-bit side information $\mathbf{s}$ is extracted from the next Q pixel whose pixel value is either $v_{\rm can}$ or $(v_{\rm can}+1)$ with

$$s(q) = \begin{cases} 0, & \tilde{f}(x,y) = v_{\rm can} \\ 1, & \tilde{f}(x,y) = v_{\rm can}+1 \end{cases}, \tag{29}$$

where Q is the number of quantization bits for $\tilde{f}(x,y)$ which is the same as that for $f(x,y)$. Non-negative integer $v_{\rm zero}$ is reproduced by decoding $\mathbf{s}$. Then, $v_{\rm peak}$ is determined by

$$v_{\rm peak} = \begin{cases} v_{\rm can}, & v_{\rm zero} \geq v_{\rm can}+1 \\ v_{\rm can}+1, & \text{otherwise} \end{cases}, \tag{30}$$

and comparing estimated $v_{\rm peak}$ and decoded $v_{\rm zero}$ brings out either Eqs. (8) or (15) was used in the embedding process.[2] Histogram-modified image $\hat{\mathbf{f}}$ is regenerated by Eq. (12) with estimated $v_{\rm peak}$, and original image $\mathbf{f}$ is finally recovered with Eq. (13).

The proposed scheme picks out payload $\mathbf{p}$ and restores original image $\mathbf{f}$ from stego image $\tilde{\mathbf{f}}$ without memorizing any side information.

If $\mathbf{f}$ satisfies Eq. (14), Eqs. (18) and (19) replace Eqs. (12) and (13) in Step 7, respectively.

3.2 Features

The features of the proposed scheme are summarized in this section. The most important feature of the proposed scheme is that it is image-dependent side information memorization-free.

Two pieces of image-dependent side -information $v_{\rm peak}$ and $v_{\rm zero}$ should be memorized for each image in the original HM-LIE scheme [17] as described in Sect. 2.1 The proposed scheme beats this disadvantage by using two mechanisms; one is estimation of $v_{\rm peak}$, and the other is concealing a part of the side information in the image. It is noted that making the proposed scheme blind is not achieved only with the latter feature and that the former is still needed. The subsequent sections describe two mechanisms in the proposed scheme.

[2]It is assumed here that Eq. (8) was used as described in the previous section.

3.2.1 Estimation of $v_{\rm peak}$

HM-LIE schemes including the proposed scheme exploit the histogram peak to gain the capacity that is the maximum amount of the conveyable payload, as Eq. (4) shows, where histogram peak $h_{\rm peak}$ is equal to $h(v_{\rm peak}) = \max h(v)$. Though Eq. (9) splits $\hat{h}(v_{\rm peak})$ into $\tilde{h}(v_{\rm peak}-1)$ and $\tilde{h}(v_{\rm peak})$ to conceal payload $\mathbf{p}$ in $\hat{\mathbf{f}}$, as shown in Figs. 2(d) and (f) where $\hat{h}(v_{\rm peak}) = h_{\rm peak}$, the summation of $\tilde{h}(v_{\rm peak}-1)$ and $\tilde{h}(v_{\rm peak})$ cannot differ from $h_{\rm peak}$, i.e.,

$$h_{\rm peak} = \tilde{h}(v_{\rm peak}-1) + \tilde{h}(v_{\rm peak}) \tag{31}$$

for $\mathbf{f}$, which satisfies Eq. (7). When $\mathbf{f}$ satisfies Eq. (14),

$$h_{\rm peak} = \tilde{h}(v_{\rm peak}) + \tilde{h}(v_{\rm peak}+1) \tag{32}$$

holds.

On the basis of the fact that pixels with two successive pixel values in a stego image carry the embedded payload, the proposed scheme first tries to identify two successive pixel values by using Eq. (25) in Step 3 of the embedded payload extraction and the original image restoration algorithm, where the number of pixels with two successive pixel values is the largest in $\tilde{\mathbf{f}}$. However, multiple pixel value pairs that satisfy Eq. (24) may exist in image $\tilde{\mathbf{f}}$. Even though a state-of-the-art steganalysis technique using an estimation mechanism based on the difference between two successive histogram bins has been proposed, it does not always estimate the peak histogram bin correctly [24]. Therefore, another mechanism for estimating $v_{\rm peak}$ correctly is required in the proposed scheme, and it is described in the next section.

3.2.2 Hiding a Part of Side Information

The proposed scheme conceals $h_{\rm peak}$ in $\hat{\mathbf{f}}$ prior to payload $\mathbf{p}$ in Step 5 of the information embedding algorithm. Since positive integer $h_{\rm peak}$ satisfies $h_{\rm peak} \leq XY$ as mentioned in Section 3.1.1, the N-length binary sequence represents $h_{\rm peak}$, where $N = \lceil \log_2 XY \rceil$. In Step 5 of the embedded payload extraction and original image restoration algorithm, $h_{\rm peak}$ represented by a N-length binary sequence is taken out from $\tilde{\mathbf{f}}$, where N can be obviously determined from the size of $\tilde{\mathbf{f}}$. To estimate $v_{\rm peak}$ exactly, the proposed scheme compares decoded $h_{\rm peak}$ and η by using Eq. (27) in Step 5. When the proposed scheme finds that Eq. (27) holds for $\tilde{\mathbf{f}}$, one of two successive pixel values should be $v_{\rm peak}$. It is noted that while Eq. (28) can extract payload $\mathbf{p}$ from $\tilde{\mathbf{f}}$, even though $v_{\rm peak}$ is not decided from the two candidates accurately yet.

There is still ambiguity in determining $v_{\rm peak}$ precisely, i.e., one of two successive pixel values should be selected as $v_{\rm peak}$, as mentioned above. The proposed

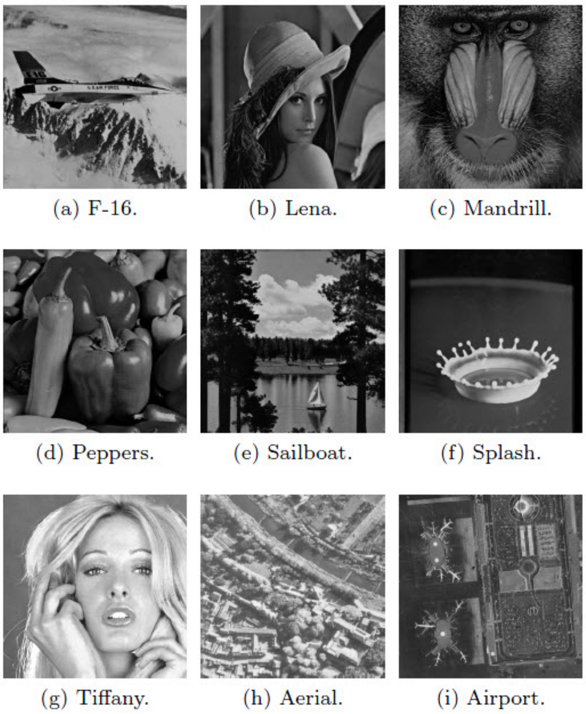


Fig. 6: *Seven* 512×512*-sized, one* 256×256*-sized, and one* 1024×1024*-sized 8-bit gray scale images for evaluation from a standard image database [28]*
.

scheme thus hides v_{zero} represented by a Q-length binary sequence into $\hat{\mathbf{f}}$ in Step 5 of the information embedding algorithm, and Step 6 of the embedded payload extraction and original image restoration algorithm takes v_{zero} out. Equation (30) decides v_{peak} by comparing candidate pixel value v_{can} with decoded v_{zero} in Step 7. Now, image-dependent side information v_{peak} and v_{zero} are available, even though the proposed scheme does not memorize them.

It is noted that hiding side information in images is useful [13–15], but it does not work properly alone in HM-LIE. That is, pixel value v_{peak} is first clarified in order to take out the embedded side information. Without the estimation of v_{peak} that the previous section describes, concealing side information in images results in a chicken-or-the-egg problem.

The proposed scheme embeds h_{peak} represented by a N-length binary sequence instead of v_{peak} represented as a binary string with Q-bits in an image, even though there is another way that is much simpler and more straightforward in which v_{peak} is concealed in the image and the extracted v_{peak} is compared with parameter w. According to a preliminary investigation using a thousand and more standard grayscale images with various sizes, it was found that several images have multiple pixel values in those stego versions, where each pixel value is exactly the same as the extracted and decoded v_{peak}. That is, there is a possibility of accidental coincidence that v_{peak} taken out from a stego image along with pixels in which the pixel value is either w or $(w+1)$ is equal to w or $(w+1)$, even though neither w nor $(w+1)$ are a true v_{peak}. In contrast, there is no such accidental nature of correspondence between real h_{peak} and fake h_{peak} obtained by extracting and decoding. Therefore, the proposed scheme hides h_{peak} represented as a N-length binary sequence into $\hat{\mathbf{f}}$ in Step 5 of the information embedding algorithm.

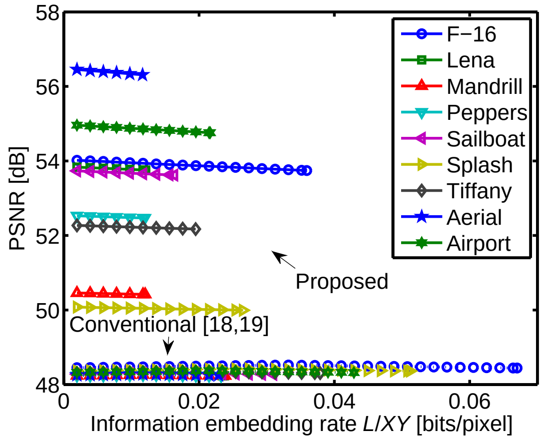


Fig. 7: *PSNR of stego images versus information hiding rate* L/XY *[bits/pixel].*

By using these mechanisms, the proposed scheme becomes free from side information memorization without introducing unnecessary distortion to stego images, whereas the conventional blind schemes [18, 19] distort stego images much more.

4. EXPERIMENTAL RESULTS

In this section, the performance of the proposed scheme is evaluated by using images from a well-known image database [28] including nine natural images shown in Fig. 6. The images shown in Figs. 6 (a), (b), (c), (d), (e), (f), and (g) are made of 512×512 pixels and are converted from color images to 8-bit grayscale images, i.e., $X = Y = 512$and $Q = 8$. The 8-bit grayscale images shown in Figs. 6 (h) and (i) are made of 256×256 and 1024×1024 pixels, respectively. Payload $\mathbf{p}$ is a L-length binary sequence consisting of equiprobable zeros and ones.

Figure 7 shows the peak signal-to-noise ratios (PSNRs) between stego images and corresponding original images, where the payload size is normalized by the image size in order to evaluate performances by using various sized images. Since every image has different tonal distribution $\mathbf{h}$ and histogram peak $h\left(v_{\text{peak}}\right)$, the information embedding capacity varies for images as described below by using Table 1. Therefore, curves in Fig. 7 stop at different points. It was confirmed that the proposed scheme is superior in terms of the PSNRs of stego images in comparison with the conventional schemes at the same information embedding rate. It is noted that the same amount of pixels are modified by Eqs. (8) or (15) regardless of the size of the payload, L, so the PSNRs of stego images for an image are approximately the same regardless of L.

The proposed scheme embeds N- and Q-bit side information in addition to the L-bit payload, where $N = \lceil \log_2 XY \rceil = 16$, 18, and 20 for 256×256-, 512×512-, and 1024×1024-sized images, respectively. The conventional schemes conceal v_{zero} represented with Q-bits in an image for each v_{zero}. The conventional schemes exploit two v_{zero}'s as described in Sect. 2.2, so two Q-bits of side information are embedded into an image in addition to the L-bit payload. As a consequence, the pure capacity for the payload, C_{pure}, of the proposed scheme and conventional blind schemes are

$$C_{\text{pure}} = h\left(v_{\text{peak}}\right) - Q - N \tag{33}$$

and

$$C_{\text{pure}} = h\left(v_{\text{peak}} - 1\right) + h\left(v_{\text{peak}} + 1\right) - 2Q, \tag{34}$$

respectively, where L should satisfy $L \leq C_{\text{pure}}$. It is noted that the first L of pixels in the left-to-right and top-to-bottom pixel scanning order are chosen from pixels for conveying payload bits in both the conventional [18, 19] and proposed schemes, when $L < C_{\text{pure}}$.

Table 1 shows pure capacity C_{pure} of the images that are normalized by the image size in the proposed and conventional schemes, where L is set to C_{pure} to evaluate the PSNR of a stego image with the maximum payload in Tables 1 (a) and (b). From Fig. 7 and Tables 1 (a) and (b), it was confirmed that the conventional blind schemes [18, 19] roughly double the capacity by using two v_{zero}'s in comparison with the proposed scheme, which uses one v_{zero}, as mentioned in Sect. 2.2. From Tables 1 (a) and (b), it was also confirmed that the proposed scheme improves the PSNRs of stego images.

It was also confirmed that both the proposed scheme and the conventional blind schemes take out the embedded payload without any error and that the schemes restore the original image without any distortion.

As a consequence, the proposed scheme is a blind HM-LIE scheme that is superior to the conventional blind schemes [18, 19] in terms of the image quality of stego images.

Table 1: *Normalized pure capacity C_{pure}/XY [bits/pixel] and PSNR of stego images at $L = C_{pure}$.*

(*a*) *Proposed scheme.*

Image	C_{pure}/XY [bits/pixel]	PSNR [dB]
F-16	0.0359	53.74
Lena	0.0121	53.75
Mandrill	0.0120	50.42
Peppers	0.0120	52.47
Sailboat	0.0163	53.62
Splash	0.0265	49.99
Tiffany	0.0195	52.17
Aerial	0.0117	56.31
Airport	0.0216	54.76

(*b*) *Conventional blind schemes* [18, 19].

Image	C_{pure}/XY [bits/pixel]	PSNR [dB]
F-16	0.0670	48.44
Lena	0.0237	48.24
Mandrill	0.0238	48.24
Peppers	0.0233	48.24
Sailboat	0.0310	48.27
Splash	0.0512	48.36
Tiffany	0.0397	48.31
Aerial	0.0229	48.25
Airport	0.0429	48.32

(*c*) *Conventional blind schemes* [18, 19] *when payload size* L *is set to the pure capacity of the proposed scheme.*

Image	L/XY [bits/pixel]	PSNR [dB]
F-16	0.0359	48.52
Lena	0.0121	48.26
Mandrill	0.0120	48.26
Peppers	0.0120	48.26
Sailboat	0.0163	48.30
Splash	0.0265	48.42
Tiffany	0.0195	48.35
Aerial	0.0117	48.28
Airport	0.0216	48.37

5. CONCLUSIONS

This paper has proposed a histogram modification-based lossless information embedding scheme that does not have to memorize image-dependent side information. The proposed scheme is free from identifying a stego image, where the image identification is required to retrieve side information corresponding to the image from a side information database. The proposed scheme introduces two mechanisms to become blind: 1) estimation of the pixel value that corresponds to the peak of the histogram of the image and 2) concealing a part of side information in the image. Thanks to these mechanisms, the proposed scheme is free from memorizing side information, whereas the conventional blind schemes [18, 19] distort stego images much more. These mechanisms of the proposed scheme can be applied to HM-LIE, which iteratively embeds payloads into an image.

Further work includes the application of the proposed scheme to HM-LIE with multiple peak-zero pairs [17].

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