A Blind Lossless Information Embedding Scheme Based on Generalized Histogram Shifting

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***Abstract*—This paper proposes a scheme for lossless information embedding based on generalized histogram shifting where the proposed scheme is free from memorizing embedding parameters. A generalized histogram shifting-based lossless information embedding (GHS-LIE) scheme embeds q-ary information symbols in an image according to the tonal distribution of the image. The scheme not only extracts embedded information but also restores the original image from the distorted image carrying concealed information. Whereas conventional GHS-LIE should memorize a set of image-dependent parameters for hidden information extraction and original image recovery, the proposed scheme is free from such memorization by three strategies; histogram peak shifting, double side modification, and guard zero histogram bins.**

I. Introduction

Information embedding technology has been diligently studied not only for security-related problems but also for non security-oriented issues [1]. An information embedding technique hides information called a *payload* in a target signal referred to as the *original* signal. Then, it 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.

Not only extracting the embedded payload but also recovering the original signal are desired in military and medical applications [2], so *lossless* information embedding (LIE) schemes that recover the original signal have been proposed [2]–[6]. In LIE for images, *histogram shifting*-based LIE (HS-LIE) is one major category, and an original image is modified in order to embed a payload in the image itself on the basis of its tonal distribution [4] or that of a preprocessed image [5], [6] in HS-LIE.

HS-LIE has been *generalized* [7]–[9] to increase the embedded payload capacity which is the maximum amount of the conveyable payload, by concealing q-ary payload symbols in images instead of binary symbols. By exploiting $(q-1)$ successive zero histogram bins, generalized HS-LIE (GHS-LIE) embeds q-ary symbols similar to the manner of q-ary pulse position modulation [7]. GHS-LIE serves the flexibility by adding operating points on the capacity-distortion curve [8]. GHS-LIE schemes, however, have a drawback; embedding parameters should be memorized per image for extracting the embedded payload and also for recovering the original image.

This paper proposes a *blind* scheme for GHS-LIE where the proposed scheme is free from parameter memorization. The proposed scheme becomes blind by involving three strategies; histogram peak shifting, double side modification from blind schemes [10], [11] for ordinary HS-LIE, and guard zero histogram bins.

II. Preliminaries

First, this section briefly describes GHS-LIE [7]–[9]. It then reviews blind schemes [10], [11] for ordinary HS-LIE and shows those limitation.

A. GHS-LIE

A GHS-LIE scheme first derives tonal distribution $\mathbf{h} = \{h(v)\}$ of an original image, where $h(v)$ represents the number of pixels with pixel value v and $v = 0, 1, \ldots, 2^K - 1$ for K-bit quantized pixels. The scheme finds pixel value v_{peak} where pixels with v_{peak} are the most significant in the original image. This scheme also finds the longest successive zero histogram bins which are from $v_{0_{\min}}$ to $v_{0_{\max}}$, i.e.,

$$v_{\text{peak}} = \arg\max_{v} h(v), \tag{1}$$

$$h_{\text{peak}} = h\left(v_{\text{peak}}\right) = \max h(v), \tag{2}$$

$$h(\omega) = 0, \quad \forall \omega : v_{0_{\min}} \leq \omega \leq v_{0_{\max}}, \tag{3}$$

where it is assumed here that

$$0 \leq v_{0_{\min}} \leq v_{0_{\max}} < v_{\text{peak}} \tag{4}$$

for the simplicity.

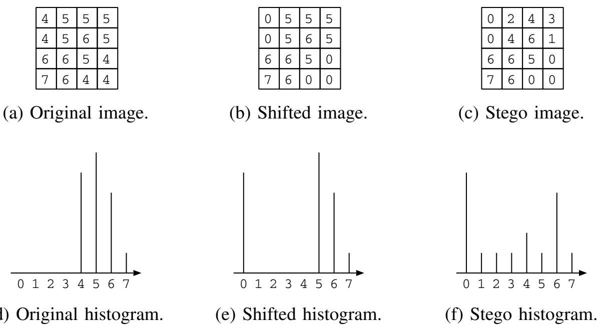
This scheme then subtracts q_m in pixel values from pixels with values between $(v_{0_{\max}} + 1)$ and $\left(v_{\text{peak}} - 1\right)$ to generate a shifted image, where

$$q_m = q - 1, \tag{5}$$

$$q = \left|v_{0_{\max}} - v_{0_{\min}}\right| + 2, \tag{6}$$

so $q \geq 2$. The histogram of the shifted image now has q_m successive zero histogram bins followed by h_{peak}. In accordance with a q-ary payload symbol to be embedded, the pixel value of a pixel with v_{peak} is changed to the value between $\left(v_{\text{peak}} - q_m\right)$ and v_{peak}. Through this process, the scheme conceals $h_{\text{peak}} \log_2 q$-bits payload in the image. Figure 1 shows an example of the information embedding of the scheme.

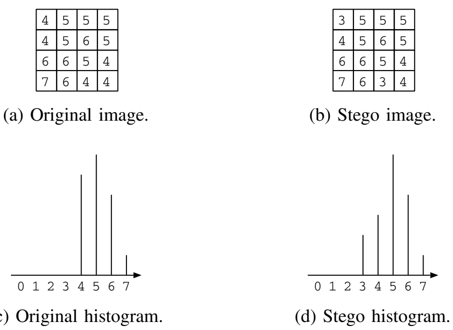
To take out the concealed payload and to restore the original image, the scheme has to memorize v_{peak}, $v_{0_{\min}}$, and $v_{0_{\max}}$. This scheme easily determines q by Eq. (6) once $v_{0_{\min}}$ and $v_{0_{\max}}$ are given, and it then extracts a hidden q-ary symbol from a pixel with pixel values between $\left(v_{\text{peak}} - q_m\right)$ and v_{peak}. After extracting all symbols, the pixel value in pixels which carried hidden symbols are returned to v_{peak}. Finally, add $(q+1)$ to



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

(d) Original histogram. (e) Shifted histogram. (f) Stego histogram.

Fig. 1. Example of GHS-LIE ($K = 3$, $v_{0_{\min}} = 0$, $v_{0_{\max}} = 3$, $v_{\text{peak}} = 5$, $h\left(v_{\text{peak}}\right) = h_{\text{peak}} = 6$, and $q = \left|v_{0_{\max}} - v_{0_{\min}}\right| + 2 = 5$). Six quinary payload symbols are embedded and the capacity is $h_{\text{peak}} \log_2 q \approx 13$ [bits].



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

(c) Original histogram. (d) Stego histogram.

Fig. 2. Example of the essence of blind HS-LIE schemes [10], [11]. Parameter $v_{0_-} = 3$ represented with 3 bits and two bits payload '01' is hidden to the 3-bit quantized image.

the pixel value of pixels with pixel values between $v_{0_{\min}}$ and $\left(v_{\text{peak}} - q\right)$ to recover the original image.

GHS-LIE should memorizes three of image-dependent parameters. It requires a database to store parameter sets to treat images. Moreover, to extract the hidden payload from a stego image, a non blind scheme should distinguish the image from any possible images to acquire the corresponding parameter set from the parameter database.

B. Blind HS-LIE

Blind schemes have been proposed [10], [11] for ordinary HS-LIE with binary symbols. The essence of these blind schemes are identical.

These blind schemes first derive $\mathbf{h}$ for an original image to find v_{peak} and one zero histogram bin v_{0_-}, where it is assumed here that $v_{0_-} < v_{\text{peak}}$. The schemes then subtract one in pixel values from pixels with values between $\left(v_{0_-} + 1\right)$ and $\left(v_{\text{peak}} - 2\right)$, instead of those between $\left(v_{0_-} + 1\right)$ and $\left(v_{\text{peak}} - 1\right)$. In accordance with a binary payload symbol to be hidden, the pixel value of a pixel with $\left(v_{\text{peak}} - 1\right)$ instead of v_{peak} is changed to $\left(v_{\text{peak}} - 2\right)$ or is left as $\left(v_{\text{peak}} - 1\right)$. That is, these schemes leave pixels with v_{peak} as they are to easily identify v_{peak}, even from stego images. It is noted that v_0 is concealed in the image prior to the payload. Figure 2 shows example of the essence of these schemes.

These schemes further find v_{0_+} which satisfies $v_{0_+} > v_{\text{peak}}$ to hide another payload to the image. The process mentioned above is applied to pixels whose value are between v_{peak} and $v_{0_+} > v_{\text{peak}}$. This *double side modification* simultaneously solves two problems: the capacity decreasing and impossibility of determining watermarked pixel values. It is obvious that $h\left(v_{\text{peak}} - 1\right) < h\left(v_{\text{peak}}\right)$ from Eq. (2), but these schemes use two histogram bins for information embedding, the capacity becomes $h\left(v_{\text{peak}} - 1\right) + h\left(v_{\text{peak}} + 1\right) - 2K$. In addition, it is obvious in the schemes that pixels with pixel values $\left(v_{\text{peak}} - 2\right)$, $\left(v_{\text{peak}} - 1\right)$, $\left(v_{\text{peak}} + 1\right)$, and $\left(v_{\text{peak}} + 2\right)$ convey payload bits, whereas non blind HS-LIE should determine either pixels with $\left(v_{\text{peak}} - 1\right)$ or $\left(v_{\text{peak}} + 1\right)$ convey a part of payload bits.

Features of blind schemes [10], [11] for ordinary HS-LIE are the following.

1) A payload is comprised of binary symbols.
2) One zero histogram bin is required on each side of h_{peak}.
3) Pixels with $\left(v_{\text{peak}} \pm 2\right)$ and $\left(v_{\text{peak}} \pm 1\right)$ convey payload bits.

On the other hand, GHS-LIE has the following characteristics.

1) A payload consists of q-ary symbols where q may vary from image to image.
2) The length of successive zero histogram bins are different on each side of h_{peak}.
3) It is difficult only from a stego image to determine which pixels convey payload symbols because of 1) and 2).

Therefore, direct applying conventional blind schemes [10], [11] for ordinary HS-LIE to GHS-LIE is difficult.

In the next section, a blind scheme for GHS-LIE is proposed. The proposed scheme fits GHS-LIE and simultaneously keeps the advantages of conventional blind schemes.

III. Proposed Scheme

This section first summarizes strategies of the proposed scheme. Then, the algorithms in the proposed scheme are described for information embedding and for the embedded payload extraction and the original image recovery.

A. Strategies

1) Histogram Peak Shifting: To enable the double side modification with the *balanced* allocation of guard zero histogram bins mentioned below, the proposed scheme shifts the histogram peak, c.f., Step 2 in Sect. III-B1. The peak is easily determined from a stego image because the height of the peak is not changed, c.f., Step 1 in Sect. III-B2. The peak can be returned to the original position (Step 3 in Sect. III-B2).

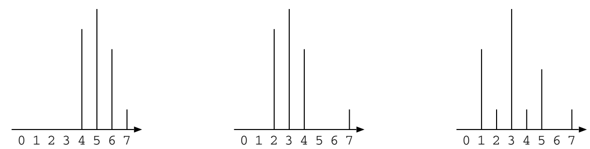
2) Double Side Modification: Pixel values are modified to place a payload over each side of the histogram peak, c.f., Step 4 in Sect. III-B1. Different from the blind schemes [10], [11] for ordinary HS-LIE, the proposed scheme aims to distinguish guard zero histogram bins from accidental zero histogram bins by allocating equidistant zero bins on each side of the histogram peak (Step 1 in Sect. III-B2).

3) Guard Zero Histogram Bins: The proposed scheme introduces *guard zero histogram bins* which distinguish pixel values conveying an embedded payload, c.f., Step 1 in Sect. III-B2 and Fig. 3.

B. Algorithms

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 K-bit pixels, where $f(x,y) \in \{0,1,\ldots,2^K-1\}$, $x = 0,1,\ldots,X-1$, $y = 0,1,\ldots,Y-1$, $p(l) \in \{0,1\}$, and $l = 0,1,\ldots,L-1$. It is assumed again that Eq. (4) is satisfied.

1) **Histogram derivation and peak-zero detection**
Derive histogram $\mathbf{h} = \{h(v)\}$ from $\mathbf{f}$, where $v = 0,1,\ldots,2^K-1$, to find histogram peak h_{peak} and its corresponding pixel value v_{peak} by Eqs. (2) and (1), respectively. The longest successive zero bins from $v_{0_{\min}}$ to $v_{0_{\max}}$ is also found from histogram $\mathbf{h}$, and q is derived by Eq. (6). Moreover, encode $v_{0_{\min}}$ and $v_{0_{\max}}$ as K-length binary strings $\mathbf{a} = \{a(k)\}$ and $\mathbf{b} = \{b(k)\}$, respectively, where $a(k), b(k) \in \{0,1\}$ and $k = 0,1,\ldots,K-1$.
2) **Histogram shifting**
Subtracts q_m given by Eq. (5) in pixel values from pixels with pixel values between $(v_{0_{\max}}+1)$ and $(v_{\text{peak}}-2)$ to make room for the payload. In addition, to allocate guard zero histogram bins on each side of h_{peak}, to prepare for double side modification, and to shift the histogram peak, subtracts
$$\theta = \lfloor q_m/2 \rfloor \tag{7}$$
in pixel values from pixels with pixel values between $(v_{\text{peak}}-1)$ and $(v_{\text{peak}}+1)$:
$$\hat{f}(x,y) = \begin{cases} f(x,y) - q_m, & v_{0_{\max}}+1 \le f(x,y) \le v_{\text{peak}}-2 \\ f(x,y) - \theta, & v_{\text{peak}}-1 \le f(x,y) \le v_{\text{peak}}+1 \\ f(x,y), & \text{otherwise} \end{cases}, \tag{8}$$
where $\hat{\mathbf{f}} = \{\hat{f}(x,y) | \hat{f}(x,y) \in \{0,1,\ldots,2^K-1\}\}$ is the histogram shifted image having one non-zero histogram bin and θ of zero histogram bins on each side of h_{peak}.
3) **Binary-to-θ-ary payload mapping**
Convert the $\lfloor h(v_{\text{peak}}-1)\log_2\theta \rfloor$-length binary string consisting of $\mathbf{a}$ and the first $(\lfloor h(v_{\text{peak}}-1)\log_2\theta \rfloor - K)$-bits of $\mathbf{p}$ to $h(v_{\text{peak}}-1)$ of θ-ary symbols $\mathbf{c} = \{c(g)\}$, where $g = 0,1,\ldots,h(v_{\text{peak}}-1)-1$ and $c(g) \in \{0,1,\ldots,\theta-1\}$. Convert the $\lfloor h(v_{\text{peak}}+1)\log_2\theta \rfloor$-length binary string consisting of $\mathbf{b}$ and the remaining $(\lfloor h(v_{\text{peak}}+1)\log_2\theta \rfloor - K)$-bits of $\mathbf{p}$ to $h(v_{\text{peak}}+1)$ of θ-ary symbols $\mathbf{d} = \{d(r)\}$ where $d(r) \in \{0,1,\ldots,\theta-1\}$ and $r = 0,1,\ldots,h(v_{\text{peak}}+1)-1$.
4) **Information Embedding**
The g-th θ-ary symbol $c(g)$ is hidden to the g-th pixel with pixel value $(v_{\text{peak}}-1-\theta)$. Simultaneously, the r-th θ-ary symbol $d(r)$ is hidden to the r-th pixel with pixel value $(v_{\text{peak}}+1-\theta)$.
$$\tilde{f}(x,y) = \begin{cases} \hat{f}(x,y) - c(g), & \hat{f}(x,y) = v_{\text{peak}}-1-\theta \\ \hat{f}(x,y) + d(r), & \hat{f}(x,y) = v_{\text{peak}}+1-\theta \\ \hat{f}(x,y), & \text{otherwise} \end{cases}, \tag{9}$$
where $\tilde{\mathbf{f}} = \{\tilde{f}(x,y)\}$ is the stego image and $\tilde{f}(x,y) \in \{0,1,\ldots,2^K-1\}$.



(a) Original histogram. (b) Shifted histogram. (c) Stego histogram.

Fig. 3. Example of the proposed scheme ($K = 3$, $v_{0_{\min}} = 0$, $v_{0_{\max}} = 3$, $v_{\text{peak}} = 5$, $h(v_{\text{peak}}) = h_{\text{peak}} = 6$, $q = |v_{0_{\max}} - v_{0_{\min}}| + 2 = 5$, $\theta = \lfloor (q-1)/2 \rfloor = 2$, $\mathbf{a} = \{0,0,0\}$ representing $v_{0_{\min}} = 0$, and $\mathbf{b} = \{0,1,1\}$ representing $v_{0_{\max}} = 3$). Guard zero histogram bins exist at pixel values $(v_{\text{peak}}-1-2\theta) = 0$ and $(v_{\text{peak}}+1) = 6$.

The above mentioned algorithm outputs stego image $\tilde{\mathbf{f}}$ having zero histogram bins at pixel values $(v_{\text{peak}}-1-2\theta)$ and $(v_{\text{peak}}+1)$ as shown in Fig. 3. Hidden payload capacity L is given as
$$L = \lfloor h(v_{\text{peak}}-1)\log_2\theta \rfloor + \lfloor h(v_{\text{peak}}+1)\log_2\theta \rfloor - 2K. \tag{10}$$

2) Embedded Payload Extraction and Original Image Recovery: The following algorithm is applied to stego image $\tilde{\mathbf{f}}$ for extracting payload $\mathbf{p}$ and for restoring original image $\mathbf{f}$.

1) **Histogram derivation and peak-zero detection**
Derive histogram $\tilde{\mathbf{h}} = \{\tilde{h}(v)\}$ from $\tilde{\mathbf{f}}$ to find histogram peak $\tilde{h}_{\text{peak}}$ and its corresponding value $\tilde{v}_{\text{peak}}$. Find the nearest zero bin on each side of $\tilde{h}_{\text{peak}}$ where the zero bins are equidistant from $\tilde{h}_{\text{peak}}$, i.e.,
$$\tilde{h}(\tilde{v}_{0_-}) = \tilde{h}(\tilde{v}_{0_+}) = 0, \tag{11}$$
$$|\tilde{v}_{0_-} - \tilde{v}_{\text{peak}}| = |\tilde{v}_{0_+} - \tilde{v}_{\text{peak}}| = z, \tag{12}$$
$$\tilde{v}_{0_-} < \tilde{v}_{\text{peak}} < \tilde{v}_{0_+}, \tag{13}$$
where $\tilde{v}_{0_-}$ and $\tilde{v}_{0_+}$ are pixel values corresponding to the guard zero bins. From distance z, parameter θ is estimated as
$$\theta = z - 1. \tag{14}$$
2) **Symbol extraction and payload inverse mapping**
From pixels with pixel values between $(\tilde{v}_{\text{peak}}-\theta)$ and $(\tilde{v}_{\text{peak}}-1)$, set of θ-ary symbols $\mathbf{c}$ is extracted. Another set of θ-ary symbols, $\mathbf{d}$, is extracted from pixels with pixel values between $(\tilde{v}_{\text{peak}}+1)$ and $(\tilde{v}_{\text{peak}}+\theta)$.
$$c(g) = (\tilde{v}_{\text{peak}}-1) - \tilde{f}(x,y),\ \tilde{v}_{\text{peak}}-\theta \le \tilde{f}(x,y) \le \tilde{v}_{\text{peak}}-1 \tag{15}$$
$$d(r) = \tilde{f}(x,y) - (\tilde{v}_{\text{peak}}+1),\ \tilde{v}_{\text{peak}}+1 \le \tilde{f}(x,y) \le \tilde{v}_{\text{peak}}+\theta. \tag{16}$$
From $\mathbf{c}$ and $\mathbf{d}$, sequence $\mathbf{a}$ which is the binary representation of $v_{0_{\min}}$, binary sequence $\mathbf{b}$ which represents $v_{0_{\max}}$, and binary payload $\mathbf{p}$ are obtained through θ-ary-to-binary mapping. Decoding $\mathbf{a}$ and $\mathbf{b}$ give pixel values $v_{0_{\min}}$ and $v_{0_{\max}}$, respectively, and q is calculated by Eq. (6). Original peak pixel value v_{peak} is given as $v_{\text{peak}} = \tilde{v}_{\text{peak}} + \theta$.
3) **Recovery of histogram shifted image**
All pixels conveyed information are restored to form

TABLE I

CAPACITY AND STEGO IMAGE QUALITY. THE CAPACITY IS ONLY FOR A PAYLOAD IN THE PROPOSED AND CONVENTIONAL BLIND [10], [11] SCHEMES. h_{PM} AND h_{PP} ARE $h(v_{\text{PEAK}}-1)$ AND $h(v_{\text{PEAK}}+1)$, RESPECTIVELY.

(a) Proposed scheme.

Image	h_{pm}	h_{pp}	q	θ	Embedding rate [bits/pixel]	Averaged PSNR [dB]
Baboon	3145	3122	41	20	0.103	18.43
F-16	8534	9044	40	19	0.285	22.29
Lena	3110	3131	37	18	0.099	18.44
Peppers	3134	2980	44	21	0.102	17.51
Sailboat	3900	4233	33	16	0.124	23.67

(b) Non blind GHS-LIE [9].

Image	h_{peak}	q	Embedding rate [bits/pixel]	Averaged PSNR [dB]
Baboon	3184	41	0.065	20.61
F-16	9440	40	0.192	24.11
Lena	3204	37	0.064	19.71
Peppers	3170	44	0.066	20.38
Sailboat	4307	33	0.083	23.84

(c) Blind HS-LIE [10], [11].

Image	h_{pm}	h_{pp}	Embedding rate [bits/pixel]	Averaged PSNR [dB]
Baboon	3145	3122	0.024	48.24
F-16	8534	9044	0.067	48.44
Lena	3110	3131	0.024	48.24
Peppers	3134	2980	0.023	48.24
Sailboat	3900	4233	0.031	48.27

histogram shifted image $\hat{\mathbf{f}}$:

$$\hat{f}(x,y) = \begin{cases} \tilde{v}_{\text{peak}}-1, & \tilde{v}_{\text{peak}}-\theta \le \tilde{f}(x,y) \le \tilde{v}_{\text{peak}}-1 \\ \tilde{v}_{\text{peak}}+1, & \tilde{v}_{\text{peak}}+1 \le \tilde{f}(x,y) \le \tilde{v}_{\text{peak}}+\theta \\ \tilde{f}(x,y), & \text{otherwise} \end{cases}. \tag{17}$$

4) **Inverse histogram shifting**

Original image $\mathbf{f}$ is recovered from $\hat{\mathbf{f}}$ as

$$f(x,y) = \begin{cases} \hat{f}(x,y)+q_m, & v_{0_{\min}} \le \hat{f}(x,y) \le v_{\text{peak}}-2-q_m \\ \hat{f}(x,y)+\theta, & \tilde{v}_{\text{peak}}-1 \le \hat{f}(x,y) \le \tilde{v}_{\text{peak}}+1 \\ \hat{f}(x,y), & \text{otherwise} \end{cases}. \tag{18}$$

Embedded payload $\mathbf{p}$ is extracted and original image $\mathbf{f}$ is restored by the above mentioned algorithm.

IV. EXPERIMENTAL RESULTS

With five 512×512-sized 8-bit quantized grayscale images, the proposed scheme was evaluated, i.e., $X = Y = 512$ and $K = 8$. Table I summarizes the payload capacity and the stego image quality where the embedding rate is the capacity averaged by the number of pixels, i.e., L/XY [bits/pixel]. Thanks to double side modification for improving the detection accuracy of guard zero histogram bins, the proposed scheme increases the capacity as shown in Tables I (a) and (b). It was found from Table I (a) and (c) that the proposed scheme is superior in terms of the capacity to the blind schemes [10], [11] for ordinary HS-LIE. Figure 4 shows examples by the proposed and non blind schemes. Table I and Fig. 4 show that the proposed scheme is comparable to the non blind GHS-LIE [9] in terms of the quality of stego images.

(a) Original. (b) Proposed (22.29 dB). (c) Non blind (24.11 dB).

Fig. 4. Examples by the proposed and non blind GHS-LIE [9] schemes.

Some discussion on the proposed scheme are given here. Guard zero histogram bins make the proposed scheme free from memorizing θ, on the other hand, it suppresses θ to $\lfloor (q-1)/2 \rfloor$ even it can be up to $\lfloor (q+1)/2 \rfloor$. Double side modification increases the capacity and automatically determines watermarked pixel values in a stego image, it may simultaneously degrade the quality of stego images. Histogram peak shifting preserves h_{peak} to distinguish v_{peak} from a stego image, whereas it can distort the image. There is room for sophistication of the algorithms in the proposed scheme.

V. CONCLUSIONS

This paper has proposed a blind scheme for GHS-LIE. By three strategies, the proposed scheme becomes free from memorizing a set of image-dependent parameters in GHS-LIE.

Further works for the proposed scheme include the investigation of capacity-distortion curves, exploiting the histogram of the preprocessed image [5], [6], and the sophistication of the algorithms.

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