Generalized Histogram Shifting-Based Blind Reversible Data Hiding with Balanced and Guarded Double Side Modification

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Abstract. This paper proposes a method of reversible data hiding based on generalized histogram shifting where the proposed method is free from memorizing embedding parameters. A generalized histogram shifting-based reversible data hiding (GHS-RDH) method increases (or decreases) particular pixel values in the image by $(q-1)$, based on the tonal distribution of the image, to hide q-ary data symbols to the image. The method not only extracts hidden data but also restores the original image from the distorted image carrying hidden data. Whereas conventional GHS-RDH should memorize a set of image-dependent parameters for hidden data extraction and original image recovery, the proposed method is free from parameter memorization and from embedding parameters in the image by introducing three mechanisms; guard zero histogram bins, double side modification, and histogram peak shifting. The proposed method does not need to identify the distorted image conveying hidden data among all possible images before the hidden data extraction, and it makes generalized HS-RDH feasible. In addition, the proposed method is naturally free from overflow/underflow problem. Experimental results show the effectiveness of the proposed method.

Keywords: Digital watermarking, Steganography, Annotation

1 Introduction

Data hiding technology has been diligently studied [1–3], not only for security-related problems [4, 5], in particular, intellectual property rights protection of digital contents [6], but also for non security-oriented issues [4, 7] such as broadcast monitoring [8]. 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 where the distorted signal is referred to as a *stego* signal. Many of data hiding techniques extract the hidden payload from the stego signal but they leave the stego signal as it is [9].

In military and medical applications, restoration of the original signal as well as extraction of the hidden payload from a stego signal are desired [10], so *reversible* data hiding (RDH) methods that restore the original signal have been proposed [10–17]. In RDH, *histogram shifting*-based RDH (HS-RDH) is one major class where an original image is modified, based on the tonal distribution of the image [14] or based on that of a processed image [15–17], to hide a payload into the image. Pixel values in a stego image are always in the dynamic range of the original image in the former, viz., no overflow/underflow problem exists in HS-RDH methods for the the histogram of unprocessed images.

HS-RDH has been *generalized* [18–20] to increase the hidden payload capacity which is the maximum amount of conveyable hidden payload, by hiding q-ary payload symbols to images instead of binary symbols. By exploiting $(q-1)$ successive zero histogram bins, generalized HS-RDH hides q-ary symbols similar to the manner of q-ary pulse position modulation [18]. Generalized HS-RDH serves the flexibility by adding operating points on the capacity-distortion curve [19]. Generalized HS-RDH methods, however, have a drawback; image-dependent embedding parameters should be memorized to extract the hidden payload and also to restore the original image. This requires a costly identification of the stego image among all possible images to recall corresponding parameters [21].

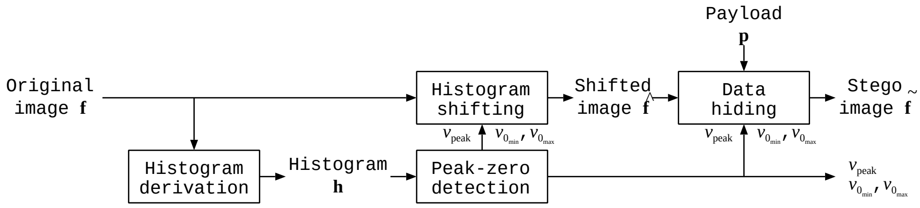
This paper proposes a *blind* method of generalized HS-RDH to make generalized HS-RDH practical where the proposed method is free from memorizing parameters and from embedding parameters in an image. The proposed method introduces three mechanisms to be blind; guard zero histogram bins, double side modification from blind methods [22, 23] for ordinary HS-RDH, and histogram peak shifting. The first one contributes for distinguishing pixel values conveying hidden payload from unmodified pixel values and for determining the successive zero bins. The second and third are introduced to improve the discrimination accuracy. This paper focuses generalized HS-RDH for the histogram of unprocessed images to concentrate the fundamental concepts of the proposed method, whereas the proposed method can be extended for the histogram of preprocessed images such as the pixel differences or prediction errors.

2 Preliminaries

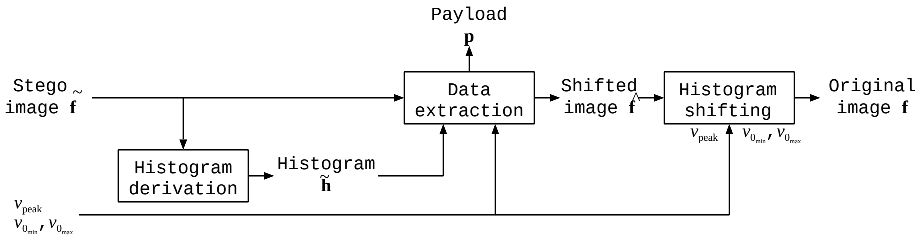
First, this section briefly describes generalized HS-RDH for the histogram of unprocessed images [18–20]. It, then, reviews blind HS-methods for the histogram of unprocessed images [22, 23] and shows those limitation.

2.1 Reversible Data Hiding Based on Generalized Histogram Shifting

As shown in Fig. 1, a generalized HS-RDH method for the histogram of unprocessed images firstly derives tonal distribution $\mathbf{h} = \{h(v)\}$ of an original image where $h(v)$ represents the number of pixels with pixel value v and $v \in \left\{0, 1, \ldots, 2^K - 1\right\}$ for K-bit quantized pixels. The method finds pixel value v_{peak} where pixels with v_{peak} are the most significant in the original image. This method also finds the longest successive zero histogram bins which are from



(a) Data hiding.



(b) Hidden payload extraction and the original image restoration.

Fig. 1. Generalized HS-RDH for the histogram of unprocessed imagees [18–20]. Side information v_{peak}, $v_{0_{\min}}$, and $v_{0_{\max}}$ should be memorized.

$v_{0_{\min}}$ to $v_{0_{\max}}$, i.e.,

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

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

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

where it is assumed here that

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

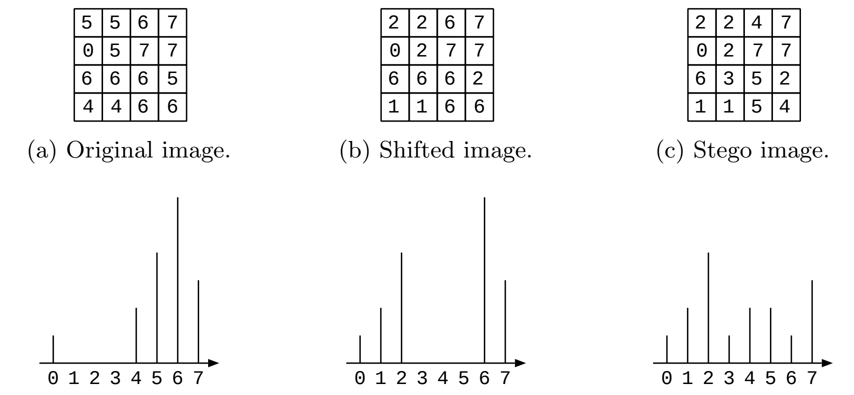
for the simplicity.

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

$$q = |v_{0_{\max}} - v_{0_{\min}}| + 2, \tag{5}$$

so $q \geq 2$. The histogram of the shifted image now has $(q-1)$ successive zero histogram bins followed by h_{peak}. According to a q-ary payload symbol to be hidden, the pixel value of a pixel with v_{peak} is changed to the value between $(v_{\mathrm{peak}}-q+1)$ and v_{peak}. Through this process, the method embeds $h_{\mathrm{peak}} \log_2 q$-bits payload to the image. Figure 2 shows an example of the data hiding of the method.

To extract hidden payload and to recover the original image, the method has to memorize v_{peak}, $v_{0_{\min}}$, and $v_{0_{\max}}$. This method easily knows q by Eq. (5)



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

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

Fig. 2. An example of generalized HS-RDH ($K = 3$, $v_{0_{\min}} = 1$, $v_{0_{\max}} = 3$, $v_{\text{peak}} = 6$, $h(v_{\text{peak}}) = h_{\text{peak}} = 6$, and $q = |v_{0_{\max}} - v_{0_{\min}}| + 2 = 4$). 6 quaternary payload symbols are hidden and the hidden payload capacity is $h_{\text{peak}} \log_2 q = 12$ [bits].

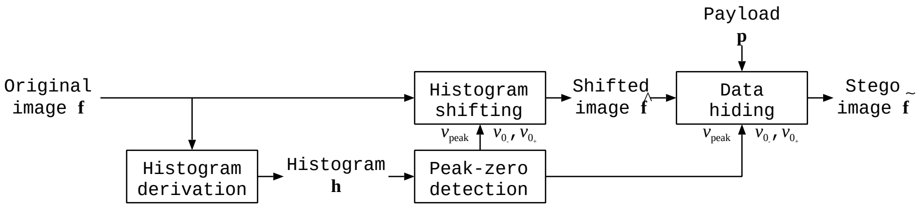
once $v_{0_{\min}}$ and $v_{0_{\max}}$ are given, and the method, then, extracts a hidden q-ary symbol from a pixel with pixel values between $(v_{\text{peak}} - q + 1)$ and v_{peak}. After extracting all symbols from pixels with pixel values between $(v_{\text{peak}} - q + 1)$ and v_{peak}, the pixel value in all pixels which carried hidden symbols in themselves are returned to v_{peak}. Finally, add $(q + 1)$ to the pixel value of pixels with pixel values between $v_{0_{\min}}$ and $(v_{\text{peak}} - q)$ to recover the original image.

As mentioned above, generalized HS-RDH should memorizes three parameters which depend on the image to be watermarked, namely, v_{peak}, $v_{0_{\min}}$, and $v_{0_{\max}}$. It requires a database to store sets of parameters. Moreover, to extract the hidden payload from a stego image, a non blind data hiding method which requires to memorize image-dependent parameters should distinguish the stego image from any possible images firstly to acquire the corresponding parameter set from the parameter database. In the system where a bunch of images are treated, identifying the stego image from the huge number of images is costly and sometimes be impractical [21]. From this viewpoint, blind methods that do not need to memorize parameters are desired for feasible generalized HS-RDH.

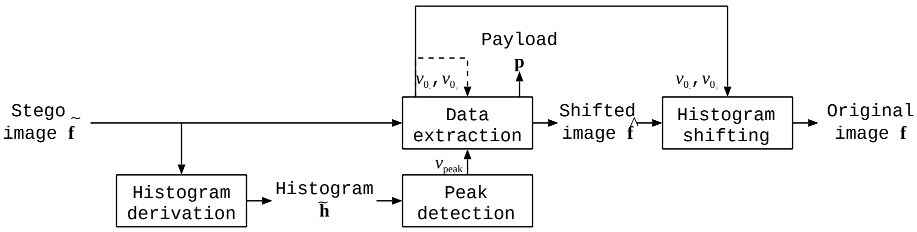
2.2 Blind Histogram Shifting-Based Reversible Data Hiding

Not for generalized HS-RDH with q-ary payloads, but for ordinary HS-RDH with binary payloads, blind methods free from parameter memorization have been proposed for the histogram of unprocessed images [22, 23]. The essence of these blind methods are identical.

As shown in Fig. 3, these blind methods firstly derive $\mathbf{h}$ for an original image to find v_{peak} and pixel value v_{0_-} for the zero histogram bin nearest to v_{peak} where it is assumed here that $v_{0_-} < v_{\text{peak}}$. The methods, then, subtract one in pixel



(a) Data hiding.



(b) Hidden payload extraction and the original image restoration.

Fig. 3. Blind HS-RDH methods for the histogram of unprocessed images [22, 23]. These methods use only one embedding technique, whereas other blind RDH methods often uses two techniques [24]; one is for hiding a payload and the other is to conceal parameters.

values from pixels with values between $\left(v_{0_-}+1\right)$ and $(v_{\text{peak}}-2)$ instead of those between $\left(v_{0_-}+1\right)$ and $(v_{\text{peak}}-1)$. According to a binary payload symbol to be hidden, the pixel value of a pixel with $(v_{\text{peak}}-1)$ instead of v_{peak} is changed to $(v_{\text{peak}}-2)$ or is left as $(v_{\text{peak}}-1)$. That is, these methods leave pixels with v_{peak} as they are to easily identify v_{peak} even from stego images. It is noted that v_{0_-} is represented as a binary string and is hidden to the image prior to the payload, similarly to blind methods for other RDH [24, 25][1]. It reduces the capacity for a payload. These methods, however, do not employ other hiding technique to embed parameters to the image, whereas other blind RDH methods often use one another technique for parameter embedding [24]. So, an implementation of these methods is easier than those of other blind RDH methods, i.e., these methods are more feasible. Figure 4 shows the essence of these methods.

These methods further find pixel value v_{0_+} for a zero histogram bin 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* of these blind methods simultaneously solves two problems; the hidden payload capacity decreasing and 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 methods use two histogram bins for data hiding, the capacity becomes

[1] Whereas the method [24] seems to be a HS-RDH method for prediction error images, it not only shifts a portion of the histogram bins but also interchanges the portion through its embedding process.

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

(a) Original image.

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

(b) Stego image.

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

Fig. 4. The essence of blind HS-RDH methods [22, 23]. Side information $v_{0\_} = 2$ represented with 3 bits and one bit payload '0' is hidden to the 3-bit quantized image.

$h\left(v_{\text{peak}} - 1\right) + h\left(v_{\text{peak}} + 1\right)^2$. In addition, it is obvious in the methods that pixels with $(v_{\text{peak}} - 2)$, $(v_{\text{peak}} - 1)$, $(v_{\text{peak}} + 1)$, and $(v_{\text{peak}} + 2)$ convey payload bits, whereas non blind HS-RDH should determine whether pixels with $(v_{\text{peak}} - 1)$ or $(v_{\text{peak}} + 1)$ convey a part of payload bits.

2.3 Limitation of Conventional Blind Methods

Features of conventional blind methods [22, 23] for ordinary HS-RDH are the following.

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

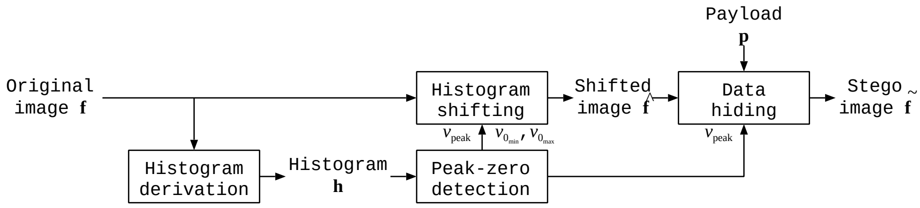
On the other hand, generalized HS-RDH has the following characteristics.

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).

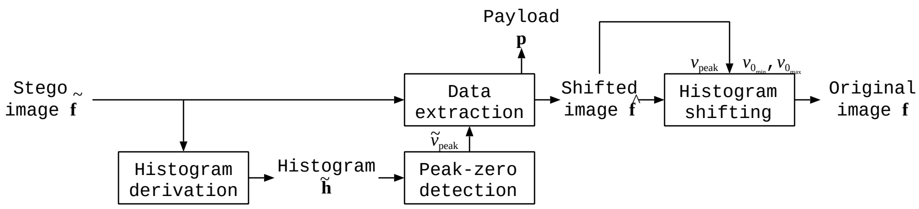
Therefore, direct applying conventional blind methods [22, 23] for ordinary HS-RDH to generalized HS-RDH is difficult. In addition, embedding parameters in the image prior to the payload decreases the capacity for the payload.

In the next section, a blind method for generalized HS-RDH is proposed. The proposed method fits generalized HS-RDH and simultaneously overcomes the disadvantages of conventional blind methods described in this section.

[2] The capacity for a payload is $h\left(v_{\text{peak}} - 1\right) + h\left(v_{\text{peak}} + 1\right) - 2K$, because two of parameters represented by K-bits are also hidden into the image.



(a) Data hiding.



(b) Hidden payload extraction and the original image restoration.

Fig. 5. Proposed method. No parameter has to be memorized or hidden to an image. No overflow/underflow problem exists.

3 Proposed Method

This section proposes a blind method for generalized HS-RDH where no parameter is memorized or hidden to an image. The algorithms in the proposed method are described for data hiding and for the hidden payload extraction and the original image restoration, and then the features of the proposed method are summarized.

The proposed method introduces guard zero histogram bins to identify pixels carrying the hidden payload in stego images and to determine the successive zero histogram bins. The method further introduces double side modification in which pixel values are modified to convey the hidden payload on each side of the histogram peak to distinguish guard zero histogram bins from accidental zero histogram bins. To achieve double side modification, this method shifts the histogram peak, whereas the height of the histogram peak is left as it is to easily find the histogram peak even from stego images. These three mechanisms make the proposed method blind and parameter embedding free.

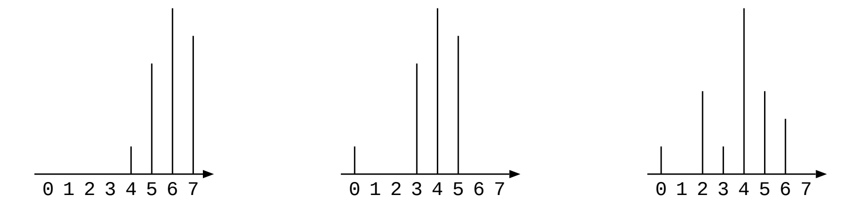
3.1 Algorithms

Two algorithms shown in Fig. 5 are described in successive sections.

Data Hiding For original grayscale image $\mathbf{f} = \{f(x, y)\}$ consisting of $X \times Y$ of K-bit quantized pixels and L-bit binary payload $\mathbf{p} = \{p(l)\}$, the following algorithm is applied to hide $\mathbf{p}$ to $\mathbf{f}$, where $f(x, y) \in \left\{0, 1, \ldots, 2^K - 1\right\}$, $x =$

$0, 1, \ldots, X-1$, $y = 0, 1, \ldots, Y-1$, $p(l) \in \{0, 1\}$, and $l = 0, 1, \ldots, L-1$. It is assumed again that Eq. (4) is satisfied.

1. **Histogram derivation and peak-zero detection**
As non blind generalized HS-RDH methods [18–20], histogram $\mathbf{h} = \{h(v)\}$ of original image $\mathbf{f}$ is obtained, where $v \in \{0, 1, \ldots, 2^K - 1\}$, 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. (5).
2. **Histogram shifting**
Subtracts $(q-1)$ in pixel values from pixels with pixel values between $(v_{0_{\max}} + 1)$ and $(v_{\mathrm{peak}} - 2)$ to make room for hiding a payload to image as non blind generalized HS-RDH. In addition, subtracts
$$\theta = \left\lfloor \frac{q-1}{2} \right\rfloor \tag{6}$$
in pixel values from pixels with pixel values between $(v_{\mathrm{peak}} - 1)$ and $(v_{\mathrm{peak}} + 1)$ to put guard zero histogram bins on each side of h_{peak}, to prepare double side modification, and to shift the histogram peak. So, the histogram shifting in the proposed method is summarized as
$$\hat{f}(x,y) = \begin{cases} f(x,y) - (q-1), & v_{0_{\max}} + 1 \le f(x,y) \le v_{\mathrm{peak}} - 2 \\ f(x,y) - \theta, & v_{\mathrm{peak}} - 1 \le f(x,y) \le v_{\mathrm{peak}} + 1 \\ f(x,y), & \text{otherwise} \end{cases}, \tag{7}$$
where $\hat{\mathbf{f}} = \{\hat{f}(x,y)\}$ is the histogram shifted image having one non-zero histogram bin and having θ of zero histogram bins on each side of h_{peak}; Non-zero histogram bins are at $(v_{\mathrm{peak}} - 1 - \theta)$ and $(v_{\mathrm{peak}} + 1 - \theta)$ and guard zero histogram bins are at $(v_{\mathrm{peak}} - 1 - 2\theta)$ and $(v_{\mathrm{peak}} + 1)$. Pixels in $\hat{\mathbf{f}}$ satisfy $\hat{f}(x,y) \in \{0, 1, \ldots, 2^K - 1\}$. It is noted that an extra zero histogram bin exists at $v_{0_{\min}}$ immediately external to a guard zero histogram bin in $\hat{\mathbf{f}}$ when q is an even integer.
3. **Binary-to-θ-ary payload mapping**
Convert the first $(\lfloor h(v_{\mathrm{peak}} - 1) \log_2 \theta \rfloor)$-bits of $\mathbf{p}$ to $h(v_{\mathrm{peak}} - 1)$ of θ-ary symbols $\mathbf{c} = \{c(g)\}$ where $c(g) \in \{0, 1, \ldots, \theta{-}1\}$ and $g = 0, 1, \ldots, h(v_{\mathrm{peak}} - 1) - 1$. Convert the remaining $(\lfloor h(v_{\mathrm{peak}} + 1) \log_2 \theta \rfloor)$-bits of $\mathbf{p}$ to $h(v_{\mathrm{peak}} + 1)$ of θ-ary symbols $\mathbf{d} = \{d(r)\}$ where $d(r) \in \{0, 1, \ldots, \theta - 1\}$ and $r = 0, 1, \ldots, h(v_{\mathrm{peak}} + 1)$.
4. **Data hiding**
The g-th θ-ary symbol $c(g)$ is hidden to the g-th pixel with pixel value $(v_{\mathrm{peak}} - 1 - \theta)$. Simultaneously, the r-th θ-ary symbol $d(r)$ is hidden to the r-th pixel with pixel value $(v_{\mathrm{peak}} + 1 - \theta)$. The data hiding equation is given as
$$\tilde{f}(x,y) = \begin{cases} \hat{f}(x,y) - c(g), & \hat{f}(x,y) = v_{\mathrm{peak}} - 1 - \theta \\ \hat{f}(x,y) + d(r), & \hat{f}(x,y) = v_{\mathrm{peak}} + 1 - \theta \\ \hat{f}(x,y), & \text{otherwise} \end{cases}, \tag{8}$$



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

Fig. 6. An example of the proposed method ($K = 3$, $v0_{\min} = 0$, $v0_{\max} = 3$, $v_{\text{peak}} = 6$, $h\left(v_{\text{peak}}\right) = h_{\text{peak}} = 6$, $q = |v0_{\max} - v0_{\min}| - 2 = 5$, and $\theta = \lfloor (q-1)/2 \rfloor = 2$). Guard zero histogram bins exist at pixel values $(v_{\text{peak}} - 1 - 2\theta) = 1$ and $(v_{\text{peak}} + 1) = 7$.

where $\tilde{\mathbf{f}} = \{\tilde{f}(x,y)\}$ is the stego image and $\tilde{f}(x,y) \in \left\{0, 1, \ldots, 2^K - 1\right\}$.

By the above mentioned algorithm in the proposed method, stego image $\tilde{\mathbf{f}}$ has zero histogram bins at pixel values $(v_{\text{peak}} - 1 - 2\theta)$ and $(v_{\text{peak}} + 1)$ as shown in Fig. 6. Hidden payload capacity L is given as

$$L = \lfloor h\left(v_{\text{peak}} - 1\right) \log_2 \theta \rfloor + \lfloor h\left(v_{\text{peak}} + 1\right) \log_2 \theta \rfloor \ \ \text{[bits]}. \tag{9}$$

Hidden 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**
   Histogram $\tilde{\mathbf{h}} = \{\tilde{h}(v)\}$ of stego image $\tilde{\mathbf{f}}$ is obtained 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 $\tilde{h}_{\text{peak}}$ which the zero bins are at equidistant z from $\tilde{h}_{\text{peak}}$, i.e.,

$$\tilde{h}\left(\tilde{v}_{0_-}\right) = \tilde{h}\left(\tilde{v}_{0_+}\right) = 0, \tag{10}$$

$$\left|\tilde{v}_{0_-} - \tilde{v}_{\text{peak}}\right| = \left|\tilde{v}_{0_+} - \tilde{v}_{\text{peak}}\right| = z, \tag{11}$$

$$\tilde{v}_{0_-} < \tilde{v}_{\text{peak}} < \tilde{v}_{0_+}, \tag{12}$$

   where $\tilde{v}_{0_-}$ and $\tilde{v}_{0_+}$ are pixel values corresponding to the guard zero bins. From distance z, parameter θ is easily estimated as

$$\theta = z - 1. \tag{13}$$

2. **Data 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. Simultaneously, another set of θ-ary symbols, $\mathbf{d}$, is extracted from pixels with pixel values between $(\tilde{v}_{\text{peak}} + 1)$ and $(\tilde{v}_{\text{peak}} + \theta)$. That is, two θ-ary sequences $\mathbf{c}$ and $\mathbf{d}$ are extracted as

$$c(g) = (\tilde{v}_{\text{peak}} - 1) - \tilde{f}(x,y), \ \tilde{v}_{\text{peak}} - \theta \le \tilde{f}(x,y) \le \tilde{v}_{\text{peak}} - 1, \tag{14}$$

$$d(r) = \tilde{f}(x,y) - \left(\tilde{v}_{\text{peak}} + 1\right), \ \tilde{v}_{\text{peak}} + 1 \le \tilde{f}(x,y) \le \tilde{v}_{\text{peak}} + \theta. \tag{15}$$

From **c** and **d**, binary payload **p** is obtained through θ-ary-to-binary mapping.

3. **Recovery of histogram shifted image**
All pixels conveyed hidden payload are restored to form histogram shifted image $\hat{\mathbf{f}}$:

$$\hat{f}(x,y) = \begin{cases} \tilde{v}_{\text{peak}} - 1, & \tilde{v}_{\text{peak}} - \theta \le \tilde{f}(x,y) \le \tilde{v}_{\text{peak}} - 1 \\ \tilde{v}_{\text{peak}} + 1, & \tilde{v}_{\text{peak}} + 1 \le \tilde{f}(x,y) \le \tilde{v}_{\text{peak}} + \theta \\ \tilde{f}(x,y), & \text{otherwise} \end{cases} . \tag{16}$$

4. **Inverse histogram shifting**
Original peak pixel value v_{peak} is clearly given as $v_{\text{peak}} = \tilde{v}_{\text{peak}} + \theta$ according to Eq. (7). Parameters q and $v_{0_{\min}}$ are estimated as

$$q = \begin{cases} 2\theta, & h\left(\tilde{v}_{0_-} - 1\right) \ne 0 \\ 2\theta + 1, & h\left(\tilde{v}_{0_-} - 1\right) = 0 \end{cases} , \tag{17}$$

$$v_{0_{\min}} = \begin{cases} \tilde{v}_{0_-}, & h\left(\tilde{v}_{0_-} - 1\right) \ne 0 \\ \tilde{v}_{0_-} - 1, & h\left(\tilde{v}_{0_-} - 1\right) = 0 \end{cases} \tag{18}$$

according to Eqs. (6) and (7)[3]. Original image **f** is, then, recovered from $\hat{\mathbf{f}}$ as

$$f(x,y) = \begin{cases} \hat{f}(x,y) + (q-1), & v_{0_{\min}} \le \hat{f}(x,y) \le v_{\text{peak}} - 2 - (q-1) \\ \hat{f}(x,y) + \theta, & \tilde{v}_{\text{peak}} - 1 \le \hat{f}(x,y) \le \tilde{v}_{\text{peak}} + 1 \\ \hat{f}(x,y), & \text{otherwise} \end{cases} . \tag{19}$$

Finally, hidden payload **p** is extracted and original image **f** is restored by the above mentioned algorithm.

3.2 Features

This section summarizes the main feature of the proposed method, i.e, blind, and three mechanisms which make the proposed method blind, namely, guard zero histogram bins, double side modification, and histogram peak shifting.

Blind The proposed method is a blind method for generalized HS-RDH. To extract the hidden payload from the given stego image, non blind RDH methods including generalized HS-RDH have to identify the stego image among all possible images to retrieve the corresponding parameters, as described in Section 2.1. If the stego image is not identified correctly, the parameters are wrongly retrieved, and the hidden payload cannot be extracted or is extracted with errors.

[3] As mentioned at Step 2 in the previous section entitled "**Data Hiding**" which describes the algorithm for data hiding, $h\left(\tilde{v}_{0_-} - 1\right) = 0$ when q is even.

The more the number of treated images in the system becomes, the more costly this identification process. Some methods overcome this disadvantage by hiding parameters as well as a payload to an image, but it reduces the capacity for the payload or requires another data hiding technique. On the other hand, the proposed method is free from memorizing parameters and from hiding parameters to images. It is easy to implement and cost effective to use, i.e., the proposed method makes generalized HS-RDH feasible.

Guard Zero Histogram Bins Even if the blind methods [22, 23] for ordinary HS-RDH is applied to generalized HS-RDH, it is still difficult to determine which pixels convey payload symbols only from a stego image, as mentioned in Sect. 2.3. To overcome this problem, the proposed method introduces *guard zero histogram bins* as shown in Fig. 6 which make estimation of θ easy as described at Step 1 in the section entitled "**Hidden Payload Extraction and Original Image Recovery**." It also contributes the estimation of q and $v_{0_{\min}}$ as shown as Eqs. (17) and (18), so the proposed method does not need to hide a set of parameters to images.

Double Side Modification The *double side modification* is introduced to the proposed method, i.e., pixel values are modified to hide a payload on each side of the histogram peak as well as the blind methods [22, 23] for ordinary HS-RDH do. Different from the blind methods for ordinary HS-RDH, this method aims to distinguish guard zero histogram bins from accidental zero histogram bins by allocating equidistant zero bins on each side of the histogram peak.

Histogram Peak Shifting The proposed method shifts even the histogram peak as described in Step 2 in Sect. 3.1, to enable the double side modification for the *balanced* allocation of guard zero histogram bins. Since the height of the peak is not changed, the peak is easily determined from a stego image as described at Step 1 in the section entitled "**Data Hiding**." It is also inversely shifted to the original position as described at Step 3 in the section entitled "**Hidden Payload Extraction and Original Image Recovery**."

The above mentioned three strategies make the proposed method free from memorizing a set of image-dependent parameters and from hiding the parameters to images in generalized HS-RDH.

4 Experimental Results

With seven 512×512-sized 8-bit quantized grayscale images [26], the proposed method was evaluated, i.e., $X = Y = 512$ and $K = 8$.

Table 1 summarizes the hidden payload capacity and the stego image quality of the methods for the histogram of unprocessed images where the embedding rate is the capacity averaged by the number of pixels, i.e., L/XY [bits/pixel]. Double side modification is introduced to the proposed method to improve the

Table 1. Hidden payload capacity and stego image quality of the methods for the histogram of unprocessed images. The capacity is only for a payload in the conventional blind HS-RDH methods [22, 23], i.e., it excludes the amount for side information. h_{pm} and h_{pp} stand for $h\left(v_{\mathrm{peak}}-1\right)$ and $h\left(v_{\mathrm{peak}}+1\right)$, respectively.

(a) Proposed method.

Image	h_{pm}	h_{pp}	q	θ	Embedding rate [bits/pixel]	Averaged PSNR [dB]
Baboon	3145	3122	41	20	0.103	18.43
Elaine	2119	2280	15	7	0.047	28.97
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
Tiffany	5054	4897	65	32	0.190	14.28

(b) Non blind generalized HS-RDH [20].

Image	h_{peak}	q	Embedding rate [bits/pixel]	Averaged PSNR [dB]
Baboon	3184	41	0.065	20.61
Elaine	2462	15	0.037	34.95
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
Tiffany	5136	65	0.118	14.35

(c) Blind HS-RDH [22, 23].

Image	h_{pm}	h_{pp}	Embedding rate [bits/pixel]	Averaged PSNR [dB]
Baboon	3145	3122	0.024	48.24
Elaine	2119	2280	0.017	48.21
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
Tiffany	5054	4897	0.038	48.31

detection accuracy of guard zero histogram bins as described in Sect. 3.2, it also increases the capacity as mentioned in Sect. 2.2, c.f., Tables 1 (a) and (b). Table 1 (c) shows the performance of the blind methods [22, 23] for ordinary HS-RDH using the histogram of unprocessed images. It was confirmed from Tables 1 (a) and (c) that the proposed method based on generalized HS-RDH is superior in terms of the capacity to the blind methods for ordinary HS-RDH because θ-ary payload symbols instead of binary symbols are used.

Figure 7 shows tangible examples by the proposed and non blind generalized HS-RDH methods. Table 1 and Fig. 7 show that the proposed method does

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

Fig. 7. Image examples of the proposed and non blind generalized HS-RDH [20] methods.

not degrade stego images drastically in comparison with the non blind method generalized HS-RDH [20].

It is noted that histogram peak shifting on which other two mechanisms are based in the proposed method is a reason of the degradation of stego images, so other approach may be desired to improve the performance of the proposed method. Guard zero histogram bins have important role to distinguish watermarked pixels from unwatermarked pixels, but it reduces θ to $\lfloor (q-1)/2 \rfloor$ from $\lfloor (q+1)/2 \rfloor$.

5 Conclusions

This paper has proposed a blind method for generalized HS-RDH where the histogram of unprocessed images are focused. By introducing three mechanisms, namely, guard zero histogram bins, double side modification, and histogram peak shifting, the proposed method becomes free from memorizing a set of image-dependent parameters in generalized HS-RDH. This method is also free from hiding parameters to an image. These features make generalized HS-RDH feasible.

Further works include the sophistication of the algorithms in the proposed method for the improvement of the hidden payload capacity and the stego image quality and the investigation of capacity-distortion curves in the proposed method for comparing the performance with other methods under the condition that the same-sized payload is hidden to an image in all compared methods. Development of an extended method for histogram of preprocessed images based on the proposed method is another future work.

Acknowledgment

This work has been partly supported by the Grant-in-Aid for Young Scientists (B), No.20336522, from the Ministry of Education, Culture, Sports, Science and Technology of Japan and from the Japan Society for the Promotion of Science.

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