A Novel Framework for Robust Lossless Data Hiding

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***Abstract*—Histogram-based lossless data hiding (LDH) has been recognized as an effective and efficient way in the field of data hiding. Recently, a LDH method using the statistical quantity histogram (SQH) has been a hotspot for its good performance, which can extract secret correctly even if stego-image has some extent distortion. However, this method has some shortcoming which limits its application in practice. For this purpose, we develop a novel framework, which consists of the following three components:1) In order to overcome the shortcomings of traditional SQH, proposing a pre-processing method to construct a suitable carrier for information embedding; 2)Applying LDH method to restore the bitmap information ,which will be used for reversibly recovering the host image; 3) Presenting a robust lossless hiding algorithm, which guarantees host images can be recovered losslessly in the case of stego-image remains intact, on the contrary, the secret information can also be resistant to a certain degree of JPEG2000 attacks. Thorough experiments over different kinds of images demonstrate the effectiveness of the proposed framework.**

***Index Terms*—lossless data hiding, robust data hiding, histogram, JPEG2000**

I. INTRODUCTION

LDH [1-5] algorithms can embed information while maintain the integrity of the host media. It has wide applications in the fields of remote sensing, military and medicine image processing, where require high fidelity of image. However, these algorithms are designed on the assumption that their work environment is lossless, i.e. when the stego-image has a little distortion, the secret information cannot be correctly extracted. For this reason, some scholars put forward the concept of the robust LDH (RLDH), whose goal is the secret information can be correctly extracted in lossless and lossy environment. As a result, RLDH is required not only to recover host images and secret information without distortion for the lossless channel, but also to resist unintentional attacks and extract as much secret information possible for the noised channel [6]. There are dozens of ideas have been proposed in this field currently [7-13], and they can be divided into two groups: histogram rotation (HR)-based methods and histogram distribution constrained (HDC) methods.

The HR-based methods [7-8] accomplish robust lossless embedding by slightly rotating the centroid vectors of two random zones in the non-overlapping blocks. But using the method of modulo-256 brings serious "salt and pepper" noise which results in severe degradation of image quality. For this reason, the idea of HDC [9-13] has been proposed, which divides the image into numbers of non-overlapping sub-block with same size, and then uses the distribution of statistical quantity histogram of these sub-block to embed information. An et al. [9] and Gao et al. [12] are only focus on the robustness, so are only fit to watermarking. Though the method of Ni et al. [13] and Zou et al. [10] are steganography, and solved the problem in [7-8], but by using the method of ECC, they have limited capacity. Zeng et al. [11] improved the Ni's method [13], has good performance compared with pervious works, and is the most representative method in the field of RLDH, up to now. All of those HDC algorithms strongly depend on the assumption that the distribution of statistical quantity histogram around zero, and there are some gaps between real scenarios and the assumption. For most of images, there are always a small number of scattered points in both ends of the histogram, which affect the performance of the algorithm.

In this paper, to target the aforementioned problems, a novel framework is proposed for RLDH, which making the histogram more concentrated and giving an improved embedding algorithm. This framework is constructed by pre-processing, LDH and RLDH procedures together. The Pre-processing eliminates the scattered points of both ends to provide a good carrier for embedding; meanwhile, in order to guarantee host image can be lossless recovery, LDH technique is used to embed the useful information into host image. RLDH module is responsible for embedding secret information, and to guarantee the correct extraction of secret when stego-image subject to a certain extent distortion. Flat and texture images are

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selected for experiments to shows effectiveness of the proposed algorithm.

The rest of this paper is organized as follows: The proposed framework will be described in detail in Section II. Section III gives the experimental results to show the effectiveness of the algorithm. Finally, conclusions are drawn.

II. Proposed Algorithm

As mentioned above, HDC achieves great improvements compared with HR algorithm, but there are still some particular drawbacks. In this section we describe our solutions to these drawbacks in detail. The novel RLDH framework, in which lossless compression, LDH, RLDH and other techniques are integrated together, as shown in Figure 1.

A. Histogram Generation

For the histogram-based RLDH algorithm, the distribution of histogram has a crucial role in it. In previous works, there are many kind of statistical quantity histograms (SQHs) have been used, which has Laplacian-like distribution. Among these SQHs, [11] is the most representative method in the field of RLDH and is block based. So we focus on it and introduce the generation of it in detail.

Given a *t*-bit host image *I* with size of $M \times N$, first divided it into non-overlapping sub-blocks with same size, denoted as

$$\Omega = \{B(i,j), i = 1,2,....,\frac{M}{m}; j = 1,2,...,\frac{N}{n}\} \quad (1)$$

Where *m*, *n* are even number, and $m \times n$ is the block size, (*i,j*) indicates the index of each block. Then divided the pixels of sub-block into two sets: A and B, where B= $\bar{A}$. The statistical quantity of sub-block can be calculated by (2).

$$\partial(i,j) = \sum_{n=1}^{k}(a_n - b_n) \quad (2)$$

Where $a_n \in A, b_n \in B$.

The selection of A and B is purposed to make the value of $\partial(i,j)$ as close to zero as possible. Inspired by the work in [13]，we choose A with

$$A = \left\{ B_i^{(j)} \mid \begin{array}{c} j = \frac{1}{2}[1+\cos(\pi r)\cos(\pi c)][(r-1).n_b + c] \\ j > 0 \end{array} \right\} \quad (3)$$

Where, (*r*, *c*) denotes the location of an elements.

B. Pre-processing

The statistical quantity histogram-based algorithms are based on the assumption that most of statistical quantity's values are close to 0. But there are some gaps between real scenarios and the assumption. For most images，there are always a small amount dispersed points in both ends of the histogram, which cause more serious impact on performance. T_{max} denotes the absolute maximum of statistical quantity. In order to achieve the maximum theoretical capacity, the histogram shifting must greater than T_{max}, which results in severe degradation of image quality; in addition, the histogram will change when stego-image suffers from attack such as compression, noise etc, and the scattered points of both ends will exacerbate histogram overlapping. For the foregoing reason, idea of pre-processing is used for the host image before information embedding, according to (4). Simultaneously, a bitmap *M* is generated for the host image recovery. There are two merits after doing so:1) pre-processing can eliminate the scattered points of both ends, makes the histogram more concentrated and more suitable as a carrier; 2) pre-processing can reduce the number of overflow points which resulted by the information embedding. Where T_1 denotes the pre-processing threshold, *M* denotes the bitmap.

$$\partial(i,j) = \begin{cases} \partial(i,j) - T_1, M(i,j) = 1 & if\, \partial(i,j) > T_1 \\ \partial(i,j) + T_1, M(i,j) = 1 & if\, \partial(i,j) < -T_1 \\ \partial(i,j), M(i,j) = 0 & \text{otherwise} \end{cases} \quad (4)$$

The change of statistical quantity is complete by the change of pixels in corresponding sub-block, as shown in (5). Where $I^k(i,j)$, $I_1^k(i,j)$ denotes the pixel value of the point (*i,j*) in the *k*th sub-block of *I* and I_1, respectively, δ is the embedding level, i.e. the change of pixel value, and $\delta = Round(T_1/(w \times h))$.

$$I_1^k(i,j) = \begin{cases} I^k(i,j) - \delta & \partial >= T_1 \,\&\, \text{mod}(i,2) = \text{mod}(j,2) \\ I^k(i,j) + \delta & \partial >= T_1 \,\&\, \text{mod}(i,2) \neq \text{mod}(j,2) \\ I^k(i,j) + \delta & \partial < -T_1 \,\&\, \text{mod}(i,2) = \text{mod}(j,2) \\ I^k(i,j) - \delta & \partial < -T_1 \,\&\, \text{mod}(i,2) \neq \text{mod}(j,2) \\ I^k(i,j) & \text{otherwise} \end{cases} \quad (5)$$

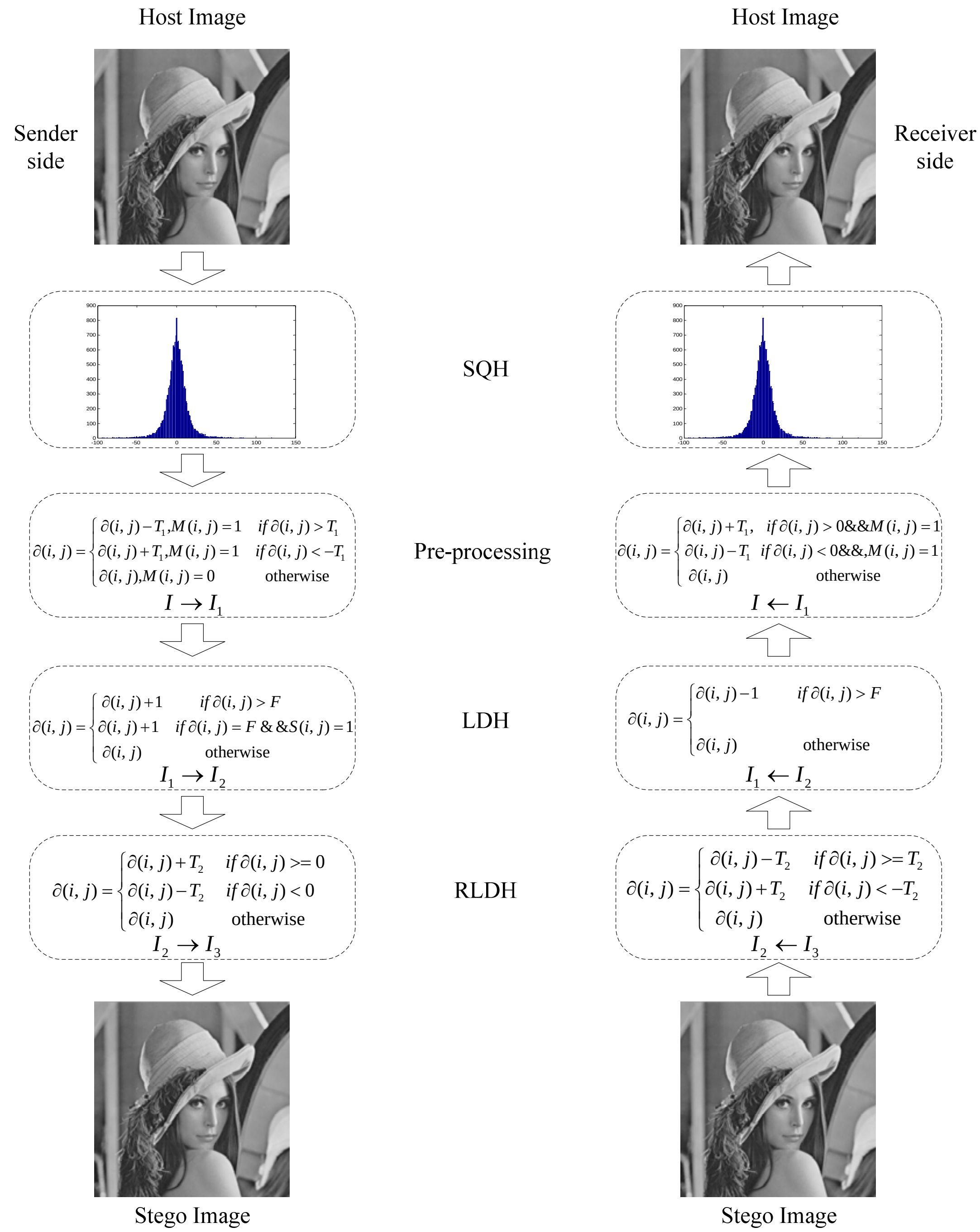

Figure1. Proposed RLDH framework

C. LDH

The main purpose of LDH in proposed framework is to find a method to storage the bitmap *M*, while make the embedding impact on image is small, i.e. to find a method to make the I_2 and I_1 as similar as possible, as shown in (6), where I_1, I_2 denotes the image after pre-processing and the image after lossless data hiding, respectively.

$$I_2^* = \arg\min_{I_2}(abs(I_2(i,j) - I_1(i,j))) \tag{6}$$

For this purpose, some measures are adopted as follows: first, minimize the bits of information need to embed; second, ensure the embedding capacity, while reducing the impact on image quality as far as possible. For the former, we apply lossless compression bitmap to reduce the bits of bitmap; for the latter, the idea is as follows: scanning the histogram from the right (left) end, find the first peak F according to the bits of compression, provided that F is greater than it. Then the right histogram of F is shifted to the right (left). Finally, information is embedded into the F. The histogram shifting can be complete by the change of pixels in the corresponding sub-block. Here we plus the top-left pixel one to achieve the shifting of histogram fixedly.

$$\partial(i,j)=\begin{cases}\partial(i,j)+1 & if\,\partial(i,j)>F\\ \partial(i,j)+1 & if\,\partial(i,j)=F\,\&\&S(i,j)=1\\ \partial(i,j) & \text{otherwise}\end{cases} \quad (7)$$

D. RLDH

Image I_2 is used as a carrier and the method of embedding according to (8). Where, T_2 denotes the robust threshold, the great the value is the more robust the performance has, and vice versa.

$$\partial(i,j)=\begin{cases}\partial(i,j)+T_2 & if\,\partial(i,j)>=0\,\&\&S(i,j)=1\\ \partial(i,j)-T_2 & if\,\partial(i,j)<0\,\&\&S(i,j)=1\\ \partial(i,j) & \text{otherwise}\end{cases} \quad (8)$$

Then let the change of ∂ reacts on the image I_2 to obtaining the stego-image I_3. The way of corresponding pixels' changing is according to (9). Where, $\beta = Round(T_2/(w\times h))$.

$$I_3^k(i,j)=\begin{cases}I_2^k(i,j)+\beta & \partial>=0\&\text{mod}(i,2)=\text{mod}(j,2)\&S=1\\ I_2^k(i,j)-\beta & \partial>=0\&\text{mod}(i,2)\neq\text{mod}(j,2)\&S=1\\ I_2^k(i,j)-\beta & \partial<0\&\text{mod}(i,2)=\text{mod}(j,2)\&S=1\\ I_2^k(i,j)+\beta & \partial<0\&\text{mod}(i,2)\neq\text{mod}(j,2)\&S=1\\ I_2^k(i,j) & \text{otherwise}\end{cases} \quad (9)$$

E. Data Extraction

The extraction of secret information can be divided into the following two situations to discuss:

- When stego-images didn't suffer from attack

In this case, the information extraction can be viewed as the inverse process of the embedding.

$$S(i,j)=\begin{cases}1 & if\ \partial>T_2 or \partial<-T_2\\ 0 & \text{otherwise}\end{cases} \quad (10)$$

- When stego-images suffered from attack

If the stego-image has been altered, the distributions of SQH will change as a result of JPEG2000 compression. As shown in Figure.2, the bit-0-zone and the bit-1-zone are overlapping. In this case, we can obtain the numbers of 0s and 1s before embedding, denoted by N_0 and N_1, respectively. When we extract secret in receiver end, we can obtain an Adj_0 such that the number of ∂ in the range of [-Adj_0, Adj_0] is equal to N_0, and we can obtain Adj_1 in same way such that the number of ∂ in the range of [-Adj_1, -Adj_0] $\cup$ [Adj_0, Adj_1] is equal to N_1.

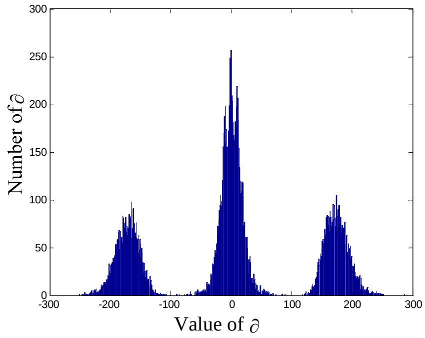

Figure2. The distribution of ∂ after compression

F. Original image recovery

When stego-image remains intact, the host image can be restored through the following methods:

Step1: Recover image I_2 by (11);

Step2: Recover image I_1 and extract the compressed bitmap M';

Step3: Decompress M' to bitmap *M*, and recover original image *I*.

$$I_2^k(i,j)=\begin{cases}I_3^k(i,j)-\beta & \partial>T_2\&\text{mod}(i,2)=\text{mod}(j,2)\\ I_3^k(i,j)+\beta & \partial>T_2\&\text{mod}(i,2)\neq\text{mod}(j,2)\\ I_3^k(i,j)+\beta & \partial<-T_2\&\text{mod}(i,2)=\text{mod}(j,2)\\ I_3^k(i,j)-\beta & \partial<-T_2\&\text{mod}(i,2)\neq\text{mod}(j,2)\\ I_3^k(i,j) & \text{otherwise}\end{cases} \quad (11)$$

III. Experimental Results and Analysis

In our experiments, six international standard images, 512×512 each, as shown in Figure 3 are used to evaluate the performance of the proposed framework. The secret data is generated by a pseudo-random number generator.

Compression ration is used for measure the robustness. In general, the higher the Compression ration is, the better the robustness is. The measurement of image quality used in the experiments is the peak signal-to-noise ratio (PSNR). The PSNR is defined as

$$\text{PSNR}=10\times\log_{10}\left(\frac{255\times255\times w\times h}{\sum_{i=1}^{h}\sum_{j=1}^{w}(C(i,j)-S(i,j))^2}\right)\text{dB} \quad (12)$$

Where *C(i,j)*, *S(i,j)* denotes the pixel in point (*i,j*) of original image and stego-image, $w\times h$ denotes the size of image.

(a)Lena (b)Boat (c)Baboon

(d)GoldHill (e)Airplane (f)Barbara

Figure3. Test image

A. Performance Experiment

The host image is divided into non-overlapping sub-block with block size 8 × 8, then the proposed framework is applied to embed the secret information. The test results of 6 images as show in Table I. Where,
EL is embedding level, and the robustness is the highest compression ration at which the test images can resist JPEG compression with secret information bit error rate (BER) is equal to 0.

TABLE I.
THE PERFORMANCE OF THE PROPOSED FRAMEWORK WITH BLOCK SIZE OF 8 × 8

Image (8 × 8)	PSNR (dB)	Capcity (bits)	EL (δ,β)	Robustness
Lena	39.08	4096	(1,4)	9.5
Airplane	39.13	4096	(1,4)	9
Boat	39.04	4096	(1,4)	7.5
Goldhill	39.03	4096	(1,4)	6.5
Baboon	33.10	4096	(4,8)	4
Barbara	39.07	4096	(2,4)	5.5

Table I shows the performance of the proposed framework. Through the results, it can be seen that the proposed framework has a good performance obviously. When capacity is 4096 bits and BER=0, the maximum compression ration test image can resist is from 4 to 9.5, and the PSNR is from 33.10 to 39.13dB. So we can say that the proposed algorithm have good performance in terms of image quality, embedding capacity and robustness.

In addition, thought the results we can find that the image quality is related to δ and β. As shown in Figure.4, suppose β =8, with the increasing of δ, the image quality is decreased, and vice versa. For the maximum absolute value of histogram is mainly influenced by δ, i.e. the smaller the δ is, the more concentrated the histogram is, and but the more information which we need lossless hiding is. But the change of δ has litter impact on image quality, which is the target of us. On the other hand, image quality is mainly determined by the β, suppose δ =3, the image quality degrades rapidly as increasing of β.

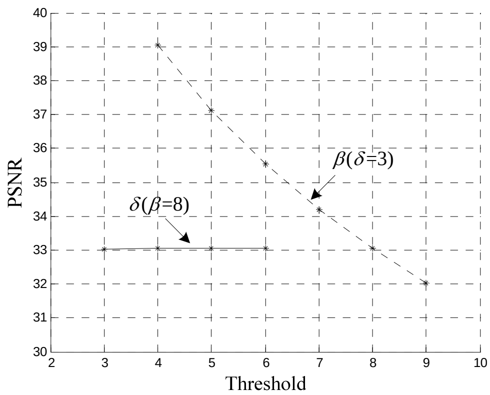

Figure4. The relationship between (δ, β) and PSNR

The robustness of algorithm influenced by (δ,β) too. The relationship of them is shown in Figure 5. Where robustness is measured by the maximum compression ration the secret information can resist with BER=0. Suppose β =8, the robustness decreases as increasing of δ, vice versa; suppose δ =3, the robustness increases as increasing of β, vice versa.

As discussed above, the image quality mainly determined by the parameter β. The main reason is that the number of scattered points in the both end of SQH is little. So the sub-blocks need to modify is few, and effect of LDH on image quality is small. The parameter δ has less effect on the image quality, but it decides the robustness of the algorithm with parameter β together. In other words, parameter δ can improve the robustness of the algorithm, while give almost no impact on the image quality. It's the strong proof to prove the effectiveness of the proposed framework.

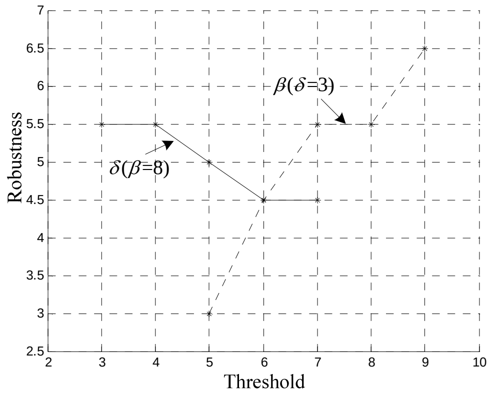

Figure5. The relationship between (δ, β) and Robustness

B. Comparison Experiment

Finally, Table II lists the experiment results in order to compare the performance between Zeng et al.'s algorithm [11] and our proposed framework in a direct way, with block size of 8×8 . Thought the results it can be see that our proposed algorithm has better performances obviously. For example, given same capacity, the proposed framework achieves higher PSNR and stronger robustness.

TABLE II.
PERFORMANCE COMPARISON BETWEEN ZENG ET AL.'S ALGORITHM AND OUR PROPOSED SCHEME

Image	Zeng et al.[11]		Proposed	
	PSNR	Robustness	PSNR	Robustness
Lena	36.17	9	39.08	9.5
Airplane	36.15	8.5	39.13	9
Boat	36.14	7	39.04	7.5
Goldhill	36.09	6	39.03	6.5
Baboon	30.06	3.5	33.10	4
Barbara	36.13	5.5	39.07	5.5

IV. CONCLUSION

In this paper, we propose a novel yet pragmatic framework for RLDH. It included pre-processing, side information storage, LDH and RLDH, has better solved the specific problem in RLDH. Provide a new idea for the application of RLDH. In comparison with the existing RLDH methods, our proposed algorithm achieved better performance in terms of image quality and robustness. There are several directions for future work including the development of new statistical quantity in transform domain to construct a more suitable carrier for embedding. In addition, we planned to enhance the performance of the proposed algorithm based on other techniques, e.g., spread-spectrum [14], Clustering [15], region selection [16], and scrambling [17].

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