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A Novel Robust Reversible Information Hiding Algorithm Based on Interval Region

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Abstract: A new method of robust reversible hiding algorithm is proposed in this study, which creates redundant space for information hiding by histogram shifting. Accommodation matrix used in this method reduced the modification extent of pixel values caused by histogram shifting and preserved the visual quality of stego-images. The design of interval region helped to realize the robustness of embedded information. Experiment results show that the new algorithm can not only extract secret information correctly and restore the original carrier image completely but also increase the resistance ability of secret information to some lossy processes.

Key words: Reversible information hiding, histogram shifting, interval region, robustness

INTRODUCTION

Generally, information hiding technology will cause some permanent distortions as a result of data hiding and cannot be inverted back to the original one (Provos and Honeyman, 2003; Cheddad *et al*., 2010). Although these changes are not perceivable to the users, modifications of carrier images are not allowed in some special application areas, such as law enforcement, medical imaging systems, military imaging systems, remote sensing and high precision systems in scientific research (Wang *et al*., 2007; Huang *et al*., 2013). Thus, it is desirable to embed secret information into carrier images without obviously distortions and restore the original images completely after information extraction. Techniques with this kind of property are referred to as reversible information hiding.

So far, the research of reversible information hiding can be classified into three main categories. The first category adopt lossless compression method of bit-plane to embed information, Fridrich *et al*. (2001) and Celik *et al*. (2006) use this kind of method. The drawback lies in the least-significant-bit plane contains abundant information so that the compression ratio of this plane is low and the embedding capacity is limited. The second category is based on difference expansion method, proposed by Tian (2003) at the earliest. Later, Alattar (2004) and Thodi and Rodriguez (2007) put forward many improvement algorithms. This kind of method will enlarge the difference value of pixels and give rise to overflow, so it is not benefit to realize multi-layer embedding. Besides, the process of embedding will produce lots of additional information, pure payload will be reduced greatly. The third category use histogram shifting technique to realize reversible information hiding (Ni *et al*., 2006). Method of this kind can generate redundant space for information embedding simply and effectively and the modification of pixels is small, therefore, it is suitable for multi-layer embedding.

Most of the secret information in reversible hiding algorithm is fragile because these algorithms have no resistant abilities to attacks for their embedding strategy. That is to say, when the stego-image suffered some lossy attacks, even some normal image processes, secret information cannot be extracted exactly. Aim at this phenomenon, we proposed a novel reversible information hiding algorithm with robustness based on histogram shifting technique. The method distributes secret information into different region of difference value histogram by setting up reasonable interval regions. It is able to restore the original carrier image under the lossless circumstance and the secret information maintains robustness when stego-image suffered from noise, cropping and other attacks.

HISTOGRAM SHIFTING REVERSIBLE ALGORITHM

The earliest reversible hiding algorithm based on histogram shifting (Ni *et al*., 2006) produce redundant space for information embedding by shifting the pixel with highest frequency. The embedding course of information hiding will scan the carrier image successively. While it

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comes to the pixel with the highest frequency and the information waiting to be embedded is "0", there will be no change. But, if it comes to the pixel with the highest frequency and the information waiting to be embedded is "1", then the value of the pixel has to be added with "1". It is obviously that the maximum extent of modification of histogram shifting method is 1 and the embedding capacity of this method equals to the highest frequency of image histogram. Although the method is simply and modification of image is low, the amount of pixels with high frequency in histogram is rarely, so embedding capacity of this kind is quite limited.

Based on the thinking of histogram shifting algorithm, many researchers gave their improvements. Hwang *et al.* (2006) take the advantage of high image quality of histogram shifting method and proposed a high-quality reversible algorithm without additional information by combining the bitmap technique. Xuan *et al.* (2006) and Wu (2007) use the characteristic that the wavelet coefficients of images have a similar distribution of Laplace and apply the histogram shifting method into integer wavelet domain. Experiment results show that methods of this kind can improve the watermark capacity and visual quality of stego-image significantly. Lin *et al.* (2008) and Tai *et al.* (2009) proposed the histogram shifting method based on prediction error. The main idea is to get error information from the prediction of adjacent pixels and then implement histogram shifting to achieve reversible watermark embedding based on the error message. Experimental results show that performance of such algorithms has been enhanced greatly.

DIFFERENCE VALUE OF HISTOGRAM BASED ON BLOCKS

Suppose the original carrier image can be divided into many non-overlapping blocks with the size of m×n. Accommodation matrix can be defined as follows, where I∈[1, m], j∈[i, n]. An 8×8 accommodation matrix is shown in Fig. 1:

$$A(i,j)=\begin{cases}1 & \text{mod}\,(i,2)=\text{mod}\,(j,2)\\ -1 & \text{mod}\,(i,2)\neq\text{mod}\,(j,2)\end{cases}$$

For every block, the difference value can be indicated by the statistics element α, which is defined as Eq. 2:

$$\alpha=\frac{1}{n}\sum_{t=1}^{n}(p_t-q_t)$$

+1	-1	+1	-1	+1	-1	+1	-1
-1	+1	-1	+1	-1	+1	-1	+1
+1	-1	+1	-1	+1	-1	+1	-1
-1	+1	-1	+1	-1	+1	-1	+1
+1	-1	+1	-1	+1	-1	+1	-1
-1	+1	-1	+1	-1	+1	-1	+1
+1	-1	+1	-1	+1	-1	+1	-1
-1	+1	-1	+1	-1	+1	-1	+1

Fig. 1: An 8×8 accommodation matrix

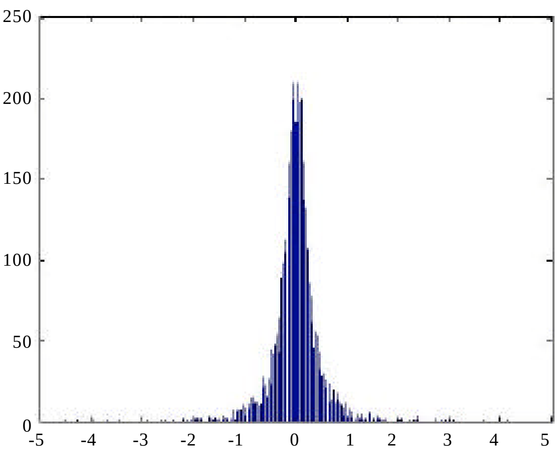

Fig. 2: Difference value histogram of "Lena"

There p_t are the pixels marked by "+" and q_t are the pixels marked by "-" in accommodation matrix. n is the No. of pixel pairs, for example, a given 8×8 block has 32 pixel pairs.

Difference value histograms of most images have the similar distribution as Fig. 2, where the X axle represents the difference value α of blocks and Y axle represents the frequency of every value. In general, pixels of a block are highly correlated and exhibit strong spatial redundancy, therefore, the difference value histograms is expected to be very close to zero.

ROBUST REVERSILE ALGORITHM BASED ON INTERVAL REGION

Reversible algorithms based on histogram modulation usually produce redundant space for information embedding by shifting the histogram of image. In order to extract the secret information correctly, histogram of embedding areas should not be overlapped.

Interval region: We use two positive value K and T to represent the threshold and interval region and divided the difference value histogram of image blocks into different regions. Calculation method of threshold K is shown as Eq. 3 and 4. α_P, α_N is the maximum and minimum value of difference value of blocks, $\lceil \; \rceil$ means to get the integer upward:

$$\alpha_{max} = \max\left(|\alpha_P|, |\alpha_N|\right)$$

$$K = \left\lceil \frac{\alpha_{max}}{2} \right\rceil + \mathrm{mod}\left(\left\lceil \frac{\alpha_{max}}{2} \right\rceil, 2\right)$$

The difference value histogram of image blocks after region division is shown in Fig. 3, image blocks can be adjusted according to the following principles in order to fill in interval regions between embedding areas. Here, B_t represents the image block t, β is the distance for histogram adjustment, concrete value is given in data embedding process:

$$B_t(i,j) = \begin{cases} B_t(i,j) + \frac{\beta}{2} & \mathrm{mod}(i,2) = \mathrm{mod}(j,2) \\ B_t(i,j) - \frac{\beta}{2} & \mathrm{mod}(i,2) \neq \mathrm{mod}(j,2) \end{cases}$$

Data embedding process: The strategy for data embedding is demonstrated in Fig. 4. Embedding process can be described as follows:

- Non-overlapping blocks partition. Split the original carrier images into many non-overlapping blocks with m×n pixels in a scan-line order, where m and n are even
- Computation of difference value. Calculate the difference value of every block according to accommodation matrix and Eq. 2 and then obtain the histogram of difference value
- Selecting threshold and interval region. The value of threshold K and interval region T can be determined by Eq. 3, 4 and the histogram of difference value.
- Embedding secret bits by histogram shifting. The embedding strategy is based on difference value α and divided into positive and negative categories as shown in Fig. 5

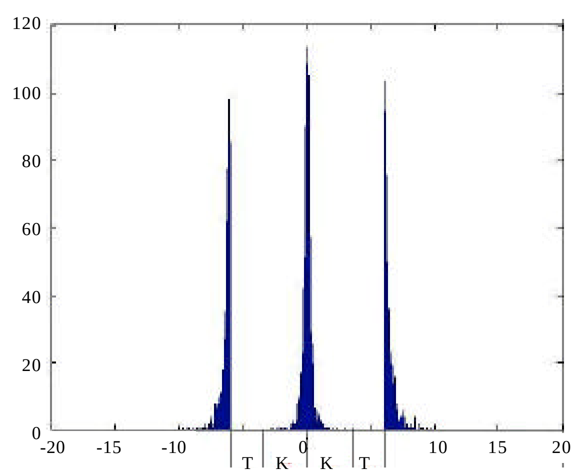

Fig. 3: Difference value histogram after region division

Category 1 the difference value α is positive: In this category, the difference value α is always positive. Therefore, two cases are considered in the following:

- $0 \leq \alpha\alpha$ K in this case, the difference value α is located between 0 and threshold K. If the bit waiting to be embedded is "1", the histogram of the block has to be shifted rightward with the distance K+T. If the bit waiting to be embedded is "0", the histogram keeps intact
- K<α iin this case, the difference value α is located in the right side of threshold K. If the bit waiting to be embedded is "1", the histogram of the block has to be shifted rightward with the distance 2K+3T. If the bit waiting to be embedded is "0", the histogram of the block is shifted rightward with the distance K+2T

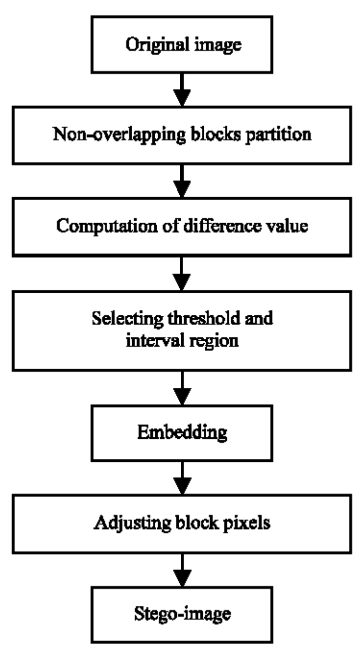

Fig. 4: Strategy of data embedding

Category 2 the difference value α is negative: In this category, the difference value α is always negative. Similarly, there are two cases in the following:

- $-K \le \alpha < 0$ in this case, the difference value α is located between -K and 0. If the bit waiting to be embedded is "1", the histogram of the block has to be shifted leftward with the distance K+T. If the bit waiting to be embedded is "0", the histogram keeps intact
- $\alpha < -K$ in this case, the difference value α is located in the left side of threshold K. If the bit waiting to be embedded is "1", the histogram of the block has to be shifted leftward with the distance 2K+3T. If the bit waiting to be embedded is "0", the histogram of the block is shifted leftward with the distance K+2T
- Adjusting block pixels. Stego-images can be gotten by adjusting the pixels within blocks according to Eq. 5. Apparently, the value of threshold K is even, so the value of interval region T should also be even, in order to prevent float value of pixels after histogram adjustment.

Data extraction and image reversion: Data extraction is the opposite process of data embedding and will extract the secret message correctly and restore the stego-image back into the original ones without any distortion. The parameters for data extraction used in this algorithm are the block size, threshold K and interval region T. Extraction process can be described as follows:

- Split the stego-image into non-overlapping blocks using the same method as embedding process
- Scanning the difference value α of every block successively
- If the difference value α falls in "zone 1", a bit of "1" will be extracted and if the difference value α falls in "zone 0", a bit of "0" will be extracted according to Fig. 5

At the meanwhile of data extraction, adjusting the pixels within blocks reversely according to the following formula and restore the original image.

$$B_t(i,j)=\begin{cases} B_t(i,j)-\dfrac{K+T}{2} & K+T\le\alpha<2K+T \\ B_t(i,j)-\dfrac{K+2T}{2} & 2K+2T\le\alpha<3K+2T \\ B_t(i,j)-\dfrac{2K+3T}{2} & 3K+3T\le\alpha \\ B_t(i,j)+\dfrac{K+T}{2} & -(2K+T)\le\alpha<-(K+T) \\ B_t(i,j)+\dfrac{K+2T}{2} & -(3K+2T)\le\alpha<-(2K+2T) \\ B_t(i,j)+\dfrac{2K+3T}{2} & \alpha<-(3K+3T) \\ B_t(i,j) & \text{otherwise} \end{cases}$$

EXPERIMENT RESULTS AND ANALYSIS

In order to prove the performance of the proposed algorithm, different kinds of gray-scale images have been selected during experiments. Using MATLAB R2009a to be the programming platform, split the original images into 8×8 non-overlapping blocks, interval region T = 2 and the secret information is a black and white logo image.

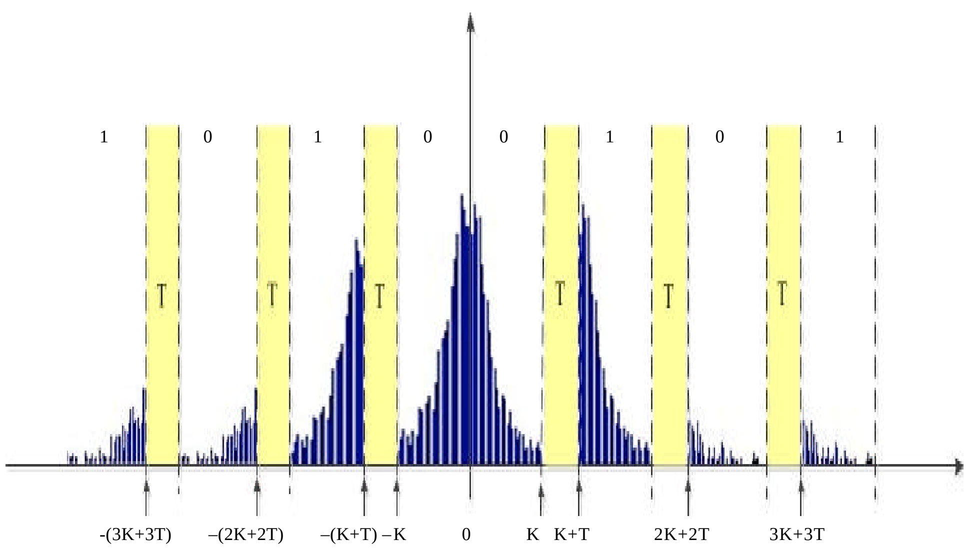

Fig. 5: Embedding strategy

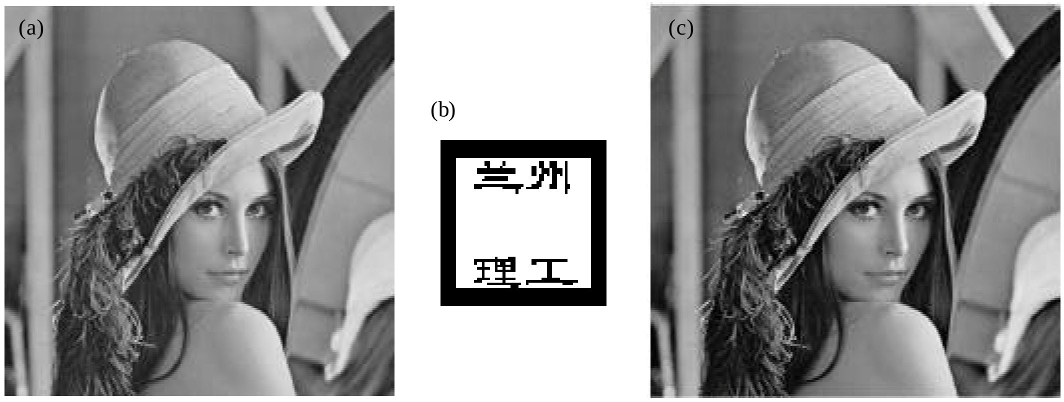

Fig. 6: Contrast results (PSNR = 40.8296)

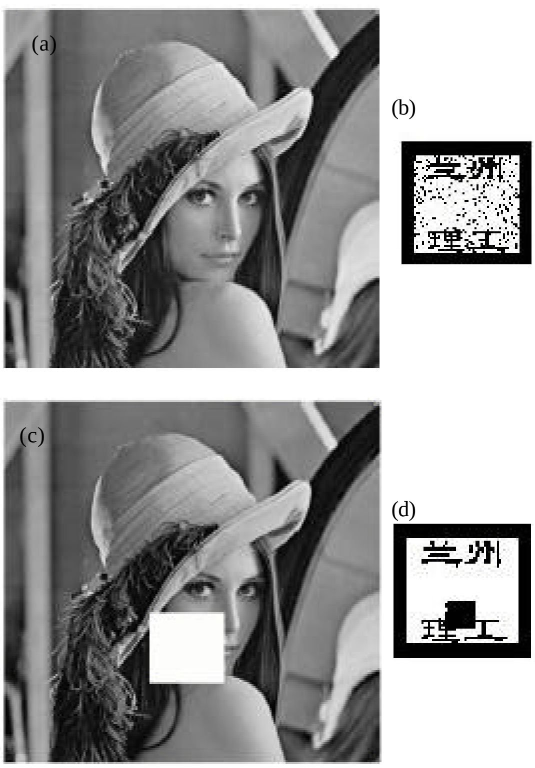

Fig. 7: Attacks and extract results

Test of transparency and analysis: Figure 6 shows the contrast effects before and after information hiding on carrier image Lena (512×512). Table 1 displays the Peak Signal to Noise Ratio (PSNR) of all the testing images.

The results indicate that all the stego-images maintained well visual quality after information embedding. That may be attributed to the embedding

Table 1: Peak signal to noise ratio

Images	Size	PSNR
Lena	512×512	40.8296
Barbara	512×512	40.4871
Elain	512×512	40.7013
Cameraman	256×256	39.6066
Peppers	256×256	39.3975
Plane	256×256	39.4203

process produced the same adjust extent to both the "+" region and "-" region in accommodation matrix, so that the modification of every pixel will be smaller when to achieve a similar shifting distance. Thereby, the visual qualities of stego-images after embedding have been improved.

Test of robustness and analysis: In order to test the robustness of secret information, some common processes and attacks have been carried out on stego-images. Some results of are shown in Fig. 7.

Figure 8 shows the contrast effect of histogram before and after attacks, we may find that the setting of threshold and interval region distribute the secret information into different embedding region. Because of the special properties of accommodation matrix, no matter adds or subtracts a certain value to the block, the difference value α will remain unchanged. That is to say, the embedded information will remain unchanged. Besides, there are interval regions between embedding regions in the histogram, so long as the change caused by attacks is not strong enough to step over the interval region, the embedding regions will not overlapping, hence, the secret information will not be influenced. Obviously, the larger the interval region is the stronger robustness the secret information has but at the meanwhile, the change of pixels caused by histogram shifting is larger and the transparency of stego-image will be reduced.

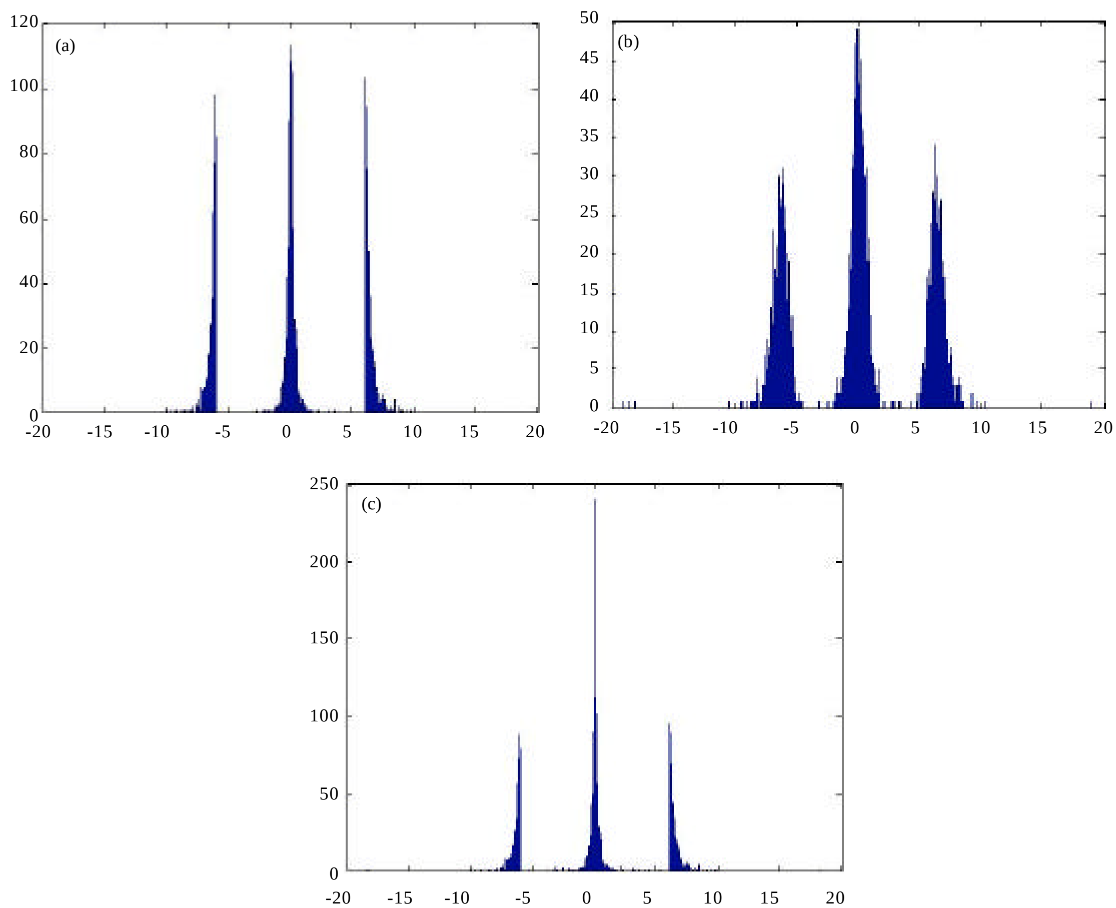

Fig. 8(a-c): Contrast effect before and after attacks (K = 4), (a) Histogram after region division, (b) Histogram after noise attack and (c) Histogram after cropping attack

CONCLUSION

In this study, a new robust reversible algorithm is proposed based on histogram shifting. The embedding strategy use histogram adjusts method to create redundant space for information hiding, data extraction and image restore only need fewer side-information. Accommodation matrix used in this algorithm reduced the modification extent of pixels caused by histogram shifting as well as the overflow phenomenon and preserved the visual quality of stego-images. The setting of interval region helped to realize the robustness of secret information. Experiment results show that the algorithm can not only extract secret information correctly and restore the original carrier image completely but also increase the resistance ability of secret information to some lossy processes. The future work will focus on the research of multi-layer embedding method based on histogram shifting and to increase the capacity of embedding information.

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