Enhanced Reversible data hiding scheme

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Abstract. We propose new reversible watermarking method for images. Being reversibility, original image and watermarked message should be recovered exactly. We propose different technique for hiding data to pairs. We use new type of histogram (pair histogram), which shows frequencies of each pair in image. We use histogram shift method for data embedding to pairs. We also propose improved version of method which allow hiding data with good performance for high capacities. This algorithm has better result compare to Tian's difference expansion method based on the Haar wavelet decomposition. For proposed algorithm capacity is higher under same PSNR.

Keywords: Data Hiding, histogram shift, two order embedding scheme.

1 Introduction

Recently the reversible watermarking algorithms have intensive development. Reversible watermarking techniques embed data to digital host signal in a reversible fashion. Main requirement for these methods is reversibility. Original host signal should be exactly recovered. Another important requirement is low distortion of output signal under high capacity. There is contradiction between capacity and distortion. If capacity is high, distortion is significant. Requirements impose hard limitations for development new methods. How to observe requirements and develop new method? The most efficient way is use useful features of input signals. For example, high correlation between neighbor pixels is significant feature of images for data embedding. There are many different reversible methods use this feature for data embedding. Another question, how to use this feature more efficient. Most of all use high correlation for efficient lossless compression.

Difference expansion transform, invented by Tian [15], is an outstanding reversible data hiding scheme in terms of high embedding capacity and low distortion in image quality. His method divides the image into pairs of pixels, then embeds one bit of information into the difference of the pixels of each pair from those pairs that are not expected to cause an overflow or underflow. A pair generally consists of two neighboring pixels. The location map indicates the modified and not modified pairs. Thus, uncompressed location size is half of image size. Location map is compressed and included in the payload. Location map looks like original image and has high correlation between neighbor bits. So efficient of lossless compression is high. Compression of location map empty rooms for useful data. This method in not able to embed data without location map compression.

The seminal paper by Tian [15] has been a steppingstone to enhanced performance. Alattar [1][2][3] has extended the difference expansion transform from a pair of pixels to a triplet, a set of three pixels, to hide two bits in every triplet of pixels. Alattar has derived an enhanced difference expansion transform that is based on a quad, a set of four pixels, to hide three bits in every quad. There are spatial triplets, cross-color triplets, spatial quads according to the combination of pixels. Alattar has shown that spatial quads can hide the largest payload at the highest signal-to-noise ratio. Location map covers all triplets or quads and indicates expandable and non expandable triplets or quads. Thus, location

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map size is 1/3 of image size for triplets and 1/4 for quads. Compressed location maps have a significantly smaller size compare to Tian's location map.

There are some method of reversible watermarking algorithms [7] [14] which don't need location map. Thodi used prediction errors for embedding data. He used shifting method for excluding intersection between embedding predictors and not embedding predictors. We will discuss shifting method more detail later.

We propose method which embed data to new type of histogram of image. We note it pairs histogram. Pairs histogram has a more appropriate shape for embedding data compare to other histograms (histogram of differences h from Tian's and Alattar's methods).

Our paper is organized as follow: Section 2 discussed some interest features of pairs. Histogram shift method are described in section 3. Proposed algorithm is presented at section 4. Section 5 described a improved proposed method. Section 6 concluded the paper.

2 Pairs histogram

Pair $P(a, b)$ is union of two neighbor pixels a,b of image. Image has high correlation between neighbor pixels, so pairs $P(a, a)$, where $a \in [0; 255]$ is pixels, has higher frequency compare to pairs $P(a, x)$, where $x \in [0; 255]$. Embedding data to high frequencies allow increasing capacity and decreasing distortion. So information about frequencies of each pair is important. Usual histogram of differences between neighbor pixels $h = a - b$ shows frequencies of differences h and do not shows pairs which have these differences h. We propose different type of histogram (pairs histogram or Ph) which shows frequencies of each pair.

Each pair $P(a, b)$ has two pixels a and b, $(a, b) \in [0; 255]$. Pixels a and b can be used such current coordinates at special image $Ph(256 * 256)$.

Algorithm for computation pairs histogram for image $(p * q)$:

1. Following predefined scanned order, collect pairs, for example, $P_1(a_{1,1}, b_{1,2})$, $P_2(a_{1,3}, b_{1,4})$, ..., $P_n(a_{i,j}, b_{i,j+1})$,..., $P_N(a_{p,q-1}, b_{p,q})$.
2. Add information about current pair $P(a, b)$ to pair histogram: $Ph(a, b) = Ph(a, b) + 1$

Each pixel's value $Ph(a, b)$ of pairs histogram Ph is number (or frequency) of $P(a, b)$ in original image. $Ph(a, b) \in N$, where N is union of positive integer numbers (see figure 1). Black pixel

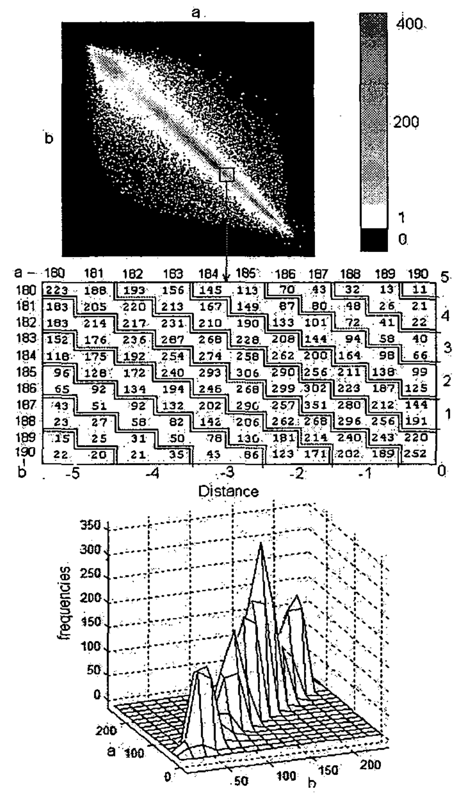

Fig. 1. Pair histogram Ph for Lena image

$P(a, b)$ at background of pair histogram mean no pair $P(a, b)$ in image. White pixel mean one pair. All other gray colors mean different number of pairs(see scale near pair histogram at figure 1). Matrix under pair histogram is increased block of histogram with $a \in [180; 190], b \in [180; 190]$. First column and first row of matrix are pixels a, b of pairs $P(a, b)$. For example, for pair $P(a, b)$, where $a = 180, b = 180$, $Ph(180, 180) = 223$. Thus, there are 233 pairs $P(180, 180)$.

Assume that distance value D for pair is:

$$D = \left\lfloor \frac{a - b}{2} \right\rfloor \quad (1)$$

Thus, each frequency or each pair from pair histogram Ph has distance D . Last column and last row are distance values D for pairs histogram (see matrix of figure 1). Among main diagonal (from $a = 1, b = 1$ to $a = 256, b = 256$) frequencies of pairs are the highest (see $Distance = 0$ for matrix of figure 1). Frequencies of pairs from other distances are less than for distance $D = 0$. 3D graph (see figure 1) shows more detail shape of pair histogram. Thus, we can estimate correlation between pairs using pair histogram and use pairs with high correlation for embedding data.

Performances of using pair histogram for embedding data we will discuss later in section 4.

3 Histogram shift method

As was mentioned before, shifting method allow hiding data without any location map. Shifting method are usually used for embedding data to predefined histograms from different signals like DCT coefficients [22] ,IWT coefficients [18] and predictors [14]. Let's note this method histogram shift method.

For embedding data using histogram shift method, elements of input signal S should be shifted at 1 position among increasing a 'distance' axis (see figure 2,3), if embedded bit is $'1'$, and without shifting, if embedded bit is $'0'$. For example, embed data to histogram with simple sharp (see figure 2.a), threshold value $T = 0$. $'0'$ became $'0'$ if embedded bit is $'0'$ and became $'1'$ if embedded bit is $'1'$. Part of values, which became $'1'$, intersects with original values $'1'$. For solving this problem we shift all values at $'1'$ position to right side, instead of values that equal $'0'$ (see figure 3.c). After shifting histogram have empty position $'1'$ (see figure 3.c). Thus, useful data embed easily to input signal without intersection (see figure 3.d).

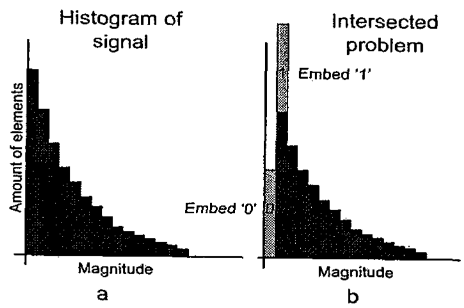

Fig. 2. Histogram shift method - intersected problem

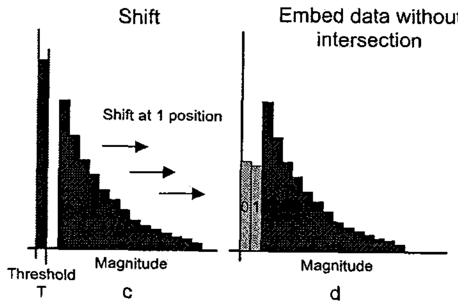

Fig. 3. Histogram shift method - embedding data

Predefined thresholds T_p and T_n, where T_p is positive threshold and P_n is negative, divide histogram's elements S_i into two part: expandable $E \in [T_n; T_p]$ and non expandable $nE \in (T_p; max(S_i)]$ and $nE \in (T_n; min(S_i)]$.

Encoder algorithm of histogram shift method:

1. Divided elements of input signal into two part: E and nE using predefined thresholds T_p and T_n.
2. Using predefined scan order, check all elements of input signal S using follow conditions:
   (a) If current input element S_i belong to expandable set E, S_i is expended to $S'_i = 2 \cdot S_i + bit$. Where $bit \in [0; 1]$ is current bit from embedded message.
   (b) If current input element $S_i \in nE$, S_i is expanded to $S'_i = S_i + T_n$ if S_i is negative and $S'_i = S_i + T_p + 1$ if S_i is positive.

Decoder algorithm of histogram shift method:

1. Using predefined inverse scan order, check all elements of input signal S' using follow conditions:
   (a) If current input element $S'_i \in [2 \cdot T_n; 2 \cdot T_p + 1]$, S'_i is restricted to $S_i = \lfloor \frac{S_i}{2} \rfloor$. Embedded bit is $bit = mod(S_i, 2)$.
   (b) Otherwise S'_i is restricted to $S_i = S'_i - T_n$ if S'_i is negative and $S_i = S'_i - T_p - 1$ if S'_i is positive.

This method has relatively better performance in case of low capacities, when thresholds T_p and T_n are low and distortion for nE and E sets are insignificant. In case of high capacities thresholds T_p and T_n are huge and distortion is also huge, because all elements from nE sets have shift equal $T_p + 1$ or T_n and all elements from

E set have shift from 0 (for $S_i = 0$) to T_p (for $S_i = T_p$) or T_n (for $S_i = T_n$).

We adapted histogram shift method for embedding data to elements of pairs histogram.

4 Proposed method

Proposed method based on embedding data to pairs from pair histogram, which have high correlation. All pair from pairs histogram have distance value D (see section 2). Distance means difference between pair and main diagonal in pairs histogram. Most of image pairs have distances '0' and ' − 1' (see matrix in figure 1). For example, union of pairs with distances '0' and ' − 1' is 31% for grayscale Lena image ($512 * 512$). For embedding data to pairs we used histogram shift method adapted to using distances D from pairs histogram.

Encoder algorithm for proposed algorithm:

1. Compute pair histogram for image.
2. Divide pair histogram into distances D.
3. Using predefined threshold T divide pairs into E and nE sets as follows: if $D \leq T$, current pair is expandable; otherwise non expandable.
4. Embedding data:
   (a) If $D \geq 0$ and if current pair $P(a, b) \in E$, pair $P(a, b)$ became $P'(a - D, b + D)$ if current embedded bit is 0 and $P(a - D - 1, b + D + 1)$ if current bit is 1.
   (b) If $D \geq 0$ but current pair $P(a, b) \in nE$, pair $P(a, b)$ became $P'(a - D - 1, b + D + 1)$.
   (c) If $D \leq 0$ and if current pair $P(a, b) \in E$, pair $P(a, b)$ became $P'(a + D + 1, b - D - 1)$ if current embedded bit is 0 and $P(a + D, b + D)$ if current bit is 1.
   (d) If $D \leq 0$ but current pair $P(a, b) \in nE$, pair $P(a, b)$ became $P'(a + D, b - D)$.

Capacity P for embedding data to pairs with distances '0' and '1' is 41248 bits (0.15bpp). Distortion for half of pairs with '0' and '1' are 0, for other pairs are 2. $PSNR = 48.8dB$. Thus, proposed method has excellent results for low capacities.

Explain more detail embedding procedure for thresholds $T_p = 0$ and $T_n = -1$, where T_p is positive threshold and T_n is negative. Figure 4 is original pairs histogram before embedding data. First row and first column are pixels a and b of tested image. Last row and last column are distances D. Different colors are marked different distances D.

Step 1: Shifting (see figure 5.1). All pairs instead pairs with $D = 0$ and $D = -1$ was shifted among increasing of distance value. Pairs with $D = 1$ was moved to $D = 2$, pairs with $D = -2$ was moved to $D = -3$ and etc. Colors of each pair are marked original distances of pairs. For example, pair $P(2, 4)$ was moved to $P'(1, 5)$ but color is same for P and P'.

Step 2: Embedding data(see figure 5.2): After shifting distances $D = 1$ and $D = -2$ are empty. Thus, we can expand pairs with distance $D = 0$ to $D = 0$, if embedded bit is 0 or to $D = 1$, if embedded bit is 1. Pairs with distance $D = -1$ are expanded to $D = -1$, if embedded bit is 0 or to $D = -2$ if embedded bit is 1.

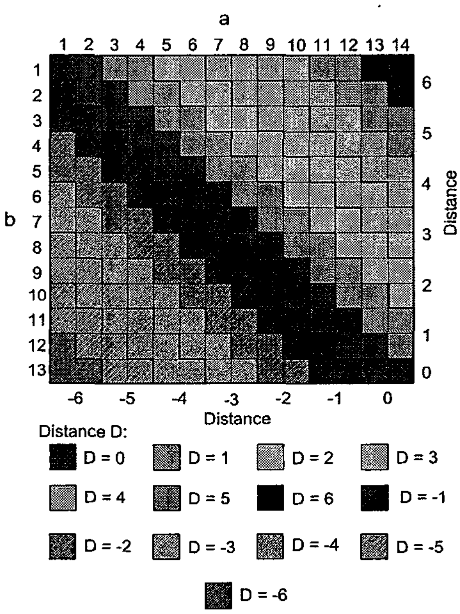

Fig. 4. Original pairs histogram

We proposed novel reversible watermarking algorithm for pairs based on using performances of pair histogram and adapted histogram shift algorithm for embedding data.

5 Improved method

As was mentioned before, proposed algorithm is non able to have high capacity under acceptable

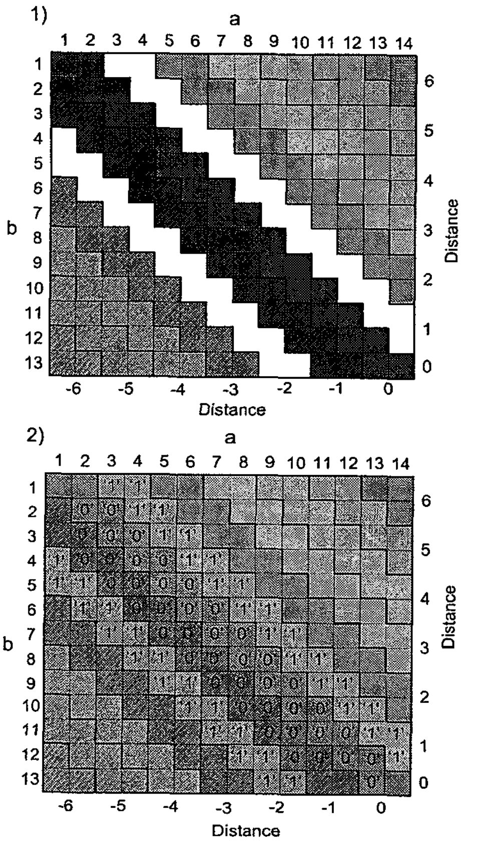

Fig. 5. Pairs histogram (1 - Pairs histogram after shifting; 2 - Pair histogram after embedding data).

PSNR. Distortion for high thresholds are very significant. For solving this problem we propose to use two order embedding algorithm, which allow hiding data with high capacity under acceptable PSNR.

Predefined scan order for previous method was follow: $P_1(a_{1,1}, b_{1,2})$, $P_2(a_{1,3}, b_{1,4})$,..., $P_n(a_{i,j}, b_{i,j+1})$,..., $P_N(a_{p,q-1}, b_{p,q})$ (see figure 6.a). But other orders are also possible (see figure 6.b). The main idea of two orders embedding algorithm is using order 1 and order 2 step by step.

Encoder of two orders embedding algorithm:

1. Divide payload P into two parts $P_1 = \lfloor \frac{P}{2} \rfloor$ and $P_2 = P - P_1$.
2. Divide pixels from original image I into pairs using order 1.
3. Embed P_1 bits to pairs of order 1 using proposed method. Find output image I'.
4. Divide already changed image I' into pairs using order 2.

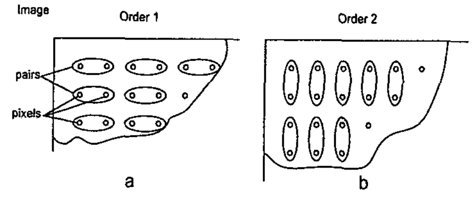

Fig. 6. Two types of pairs

5. Embed P_2 bits to pairs of order 2 using proposed method. Find output image I''

Decoder of two orders embedding algorithm:

1. Divide pixels from image I'' into pairs using order 2.
2. Extract P_2 bits from pairs of order 2 using proposed decoding method. Recover image I'.
3. Divide recovered image I' into pairs using order 1.
4. Extract P_1 bits from pairs of order 1 using proposed decoding method. Recover original image I.

Main contribution of using two order embedding algorithm is minimizing distortion. For some pairs distortion after using embedding data to order 2 are decreased (see figure 7). For example, we want to embed 2 bits in 4 pixels (see figure 7). First step is same for previous and improved method. We embed data to pair 1 $P_1(11, 12)$, distance $D = -1$, embedded bit is 1, so output pair is $P'(10, 13)$. At second step there are two ways for embedding data. First is embed data to pair 2, second is change order and embed data to pair from order 2. First way: $P_2(9, 10)$, distance $D = -1$, embedded bit is 1, so output pair $P_2'(8, 11)$. Second way: first pair for order 2 is $Pc_1(10, 9)$, distance $D = 0$, embedded bit is 1, so output pair is $Pc_1'(11, 8)$. Distortion for previous method is 4(see figure 7), but for improved method is only 2.

6 Conclusion

We applied our methods for many images and proved that proposed methods have essential advantage in low capacity area (around 0.05-0.15 bpp). Improved method is better for middle capacity area (0.15 - 0.5 dB) and can compete with others reversible watermarking algorithms, which

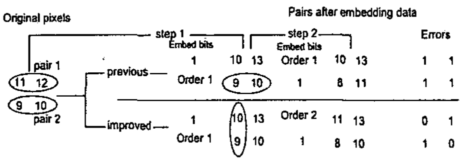

Fig. 7. Example

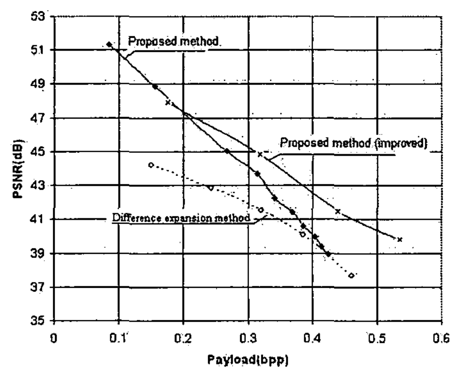

Fig. 8. Experimental result

use location map. Idea of improved method has depth potential and can develop as new direction at reversible watermarking. At results we compared proposed algorithms with difference expansion method proposed by Tian.

We proposed reversible watermarking algorithm which has performance compare to others reversible watermarking algorithms. Proposed algorithm allows hiding 0.083 bpp of data with PSNR 51.33 dB. Our algorithm has not difficult mathematic equation, so computations are considerably fast and implementation is easy.

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