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Research Article

RHOMBUS PATTERN BASED REVERSIBLE WATERMARKING USING PAIRWISE PREDICTION ERROR EXPANSION

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ABSTRACT

Prediction-error expansion (PEE) method in reversible watermarking is an important technique which can embed large payload into digital images with low distortion. This technique makes use of prediction error to embed data into an image. In this technique, the correlations among prediction-errors are not considered and not utilized in current PEE based techniques. But, the prediction-errors are modified individually in data embedding. In this paper we propose a new idea in reversible data hiding framework which is using prediction-error expansion (PEE) with Pair in image authentication. This algorithm is named as pairwise prediction-error expansion. We propose that every two adjacent prediction-errors compositely and make pair. All pair consider to generate a sequence which consisting of prediction-error. Pixel selection is used for sorting in decreasing order of prediction pair. To make an entry of prediction error pairs based on magnitude. Based on the sequence, we making 2D prediction-error histogram. A more efficient embedding strategy can be designed where expanding and shifting in histogram bins. To achieve an improved performance we use pairwise prediction error expansion and, a reduced size of location map. This may help us to improve capacity into the image with less distortion.

INTRODUCTION

RDH FRAMEWORK BASED ON CONVENTIONAL PEE

In this segment, the basic principle of the conventional PEE is describe which is used 1D one dimensional PEH is shown at first.

Conventional PEE

The PEE embedding procedures are having following steps.

First of all predict image pixels which are gain with the help of prediction pattern scheme. Find a prediction-error sequence. Each pixel is selecting through specific method and scan sequentially. The cover image pixels are selected and treated into a one dimensional sequence as $(x_{1,}x_{2,}x_{3,} \ldots\ldots x_{N,})$. After finding pixel sequence, using a specific predictor. Predictor is specifying the prediction of pixel x_i. Prediction pixel is notified as $\overline{x_i}$. Next, the prediction-error calculated by $e_i = x_i \quad \overline{x_i}$ here $\overline{x_i}$ is an integer. Finally, the prediction-error series $(e_{1,}e_{2,} \ldots\ldots e_N)$ are getting.

Prediction error histogram (PEH) is produced through prediction error. Histogram is made by counting the repetition of prediction-errors. And, the PEH is determined as

$$(k) = \#\{1 \leq i \leq N : e_i = k \qquad (1)$$

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Here # represents the cardinal number of a set. Normally, the PEH is design a Laplacian-like distribution which centered at 0 or close to 0. Sharpness of histogram is related upon distortion. When the PEH is give up more sharp, the distortion is lower for embedding bits of the same amount.

After design PEH, modifying in histogram bins through shifting and expansion for embed data. For each prediction-error e_i it is shifted or expanded as e_i' as

$$e_i' = \begin{cases} 2ei + b, if\ ei\ \in (\quad T, T) \\ ei + T, if\ ei\ \in\ (T, +\infty) \\ ei \quad T, if\ ei\ \in\ (\quad \infty, \quad T) \end{cases} \tag{2}$$

Where T is a threshold which is parameter value of capacity-dependent integer, and b ∈ {0, 1} is data bit for embedding. Here, the bins which are in region of (T, T) are enlarged. This limit called inner region. That means bin are expanded to embed data. Those bin in region of (∞, T) ∪ (T, +∞) are shifted from outside to create vacancies. This is called outer region. Finally, each pixel value suppose x_i is improved to $x_i' = \bar{x_i} + e_i'$ to getting an image. This image called watermarked image.

For above conventional PEE embedding, the embedding capacity *EC* is

$$EC = \sum_{k=-T}^{T-1} \quad (k) \tag{3}$$

The embedding distortion *ED* in based on l^2-error. It is formulated as.

$$ED = \sum_{k=-T}^{T-1} \left(k^2 + k + \frac{1}{2}\right) \quad (k) + T^2 (\sum_{k=-\infty}^{-T-1} \quad (k) + \sum_{k=T}^{+\infty} \quad (k) \tag{4}$$

Image Authentication is used to indicate that image is really what the user deems it is. When an image just a pixel or just one bit of data has been changed, it consider as non authentic. Image authentication is a new and current topic in image processing. And several techniques are enforced in authentication method to renovate its quality. There are many techniques in image processing operation that change pixel value without modifying the content of image. Several watermarking schemes have been initiated. Digital watermarking is a technique which hides information in cover image for the purpose of authentication. The embedding side when information is embedded into a cover image, and its opposite side when information is extract in such a way, the cover image distort due to watermarking is almost.

In addition, in reversible watermarking, after the watermark extraction, the cover image restored as identical bit-by bit to the original cover image. Reversible watermarking use spread over a large area in military, law enforcement and medical applications. In these field distortion–free and recovery of the original image is most important after extraction. A huge reversible watermarking algorithm has been proposed already by various authors. Majority of reversible watermarking algorithms has been for grayscale images. Data hiding offering a way to situate data into cover medium for the motive of ownership fingerprinting, protection, secret communication authentication, and annotation (Wu and Liu, 2003; Wu *et al*., 2003). Reversible data hiding (RDH) (Shi *et al*., 2004; Caldelli *et al*., 2010) techniques hide data in a host signal. In reversible watermarking two main issues are necessary that keep in mind: the embedding capacity should be high; and distortion should be low. Both two requirements conflict with each other. Generally, a higher embedding capacity causes a higher degree of distortion. Until now, various RDH algorithms have been introduced, e.g., compression based algorithms (Fridrich *et al*., 2001; Celik *et al*., 2006) difference expansion (DE) based algorithms (Tian, 2003; Alattar, 2004; Kamstra and Heijmans, 2005), histogram shifting (HS) based algorithms (Lee *et al*., 2006; Hwang *et al*., 2006), prediction-error expansion (PEE) based algorithms (Thodi and Rodriguez, 2007; Hu *et al*., 2009; Sachnev *et al*., 2009; Luo *et al*., 2010; Li *et al*., 2011; Coltuc *et al*., 2011; Wu and Huang, 2012) and integer-to-integer transform based algorithms (Lee *et al*., 2007; Coltuc, 2012; Gui *et al*., 2012), few other RDH work have also been given (Lin and Chung, 2012; Bas *et al*., 2011)etc. All of these technique, PEE is largely applied nowadays because of its efficient capacity distortion trade-off.

PEE was firstly proposed by Thodi and Rodriguez (Thodi and Rodriguez, 2007). They proposed the differences between the pixel and its prediction. Differences are expanded for embedding the data. They compare between DE and HS based methods, PEE has a better performance. So the derived prediction-error histograms (PEH) are more rapidly distributed. After that, Hu *et al.* (2009) proposed PEE with an effective smaller size location map, and thus increase the capacity. Afterwards, Sachnev *et al.* (2009) proposed to sorting prediction errors based on magnitude of local variance. The PEH is distributed and modification is in histogram bins. Compared with previous methods, the result show sorted prediction-errors embedding introduce low distortion especially for low capacities. Li *et al.*(2011) were proposed a method where image divide two parts. Smooth pixel and rough pixel. Method is adaptive embed based which selects two bits in a smooth pixel and one bit in a rough one. In such a way they obtained a better execution for high capacities. Coltuc (2011) proposed a novel PEE which is transformation of modifying pixel. This transformation of modification was not only applied in the current pixel but also its next three context pixels. Since it is sure the total changes on four pixels to be smaller than that of only modification of one pixel. This method performs less distortion than the other ones which based on high-performance predictors such as MED and GAP.

The conventional PEE methods mainly focus on inter pixel correlations. This method not correlates within next prediction errors. If we combine two adjacent pair and each pair is worked as a unit. Such type of correlations can also be make use to reduce the distortion. Yet, the one-dimensional prediction-error histogram (1D PEH) in the conventional PEE, work as a low-dimensional projection of image data. It is necessary to make a new pattern of PEE that work as a higher dimensional projection to better exploit for correlations.

In this paper, we proposed a new RDH framework that called pairwise PEE. In resist to the conventional PEE methods, we propose rhombus pattern prediction scheme to predict prediction value of pixel. Difference between pixel value and prediction value is called prediction error and make sequence of error. We take every two adjacent prediction-errors and generate a sequence of unit. Unit consists of prediction-error pairs. Using a pixel selection method for sorting of prediction pair. Sorting is in decreasing order, sorting is based on magnitude of prediction pair. After that we get a two-dimensional prediction-error histogram (2D PEH). Finally, embed data by Histogram modification such as shifting or expanding. Modification is in the bins of 2D PEH. Comparing both PEE. And pairwise PEE is better exploit image redundancy than conventional PEE and achieves an improved performance.

To be left part of this paper is arranged as follows. In Section II, the basic idea of conventional PEE is introduced. Then, in Section III the proposed RDH method is described in details. And finally, Section IV describes conclusion of this paper.

IIn other side the conventional PEE extraction method where original image is recover from watermarked image. In this procedure original image prediction-error e_i are recovered from the present marked prediction-error $e_i^{'}$ as

$$e_i = \begin{cases} e_i'/2 \ , if \ e_i' \epsilon \ (\ \ 2T, 2T) \\ e_i' \quad T, if \ e_i' \ \epsilon \ (2T, +\infty) \\ e_i' + T, if \ e_i' \ \epsilon \ (\ \ \infty, \ \ 2T) \end{cases} \tag{5}$$

Here .. is floor function. The embedding bits are extracted from inner region. Embedding bit as the least significant bit (LSB) of range $e_i' \epsilon \ (\ \ 2T, 2T)$. Finally, the cover image is restored through the recovered prediction-errors. It is guaranteed of reversibility that, the prediction values getting in extraction and prediction value in embedding should be the same.

PROPOSED PAIRWISE PEE SCHEME

The equilateral parallelogram pattern (12) is used in our work for prediction

Pixel Prediction Using a Rhombus Pattern

We propose a new method. We take an image that named as cover image. All pixels of cover image are divided into two sets: the blank pixel set and shadow pixel set. Both sets follow each other one by one. That means first is shadow pixel second is blank pixel. The shadow pixel set is used for embedding data and blank pixel set is used for computing predictors. For pixel prediction value we use prediction scheme which is suitable for sorting. For this reason we select rhombus pattern prediction scheme. In this scheme we take a pixel position $x_{ij.}$ To predict the pixel value of it, we take four surrounding neighboring pixels ($y_{i,j-1}$, $y_{i+1,j}$, $y_{i,\ j+1}$, and $y_{i\ \ 1,\ j}$). The five pixels including $x_{i,j}$ all pixel making a cell. A cell is simply using to hide data of one bit. The shadow pixel sets embedding scheme for a single cell encoding is given follows. The center pixel $x_{i,\ j}$ of the cell can be predicted from its four surrounded neighboring pixels. The pixel x_{ij} and its predicted value $\overline{x_{\iota,J}}$ is computed as follows:

$$\overline{x_{\iota,J}} = \left\lfloor \frac{y_{i,j-1}+y_{i+1,j}+y_{i,j+1}+y_{i-1,j}}{4} \right\rfloor \tag{6}$$

Note that shadow set and blank sets both are independent of each other. Independence means if we change in one set then not any affect the other set. Based on predicted value $\overline{x_{\iota J}}$ and original value x_{ij}prediction-error calculated by $e_{ij} = x_{ij} \quad \overline{x_{\iota J}}$ Finally, after the prediction error sequence (e_1, e_2, . . . , e_N) is produced, we propose a new method. In this new method we take prediction error sequence. This sequence divided into pairs of sequence. Each pair consist two prediction errors. Each pair called a unit. For example pair of sequence by taking $e_i = (e_{2i}, e_{2i\ \ 1})$.

Using Pixel selection scheme for Sorting

Use of sorting introduced considerable performance methods. In other way, sorting is able to happen only when cells are not affected. In other words, embedding data into one cell should not have an effect on other cells. However, dependent cell (12) produces, where embedding data to one cell changes prediction errors of other cells. Shadow and blank sets of the rhombus scheme are independent each other. A sequence of prediction error pair produced. A new technique refined pixel selection (16) is used in proposed method. The main phenomenon of pixel selection is to keep prediction pair in sorting order. The sorting order is in decreasing manner which is based on prediction accuracy. In decreasing order the pair with small magnitude that will process first. To determine that prediction is accurate or not, a common method is used. Calculate local complexity of prediction pair. Specifically, local complexity LC ($\mathbf{e}_i$) of a pair $\mathbf{e}_i$, is computed as follows (see Fig. 1)

$$LC_{(e_i)} = |p_1 \quad p_2| + |p_2 \quad p_3| + |p_3 \quad p_4| + |p_4 \quad p_1| + |p_3 \quad p_6| + |p_6 \quad p_5| + |p_5 \quad p_4| + |p_4 \quad p_7| + |p_3 \quad p_8| \qquad (7)$$

Local complexity is defined as the sum of absolute differences between diagonal blank pixels sets in the 4×4 sized surrounding neighborhood pixel. A small LC represents that prediction pair is situated in smooth region of image. And preferentially used for data embedding. Setting a capacity dependent integer valued parameter threshold ρ. The pairs who are satisfying this condition LC($\mathbf{e}_i$) $\leq \rho$**.** They are utilized in data embedding, while the other pairs are skipped. For a specific payload, ρ is determined as the smallest integer such that it can ensure the enough capacity.

2D PEH

Sorting in decreasing orders based on their accuracy the prediction error pair. Next is to made histogram. In our proposed method we use 2D histogram (24) instead of 1D histogram. Shape of histogram totally defines performance of data embedding. In normally, distribution of the prediction errors is similar as a Laplacian distribution. The shape of the distribution is decided by the mean and variance. Generally the mean is zero so essentially variances determine the shape of histogram. Two dimensional histogram of prediction error pair are laplacian distribution. It is dependently distributed each other. In fact, in a pair two adjacent prediction-errors are normally highly correlated. For example, the correlation of two adjacent prediction-errors e_i and e_{i+1}, is given. This is computed by

$$\frac{|\sum_{i=1}^{N-1}(e-\bar{e})(e_{i+1}-\bar{e})|}{\sqrt{\sum_{i=1}^{N-1}(e_i-\bar{e})^2}\sqrt{\sum_{i=1}^{N-1}(e_{i+1}-\overline{e})^2}} \qquad (8)$$

Based on equation (8) taking standard 512 × 512 sized gray-scale some image for example value for Lena is 0.213. Baboon is 0.294, image of Airplane value is 0.293 and value for Barbara is 0.575, where in calculation *e* is the mean of$(e_{1,}e_{2,} \ldots\ldots e_N)$. This correlation coefficient in equation (8) ranges from 0 to 1, and the more correlated two prediction-errors. It is verified that e_i and e_{i+1} are correlated to some range, or evenly high correlated for some specific images (e.g., Barbara).

Now 2D PEH is explaining. And show 2D PEH is better than 1D PEH. By considering every two adjacent prediction-errors together, the sequence $(e_{1,}e_{2,} \ldots\ldots e_{N,})$ can be transformed into a new one $(\boldsymbol{e}_{1,}\boldsymbol{e}_{2,} \ldots\ldots \boldsymbol{e}_{N/2,})$ with $\mathbf{e_i}$ = (e_{2i-1}, e_{2i}) (suppose for simplicity that *N* is even), and the associated 2D PEH is

$$g(k_1,k_2) = \#\{1 \leq i \leq \tfrac{N}{2} : e_{2i-1} = k_1, e_{2i} = k_2\} \qquad (9)$$

For convenience, the sequences $(e_{1,}e_{2,} \ldots\ldots e_{N,})$, $(e_{1,}e_{3,} \ldots\ldots e_{N-1,})$ and $(e_{2,}e_{4,} \ldots\ldots e_{N/2,})$ are denoted as E, E_{odd}, E_{even} and E^*, respectively. Clearly, it can be assumed that

$$H(E) = H(E_{odd}) = H(E_{even}) \qquad (10)$$

Here the function *H* calculates the entropy of a distribution. Then, the entropy of E^* satisfies

$$H(E^*) = H(E_{odd}, E_{even}) \leq H(E_{odd}) + H(E_{even}) = 2H(E) \qquad (11)$$

And the equality holds if and only if E_{odd} and E_{even} are independent. However, as mentioned above, E_{odd} and E_{even} are usually correlated.

Pairwise PEE

The result of 2D PEH (24) can better perform with complex dependencies than 1D PEH in image data. In our proposed method, the histogram modification such as expanding and shifting strategy based on 2D PEH is called Pairwise PEE. In this work data embedding is applied by modification like expanding and shifting the bins of 2D PEH. Pairwise PEE is a natural expansion and upper dimensional space of the conventional PEE. Based on 2D PEH, various histogram correction strategies are designed with different performance.

The capacity-distortion performance is examined in proposed Pairwise PEE as follows. The conventional PEE capacity and the proposed Pairwise PEE capacity, denoted as EC_{con} and EC_{pro}, can be written as

$$EC_{con} = 2\sum_{e\epsilon A} g(e) + \sum_{e\epsilon C} g(e) \qquad (12)$$

And

$$EC_{Pro} = log_2 3\sum_{e\epsilon A} g(e) + \sum_{e\epsilon B} g(e) + \sum_{e\epsilon C} g(e) \qquad (13)$$

Here g is used in 2D PEH and its explained in equation (9). And the other term, the distortion in as similar of l^2-error, the conventional PEE distortion and the proposed pairwise PEE distortion, formulated as ED_{con} and ED_{pro}, and

$$ED_{con} = \sum_{e \epsilon A} g(e) + 2\sum_{e \epsilon B} g(e) + \frac{3}{2}\sum_{e \epsilon C} g(e) + 2\sum_{e \epsilon D} g(e) \quad (14)$$

And

$$ED_{Pro} = \frac{2}{3}\sum_{e \epsilon A} g(e) + \sum_{e \epsilon B} g(e) + \frac{3}{2}\sum_{e \epsilon C} g(e) + 2\sum_{e \epsilon D} g(e) \quad (15)$$

In equation (14) and (15), comparing both the conventional PEE and proposed Pairwise PEE, we saying that the pairwise PEE distortion is minimize.

Overflow and Underflow Problem

Overflow/underflow problem of the histogram modification i.e. expanding and shifting method over prediction errors pair cannot be keep away. For other side when extraction and restoration are proceeding, some information is required to extract original image and information. For this purpose some side information needs to be embedded into cover image or original image as well. In our method, the side information considers as location map. Location map is every part of the time of embedding process, some pixels may come upon the overflow/underflow problem, for example, a pixel value of the gray-scale image may be out of the range (0, 255) after data embedding. To stop this out of range value, preprocess should be done before embedding to making different these pixel values into a trusted range. Since modify the quality to each such pixel value is at most, Since the changing to each pixel value is at most 1 in our method, only those pixel value which are in border need to be changed as follows. We change xi to 254 if it is 255 and to 1 if it is 0. At the same time, each modified pixel is marked with 1 in a location map during the time the others are marked with 0. Then the location map is losslessly compressed to in addition reduce its size.

Using Double Embedding Scheme

The double embedding scheme requires following one after other in regular order usage of the blank embedding scheme and the shadow embedding scheme. And its results are about double the embedding capacity. It is clear that the capacity of the double embedding scheme is more than that of the single embedding scheme. However, in disagreement to expectations, the distortion after double embedding data hiding scheme using is less than the single embedding distortion resulting. The reason for such a strange thing is that, when using single embedding, cells with larger errors have to be modified in order to hide required payload. In the double embedding, two sets of sorted prediction errors with smaller magnitudes are used. The needed payload for every set is near about half of the single embedding scheme, which permits us to utilize the cells with smaller magnitudes of errors.

Appropriate Threshold Values

In order to gain successfully the best possible PSNR, it is need to find and use appropriate threshold values based on the required payload. The improved PSNR is in order to produce through threshold values for required payload. As PSNR value increase the quality of image is also improve. Threshold value range provide the largest number of embed pixels with the smallest possible size of the location map. In our proposed method for embedding data three parameters are used. First parameter is pixel-selection threshold ρ, second parameter is compressed location map size and third parameter is message size. For example in embedding we take a 512 × 512 sized gray-scale image, and bit size of each parameter respectively 12 + 18 + 18 = 48 bits. For data embedding 48 bits are sufficient to encode these parameters. In our proposed method, the LSB consist three parameters. The first line of cover image is using LSB replacement, and should be pulling out first at data extraction phase. The replaced LSBs of the first-line pixels and the compressed location map both will embed into the cover image. Location map is also as a part of payload. Now, we describe the embedding and extraction procedures for the blank layer in detail. Both the shadow and blank layers pixel are embedded equally. Each layer from shadow or blank is complete embedding process with half of secret message bits.

Embedding Procedure

Step1: To leave out first-line pixels which are better suited the pixels of boundary-valued into the reliable range, and build up the location map accordingly. Then minimum losses compress the location map. Step2: To predict shadow pixels in the scanning order and then find out the prediction error pair series ($\mathbf{e}_1$, $\mathbf{e}_2$….. , $\mathbf{e}_N$) with the rhombus pattern prediction scheme as mentioned above. For each $\mathbf{e}_i$, compute its local complexity LC($\mathbf{e}_i$) using equation (7). Step3: Empty LSB of few first-line pixels. To create 48 bits space for embedding of the three parameters. The replaced LSB with compressed location map put as a part of payload. Step4: find smallest integer ρ . There are many pairs to embed the payloads. It includes the replaced LSBs, the compressed location map and the secret message bits. Step5:. With the use of LSB replacement, the values of ρ , the compressed location map size and the message size are embedded into LSBs of few first-line pixels. Step6: Process the prediction-error pairs, if satisfying LC(**ei**) ≤ ρ to embed the payload. After this step, the shadow layer embedding is completed.

Extraction Procedure

Step1: After reading LSBs of some first-line pixels, the values of three parameters are found out.

Step2: Use same prediction and scan order to get marked prediction-error pair sequence ($e_1^{'}$, $e_2^{'}$……$e_N^{'}$) For each $\mathbf{e_i}^{'}$ calculate its local complexity LC($\mathbf{e_i}^{'}$) which is the same as the one used in the embedding phase.

Step3: To Processing that pairs which are satisfying LC($\mathbf{e_i}^{'}$) ≤ ρ. To become well again of these pairs is applied by the inverse mapping of the proposed pairwise PEE, and the embedded payload is extracted from the pairs.

Step4: After the process of embedded payload pull out, then the location map and replaced LSBs can be getting.

Step5: After returning the first-line pixels through the extracted LSBs. At last finally, the original shadow pixels are getting back.

Conclusion

The proposed reversible watermarking technique is a combination of both efficient existing conventional techniques and some new techniques. This is able to perform significantly. Using a rhombus pattern prediction enables to efficiently use of hiding data. Pixel selection for sorting prediction error pair is used for low distortion in data hiding. Pairwise PEE method proposed that it can produce excellent ratio between capacity and distortion. In addition, the 2D PEE method in the proposed scheme significantly use lossless and reduce sized location map. So, capacity will be increased considerably. The Pairwise PEE is a 2D mapping method and it uses the correlations between prediction errors in a pair. The double embedding scheme stops using each pixel for data hiding in the perfect case. Such ideas in designs are supposed to less the distortion or increase the capacity to gain better RDH schemes. It is valuable to examine this issue in the future work.

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