



EFFICIENT REVERSIBLE HIDING TECHNIQUE BASED ON PAIRWISE PREDICTION ERROR EXPANSION

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ABSTRACT

Being reversible, the original digital content can be completely restored after data extraction. Prediction-error expansion (PEE) is an important method in reversible watermarking. PEE can embed large payload with low distortion into digital images. PEE is advantageous use in image redundancy usually gives better performance. But, the correlations between prediction-errors are not regarded and not use in conventional PEE based methods. In PEE, the prediction-errors are expanded and modified individually for embedding the data. In this paper an efficient reversible watermarking technique has proposed. In this paper every two adjacent prediction-errors together consider as pair. And generate a sequence which consisting of prediction-error pairs. Then Pixel selection method is used for sorting in decreasing order of prediction pair. To make a sequence of prediction error pairs, we making 2D prediction-error histogram. With the help of 2D histogram an efficient embedding strategy namely pairwise prediction error expansion can be designed. Prediction error pairs was expanding and shifting in histogram bins. Expanded bin are embed data. To achieve an improved performance we use a reduced size of location map. The result of our method is better is verified through many experiments.

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INTRODUCTION

Reversible watermarking techniques are used to put back whole original cover content after the extraction of data. As a basic need, the quality of digital cover image content should be low after data embedding. When embedding the data into cover images, the pixel value of cover image will be changed. Thus the image quality is disgraced. At a time of reverse when secret messages are extracted, cover image cannot become into their original state. Lasting distortion will take place. Distortion for some application is unacceptable, for example medical images. And here reversible data hiding is necessary. An aspect of reversible data hiding is the reversibility, specifically, when the digital content has been authenticated, one can eradicate the embedded data to restore the original content. This is main reason of reversible data hiding is distortion free data hiding.

In susceptible images such as military law enforcement and medical images, every bit of information is most important. Reversible data embedding method will provide the original data when the digital content is authenticated. Reversible watermarking is used to embed the useful information into a digital work such as audio, video, image. In addition, in reversible after the watermark extraction, the cover image restored as identical bit-by bit to the original cover image. A huge reversible watermarking algorithm has been proposed already by various authors. Majority of reversible watermarking algorithms has been for grayscale images. Reversible watermarking offering a way to situate data into cover medium for the motive of ownership finger printing, protection, secret communication authentication, and annotation [Wu, 2003; Wu et al., 2003]. Reversible data hiding (RDH) [Shi et al., 2004; Caldelli et al., 2010] techniques hide data or embed 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.

Literature Review

Until now, various RDH algorithms have been introduced, e.g., compression based algorithms [Fridrich, 2001; Celik, 2006], difference expansion (DE) based algorithms [Tian, 2003; Alattar, 2004; Kamstra, 2005], histogram shifting (HS) based algorithms [Lee et al., 2006; Hwang, 2006], prediction-error expansion (PEE) based algorithms [Thodi, 2007; Hu, 2009; Sachnev et al., 2009; Luo et al., 2010; Li et al., 2011; Coltuc, 2011; Wu, 2012] and integer-to-integer transform based algorithms [Lee, 2007; Coltuc, 2012; Gui, 2012], few other RDH work have also been noticed [Lin, 2012; Bas, 2011]. 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, 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) has 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 for low capacities specially. Li et al. [2011] were proposed method where image divide two parts i.e., 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 it obtained a better execution for high capacities. Coltuc [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 interpixel correlations. This method is not correlate within next prediction errors. If we combine two adjacent pair and each pair is worked as a unit then such type of correlations can also be make use to reduce the distortion. Yet, the one-dimensional prediction-error histogram (1DPEH) 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 was in decreasing order, sorting was 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 in the 2D PEH bins. Comparing both PEE, where pairwise PEE is better exploit image redundancy than conventional PEE and achieves an improved performance.

PROPOSED PAIRWISE PEE SCHEME

In our work the Pair wise PEE embedding procedures are having following steps.

Rhombus Pattern Used for Prediction of pixel

First of all we decompose cover image into pixels. Next we use rhombus pattern scheme [Thodi, 2007], for prediction of pixel. In this arrangement all pixels are divided into two sets: the shadow pixel set and blank pixel set shown in Fig 1.

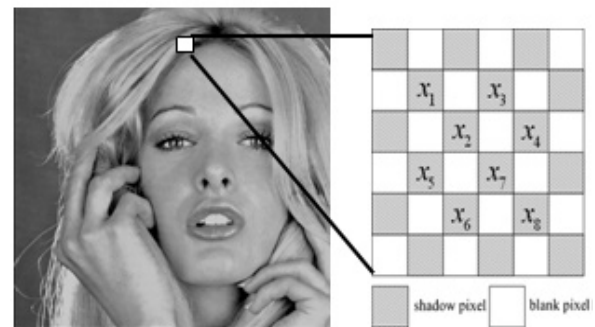


Fig.1. Prediction pattern. Shadow pixel set can predict and expand to hide one bit of data

The shadow pixel sets are used for embedding data and other set blank pixel sets are used for computing predictors. According to this scheme we take a pixel position x_{ij} from shadow set. To predict pixel value of it, we take its four surrounding neighboring pixel $(y_{i,j-1}, y_{i,j+1}, y_{i-1,j}, y_{i+1,j})$. All pixels including x_{ij} making a cell. The shadow pixel sets embedding scheme for a single cell encoding is given follows.

The pixel x_{ij} and its predicted value \bar{x}_{ij} are computed as follows:

$$\bar{x}_{i,j} = \left\lfloor \frac{y_{i,j-1} + y_{i,j+1} + y_{i-1,j} + y_{i+1,j}}{4} \right\rfloor \quad (1)$$

Here shadow set pixel and blank sets pixel 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 \bar{x}_{ij} and original value x_{ij} the prediction-error calculated by $e_{ij} = x_{ij} - \bar{x}_{ij}$. Finally, after the prediction error sequence (e_1, e_2, \dots, 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

A sequence of prediction error pair found. A new technique refer refined pixel selection [Li et al., 2011] is used. The main phenomenon of pixel selection technique 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 $LC(e_i)$ of a pair e_i , is computed as follows (see Fig. 2)

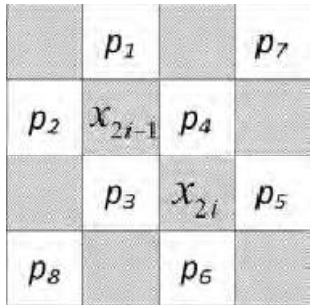


Fig. 2. Context of a shadow pixel pair

$$LC(e_i) = |p_1 - p_2| + |p_2 - p_3| + |p_3 - p_4| + |p_4 - p_1| + |p_3 - p_6| + |p_6 - p_5| + |p_5 - p_4| + |p_4 - p_7| + |p_5 - p_8| \quad (2)$$

Local complexity is defined as the sum of absolute differences between diagonal blank pixels sets in the 4x4 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 T . The pairs who are satisfying this condition $LC(e_i) \leq T$. They are utilized in data embedding, while the other pairs are skipped. 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.

Losslessly Compressed Location Map

We use the side information to take as location map. Location map is every part of embedding process, when some pixels come upon the overflow or 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 almost 1 in our method, only those pixel value which are in border need to be changed as follows. We change x_i 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 reduce its size

2D PEH

After getting 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. By considering every two adjacent prediction-errors together, the sequence (e_1, e_2, \dots, e_N) can be transformed into a new one $(e_1, e_2, \dots, e_{N/2})$ with $e_i = (e_{2i-1}, e_{2i})$ (suppose for simplicity that N is even), and the associated 2D PEH is

$$g(k_1, k_2) = \#\{1 \leq i \leq \frac{N}{2} : e_{2i-1} = k_1, e_{2i} = k_2\} \quad (3)$$

We illustrate firstly conventional PEE in 1D PEH. For embedding data into PEH, prediction error is expanded or shifted as

$$e'_i = \begin{cases} 2ei + b, & \text{if } ei \in (-T, T) \\ ei + T, & \text{if } ei \in (T, +\infty) \\ ei - T, & \text{if } ei \in (-\infty, -T) \end{cases} \quad (4)$$

Where T is a threshold which is parameter value of capacity-dependent integer, and $b \in \{0, 1\}$ 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 $(-\infty, -T) \cup [T, +\infty)$ are shifted from outside to create vacancies.

The transformation of prediction error in term of mapping for the case of $T=1$, the mapping between e_i and e'_i is

$$\begin{aligned} e_i = 0 &\rightarrow e'_i \in \{0, 1\} \\ e_i = -1 &\rightarrow e'_i \in \{-1, -2\} \\ e_i > 0 &\rightarrow e'_i = e_i + 1 \\ e_i < -1 &\rightarrow e'_i = e_i - 1 \end{aligned}$$

Now, we illustrate 1D PEH can also be implementing in 2D PEH.

For the pair $(e_{2i-1}, e_{2i}) = (0, 0)$, in the 1D mapping, e_{2i-1} is expanded to 0 or 1 to embed a data bit $b_1 \in \{0, 1\}$, e_{2i} is also expanded to 0 or 1 to embed another data bit $b_2 \in \{0, 1\}$. Accordingly, in the 2D case shown in Fig. 3, the pair $(0, 0)$ is expanded to $(0, 0)$, $(0, 1)$, $(1, 0)$ and $(1, 1)$ when (b_1, b_2) is $(0, 0)$, $(0, 1)$, $(1, 0)$ and $(1, 1)$, respectively.

For $(e_{2i-1}, e_{2i}) = (1, 0)$, in 1D case, e_{2i-1} is shifted to 2, and e_{2i} is expanded to 0 or 1 to embed a data bit $b \in \{0, 1\}$. So, in 2D case, the pair $(1, 0)$ is expanded to $(2, 0)$ if $b = 0$, and $(2, 1)$ if $b = 1$.

For $(e_{2i-1}, e_{2i}) = (2, 1)$, in 1D case, e_{2i-1} and e_{2i} are shifted to 3 and 2, respectively. So, in 2D case, the pair $(2, 1)$ is shifted to $(3, 2)$

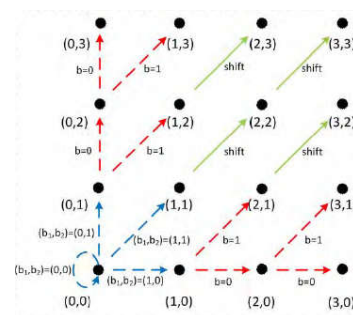


Fig. 3. Transformation of prediction-error pairs in conventional PEE, for $T = 1$

Pairwise PEE

We now present our pairwise PEE strategy to enhance the conventional PEE shown in Fig.3. Notice that, we do not intent to analyze every possible case of pairwise PEE, but investigate the generic case that leads to insightful results. In doing so, here we only consider the case that the maximum modification to each pixel value is restricted to 1. Our idea is straightforward. We want to expand or shift bins in a less distorted direction as much as possible. For example, for the pair (0, 0) in Fig. 3, it is embedded with 2 bits (b_1, b_2), and the distortion is 0, 1, 1 and 2 when (b_1, b_2) is (0, 0), (0, 1), (1, 0) and (1, 1), respectively. In this case, the cost for mapping (0, 0) to (1, 1) is 2, while mapping (0, 0) to (0, 0), (0, 1) or (1, 0) costs much less. So, to reduce the distortion, the directions with high distortion, e.g., mapping (0, 0) to (1, 1), should be discarded shown in fig.4 Based on this consideration, we propose a new 2D mapping as shown in Fig. 4. In this new mapping, for each pairing $\{(0, 0), (0, -1), (-1, 0), (-1, -1)\}$, it is embedded with $\log_2 3$ bits instead of 2 bits in the conventional PEE. Moreover, since the mappings between (0, 0) and (1, 1), (0, -1) and (1, -2), (-1, 0) and (-2, 1), (-1, -1) and (-2, -2), are discarded, each pair in $\{(1, 1), (1, -2), (-2, 1), (-2, -2)\}$ can be embedded with 1 bit in the new mapping while they are just shifted in the conventional PEE.

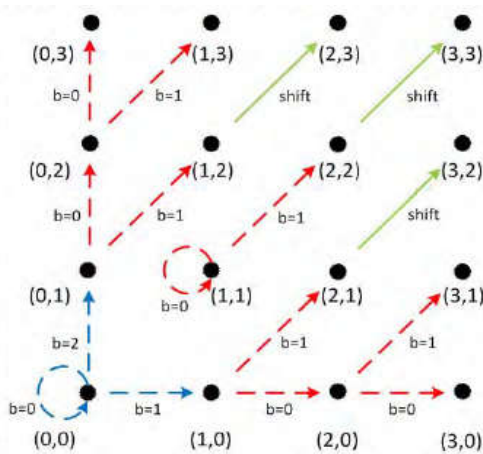


Fig. 4. Proposed pairwise PEE

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

$$EC_{pro} = \log_2 3 \sum_{e \in A} g(e) + \sum_{e \in B} g(e) + \sum_{e \in C} g(e) \quad (5)$$

Here g is used in 2D PEH and it explained in equation (3). And the other term, the distortion in as similar of l^2 -error, the proposed pairwise PEE distortion, formulated as ED_{pro} , and

$$ED_{pro} = \frac{2}{3} \sum_{e \in A} g(e) + \sum_{e \in B} g(e) + \frac{3}{2} \sum_{e \in C} g(e) + 2 \sum_{e \in D} g(e) \quad (6)$$

In our proposed method for embedding data three parameters are used. First parameter is pixel-selection threshold T , 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.

There placed 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. Note that here the same as the method of Sachnev et al.[12] 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 (e_1, e_2, \dots, e_N) with the rhombus pattern prediction schemes mentioned above. For each e_i , compute its local complexity $LC(e_i)$ using equation (7).

Step3: Empty LSB of few first-line pixels. To create 48 bits space for embedding of the three parameters. There placed 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 thereplaced 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 $LC(e_i) \leq \rho$ 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, \dots, e_N) for each e_i calculate its local complexity $LC(e_i)$ which is the same as the one used in the embedding phase.

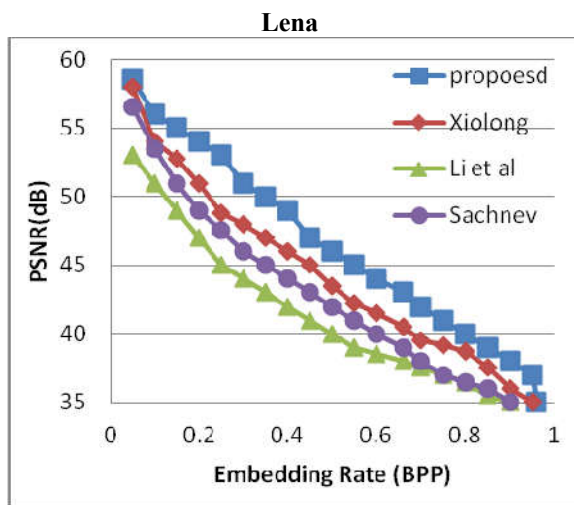
Step3: To Processing that pairs which are satisfying $LC(e_i) \leq \rho$. To become well again of these pairs is applied by the inverse mapping of the proposed pairwise PEE, and the embedded payload is extracted from the pairs.

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

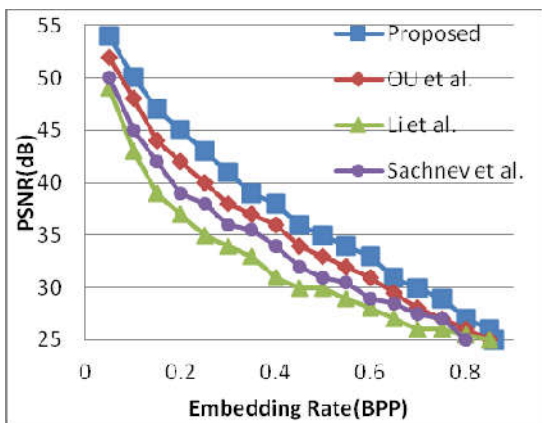
Step5: After returning the first-line pixels through the extracted LSBs. At last finally, the original shadow pixels are getting back.

EXPERIMENTAL RESULTS

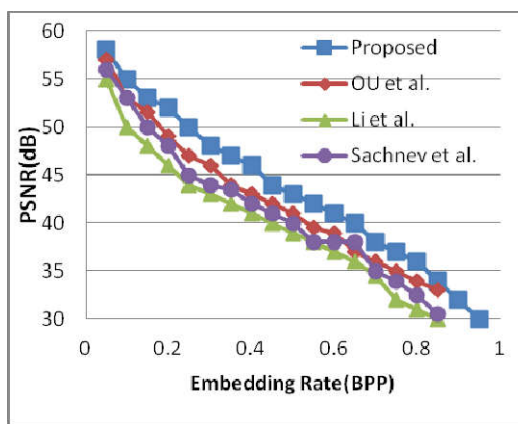
In this part, the capacity-distortion performance of the proposed method is evaluated by comparing it with some state-of-the-art works including OU *et al.* [2011], Sachnev *et al.* [2011], and Li *et al.* [29]. The first experiment, as shown in Fig. 5, is enforced on six standard 512 × 512 sized gray-scale images: Lena, Baboon, Barbara, Boat, Peppers and Man. Here, except Barbara, the other five images are downloaded from the USC-SIPI database. Since the maximum modification of each pixel value is 1 in the proposed method, According to Fig.5 one can see that the proposed method outperforms works. Our method can provide a larger PSNR and maximum embedding rates rather than other. Among the comparison methods, Sachnev *et al.*'s is a hybrid PEE method using a sorting technique to preferentially process the smooth pixels.



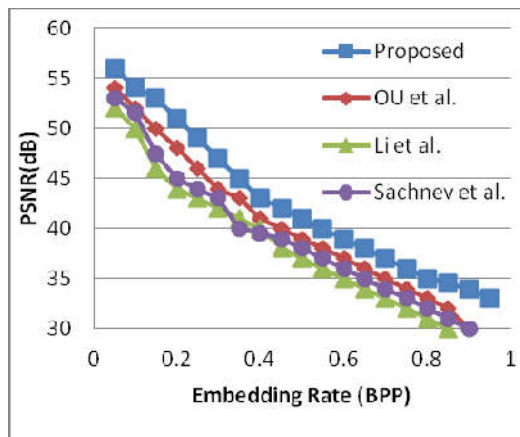
Baboon



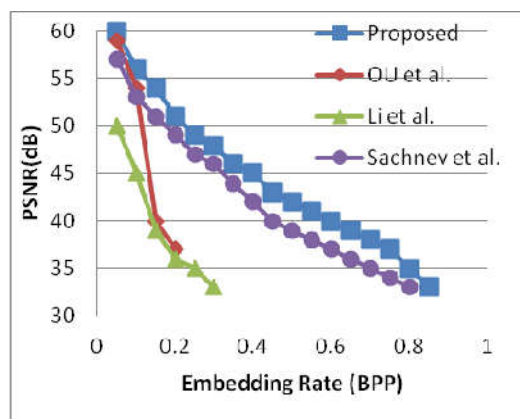
Barbara



Boat



Man



Pepper

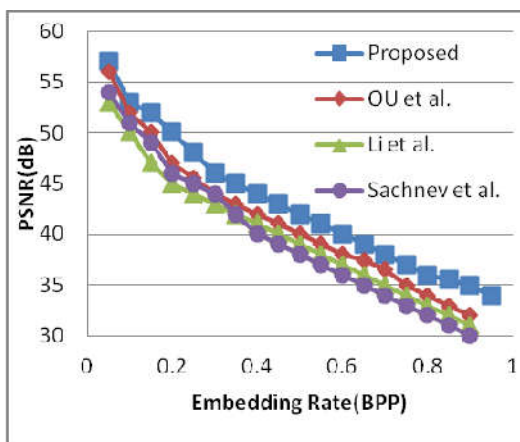


Fig.5. Comparisons in terms of capacity-distortion performance

Although the predictor is simple, the sorting technique makes the data embedding more efficient and hence Sachnev *et al.*'s method significantly outperforms the typical PEE method of others conventional PEE, Li *et al.*'s method utilizes GAP for prediction, and mainly focuses on the performance of very high capacity by embedding more bits into smooth pixels. Although employing a pixel selection technique, for low capacity, their method usually yields a smaller PSNR than Sachnev *et al.*'s OU et al.'s method gives better result from Sachnev. They are effective attempt for low capacity. OU et al is a 2D PEH method uses pixel selection technique and rhombus pattern predictor and improved PSNR but embedding capacity is low. Typically, compared with OU *et al.*'s method, although the same predictor and a similar sorting technique and 2D PEH are utilized, our method is better by increasing PSNR with 1.25 dB in average for maximum possible capacity with 1 bit per pixel see Tables I and II, respectively.

Table 1. comparisons in terms of psnr (db)

Image	Li et al	Sachnev	Ou et al	Proposed
Lena	53	56.5	58	58.5
Baboon	49	50	52	54
Barbara	55	56	57	58
Boat	52	53	54	56
Man	50	57	59	60
Pepper	53	54	56	57
Average	52	54.42	56	57.25

Table 2. Comparisons In Terms of Embedding Rate (Bpp)

Image	Li et al	Sachnev	Ou et al	Proposed
Lena	0.9	0.9	0.95	0.96
Baboon	0.85	0.8	0.85	0.86
Barbara	0.85	0.85	0.85	0.95
Boat	0.85	0.9	0.9	0.95
Man	0.3	0.8	0.2	0.85
Pepper	0.9	0.9	0.9	0.95

Table I represent PSNR value of different method for different Images. Table II represent Embedding Rate in Bit per Pixel. (BPP). The main advantage of our method is it has limitation of maximum possible capacity with near about 1 bit per pixel.

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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