THREE STAGES PREDICTION-ERROR EXPANSION REVERSIBLE WATERMARKING

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ABSTRACT

This paper proposes a three-stages difference expansion reversible watermarking scheme. In the first stage, a quarter of the pixels are estimated by using the median of the eight original neighbors of the 3×3 window. In the second stage, a quarter of the pixels are estimated as the average on the rhombus of the four horizontal and vertical original pixels. Finally, the remaining pixels are estimated on the rhombus context, using the modified pixels computed in the two previous stages. The experimental results show that the proposed scheme can provide slightly improved results than the classical two-stages reversible watermarking based on the rhombus context.

***Index Terms*—** reversible watermarking, prediction-error expansion, three-stages embedding

1. INTRODUCTION

Image reversible watermarking extracts the embedded data and recovers the original host image without any distortion. Among the approaches developed so far for reversible watermarking, much attention has been devoted to difference expansion based schemes and notably, to prediction-error expansion (PEE) ones [1, 2], etc. The PEE schemes consider for embedding the prediction errors. The pixels are modified in order to expand two times the prediction error. The expansion is in fact a multiplication by two that sets to zero the least significant bit of the prediction error and, implicitly, creates space for embedding one bit of data.

The performance of the PEE watermarking schemes (distortion with respect to embedding bit-rate) depends on prediction. The efficient predictors developed for lossless compression are also used in reversible watermarking. A prominent example is the median edge detector (MED) of JPEG-LS [3]. With MED [1, 2] etc., the prediction context is composed of the right, lower and lower-diagonal neighbors of a pixel. The predictor selects the lower vertical neighbor in cases where a vertical edge exists right to the current location, the right neighbor in cases of a horizontal edge below it, or a linear combination of the three context pixels.

The gradient-adjusted predictor (GAP), used in CALIC [4], outperforms MED. GAP works on a context of 7 pixels. A simplified version of GAP, SGAP, provides almost similar results, but at a lower cost. The schemes based on GAP and SGAP outperform the ones based on MED (see [5]).

Better results than the ones of MED or GAP are obtained by estimating the pixels with the average on the rhombus of the four horizontal and vertical neighbors [6]. While MED, GAP, SGAP are causal predictors, the rhombus is a noncausal predictor. It should be noticed that the rhombus estimates pixels by using the information on an entire neighborhood around the pixel, not only on a part of it as the causal predictors do. The scheme of [6] has inspired a lot of work in reversible watermarking. Most of the newly developed PEE reversible watermarking schemes are based on the rhombus predictor [7–11], etc.

This paper aims at improving the scheme of [6]. The basic idea is to extend for a part of pixels the prediction context from rhombus to the entire 3×3 window. The extension from rhombus to the 3×3 window provides more information and thus, the estimation of the current pixel could be improved. Compared with the scheme of [6] that operates on two stages, our scheme operates on three ones. The extension from two to three stages ensures that the prediction on the entire window is done by using only original pixels.

The outline of the paper is as follows. The basic principles of PEE and the scheme of [6] are briefly introduced in Section 2. The proposed scheme is presented in Section 3. Experimental results are presented in Section 4. Finally, the conclusions are drawn in Section 5.

2. PREDICTION-ERROR EXPANSION PRINCIPLE

We briefly remind the basic principle of the PEE reversible watermarking in connection with the well-known scheme of [6]. Let $\hat{x}_{i,j}$ be the estimated value of the pixel $x_{i,j}$. The prediction error is:

$$e_{i,j} = x_{i,j} - \hat{x}_{i,j}. \tag{1}$$

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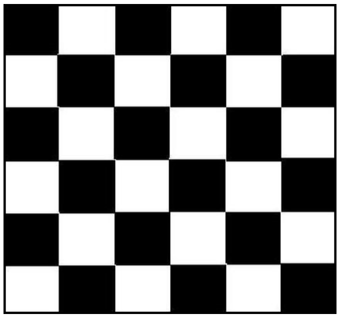

Fig. 1: Image halves for two-stages embedding of [6]

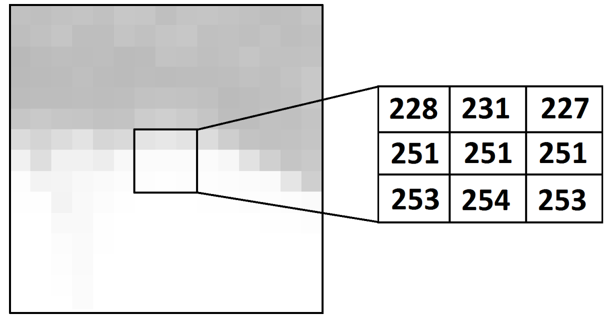

Fig. 2: A 3×3 window extracted from the *Tiffany* image.

Let $T > 0$ be the threshold. The threshold controls the distortion introduced by the watermarking. Thus, if the prediction error is less than the threshold and no overflow or underflow is generated, the pixel is transformed and a bit of data, b is embedded. The transformed pixel is:

$$X_{i,j} = x_{i,j} + e_{i,j} + b. \tag{2}$$

The pixels that cannot be embedded because $|e_{i,j}| \geq T$ are shifted in order to provide, at detection, a greater prediction error than the one of the embedded pixels. These pixels are modified as follows:

$$X_{i,j} = \begin{cases} x_{i,j} + T, & \text{if } e_{i,j} \geq T \\ x_{i,j} - (T-1), & \text{if } e_{i,j} \leq -T. \end{cases} \tag{3}$$

The underflow/overflow cases are solved either by creating a map of underflow/overflow pixels or by using flag bits [1].

From equation (2) it clearly appears that the distortion introduced by the PEE reversible watermarking depends on the prediction error. For anticausal predictors like MED, GAP, SGAP etc., the embedding performs in raster scan order, starting with the upper left corner. The detection performs in reverse order, starting with the last embedded pixel.

It immediately appears that the use of anticausal predictors with embedding into raster scan order ensures that only original pixels take part in prediction. As said in Section 1, the average on the rhombus context outperforms well-known predictors like MED, GAP SGAP. Let us investigate the use of the average on the rhombus context with the usual raster scan order. One can observe that each watermarked pixel takes part in the prediction of two other pixels, namely of the right horizontal and of the lower vertical neighbors. In other words, pixels are predicted by using two original pixel values and two modified ones. This is because the average of the horizontal and vertical pixels is neither a causal nor an anticausal predictor.

A better solution is provided by the two stages embedding of [6]. The image pixels are split in two equal sets, diagonally connected, as the black and white squares of a chessboard (Fig. 1). The watermark is embedded in two stages. The pixels of a set are marked by using for prediction the pixels of the other set. The prediction of the first set is done with original pixels, while the one for the second set uses already modified pixels. On the entire image, the overall performance of the two stages scheme slightly outperforms the direct raster scan watermarking.

3. PROPOSED SCHEME

The prediction on the entire 3×3 window centered on the current pixel is first discussed. The extension of the context from the rhombus to the entire window is performed in order to provide more pertinent information for the estimation of the current pixel. Then a three stages embedding scheme is proposed. The newly proposed scheme allows, for a quarter of the image pixel, the prediction on the entire 3×3 context with original image pixels. For the other three quarters, the prediction is performed on the rhombus context as in [6].

3.1. Prediction on 3×3 window

By investigating 3×3 windows, one can see various configurations from uniform regions to non-uniform ones where we can have two orientations (horizontal, vertical, diagonal, etc.). A good prediction in all this type of regions could be rather complex.

Let us consider the case of the current pixel at the border of two uniform (noisy) regions separated by a straight line (see Fig. 2). If one considers the 3×3 window centered on the current pixel, one has six pixels belonging to a region and three to the other one. The current pixel is among the six ones. In order the estimate the central pixel, an approach could be to separate its eight neighbors into the two regions and to use the five pixels classified as belonging to the same region for prediction (for instance, one can take the average of the 5 pixels).

A simple solution for the problem of two regions is the estimation of the central pixel as the median of its eight neighbors. Let $x_{i,j}$ be the current pixel. In order to compute the median, the sequence of 8 neighbors $x_{m,n}$, with $m = \{i-1, i, i+1\}$, $n = \{j-1, j, j+1\}$ and $(i,j) \neq (m,n)$, is

A	C	A	C	A	C
C	B	C	B	C	B
A	C	A	C	A	C
C	B	C	B	C	B
A	C	A	C	A	C
C	B	C	B	C	B

Fig. 3: Image partition: A, B and C classes.

sorted in ascending order. The sorted sequence is:

$$x_{(1)} \leq x_{(2)} \leq x_{(3)} \leq x_{(4)} \leq x_{(5)} \leq x_{(6)} \leq x_{(7)} \leq x_{(8)}.$$

The predicted value follows as the median, i.e., for an even number of samples, the rounded value of the average of the two middle samples of the sorted sequence:

$$\hat{x}_{i,j} = \left\lfloor \frac{x_4 + x_5}{2} \right\rceil. \tag{4}$$

For two regions case, the middle samples for the ordered string belong to the larger region, regardless which region is bright and which one is dark. For the case of two regions, the median is expected to provide better results than the average on rhombus. By using the rhombus predictor, three pixels belong to the same region with the central pixel, while the fourth pixel belongs to the other region. An example is provided in Fig. 2 The estimated value of the central pixel from Fig. 2 using the rhombus context is $\hat{x} = \lfloor \frac{251+231+251+254}{4} \rceil = 247$. By using the proposed scheme, the sorted vector is $v_s = [227, 228, 231, 251, 251, 253, 253, 254]$ and the predicted value is $\hat{x} = \lfloor \frac{251+251}{2} \rceil = 251$, which is more accurate than the one provided by the rhombus context.

3.2. Three stages embedding

The proposed predictor is further used together with the classical average on rhombus in a difference expansion reversible watermarking scheme. Similar to the scheme of [6], half of the pixels are predicted by using into the prediction context only original pixels. The proposed scheme proceeds as follows.

According to their positions, image pixels are divided into three classes: A, B and C (Fig. 3). The marking proceeds in three stages as follows:

1. The pixels labelled A are predicted by using their original eight neighbors as described in Sect. 3.1;
2. The pixels labelled B are predicted as the average of their original four horizontal and vertical neighbors;
3. The pixels labelled C are predicted as the average of their four already embedded horizontal and vertical neighbors.

For each stage, pixels are processed in raster scan order, from the upper left corner, to the lower right one. For each pixel, the predicted values and the corresponding prediction errors are computed as explained above. As described in Sect. 2, given a threshold T, pixels are embedded with equation (2) if the prediction error is less than the threshold, or shifted otherwise. The pixels that, because of overflow/underflow cannot be neither embedded, nor shifted are resolved either by using flag bits or an overflow/underflow map [1].

Fig. 4: Test images.

The detection proceeds in reverse order of the marking, starting with C pixels. The prediction error is computed:

$$e_{i,j} = x_{i,j} - \hat{x}_{i,j}. \tag{5}$$

If $-2T < E_{i,j} < 2T$, the pixel was embedded. One has

$$e_{i,j} = 2e_{i,j} + b, \tag{6}$$

b follows as the LSB of prediction error:

$$b = e_{i,j} \bmod 2. \tag{7}$$

The original pixel is recovered as:

$$x_{i,j} = \frac{X_{i,j} + \hat{x}_{i,j} - b}{2}. \tag{8}$$

If $|e_{i,j}| \geq 2T$, the pixel was shifted with equation (3) and the original value is recovered by inverse shifting.

A comparison with the well-known two-stages scheme of [6], shows that the second stage of the proposed scheme is identical with the one of [6]. The difference appears for the first stage, where one fourth of pixels (class A) are predicted by using the median of the eight close neighbors instead of the average on rhombus. The gain is expected from the first stage.

4. EXPERIMENTAL RESULTS

In this section, experimental results for the proposed three stages reversible watermarking scheme are presented. Six standard test images of 512×512 extensively used in the reversible watermarking literature are considered. The test

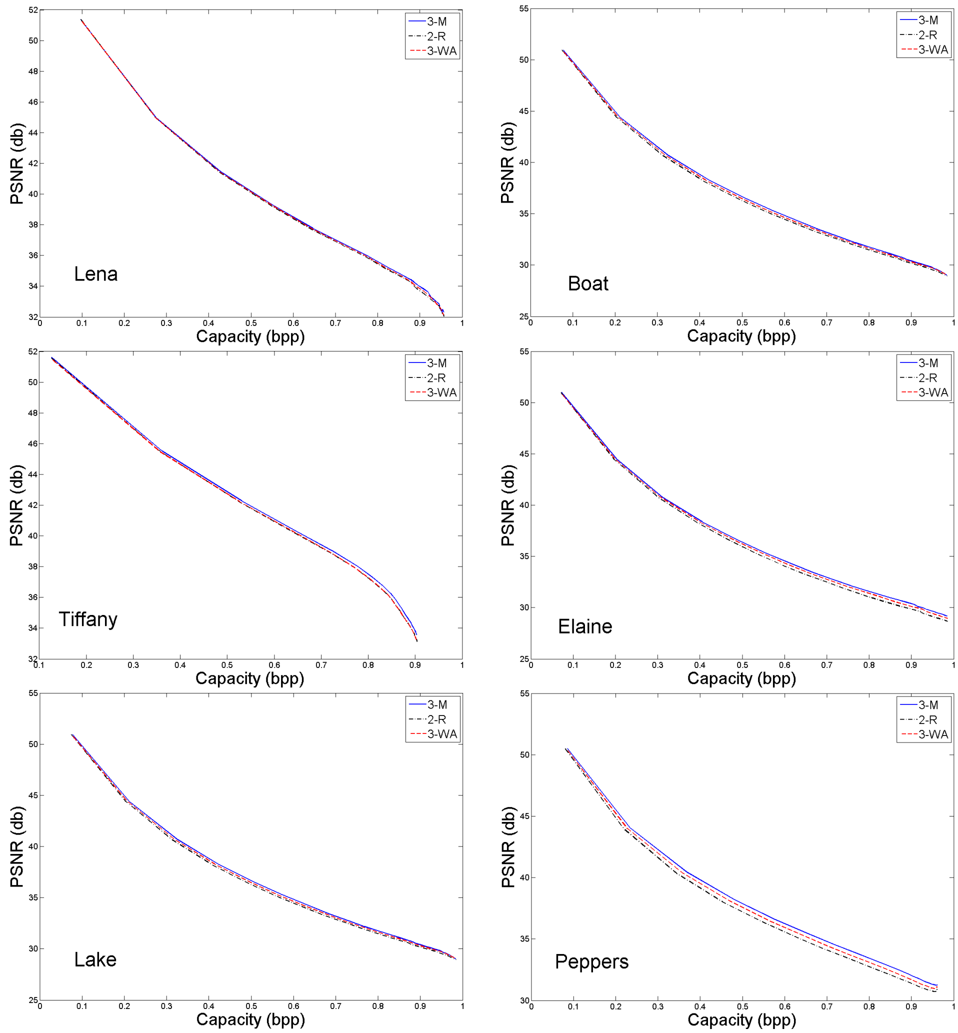

Fig. 5: Experimental results: three stages with median (3-M, blue), three stages with weighted average (3-WA, red) and two stages with rhombus (2-R, black) schemes.

images *Lena, Boat, Tiffany, Elaine, Lake* and *Peppers* are displayed in Fig. 4.

The proposed scheme is meant to provide for half of the pixels the estimation by using only original pixels. Thus, a quarter of pixels is estimated by using their eight close neighbors inside the 3×3 window and a quarter of pixels is estimated by using the classical rhombus of vertical and horizontal pixels. The scheme is designed for the median predictor on the 3×3 context discussed in Section 3.1.

Another predictor that operates on the 3×3 context was proposed in [12]. The current pixel is estimated as the sum between three quarters of the average on the rhombus context and a quarter of the average of the four diagonal neighbors.

Experimental results are performed considering the proposed scheme with the median predictor (3-M), the scheme proposed in [12] with the weighted average predictor (3-WA) and the standard two stages scheme with the rhombus predictor (2-R) are presented in Fig. 5. Each stage is implemented as a basic prediction error expansion scheme with simple threshold control.

From Fig. 5, it appears that the three stages scheme with median predictor slightly outperforms both the three stages scheme with weighted predictor and the two stages scheme. The best results are obtained for the test image *Peppers*. The worst results are obtained for the test image *Lena*, where the three curves are indistinguishable.

5. CONCLUSIONS

The estimation of the current pixel as the median of its neighbors within the 3×3 window has been considered and a three stages scheme using the proposed predictor together with the classical average on the rhombus context has been proposed. The proposed predictor provides slightly better results than the classical rhombus predictor and the weighted average on the 3×3 window. Consequently, the proposed three stages scheme with the median predictor slightly outperforms the well-known two stages reversible watermarking based on rhombus prediction.

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