# ALTERNATE MULTIBIT EMBEDDING METHOD FOR REVERSIBLE WATERMARKING

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**ABSTRACT**

This paper proposes a new embedding scheme for multibit difference expansion reversible watermarking. The prediction error expansion (PEE) schemes expand $n$ times the difference in order to embed up to $\log_2 n$ bpp. For natural images, this capacity cannot be achieved because overflow or underflow is generated by the embedding process. The proposed method aims to increase the capacity of the embedded information by using a different embedding procedure when the classical one fail. Although the proposed embedding method introduces larger distortion than classical procedure, the experimental results show that the proposed scheme provide an increase of the embedding capacity and outperforms the classical method regarding the image quality with respect to capacity. Experimental results using the classical and proposed multibit difference expansion based on the MED predictor are provided.

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

## 1. INTRODUCTION

Digital watermarking is a process of hiding a user signal within a standard video covert signal for the purposes of identification. 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 PEE ones [1]. The PEE schemes consider for embedding the payload along with 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.

One way to improve the capacity of the watermarking process, is to develop a superior predictor for the PEE. If the prediction error will have low values, the image quality will increase. The capacity will also increase due to increased probability of an watermarked/shifted pixel to have a value that lie in the sampling interval of the image.

The median edge detector predictor (MED) used in [5] and [8] is already a very good predictor. MED is a prediction context estimator and is composed of the right, lower and lower-diagonal neighbors of a pixel. The predictor tends to select 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 context pixels if no edge is detected. The gradient-adjusted predictor (GAP) used in CALIC (context-based, adaptive, lossless image coding) algorithm [2], outperforms MED. GAP is more complex than MED. It works on a context of 7 pixels and selects the output based not only on the existence of a horizontal/vertical edge, but also on its strength. A simplified version of GAP, SGAP, provides almost similar results, but at a lower cost. In [3] and [7] is presented the rhombus predictor, which is a non-causal one and yields good performance. The local prediction proposed in [4] use least square predictor on a square block centered on the pixel. Instead of a single global predictor, multiple local predictors are used.

In [5], it is described an improvement of PEE for enhanced capacity. The authors describe multibit PEE algorithm, which expand $n$ times the difference in order to embed up to $\log_2 n$ bpp. By expanding $n$ times the difference, instead of embedding a single data bit, it can embed an integer code in the range $[0, n]$.

In [6] the algorithm developed by Tian is improved using difference expansion of vectors, instead of pairs, to increase the hiding ability and the computation efficiency of the algorithm. This approach allows the algorithm to embed several bits in every vector in a single pass through the image data.

This paper defines a new transform for the case of overflow and underflow for the multibit DE algorithm. The overflow/underflow pixels are marked in a location map (LM) and are embedded using a different scheme. Since the embedded and shifted values that generate overflow/underflow lie in the same interval, a procedure is developed to solve the ambiguity between shifted and embedded pixels. Compared with the classical scheme, this method is able to embed more informa-

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tion.

The outline of the paper is as follows. The multibit embedding scheme is briefly introduced in Section 2. In Section 3 the proposed method is described. The decoding procedure for both methods is explained in Section 4. Experimental results and comparisons with the classic multibit embedding method are presented in Section 5. Finally, the conclusions are drawn in Section 6.

## 2. MULTIBIT EMBEDDING REVERSIBLE WATERMARKING

We briefly remind the difference expansion (DE) algorithm for reversible watermarking described in [5].

The prediction error $e_{i,j}$ is the difference between the original value of the pixel $x_{i,j}$ and the estimated value $\hat{x}_{i,j}$:

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

We can embed a value $b \in \{0, 1\}$ that can be decoded and the original value of the pixel restored by using DE:

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

If we replace $b \in \{0, 1\}$ with $w \in [0, 2^c - 1]$ a number of $c$ bits can be inserted. In [5] is described the method for multibit embedding reversible watermarking. The watermarked pixel with the inserted value $w$ is:

$$X_{i,j} = x_{i,j} + (n-1)e_{i,j} + w_{i,j}, \qquad (1)$$

with $n \geq 2$ and the embedded value $w \in [0, n-1]$.

The new value of the embedded pixel should lie in the interval: $[0, 2^r - 1]$, where $r$ represent the number of bits the image is represented on. For an image represented on 8 bits ($r = 8$), $X_{i,j} \in [0, 255]$, i.e. $o \leq x_{i,j} + (n-1)e_{i,j} + w \leq 255$. If the embedded value is outside the sampling interval (overflow/underflow), the location of the pixel will be stored in the LM and no bits will be inserted.

From (1) we subtract the original value of the the pixel $x_{i,j}$ to compute the distortions induced by the embedding process:

$$X_{i,j} - x_{i,j} = (n-1)e_{i,j} + w_{i,j}. \qquad (2)$$

From (2) it can be seen that the distortions are correlated to the prediction error value $e_{i,j}$. Therefore, is used a threshold $T > 0$ to control the distortions by limiting the prediction error used to insert the value $w_{i,j}$. The threshold $T$ will slightly reduce the embedding capacity and the distortions produced by the embedding process will significantly decrease. Thus, if the prediction error is less than the threshold and no overflow or underflow is generated, the pixel is transformed and two or more bits are embedded.

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

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

Some pixels cannot be shifted because overflow/underflow is generated. For these pixels, we will not perform histogram shifting (HS) and we will store their positions in LM. Alternatively, we can use the flag bits [1] for the pixels that cannot be shifted.

## 3. PROPOSED EMBEDDING SCHEME

Storing the location of the pixels that generate overflow/underflow will decrease the capacity of the embedding. In this section is described an alternative method for multibit reversible watermarking, able to increase the capacity of the embeddable data. We will insert the values that generate overflow/underflow with the following equation:

$$X_{i,j} = x_{i,j} - (n+1)e_{i,j} - w_{i,j}. \qquad (4)$$

Assume the original value $x_{i,j} = 10$ with the predicted value $\hat{x}_{i,j} = 15$ and the embedding bits $\overline{11}$ ($w = 3$). By using equation (1), the watermarked value is $X_{i,j} = -2$, which is not a proper value, because $X_{i,j} \notin [0, 255]$. By using equation (4) instead of (1) the new watermarked value is $X_{i,j} = 32$ and $X_{i,j} \in [0, 255]$.

The watermarked pixels generated by equation (4) will be also stored in the LM for the decoding process.

## 4. DECODING

Since the watermarking was performed in raster scan order, the decoding process will be performed in inverse embedding order. Firstly, the predicted value will be computed using the same predictor that was used for embedding. A new prediction error $e'_{i,j}$ will be calculated by subtracting the predicted value $\hat{x}_{i,j}$ from the watermarked pixel $X_{i,j}$ and the inserted value along with the original value will be computed.

### 4.1. Decoding for classical method

For the pixels which have $e_{i,j} \in (-T, T)$ and were successfully embedded (without overflow/underflow) using (1), the new prediction error is:

$$e'_{i,j} = ne_{i,j} + w_{i,j}. \qquad (5)$$

From (5) we can extract the embedded value $w_{i,j}$:

$$w_{i,j} = e'_{i,j} \bmod n.$$

After $\hat{x}_{i,j}$ and $w_{i,j}$ are computed, the original value can be restored as:

$$x_{i,j} = \frac{-X_{i,j} + \hat{x}_{i,j}(n+1) - w_{i,j}}{n}.$$

For the pixels with $e_{i,j} \notin (-T, T)$, that were shifted and are not marked in the LM as overflow/underflow, the original value will be recovered by inverse re-shifting:

$$x_{i,j} = \begin{cases} X_{i,j} - (n-1)T, & \text{if } e'_{i,j} > nT - 1 \\ X_{i,j} + T(n-1) - n + 1, & \text{if } e'_{i,j} < -n(T-1). \end{cases}$$

### 4.2. Decoding for the proposed method

For the pixels which have $e_{i,j} \in (-T, T)$ and were watermarked using (4) because the embedding with (1) generates overflow/underflow, the new prediction error is:

$$e'_{i,j} = -ne_{i,j} - w_{i,j}. \tag{6}$$

From (6) the value of $w_{i,j}$ is computed as:

$$w_{i,j} = -e'_{i,j} \bmod n. \tag{7}$$

Once the $\hat{x}_{i,j}$ and $w_{i,j}$ are computed, the original value is restored as:

$$x_{i,j} = \frac{-X_{i,j} + \hat{x}_{i,j}(n+1) - w_{i,j}}{n}. \tag{8}$$

By replacing equation (1) with (4), the overflow/underflow may still arise for a high threshold value. To overcome this situation, the maximum value of the threshold $T$ must be set. The worst case scenario is for predicted pixels which have mid range sampling interval values. For an 8 bit image, with the predicted value $\hat{x}_{i,j} = 128$ and a prediction error $e_{i,j} = 32$, two bits ($n = 4$,$w \in \{0, 1, 2, 3\}$) cannot be embedded without overflow/underflow, either by using equation (1) or (4). Therefore, for an image sampled on the interval$[0, 2^r]$, the threshold interval should be: $T \in [0, 2^r/2n]$.

For the pixels with a prediction error $e_{i,j} \in (-T, T)$, the new prediction error of the embedded values using equation (1) or (4) lies in the interval $[-n(T-1), nT-1]$ . The locations of the pixels marked with the equation (4), will be added to the LM for decoding. The same map it is also used for the overflow/underflow generated by HS. The shifting is performed according to the equation (3), that implies the shifted interval is $[e_{\min}, -T] \cup [T, e_{\max}]$ (where $e_{\min}$ and $e_{\max}$ represent the maximum negative and positive prediction errors) and the overflow/underflow values will lie in this interval. Therefore, for the pixels with prediction error that lies in the interval: $[-n(T-1), -T] \cup [T, nT-1]$ and cannot be shifted because of the overflow/underflow, the ambiguity of embedding using equation (4) or unshifted pixels arise (Fig. 1). The decoding is impossible without a secondary location map (SLM), because of the ambiguity problem. The SLM will reduce the embedding capacity, therefore we will present a method that will reduce the SLM size. We analyse the ambiguity of the pixels that have been marked with equation (4) and of those with the prediction error that lies in the interval: $[-n(T-1), -T] \cup [T, nT-1]$ and cannot be shifted because

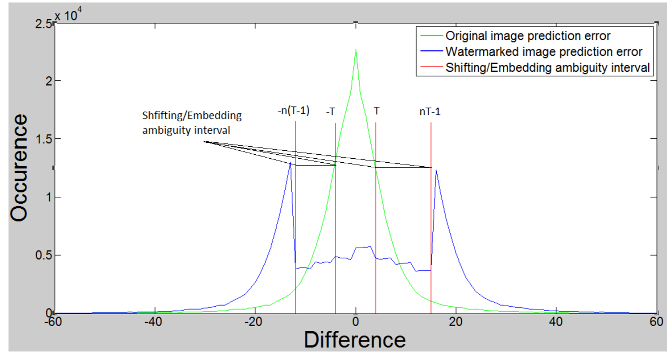


**Fig. 1**: Shifting/Embedding ambiguity for multibit PEE.

**Fig. 2**: Test images.

overflow/underflow is generated. We assume that these pixels have been embedded and we simulate the extraction of the embedded value $w'_{i,j}$ using equation (7) and the original pixel value $x'_{i,j}$ with equation (8).

$$w'_{i,j} = -e_{i,j} \bmod 2$$

$$x'_{i,j} = \frac{-x_{i,j} + \hat{x}_{i,j} - w\prime_{i,j}}{n}$$

With the values obtained it is computed the watermarked pixel $X'_{i,j}$ using equation (1).

$$X'_{i,j} = x'_{i,j} + (n-1)(x'_{i,j} - \hat{x}_{i,j}) + w'. \tag{9}$$

Equation (9) can be written as:

$$X'_{i,j} = 2\hat{x}_{i,j} - x_{i,j}. \tag{10}$$

Since the value $w_{i,j}$ is embedded with equation (4) as an alternative and having in mind that using equation (1) the overflow/underflow arise, when now analyse the watermarked pixel computed in (10). If $0 \leq X'_{i,j} \leq 255$, it means that the bits were not embedded with equation (4), and a shifting was performed. Therefore, the original pixel $x_{i,j}$ will be recovered by reshifting. The location of the $x_{i,j}$ will not be added to the SLM, and the size of the specified map will decrease.

## 5. EXPERIMENTAL RESULTS

In this section, experimental results for the proposed three stages reversible watermarking scheme are presented. Four standard test images of $512 \times 512$ extensively used in the reversible watermarking literature are considered. The test images *Lena, Elaine, Airplane* and *Peppers* are displayed in Fig. 2.

Experimental results were performed considering the proposed scheme, estimating $\hat{x}_{i,j}$ with the MED predictor. The same predictor was used for the classical multibit method. From Fig. 3, it appears that the proposed method outperforms the classical scheme described in [5]. In the same article it was demonstrated that the multibit method outperforms the multilevel watermarking approach (where PEE is performed multiple times, inserting up to one bit/pixel for every iteration).

As you can see in Fig. 3, the proposed algorithm is more suitable for 3 bits embedding.

## 6. CONCLUSIONS

The proposed method is able to watermark pixels that cannot be embedded using the classical method. The proposed method produce more distortions than the method described in [5]. Although the PSNR value will decrease because the proposed method generate more distortions ($+2e$), it provides superior capacity and overall outperforms the classical algorithm. Consequently, the classical method outperforms the multilevel approach.

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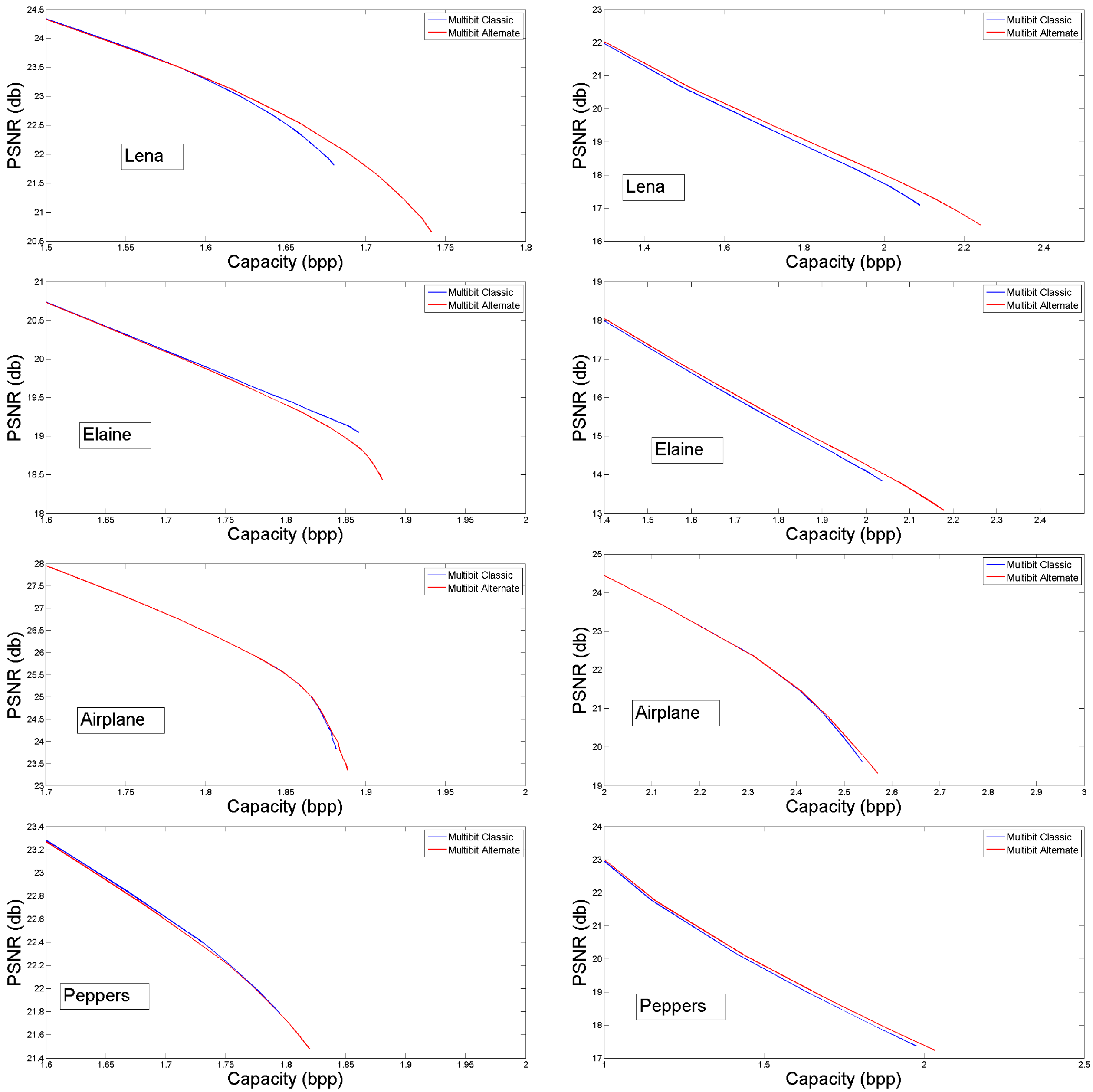


**Fig. 3**: PSNR vs capacity performed on test images for embedding of 2 bits (left) and 3 bits (right).