ISSN 23499842(Online), Volume 1, Special Issue 2(ICITET 15), March 2015

International Journal of Innovative Trends and Emerging Technologies

REVERSIBLE WATER MARKING ALGORITHM BASED ON EMBEDDING PIXEL

MRS.K.SUBHA,AP(SR.G), D.GOMATHI, V.T.HARSHINI
Surya Group Of Institutions, India

Abstract

Many works have demonstrated that the performance of the prediction error (PE) based reversible watermarking algorithm depends on the precision of the prediction value. However, most algorithms compute the prediction value by exploiting only the correlation between the embedding pixel and its neighboring pixels, thus limiting the watermarking performance of these algorithms. In this work, we obtain twelve prediction candidates from neighboring pixels of the embedding pixel based on the modeling assumption -- it is easy to find out that an embedding pixel value is identical or similar to one of its neighboring pixel values in an image. The final prediction value can then be selected from these prediction candidates by using the prediction value and the original pixel value. A more accurate final prediction value can then be obtained. Certainly, the original pixel value is also recovered exactly during the decoding process, in which the final prediction value is obtained according to the twelve prediction candidates, the prediction value and the watermarked pixel value. Experimental results indicate that the variance of the prediction error histogram obtained by the proposed method is about 44.2% less than that proposed by Sachnev et al. Moreover, the mean peak signal-to- noise ratios (PSNRs) are about 1.47 dB and 1.1 dB greater than those of proposed by Sachnev as the watermark capacities are 0-0.04 bits per pixel (bpp) and 0.04-0.5 bpp, respectively. The proposed algorithm performs better than existing reversible watermarking approaches.

Keywords: Reversible watermarking, Prediction error, Difference expansion, Histogram shifting.

1 Introduction

Rapid advances in Internet-based technologies and an increasing network bandwidth have led to the exchange and transfer of a tremendous amount of online digital information, including digital images as well as video and audio files. Security issues involving interception, modification and reproduction of these digital contents are subsequently emerging, explaining the increasing importance of copyright protection in information security research.

Reversible watermarking technology protects digital copyrights by embedding a watermark into the original image. The watermark can then be later extracted from the watermarked image to allow the possessor to authenticate the image [1-4]. Owing to the sensitivity of some applications such as in the military and medical sectors, the reversible watermarking algorithm has been developed to restore the original image from the watermarked one [5]. Generally, the reversible watermarking technology is categorized as a fragile watermarking, so this technology cannot tolerate lossy compression, image processing, and possibly malicious attacks.

A reversible watermarking scheme generally requires a high embedding capacity and low distortion of the watermarked image. However, according to the literature, most reversible watermarking approaches are limited in terms of these requirements, because they conflict with each other in practice.

Tian [5] developed the well-known difference expansion scheme (DE), which supports a higher embedding capacity and lower image distortion than earlier approaches [6-7]. In addition to expanding the difference between each pair of pixels in the original image for embedding one bit of information, the DE scheme utilizes a location map to restore the original image. Nevertheless, although the location map has been compressed, a large payload still remains for the watermarked image. Thus, subsequent works [8-12] have focused on improving the performance of the DE scheme by reducing the size of the location map.

In [9], Kamstra and Heijmans transformed the original image **I** into low-pass image **L** and high-pass image **H** by Haar-wavelet transform. Their modeling assumption $H(i, j)$ is highly correlated with the local variance of $L(i, j)$, which is denoted as $\mu(i, j)$. Therefore, the watermark embedding sequence of H is according to the ascending magnitude of μ. This sorting reduces the size of location bit streams.

Another classical algorithm for reversible watermarking is histogram shifting [13-18], which was first proposed by Ni et al. [13]. That work first found the maximum point $h(a)$ and the minimum zero point $h(b)$ of the image histogram. Then, under the assumption that a < b, the pixels between $h(a)$ and $h(b)$ were shifted to the right by one unit. Finally, the watermark was embedded into the pixels whose gray value is a. In [16], Xuan proposed a scheme which reversibly embeds watermark bits into image prediction errors by using the histogram-pair method only when the magnitude of the prediction error is within the predefined embedding threshold and fluctuation threshold.

Many reversible watermarking schemes [17-27] that use prediction error expansion have been developed in recent years, because prediction error expansion exploits the correlation inherent in the neighborhood of a pixel better than the difference expansion scheme does. Thodi and Rodriguez [21] obtained the prediction errors by using JPEG-LS. The prediction errors were then embedded with watermark bits by using the histogram shifting scheme, which combines the prediction error expansion method with the variation of the histogram shifting method. Sachnev et al. [19] proposed several methods to improve the embedding performance, including the rhombus pattern prediction scheme, the double embedding scheme and the sorting procedure. In this paper, the performance of the proposed scheme is compared with that obtained by Sachnev. A detailed discussion of both our and Sachnev's approaches will be made in later sections.

The rest of this paper is organized as follows. Section 2 reviews the reversible watermarking method of Sachnev et al. [19]. Section 3 then elucidates the proposed reversible watermarking scheme. Next, Section 4 summarizes the simulation results with respect to performance of the watermarking scheme. Conclusions are finally drawn in Section 5.

2 Sachnev's Watermarking Algorithm

Sachnev's watermarking algorithm [19] first divides the original image into two sets, namely the "Cross" set $\mathbf{I}^c$ and the "Dot" set $\mathbf{I}^d$, based on the rhombus pattern. Each pixel in the Cross set and its four neighboring pixels that belong to the Dot set comprise the prediction pattern, as shown in Figure 1.

To embed one bit of watermark into the prediction pattern, the center pixel value $I_{i,j}$ is predicted by computing its four neighboring pixel values as

$$p_{i,j} = \left\lfloor \frac{I_{i-1,j} + I_{i+1,j} + I_{i,j-1} + I_{i,j+1}}{4} \right\rfloor. \quad (1)$$

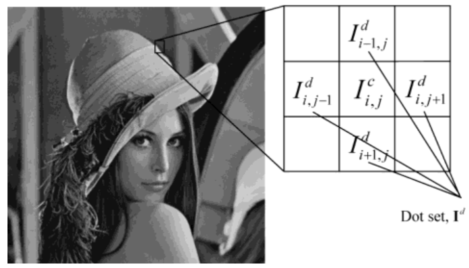

Figure 1 Prediction Pattern

The prediction error $d_{i,j}$ is then computed as

$$d_{i,j} = I_{i,j} - p_{i,j}. \quad (2)$$

Based on the histogram shifting scheme of Thodi and Rodriguez [21], the modified prediction error $d'_{i,j}$ is obtained as

$$d'_{i,j} = \begin{cases} 2d_{i,j} + w, & \text{if } d_{i,j} \in [T_n;\ T_p] \\ d_{i,j} + T_p + 1, & \text{if } d_{i,j} > T_p \text{ and } T_p \geq 0 \\ d_{i,j} + T_n, & \text{if } d_{i,j} < T_n \text{ and } T_n < 0 \end{cases}, \quad (3)$$

where T_n and T_p are the negative threshold and positive threshold, respectively, and w is the watermarked bit value, $w \in \{0, 1\}$.

In Equation (3), the watermark is embedded into the prediction errors between T_n and T_p; the prediction errors outside the range of T_n to T_p are shifted and made bins for embedding watermark.

After the watermark is embedded, the original pixel value $I_{i,j}$ is changed to $I'_{i,j}$ as

$$I'_{i,j} = p_{i,j} + d'_{i,j}. \quad (4)$$

During the encoding process, the Cross set is altered and the Dot set only is used for prediction; they are independent of each other. After the Cross set has been embedded with watermark bits, the Dot set can be embedded with watermark bits by using the watermarked Cross set to predict pixel values. Consecutive usage of the Cross embedding scheme and the Dot embedding scheme is referred to as the double embedding scheme.

During the decoding process, the sets of encoding sequence are reversed. That is, the Dot set is recovered first, followed by recovery of the Cross set. To restore the original image from the watermarked image, the modified prediction error $d'_{i,j}$ is calculated as

$$d'_{i,j} = I'_{i,j} - p_{i,j}. \quad (5)$$

The original prediction error is computed as

$$d_{i,j} = \begin{cases} \lfloor d'_{i,j}/2 \rfloor, & \text{if } d'_{i,j} \in [2T_n;\ 2T_p+1] \\ d'_{i,j} - T_p - 1, & \text{if } d'_{i,j} > 2T_p+1 \text{ and } T_p \geq 0 \\ d'_{i,j} - T_n, & \text{if } d'_{i,j} < 2T_n \text{ and } T_n < 0. \end{cases}$$

$$w = d'_{i,j} \mod 2. \tag{7}$$

s

$$I_{i,j} = p_{i,j} + d_{i,j} \tag{8}$$

Before the Cross set and the Dot set are embedded with a watermark, the pixel sequence of the embedding set is rearranged according to the ascending order of the local variances of all pixels, where each local variance is computed by the four neighboring pixels of each pixel as

$$v_{i,j} = \frac{1}{4}\sum_{i=1}^{4}(r_i - r_m)^2, \tag{9}$$

where $r_1 = |I_{i-1,j} - I_{i,j-1}|$, $r_2 = |I_{i,j-1} - I_{i+1,j}|$, $r_3 = |I_{i+1,j} - I_{i,j+1}|$,
$r_4 = |I_{i,j+1} - I_{i-1,j}|$ and $r_m = (r_1 + r_2 + r_3 + r_4) / 4$.

Since the local variance strongly correlates with the prediction error, most prediction errors are expanded for embedding watermark instead of shifted for creating error histogram bins. Furthermore, since the Cross set and the Dot set are independent of each other, each pixel during the
e

local variance during the encoding process. Therefore, the pixels of encoding sequence are identical to the pixels of the decoding sequence.

A pixel value after the prediction error expansion or the prediction error shifting may out of the range, i.e., $I'_{i,j} < 0$ or $I'_{i,j} > 255$. Sachnev attempted to solve these underflow and overflow problems by developing a two-pass testing method. This method tests all of the pixels twice and then records the problematic pixels and modified pixels, which overlap with problematic pixels, in a location map using bits “1” and “0,” respectively. The location map is also embedded into the watermarked image to facilitate the recovering process.

3 Proposed method

3.1 Prediction Pixel Value Dependent on Multiple Prediction Candidates and Predicting Pixel Value

Since most image pixels are highly correlated with their neighboring pixels, the gray value of a predicting pixel is easily found to be similar or identical to one of its neighboring pixel values. Therefore, in this work, a more precise prediction value is obtained using these neighboring pixels as parts of the prediction candidates.

In the proposed algorithm, the original image **I** is first divided into four sets $\mathbf{I}^k$, $k \in \{0, 1, 2, 3\}$, based on the 2-D interleaving pattern where interleaving intervals both in row-wise and column-wise directions are one pixel. Each pixel in a set and its eight neighboring pixels, which belong to the other three sets, compose a prediction pattern. For example, in the “0” set, pixel $I^0_{i,j}$ and its eight neighboring

and $_{i}I^{3}_{+\ 1,\ j\ +\ 1}$ constitute a prediction pattern, as shown in Figure 2. The fact that each set is embedded individually with watermark bits explains that, when a set is altered, the other three sets used for prediction remain unchanged, i.e., the four sets are independent of each other.

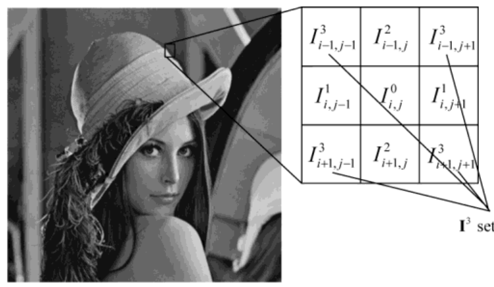

Figure 2 Prediction Pattern

The center pixel value $I_{i,j}$ of a prediction pattern is estimated from twelve prediction candidates, denoted from I_0 to $_{11}$. These candidates are eight neighboring pixels of
I
the center pixel, and the other four pixels are obtained by

$$\begin{aligned} I_8 &= \lfloor (I_{i,j-1} + I_{i,j+1})/2 \rfloor, \\ I_9 &= \lfloor (I_{i-1,j} + I_{i+1,j})/2 \rfloor, \\ I_{10} &= \lfloor (I_{i-1,j-1} + I_{i+1,j+1})/2 \rfloor, \\ I_{11} &= \lfloor (I_{i-1,j+1} + I_{i+1,j-1})/2 \rfloor. \end{aligned} \tag{10}$$

Following sorting of these prediction candidates, twelve ascending prediction candidates $I_{c,0} \leq I_{c,1} \leq \ldots \leq$
$I_{c,11}$ are obtained. These candidates divide the gray-level [0, 255] into eleven sections, where Section 0 ≤ $I_{c,1}$, $I_{c,1}$ ≤ Section 1 ≤ $I_{c,2}$, $I_{c,k}$ ≤ Section k ≤ $I_{c,k+1}$, …, $I_{c,10}$ ≤ Section 10, as shown in Figure 3.

Xuan et al. [16] computed a prediction pixel value by its eight neighboring pixels as

$$p_{i,j} = \left\lfloor \frac{I_{i-1,j} + I_{i+1,j} + I_{i,j-1} + I_{i,j+1}}{6} + \frac{I_{i-1,j-1} + I_{i-1,j+1} + I_{i+1,j-1} + I_{i+1,j+1}}{12} \right\rfloor \tag{11}$$

Extraction algorithm

```
if I_{i,j} ⇦ p_{i,j}
    p_{i,j} ↥ I_{c,s}
    d_{i,j} ↥ I_{i,j} ▯ p_{i,j}
    if d_{i,j} ⇦ T_{o,e}
        if d_{i,j} ⇦ 2T_{0,b} ▯ T_{0,e} ▯ 1
            d_{i,j} ↥ ⌊(d_{i,j} ↖ T_{0,e}) / 2⌋ ⤒ T_{0,e}
            w ↥ (d_{i,j} ↖ T_{0,e}) mod 2
        else
            d_{i,j} ↥ d_{i,j} ↖ (T_{0,b} ↖ T_{0,e} ↖ 1)
        endif
        I_{i,j} ↥ p_{i,j} ⤒ d_{i,j}
    else
        I_{i,j} ↥ I_{i,j}
    endif
else
    p_{i,j} ↥ I_{c,s⤒1}
    d_{i,j} ↥ ↖(I_{i,j} ↖ p_{i,j})
    if d_{i,j} 🠅 T_{1,e}
        if d_{i,j} ◀ 2T_{1,b} ↖ T_{1,e} ↖ 1
            d_{i,j} ↥ ⌊(d_{i,j} ↖ T_{1,e}) ⤒ T_{1,e} / 2
            w ↥ (d_{i,j} ↖ T_{1,e}) mod 2
        else
            d_{i,j} ↥ d_{i,j} ↖ (T_{1,b} ↖ T_{1,e} ↖ 1)
        endif
        I_{i,j} ↥ p_{i,j} ↖ d_{i,j}
    else
        I_{i,j} ↥ I_{i,j}
    endif
endif
```

Figure 7 shows the watermark extraction flowchart.

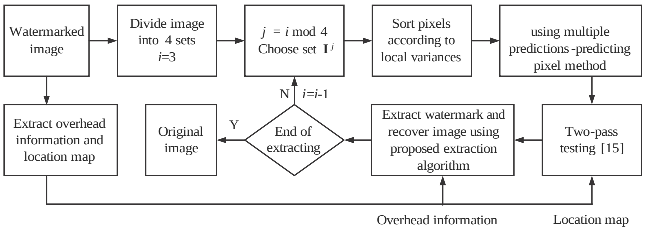

Figure 7 Flowchart of Watermark Extraction

4 Experimental Results

the smaller variance, the higher watermarking performance.

Figure 8 shows the prediction error histograms of test image Lena obtained by using the algorithms of Xuan [16], Sachnev [19], and Thodi [21], as well as the proposed algorithm. This figure reveals that the number of prediction error $d = 0$ obtained by the proposed method is 30,829 larger than that obtained by the algorithm of Sachnev; in addition, the histogram variances of the proposed method and the method of Sachnev are 14.0 and 25.1, respectively. A significant 44.2% improvement is obtained by using the proposed method rather than that of Sachnev.

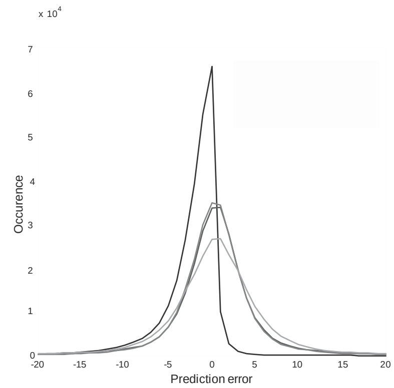

Figure 8 Histograms of the Prediction Error

Watermarking performance of the proposed method is evaluated using four 8-bit gray-level images of size 512 × 512, as shown in Figure 9. The test watermark is a random binary string. The performance of the proposed method is compared with that of Sachnev et al. [19], since the latter is known as a utilization of novel techniques attempting to enhance the embedding performance. Besides, the work of Sachnev et al. indicated that their approach performs better than those of Kamstra and Heijmans [9], Lee et al. [10] and Thodi and Rodriguez [21-22]. Therefore, effectiveness of the proposed approach is demonstrated based on the results of using obtained by employing Sachnev's method.

Figures 10 and 11 show the PSNRs of the four

0-0.04 bpp and 0.04-0.5 bpp, respectively. According to these figures, the proposed algorithm obviously performs better than that of Sachnev. For instance, for the Lena image, the mean PSNRs obtained by the proposed method are 1.47 dB and 1.1 dB higher than that obtained by Sachnev's method when the watermark payloads are 0-0.04

Sachnev et al. [19] and Chen et al. [20] indicated that the prediction error histogram generally has a Laplacian distribution, and the performance of a watermarking algorithm depends on the variance of the distribution, i.e., bpp and 0.04-0.5 bpp, respectively.

Figures 10 and 11 show the watermark capacities ranging from 0 to 0.5 bpp. However, the proposed method still performs excellently when the payload exceeds 0.5 bpp. For instance, for the Lena image, the PSNR obtained by the proposed method is 0.17 dB lower than that obtained by Sachnev's method when the watermark capacity is 0.8 bpp.

CONCLUSION

The reversible watermarking method has been adopted for copyright protection in sensitive fields, due to its ability to extract the watermark from the watermarked image in order to enable the possessor to authenticate the image. Therefore, this approach focuses on a high watermark capacity and low image distortion. To achieve these objectives, many works have prioritized the variance of the prediction error histogram.

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