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A Reversible Watermarking Framework Based on Down-sampling and Prediction

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Abstract: One of the main aim of the research on reversible watermarking is to achieve higher data-hiding capacity with as low distortion as possible. In this study, an effective reversible watermarking framework is proposed. First a host image is down sampled into two sub-images. Then the Difference Expansion (DE) technique is applied to one sub-image and output its location map and watermarked image. Next the suitable pixel pairs in the other sub-image are chosen by a simple predictor to embed more data. Finally the watermarked host image is reconstructed by combination of two watermarked sub-images. The experimental results show the size of compressed location map decreases dramatically by more than half of the traditional one. The schemes based on the framework are effective on different test images and can achieve a high data-hiding capacity.

Key words: Reversible watermarking, reversible data embedding, difference expansion, down sampling, prediction

INTRODUCTION

Most of images are processed, transmitted, stored in digital form. Some of them, such as medical images, surveillance images, are not allowed to be tampered. So some fragile watermarking schemes are designed for integrity authentication. They are also required to be completely restored. Reversible watermarking, which allows complete and blind restoration of the host image, has drawn lots of interests. One of the main aims for researchers in this field is to achieve higher data-hiding capacity with as low distortion as possible. A reversible watermarking scheme using the difference expansion technique is proposed, which embeds the message into the Least Significant Bits (LSBs) of the expanded pixel pairs (Tian, 2003). The method is extended by using difference expansion of vectors to increase the data-hiding capacity (Alattar, 2004). Several bits are embedded in the vector each time. It is a more general form. Two different reversible watermarking schemes based on prediction-error expansions are designed (Thodi and Rodriguez, 2004; Chang and Lu, 2006). Coltuc and Chassery (2007) proposed a fast reversible watermarking based on the Reversible Contrast Mapping (RCM). The host image is divided into pixel pairs (for example, on columns, on rows). For each pixel pair, the LSB of the first pixel is used to determine whether it is transformed or not and the second one is employed for data embedding. The method is efficient and robust against cropping, but its data-hiding capacity is less than that of the previously introduced methods. A novel principle of creating more compressible location map is presented (Chang *et al*., 2007), which is benefit to the schemes (Tian, 2003; Alattar, 2004; Thodi and Rodriguez, 2004; Chang and Lu, 2006). The repetitive pixels in a medical image are properly used for watermarking with no location map (Chang and Xu, 2011).

For reversible watermarking schemes using the DE, decreasing the size of the location map and choosing more pixel pairs with small difference for data embedding are key ways to achieve the higher data-hiding capacity with low distortion. In this study down sampling and prediction techniques are introduced to improve the performance of the existing reversible watermarking schemes.

DIFFERENCE EXPANSION

Assume (p_1, p_2) is a pixel pair in a digital image. The integer Haar wavelet transform is Eq. 1:

$$a = \lfloor (p_1 + p_2)/2 \rfloor,\ d = p_1 - p_2 \tag{1}$$

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In Eq. 1, $\lfloor x \rfloor$ is the floor function, which returns a largest integer not greater than x. b is 1-bit data. It can be embedded into the least bit of the expanded d using Eq. 2:

$$d' = 2 \times d + b \tag{2}$$

The data embedded pixel pair (p_1', p_2') can be calculated using Eq. 3:

$$p_1' = a + \lfloor (d'+1)/2 \rfloor,\ p_2' = a - \lfloor d'/2 \rfloor \tag{3}$$

For a 256-gray-level image, the data embedded expanded pixel pair (p_1', p_2') must satisfy Eq. 4:

$$0 \le p_1', p_2' \le 255 \tag{4}$$

During the restoration stage, d and b can be computed with Eq. 5:

$$\begin{aligned} d' &= p_1' - p_2',\ d = \lfloor d'/2 \rfloor \\ b &= d' - 2 \times \lfloor d'/2 \rfloor \end{aligned} \tag{5}$$

The corresponding inverse transform of Eq. 1 is shown in Eq. 6:

$$p_1 = a + \lfloor (d+1)/2 \rfloor,\ p_2 = a - \lfloor d/2 \rfloor \tag{6}$$

THE PROPOSED REVERSIBLE WATERMARKING FRAMEWORK

When a host image is down sampled into two sub-images shown in Fig. 1, the difference of the pixel pair in one sub-image is close to that of its neighboring pixel pairs in the other sub-image. For example, if the differences of pixel pairs, $p_1(1, 1)$ and $p_1(1, 2)$, are small, it can be deduced that the difference value of $p_2(1, 1)$ is small too.

Based on the above fact, a simple and effective predictor (7) is proposed to choose the suitable pixel pairs in sub-image I_2 for watermarking:

$$\rho(p_2(i,j)) = \begin{cases} 1 & (m_1(i,j)=1) \wedge (m_2(i,j+1)=1) \\ 0 & \text{otherwise} \end{cases} \tag{7}$$

In Eq. 7, $p_2(i, j)$ is a pixel pair in I_2, $\rho(p_2(i, j))$, is a Boolean value called 'prediction value', ^ denotes the logical operator 'AND' and $m_1(i, j)$ is the binary value in the location map of sub-image I_1. When $m_1(i, j)$ is 1, it means $p_1(i, j)$ in I_1 is expanded. If $\rho(p_2(i, j))$ is 1 and $p_2(i, j)$ is expandable, $p_2(i, j)$ will be expanded for data-embedding.

Not all pixel pairs in I_2 with prediction values being 1 are expandable for a few of them may cause overflow or underflow problem. Here a binary vector is employed to record them. For each pixel pair with prediction value being 1, there is a corresponding binary value in the vector initialized with zero. If it is unexpandable and incurs overflow or underflow, the value in the vector is set to 1. The vector is compressed by the arithmetic coder before concealed in I_2. Since most of the pixel pairs are expandable, the compression ratio of the binary vector is very high.

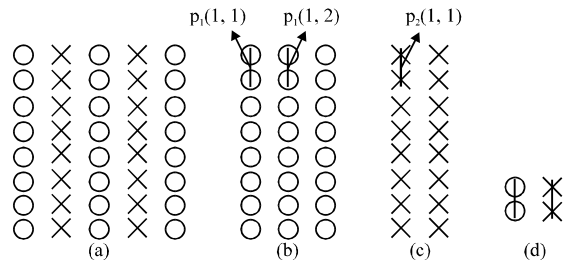

Fig. 1(a-d): The down sampling technique, (a) The entire host image, (b) The down sampled sub-image I_1, (c) The down sampled sub-image I_2 and (d) Pixel pairs

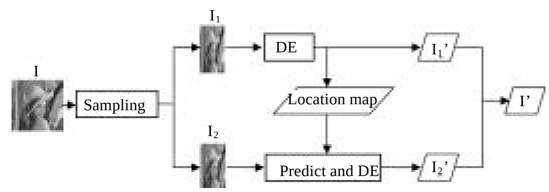

Fig. 2: The proposed reversible watermarking framework

Based on the down sampling and prediction techniques, a novel reversible watermarking framework is proposed, which is shown in Fig. 2. More details about this framework are described in the watermarking and restoring stages.

Watermarking stage:

Step 1: The host image I is down sampled into two sub-images I_1 and I_2

Step 2: Sub-image I_1 is watermarked with the difference expansion technique

For each pixel pair in I_1 if it is expandable and its difference value is smaller than a predefined threshold, the DE technique is applied to it for data embedding. A location mapis used to mark the expanded pixel pairs. The compressed location map and the predefined threshold are concealed in I_1. Finally output the watermarked I_1'.

Step 3: Sub-image I_2 is watermarked with prediction and DE

Fig. 3(a-d): The standard test images used in the experiment, (a) Jet, (b) Barbara, (c) Lena and (d) Baboon

For each pixel pair $p_2(i, j)$ in I_2 if its prediction value $\rho(p_2(i, j))$ equals to 1 and it is expandable, 1-bit message is concealed in it. If its prediction value $\rho(p_2(i, j))$ equals to 1 and it is unexpandable, set 1 to its vector value. Otherwise, nothing is done. In the end conceal the compressed binary vector and output the watermarked sub-image I_2'.

Step 4: The watermarked host image I' is reconstructed by I_1' and I_2'

Restoring stage:

Step 1: The watermarked image I' is sampled into two sub-images I_1' and I_2'

Step 2: First the compressed location map and the predefined threshold are extracted. Next the location map is decompressed. In the final the original sub-image I_1 and information are restored with (5) and (6)

Step 3: Watermarked sub-image I_2' and the information in it are restored

The binary vector is extracted and decompressed. For each pixel pair $p_2'(i, j)$ in I_2' its prediction value $\rho(p_2'(i, j))$ is calculated by Eq. 8:

$$\rho(p_2'(i,j)) = \begin{cases} 1 & (m_1(i,j)=1) \wedge (m_2(i,j+1)=1) \\ 0 & \text{otherwise} \end{cases} \tag{8}$$

where, $\rho(p_2'(i, j))$ is identical to $\rho(p_2'(i, j))$ for they are computed using the same location map. If $\rho(p_2'(i, j))$ is 1 and its vector value is 0, 1-bit information is extracted from the data-embedded pixel pair and the original pixel pair is restored. Otherwise, nothing is done to the pixel pair. Finally output the original sub-image I_2 and watermark.

Step 4: The original host image I is reconstructed by I_1 and I_2 and the original information is restored by concatenation of the two information streams, which are restored from I_1' and I_2', respectively

EXPERIMENT AND APPLICATION

The reversible watermarking schemes using different location maps based on the proposed framework are simulated. Scheme || employs the traditional location map (Tian, 2003) and scheme || uses the more compressible one (Chang *et al*., 2007).

The schemes are tested on many 512×512 8-bit standard test images. Jet, Barbara, Lena and Baboon, are specifically chosen, shown in Fig. 3, to demonstrate the experimental results for they stand for two different kinds of images. Jet and Lena contain more plane regions and Barbara and Baboon consist of more complex textures.

The watermark is a chain of pseudo random numbers. Peak Signal-to-Noise Ratio (PSNR) and Bits Per Pixel (bpp) are employed to evaluate the quality of watermarked images and data-hiding capacity, respectively.

Firstly, experiments are done to compare the size of the compressed location map in different schemes, which is shown in Fig. 4. Secondly, capacity versus PSNR comparison is shown in Fig. 5. Experimental results prove both of the proposed schemes are superior to Tian's.

In Fig. 4, the size of the compressed location map in Scheme || is the smallest and that of Tian's is the largest. For Jet and Barbara, the size of compressed location maps in Scheme || are decreased by more than half of the traditional one at 46 and 41 dB, respectively. Scheme || can conceal more watermark than scheme || at the same PSNR, which is shown in Fig. 5.

Scheme || can achieve about 0.1 bpp more than that of Tian's at high PNSR for Jet and Lena. It can hide about 0.08 bpp more than that of Tian's at high PSNR for Barbara and Baboon.

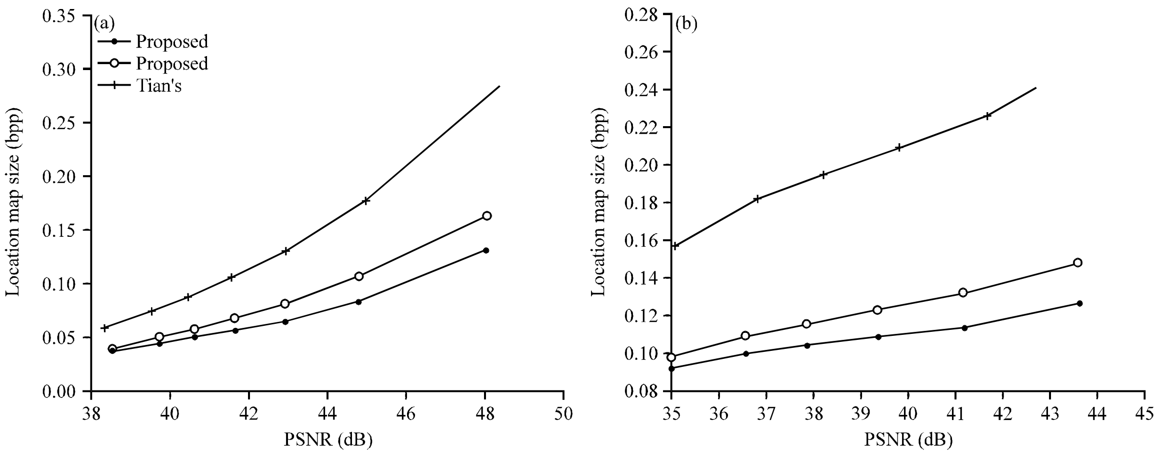

Fig. 4(a-b): A comparison between the size of the compressed location map of the proposed and that of Tian's scheme, (a) Jet and (b) Barbara

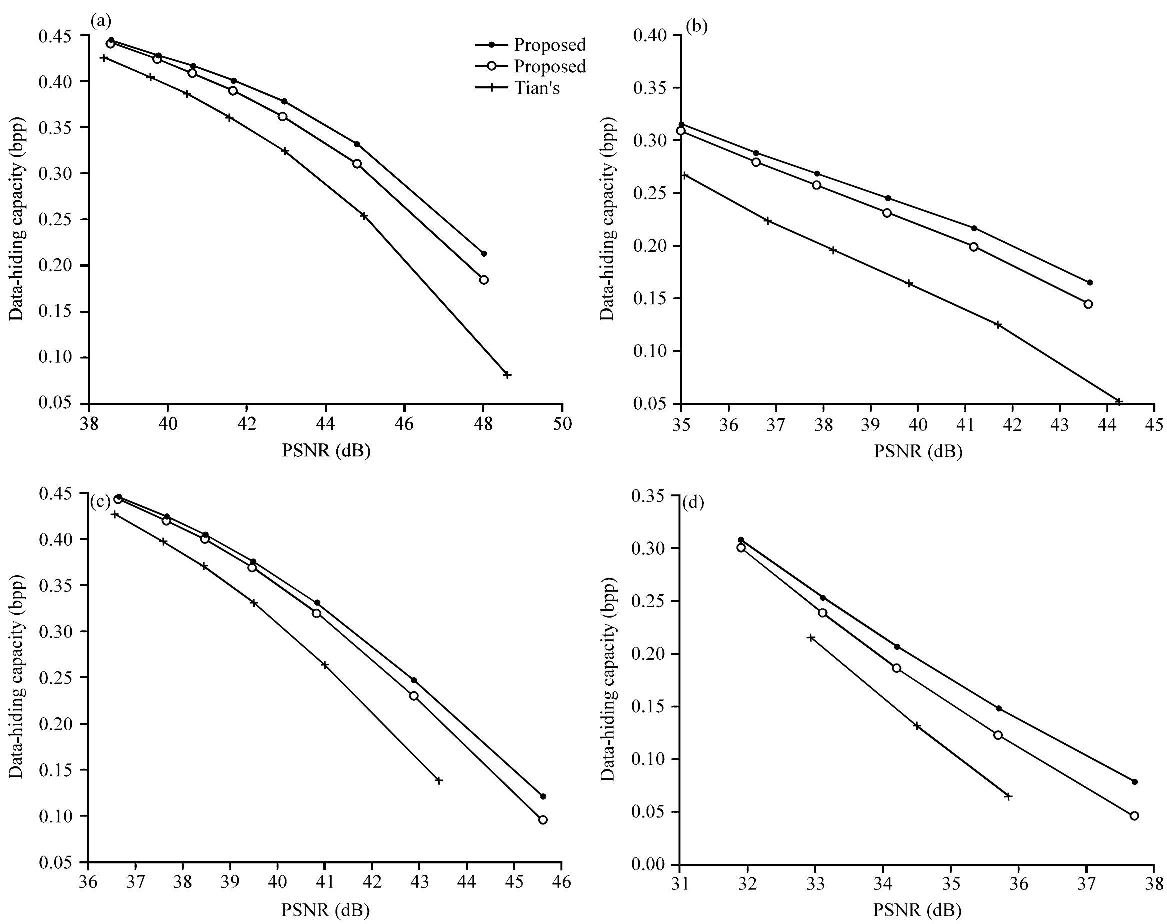

Fig. 5(a-d): Capacity versus PSNR comparison on test images (a) Jet, (b) Barbara, (c) Lena and (d) Baboon

The schemes are also compared with the proposed by Thodi and Rodriguez (2004). Its data-hiding capacity is larger than that of Thodi's method at middle and high PSNR.

CONCLUSION

After the correlation between the two sub-images of a host image is analyzed, a reversible watermarking framework based on down sampling and prediction is proposed. Experimental results show it can achieve a higher data-hiding capacity than the corresponding scheme without using down sampling technique. The future work will focus on the improvement of location map, down sampling and prediction techniques.

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