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Reversible Data Hiding Based on Wavelet Spread Spectrum

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***Abstract*:** This paper presents a reversible data hiding method based on wavelet spread spectrum and histogram modification. Using the spread spectrum scheme, we embed data in the coefficients of integer wavelet transform in high frequency subbands. The pseudo bits are also embedded so that the decoder does not need to know which coefficients have been selected for data embedding, thus enhancing data hiding efficiency. To prevent the overflow and underflow, an efficient histogram modification method is developed and utilized. Experimental results on some frequently used images show that our method has achieved superior performance in terms of high data embedding capacity and high visual quality of marked images, compared with the existing reversible data hiding schemes.

***Index Terms*: Integer wavelet transform(IWT), spread spectrum, histogram modification, reversible data hiding**

1. Introduction

Data hiding has drawn increasingly extensive attention recently. Most multimedia data hiding techniques modify and, hence, distort the cover media in order to insert the additional information. Even though the distortion is often small and imperceptible to human visual systems (HVS), the original cover media usually cannot be restored completely. In other words, they are noninvertible data hiding, which is not admissible to some sensitive applications, such as legal and medical imaging. For these applications, reversible data hiding is desired to extract the embedded data as well as to recover the original host signal. Reversible (also often referred to as lossless, invertible, or distortion-free) data hiding has been a very active research subject in the last a few years. Many reversible data hiding schemes have been reported [1-11]. Some schemes that are relevant to the proposed scheme are briefly described in this section. The scheme proposed by Fridrich et al. [3] losslessly compresses the bit-planes in the spatial domain and hence saves space to embed the payload (to-be-embedded data) and overhead (bookkeeping data) to achieve reversible data hiding. The payload of this technique is quite small owing to the low compression ratio. Based on this, a general least significant bit-plane (LSB) embedding technique in the spatial domain was proposed by Celik et al. [6]. The payload and imperceptibility of embedded data are largely improved because of the more efficient compression technique. Domingo-Ferrer et al. [5] proposed a spread spectrum data hiding method that is only reversible with respect to the modified version of the original host signal. Xuan et al. [7] proposed a reversible data hiding algorithm carried out in the integer wavelet transform (IWT) domain. An improved version of this algorithm was reported in [11]. By exploiting the superior features of wavelet transform, in particular, the high decorrelation between IWT coefficients and visual consistency with HVS, this technique compresses some bit-planes of IWT coefficients in high frequency subbands to save space to embed data, achieving high payload and visual quality. Tian [9] embeds the data using the difference expansion technique, resulting in one of the best reversible data hiding methods among all reported in the literature. Recently, Yang et al. [10] proposed a reversible data hiding technique using the companding technique. This technique embeds data in discrete cosine transform (DCT) coefficients. Motivated by [7,11] and [5], this paper presents a novel reversible embedding method based on wavelet spread-spectrum. The pseudo bits are also embedded so that the decoder does not need to know which coefficients have been selected for data embedding. To prevent the overflow and underflow problem, histogram modification is used. Our experimental results have indicated that the proposed scheme has achieved superior performance in terms of high data embedding capacity and high visual quality of marked images, compared with the existing reversible data hiding schemes on some commonly used images.

The rest of the paper is organized as follows. The proposed algorithm is introduced in Section 2. Some experimental results are presented in Section 3.The paper is concluded in Section 4.

2. Algorithm

Wavelet transform is widely applied to different tasks in image processing. Since wavelet transform coefficients are highly decorrelated having compact energy concentration, and are consistent with the feature of the human visual system (HVS), wavelet transform is also widely applied to image data hiding. The study on HVS points out that slight modification of wavelet transform coefficients in high frequency subbands is hard to be perceived by human eyes. Hence we choose to embed data in wavelet domain.

2.1 Integer Wavelet

To recover the original image losslessly, reversible wavelet transform should be used. Hence we employ the integer wavelet transformation which maps integer to integer and can reconstruct the original signal without any distortion. Although various wavelet families can be applied to our reversible embedding scheme, through experimental comparison we have discovered that CDF(2,2) is better than other wavelet families in terms of embedding capacity and visual quality of embedded images. In addition, it is noted that CDF(2,2) format has also been adopted by JPEG2000 standard [14]. Table 1 is the forward and inverse transform formula of CDF(2,2).

Table 1. CDF(2,2) integer wavelet transform.

Forward Transform	Inverse Transform
Splitting: $s_i \leftarrow x_{2i}$, $d_i \leftarrow x_{2i+1}$ Dual lifting: $d_i \leftarrow d_i - \left\lfloor \frac{1}{2}(s_i + s_{i+1}) + \frac{1}{2} \right\rfloor$ Primary lifting: $s_i \leftarrow s_i + \left\lfloor \frac{1}{4}(d_{i-1} + d_i) + \frac{1}{2} \right\rfloor$	Inverse primary lifting: $s_i \leftarrow s_i - \left\lfloor \frac{1}{4}(d_{i-1} + d_i) + \frac{1}{2} \right\rfloor$ Inverse dual lifting: $d_i \leftarrow d_i + \left\lfloor \frac{1}{2}(s_i + s_{i+1}) + \frac{1}{2} \right\rfloor$ Merging: $x_{2i} \leftarrow s_i$, $x_{2i+1} \leftarrow d_i$

2.2 Reversible Spread Spectrum Hiding

After wavelet transformation, we have three high-frequency subbands: HL, LH, and HH. Suppose W is one coefficient from these three subbands and |W|<A (A>0).

(a) Embed one bit ("0" or "1") in W:

$$W' = W + A*S \tag{1}$$

here,

$$S = \begin{cases} 1, & \text{if the bit to be embedded is "1"} \\ -1, & \text{if the bit to be embedded is "0"} \end{cases} \tag{2}$$

(b) Extract one bit from W':

Because of |W|<A, so,

$$\text{Sign (W')} = \text{Sign (W+A*S)} = \text{Sign (A*S)} = \text{Sign (S)} \quad (3)$$

That's to say, we can extract the bit from the sign of W'.

(c) Recover W:

After extracting the bit, we can restore W:

$$W = W' - A*S \quad (4)$$

In order for the above embedding scheme to be indeed reversible, the following two conditions must be met:

(1) There is no overflow/underflow when inverse wavelet transformation is applied. We will discuss this condition in detail in next subsection.

(2) |W|<A.

Actually if |W| ≥ A, we can embed one pseudo bit in it. We use the following simple way:

(a) If W ≥ A, we let S=1. That is to say, we embed one pseudo bit "1" in W. So when decoding, surely we will extract one bit "1" from W' (because W' must be positive) and subsequently we can recover the original W through formula (4). Now that we have the original W and we find |W| ≥ A, we know that the bit "1" is pseudo bit which is not the bit we want to embed. Then we can throw it away and go ahead.

(b) If W≤-A, we let S = -1. That is to say, we embed one pseudo bit "0" in W. So when decoding, surely we will extract one bit "0" from W' (because W' must be negative) and subsequently we can recover the original W through formula (4). Now that we have the original W and we find |W| ≥ A, we know the bit "0" is pseudo bit which is not the bit in the watermark signal. Then we can ignore it and go ahead.

By embedding the pseudo bits, we have also solved the problem that when decoding, we don't need to know which coefficients have been selected for embedding. Compared to the method in [9] which uses the "location map" to record the modified coefficients and then compresses and embeds it as overhead, embedding pseudo bits is simpler and more effective.

2.3 Histogram Modification

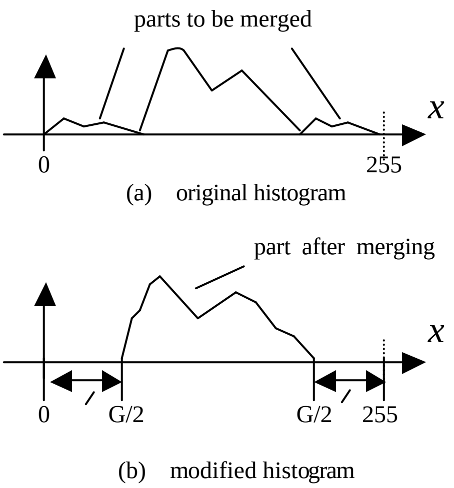


Figure 1. Histogram modification.

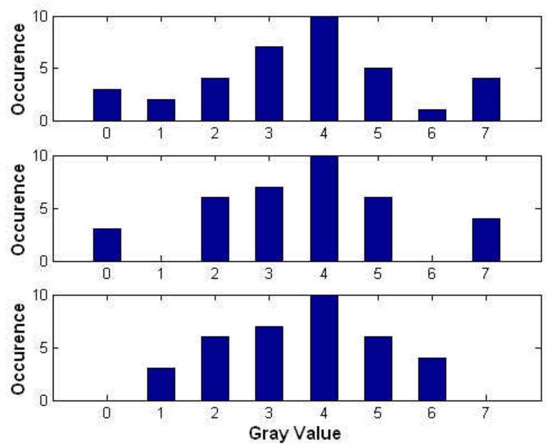


Figure 2. Histogram modification process, (a) top, before modification, (b) middle, in modification, (c) bottom, after modification.

For a given image, after data embedding in some IWT coefficients, it is possible to cause overflow and/or underflow, which means that after inverse wavelet transform the grayscale values of some pixels in the marked image may exceed the upper bound (255 for an eight-bit grayscale image) and/or the lower bound (0 for an eight-bit grayscale image). In order to prevent the overflow and underflow, we adopt histogram modification, which narrows the histogram from both sides as shown in Figure 1.

In order to illustrate the histogram modification process, let's see a simplified example, where the size of an original image is 6x6 with $8=2^3$ grayscales (6x6x3). The whole process is shown in Figure 2. From Figures 2, we can see that the range of modified histogram now is from 1 to 6 instead of from 0 to 7, i.e., no pixel assumes grayscales 0 and 7 after the histogram modification. During the modification, grayscale 1 is first merged into grayscale 2. Grayscale 0 then becomes grayscale 1. In the similar way, grayscale 6 is first merged into grayscale 5. Grayscale 7 then becomes grayscale 6.

In narrowing down a histogram to the range [G/2, 255-G/2], we need to record the histogram modification information (we call it bookkeeping information) as part of the embedded data. So the data to be embedded comes from two parts: 1) watermark signal; 2) bookkeeping information of histogram modification. Generally speaking, the amount of bookkeeping information is small. Through the bookkeeping information we can restore the original image losslessly.

At last, a diagram for this new reversible embedding method is given in Figure 3.

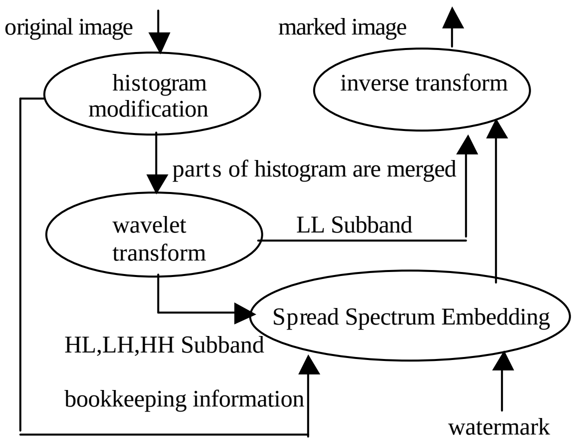
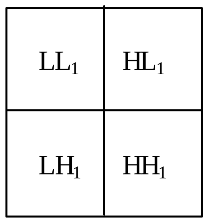
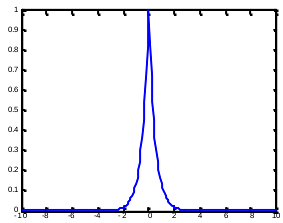


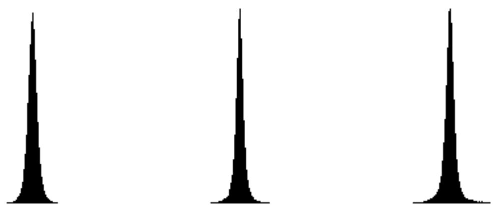
Figure 3. Data embedding diagram.



(a) Wavelet subbands



(b) Laplacian function



HH_1 HL_1 LH_1

(c) Wavelet coefficients distribution for Lena

Figure 4 Laplacian-like distribution of wavelet high frequency coeffiecients

3 Experiment results

For most of images, the distribution of high frequency coefficients of integer wavelet transform obeys in general a Laplacian-like distribution. One of such examples is shown in Figure 4. From Figure 4, we can see that most high-frequency wavelet subband coefficients are small. That's to say, even for some small A, we can embed one bit of information in most coefficients. We can choose different A for different payload. If the payload size is small, we choose small A so we can keep the distortion small; if the required payload is large, we choose a larger A. This method is flexible and simpler than MSE minimization method proposed in [9]. Table 2-5 present some experiment results of embedded payload size vs. PSNR of embedded image.

The capacity vs. distortion comparison results to the state-of-the-art [6, 9, 10] on "Lena" and "Barbara" are shown in Figure 6 and Figure 7, respectively. The top curve is for wavelet spread-spectrum method. It is observed that as embedding a payload of the same size, the PSNR of the marked images by using wavelet spread spectrum method is higher than that by other methods in general.

Table 2 Payload VS PSNR of marked "Lena" image

Payload (bpp)	0.1	0.2	0.3	0.4	0.5	0.6
PSNR (dB)	48.61	44.99	41.72	39.16	36.71	34.54

Table 3 Payload VS PSNR of marked "Baboon" image

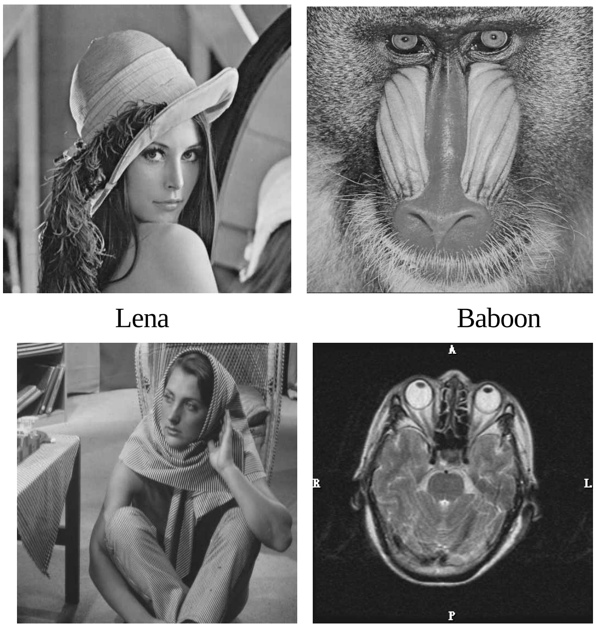
Payload (bpp)	0.1	0.2	0.3	0.4	0.5	0.6
PSNR (dB)	42.04	38.31	34.52	31.07	27.01	23.17

Table 4 Payload VS PSNR of marked "Barbara" image

Payload (bpp)	0.1	0.2	0.3	0.4	0.5	0.6
PSNR (dB)	48.67	45.18	41.78	39.03	36.10	30.87

Table 5 Payload VS PSNR of marked "Medical" image

Payload (bpp)	0.1	0.2	0.3	0.4	0.5	0.6
PSNR (dB)	52.06	48.42	44.80	41.64	40.48	36.30



Lena Baboon

Barbara Medical

Figure 5 some experiment images

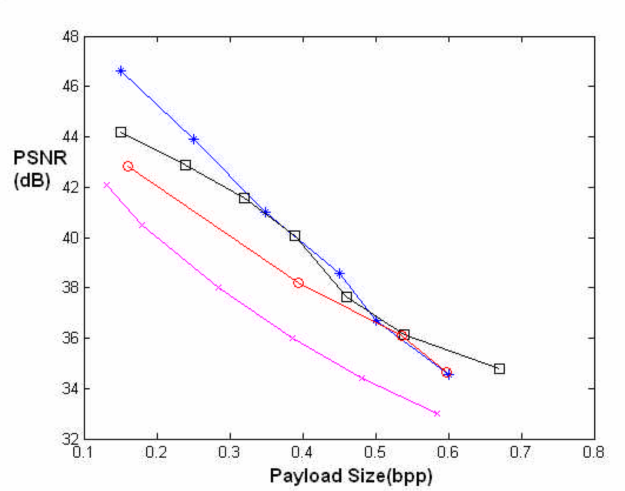


Figure 6 Capacity vs. distortion comparison on Lena

SS technique proposed in this paper
Difference expansion technique [9]
DCT companding technique [10]
GLSB technique [6]

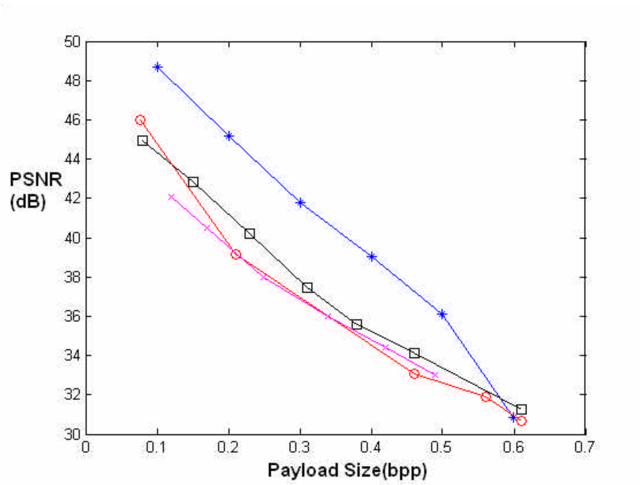


Figure 7 Capacity vs. distortion comparison on Barbara

SS technique proposed in this paper
Difference expansion technique [9]
DCT companding technique [10]
GLSB technique [6]

4 Conclusions

In this paper we present a reversible data hiding method for digital images which has high embedding capacity and high visual quality of marked images. We use the spread-spectrum technique to embed the data in wavelet coefficients and use histogram modification to prevent the overflow and underflow. The pseudo bits are embedded at the same time to solve the problem that when decoding, we don't know which coefficients have been selected for embedding. Comparison with other methods shows both the embedding capacity and the visual quality of marked images achieved by our proposed method are among the best in the literature.

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