Lossless Data Hiding Based on Integer Wavelet Transform

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***Abstract*—**This paper proposes a novel data hiding algorithm having large data hiding rate based on integer wavelet transform, which can recover original image without any distortion from the marked image after the hidden data have been extracted. This algorithm hides the data and the overhead data representing the bookkeeping information into a middle bit-plane of the integer wavelet coefficients in high frequency subbands. It can embed much more data compared with the existing distiortionless data hiding techniques and satisfy the imperceptibility requirement. The image histogram modification is used to prevent grayscales from possible overflowing that may take place due to the data embedding. The algorithm has been applied to a wide range of different images successfully. Some experimental results are presented in this paper to demonstrate the validity of the algorithm.

Key words*—*lossless (invertible) data hiding, integer wavelet transform, lifting scheme, watermarking, histogram modification

I. INTRODUCTION

In data hiding, pieces of information represented by the data are hidden in the cover media. In some applications, people do care about the cover media. That is, the hidden data and the cover media may be closely related. For this type of data embedding, in addition to perceptual transparency, for some applications such as medical diagnosis and law enforcement, it is desired to invert the marked media back to the original cover media after the hidden data have been retrieved. The marking techniques satisfying this requirement are referred to as lossless, *distortion-free* or *invertible* data hiding techniques. From this point of view, it is observed that most of the current digital watermarking algorithms are not lossless.

Recently, some lossless marking techniques have been reported in the literature. The first method [1] is carried out in the image spatial domain. Another spatial domain technique was reported in [2]. There also exists a lossless marking technique in the transform domain [3]. These techniques aim at authentication, instead of data embedding. As a result, the amount of hidden data is quite limited. The first lossless marking technique that is suitable for data embedding was presented in [4]. While it is novel, and successful in lossless data hiding, the amount of hidden data by this technique is still not large enough for, say, some medical applications. From what is reported in [4], the pay-load ranges from 3,000 bits to 24,000 bits for a $512\times512\times8$ grayscale image.

We propose a new lossless marking technique, which can embed a larger amount of data. It is carried out in the integer wavelet transform (IWT) domain.

The rest of the paper is organized as follows. The proposed algorithm is introduced in Section II. Some experimental results and conclusions are presented in Sections III and IV, respectively.

II. ALGORITHM

A. Integer WT (IWT)

In the following discussion, we consider eight-bit grayscale images and denote the least significant bit-plane by the 1^{st} bit-plane, ……, the most significant bit-plane the 8^{th} bit-plane. Our study on many commonly used grayscale images has shown that binary 0s and 1s are almost equally distributed in the first several “lower” bit-planes. The bias between 0s and 1s starts to gradually increase in the several “higher” bit-planes, but not large. This kind of bias indicates redundancy, implying that one may compress bits in a bit-plane or more than one bit-plane so as to leave space to hide data. To achieve a large bias between 0s and 1s, we then resort to image transforms. To eliminate more redundancy to embed more data while avoiding round-off error, we propose to use the second generation wavelet transform such as IWT [5], which maps integer to integer and whose CDF (2,2) format has been adopted by JPEG2000. This technique is based on the lifting scheme [6].

B. Bit-plane Embedding Using Arithmetic Coding

Our study on the commonly used images have demonstrated that we can achieve a larger bias between binary 0s and 1s starting from the 2^{nd} bit-plane of the IWT coefficients than that in the spatial domain. The higher the bit-plane, the larger the bias. However, a change made in a high bit-plane will lead to a larger distortion. In order to have the marked image perceptually the same as the original image, we choose to hide data in a “middle” bit-plane in the IWT domain. To let the marked image have a high PSNR, we embed data only in the high frequency subbands, specifically in the LH_1, HL_1 and HH_1 subbands (refer to Figure 1). Hence, one or multiple middle bit-plane(s) in the high frequency subbands is chosen to hide data.

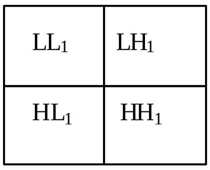


Figure 1 Wavelet subbands.

In the chosen bit-plane(s) of the high frequency subbands, the arithmetic coding is chosen to losslessly compress binary 0s and 1s because of its high coding efficiency [7]. Due to the large bias mentioned-above, the difference between the capacity of the subbands in the bit- plane and the amount of the compressed data is able to accommodate the hidden data together with some book-keeping data. The block diagrams of our proposed lossnless data embedding algorithm are shown in Figures 2 and 3.

C. Block Diagrams

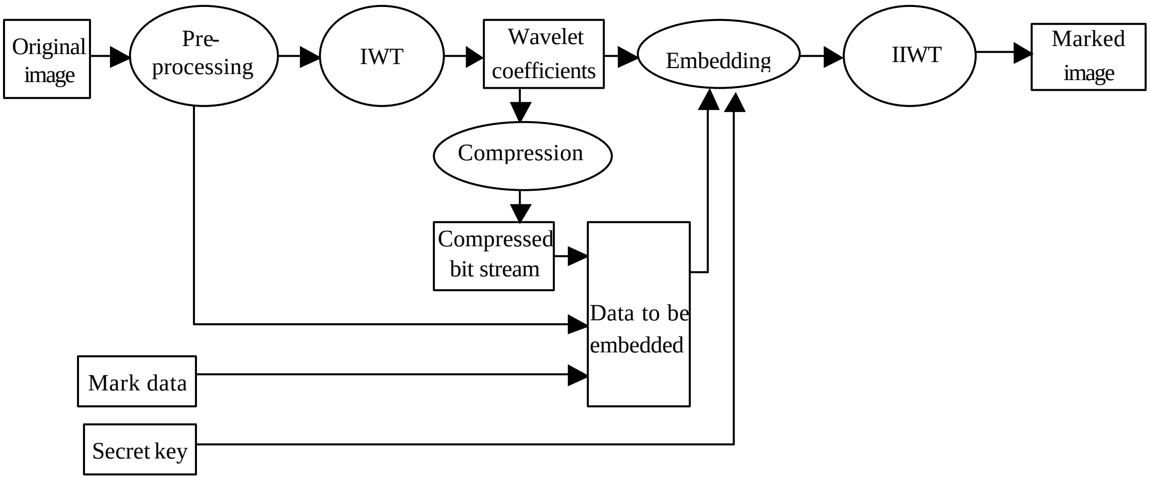


Figure 2 Data embedding algorithm (IWT denoting integer discrete wavelet transform, IIWT inverse IWT).

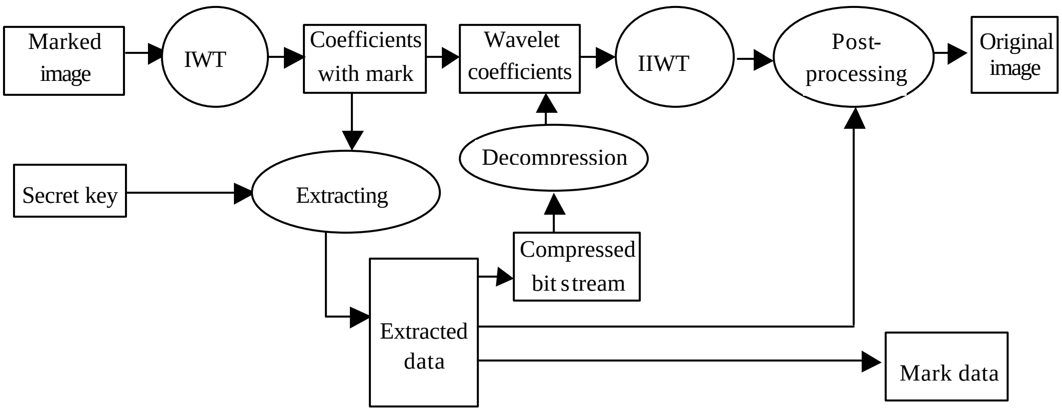


Figure 3 Data extracting algorithm (IWT denoting integer discrete wavelet transform, IIWT inverse IWT).

D. Secret Key

The secret key is used to make the hidden data remaining in secret even after the algorithm is known to the public.

E. Preventing Possible " Overflow"

It is noted that it is possible for a marked image generated by using the above method to have some pixels with *overflowed* grayscale values, meaning that 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). This is possibly caused by changes taking place in the chosen bit-plane of the high frequency IWT coefficients when data are embedded. This problem needs to be resolved in order not to violate the lossless criterion. For this consideration, the blocks of "pre-processing" and "post-processing" are designed and included in the above block diagrams to prevent overflow. For instance, either histogram modification or grayscale mapping can be used to prevent overflow.

In the next section in addition to experiment results, more details of the proposed algorithm are presented.

III. SOME EXPERIMENTAL RESULTS

The proposed lossless data hiding algorithm has been applied to many typical grayscale images and medical images, and has achieved satisfactory results. Here the results with commonly used grayscale images are presented, in particular, the details with "Lena" image are provided. The Lena image is 512x512x8. The data are embedded into the 5^{th} bit-plane of the IWT coefficients in the high frequency subbands LH_1, HL_1 and HH_1. The pre-processing is carried out by the following histogram modification. That is, the lowest and the highest 16 grayscale values are mapped to grayscale values 15 and 240, respectively. In this way, the overflow is avoided. In order to recover the original image losslessly late, the data representing the necessary book-keeping information are also hidden as overhead. The mark signal in the experiment is a binary logo image as shown in Figure 4, equivalent to a binary sequence of 23,040 bits. Hence the hidden data consist of three parts: the mark data, the book-keeping data, and the losslessly compressed data of in the original 5^{th} bit-plane associated with the high frequency subbands. In other words, these three groups of data are embedded into the 5^{th} bit-plane of IWT coefficients of the high frequency subbands. The secret key function used is $y=(k0+k1 \times x) \bmod s$, in which k0=1030, k1=289, $s=3\times256\times256$, and x, y are the coordinates in the 5^{th} bit-plane. This secret key function is to make the data hiding positions secret to the third party.

Figures 5 and 6 are the original and marked "Lena" and "Pepper" images, respectively. It is observed that the imperceptibility requirement is met. Note that even though the PSNR of the marked "Pepper" image versus the original "Pepper" image is only 29.11 dB, there is no any annoying structural interference that can be observed. Our study has shown that the not very high PSNR is attributed to the histogram modification in the pre-processing stage. Because there is no annoying artifact in the marked image, and the original image can be losslessly recovered from the marked image after the hidden data has been extracted, this should not be a problem to worry about. Of course, further improvement is currently under investigation. It is expected that there are efficient ways to enhance our proposed algorithm.

Figure 7 contains other six marked images. Table 1 provides some experimental results. Comparison between the existing lossless marking techniques and the proposed technique in terms of pay-load is presented in Table 2.

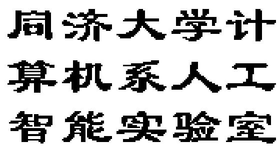


Figure 4 Watermark (a binary image of 192×120).

Figure 5 (a) Original Lena image.

Figure 5 (b) Marked Lena image (PSNR=36.64 dB).

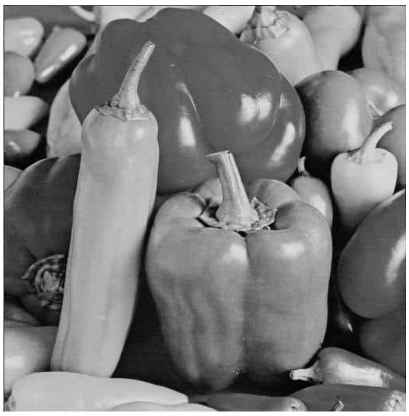


Figure 6 (a) Original Pepper image.

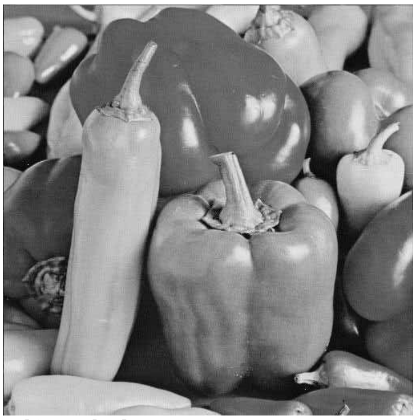
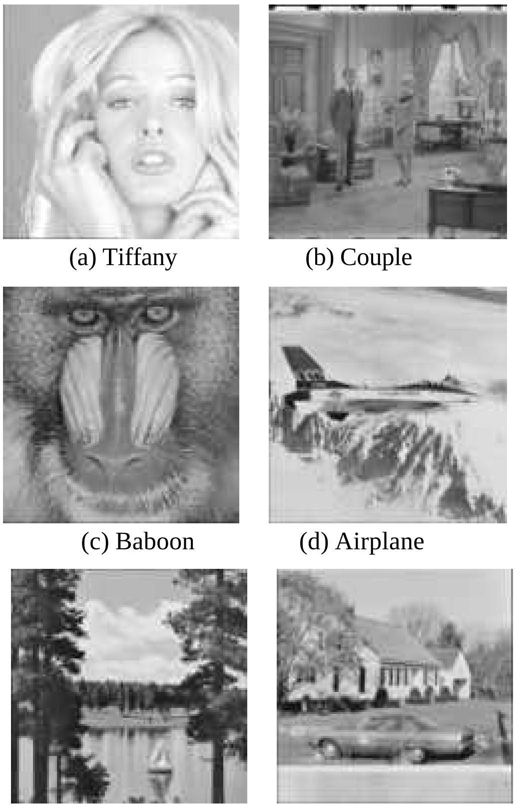


Figure 6 (b) Marked Pepper image (PSNR=29.11 dB).



(a) Tiffany (b) Couple

(c) Baboon (d) Airplane

(e) Sailboat (f) House

Figure 7 Other six marked images.

Table 1 Some experimental results.

Images (512x512x8)	PSNR of marked image (dB)	Pay-load (bits)
Lena	36.64	85,507
Pepper	29.11	69,285
Tiffany	28.91	89,848
Couple	29.83	84,879
Baboon	32.76	14,916
Airplane	36.30	93,981
Sailboat	35.47	44,086
House	36.01	77,726

Table 2. Comparison between two lossless marking methods in [3,4] and our proposed method in terms of the amount of data embedded.

Methods	The amount of data embedded in a 512×512×8 image
Macq's	Upper bound: 2,046 bits
Goljan's	3,000-24,000 bits
Our proposed	15,000-94,000 bits

IV. CONCLUSION

The proposed distortion-free data embedding technique is able to embed about 15k-94k bits into a grayscale image of 512×512× 8 imperceptibly, that is much more than what the existing techniques can do. The key elements of the technique include the utilization of: 1) integer wavelet transform that maps integer to integer; 2) arithmetic coding that losslessly compresses the binary bits in the selected bit-plane of IWT coefficients in the high frequency subbands; 3) pre-processing that prevents the possible overflow; 4) secret key function that maintains the hidden data secret even after the algorithm is revealed. Consequently, the lossless recovery of original image is achieved. The invertible data hiding has wide applications in practice such as in the medical field and law enforcement.

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