HIGH CAPACITY LOSSLESS DATA HIDING BASED ON INTEGER WAVELET TRANSFORM

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ABSTRACT

This paper proposes a novel approach to high capacity lossless data hiding based on integer wavelet transform, which embeds high capacity data into the most insensitive bit-planes of wavelet coefficients. Specifically, three high capacity lossless data hiding methods, namely A, B and C are proposed. Method A is the traditional lossless data hiding technique, which can losslessly recover the original image. The capacity can reach 1/10 of the data volume that the original image occupies and histogram modification is used to prevent over/underflow. Method B is not a traditional lossless data hiding technique. It can only losslessly recover the pre-processed image instead of the original image. However, the capacity can reach 1/2 of the data volume that the original image occupies. It has better visual quality than replacing the four least significant bit-planes in the spatial domain. Method C has not only the larger capacity but also better visual quality than Method B. However, it can only losslessly recover the hidden data. These three methods passed through the test on all 1096 images of CorelDraw database. These techniques can be applied to e-government, e-business, e-medical data system, e-law enforcement and military system.

Key words—integer wavelet transform, high capacity data hiding, histogram modification, pre-processing.

1. INTRODUCTION

With the development of network, people can easily transmit a lot of data over networks, which leads to possible increase of data disclosure. Hence it is necessary to advance research on network transmission security with high capacity data hiding techniques. This paper proposes three lossless high capacity data hiding methods, i.e., Methods A, B and C. Method A is the traditional lossless data hiding technique, which can losslessly recover the original image. Xuan et al. [1] utilized some insensitive wavelet subbands to embed data into one bit-plane of wavelet coefficients. Based on [1], Method A embeds data into multiple bit-planes. Together with the newly developed, more efficient histogram modification and bookkeeping schemes, the visual quality of marked image and embedding capacity have been largely enhanced with Method A. The capacity can reach 1/10 of the data volume that the original image occupies. Method B is not the traditional lossless data hiding technique. It can losslessly recover the pre-processed image instead of the original image. However, the capacity can reach 1/2 of the data volume occupied by the original image because of the pre-processing applied to wavelet coefficients. For a 256 levels gray image, the hidden data capacity can reach 4 bpp (bits per pixel). It has much better visual quality than simply replacing the four least bit-planes in the spatial domain. Method C can only losslessly recover the hidden data instead of the original image or the pre-processed image. However, it has not only higher capacity but also better visual quality than method B. These high capacity data hiding techniques can be applied to e-government, e-business, e-medical data system, e-law enforcement and military system.

The rest of the paper is organized as follows. The integer wavelet transform and the bit-plane allocation are introduced in Section 2, while histogram modification in Section 3. After these fundamentals, high capacity data hiding methods and the experimental results are presented in Section 4. Some applications and conclusions are presented in Sections 5 and 6, respectively.

2. INTEGER WAVELET TRANSFORM AND BIT-PLANES ALLOCATION

2.1. Integer wavelet transform (IWT)

Since it is required to reconstruct the original signal without distortion, we use the integer lifting scheme wavelet transform. Specifically, we adopt the CDF(2,2) and similar series used in JPEG2000 standard. Below is the forward and inverse transform of CDF(2,2) integer wavelet transform.

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

Forward transform	
Splitting:	$s_i \leftarrow x_{2i}$; $d_i \leftarrow x_{2i+1}$
Dual lifting:	$d_i \leftarrow d_i - \{(s_i + s_{i+1})/2\}$
Primary lifting:	$s_i \leftarrow s_i + \{(d_{i-1} + d_i)/4\}$
Inverse transform	
Inverse primal lifting:	$s_i \leftarrow s_i - \{(d_{i-1} + d_i)/4\}$
Inverse dual lifting:	$d_i \leftarrow d_i + \{(s_i + s_{i+1})/2\}$
Merging:	$x_{2i} \leftarrow s_i$; $x_{2i+1} \leftarrow d_i$

2.2. Bit plane allocation

Bit plane allocation is to allocate the to be embedded data into subbands and corresponding bit-planes of wavelet transform. LSB replacement method in wavelet domain performs better than that in spatial domain because wavelet is closer to human visual system (HVS). HVS model points out different insensitivities among different level subbands. The lower level a subband belongs to, the more insensitive to the HVS it is. In the same level, HH subband is the least sensitive, HL and LH subbands are the next, and LL subband is the most. More insensitive to HVS means that more data can be embedded without causing notable visual artifacts.

3. HISTOGRAM MODIFICATION

3.1. Principle of histogram modification

For a given image, after data embedding in some IWT coefficients, it is possible to cause *over/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 over/underflow, we adopt histogram modification, which narrows the histogram from both sides as shown in Figure 1.

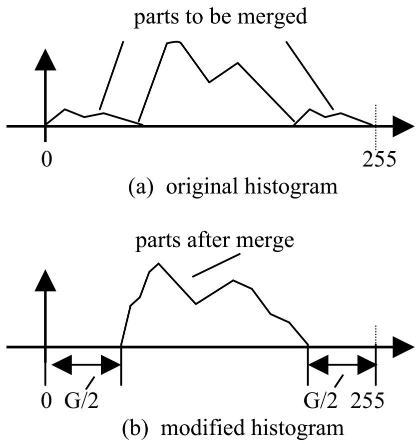
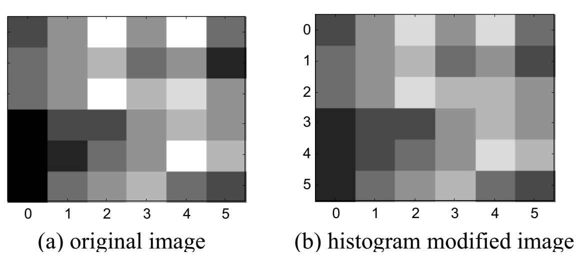


Figure 1. Histogram modification.

In narrowing down a histogram to the range [G/2, 255-G/2], we need to record the histogram modification information as part of the embedded data. To be embedded data come from three parts: 1) watermark signal; 2) bookkeeping information of histogram modification; 3) JBIG losslessly compressed data from the original bit-planes. It is possible to embed data losslessly if the data from these three parts are less than the capacity original bit-planes occupies.

Data are embedded in the order from high frequency (HH,HL,LH) to low frequency (LL), from low level to high level, and from least bit-plane to high bit-planes. In this way, marked image can have the best visual quality.



2	4	7	4	7	3
3	4	5	3	4	1
3	4	7	5	6	4
0	2	2	4	5	4
0	1	3	4	7	5
0	3	4	5	3	2

(c) original image data

2	4	6	4	6	3
3	4	5	3	4	2
3	4	6	5	5	4
1	2	2	4	5	4
1	2	3	4	6	5
1	3	4	5	3	2

(d) modified image data

Figure 2. A simplified histogram modification example.

3.2. A simplified histogram modification example

In order to illustrate the histogram narrow down process, we use a simplified example, where the size of an original image is 6x6 with $8=2^3$ gray scales (6x6x3) as shown in Figure 2.

From Figure 2 and Table 2, we can see that the range of modified histogram now is from 1-6 instead of 0-7, i.e., no pixel assumes gray scales 0 and 7. After modification, gray scale 1 is merged into gray scale 2. Gray scale 0 becomes gray scale 1. In the same way, gray scale 6 is merged into gray scale 5. Gray scale 7 becomes gray scale 6. Histogram before and after modification and bookkeeping information are shown in Table 2 and Table 3, respectively.

Table 2. Histogram data before and after modification.

Gray value	0	1	2	3	4	5	6	7
No. before modification	3	2	4	7	10	5	1	4
No. in modification	3	0	6	7	10	6	0	4
No. after modification	0	3	6	7	10	6	4	0

Table 3. Bookkeeping information.

For image (6×6×3), the histogram is narrowed down 1 gray scale for both sides. G=2, G/2=1. The total bits length is 37 bits.

S=the total book-keeping bit length 37 bits (00100101) +
compressed number of gray scale 2 (010) +
the first histogram from left hand side gray scale “1” (001) +record length 6 (0110) + scan sequence (101101)+
the first histogram from right hand side gray scale “6” (110) + record length 6 (0110) + scan sequence (110111)
S=[00100101 010 001 0110 101101 110 0110 110111]

The left hand side record bits with its left neighbor gray scale (101101) in Table 3 shows that both second and fifth “2” by scanning (<x=5,y=1>,<(x=1,y=4>) in Figure 2(d) are “1” in Figure 2(c) originally. Also the right hand side record bits with its right neighbor gray scale (110111) in Table 3 shows that the third “5” by scanning (<x=4,y=2>) in Figure 2(d) is “6” in Figure 2(c) originally.

4. HIGH CAPACITY DATA HIDING METHODS

4.1. Method A (lossless data hiding)

The principle of high capacity lossless data hiding Method A is similar to [1] except that 1) the data are embedded into multiple bit planes; 2) new schemes for histogram modification and bookkeeping. A block diagram is shown in Figure 3.

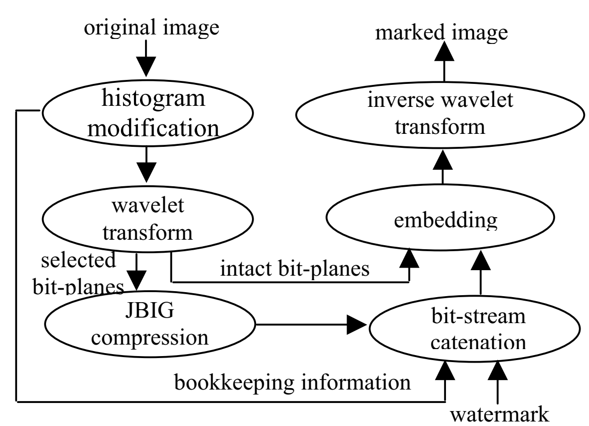


Figure 3. Data embedding diagram.

Three marked images by Method A are in Figure 4.

(a) Lena (b) Barbara (c) Mpic2

Figure 4. Three marked images (512×512).

The curves of embedding capacity versus PSNR of these three images are shown in Figure 5. The hidden data come from MATLAB two dimensional "rand" function. Compared with other methods [1, 2] in terms of capacity and PSNR, the performance of this method is quite high, refer to Table 4. Note that with the same PSNR (36.5 dB), we applied both Method A and Tian's method [2] to Mpic2, shown in Figure 4 (c). Method A achieves higher embedding capacity than Tian's method [2], which is one of the most recent and advanced lossless data hiding schemes. Compared with our previous method [1], Method A has performed much better.

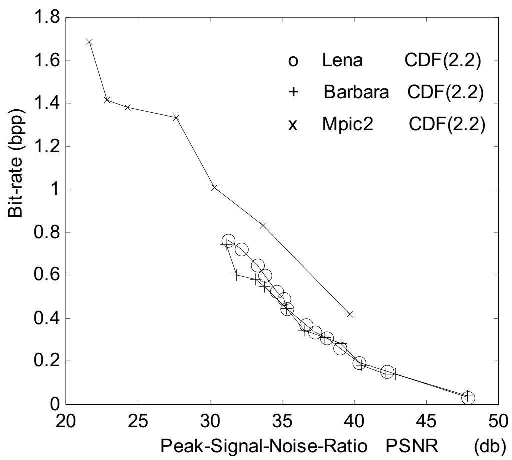


Figure 5. Test results of Method A.

Table 4. Performance comparison on Mpic2 image.

	Method A	Method [1]	Tian's [2]
bit/pixel	0.7 bpp	0.27 bpp	0.55 bpp
PSNR	36.5 db	30 db	36.5 db

4.2. Method B

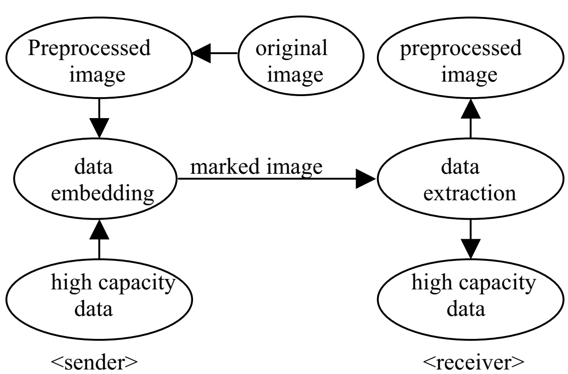


Figure 6. Block diagram of Method B.

The pre-processing on the wavelet coefficients includes: 1) histogram modification to prevent over/underflow; 2) forward integer wavelet transform; 3) clearance of multiple bit planes of wavelet domain; 4) inverse integer wavelet transform. Here, instead of the original image, only the pre-processed image can be losslessly recovered . A block diagram of Method B is shown in Figure 6.

4.3 Method C

In histogram modification, sometimes it has to further narrow down the histogram just for the possible over/underflow of several pixels. If we save the information of these pixels instead of further narrow down the histogram, we can get higher PSNR. In data embedding, Method C selectively replaces the bits of multiple bit planes and remembers the location instead of clears all bits of the bit planes. Hash function is used in the data embedding. Method C can losslessly recover the hidden data while the original image has been lossy.

4.4 Three curves of capacity versus PSNR for Lena image

Figure 7 shows curves of embedding capacity versus PSNR for Methods A, B and C for Lena image. The hidden data come from form MATLAB 2-D "rand" function. It is observed Method A keeps high PSNR and relatively lower embedding capacity. This is expected since it can reverse a marked image to its original image. While both can achieve high embedding capacity, Method C achieves higher PSNR than Method B as expected.

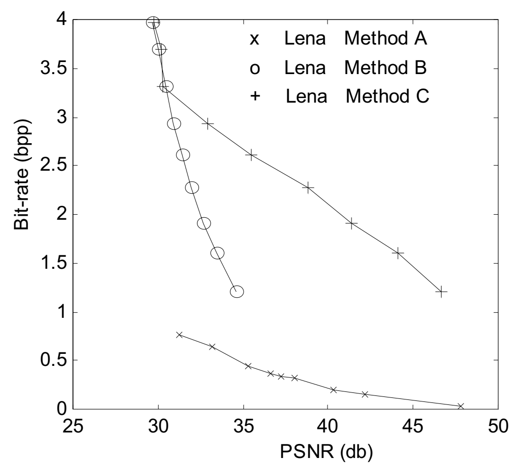


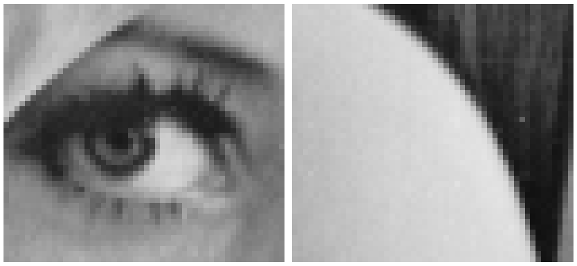
Figure 7. Data hiding of Lena image for method A, B and C.

Table 5 provides a comparison between Method C and the method in spatial domain, which embeds data from the LSB to the second LSB and so on, both at an embedding capacity of 1.9 bpp. We do see Method C constantly achieves much higher (6 – 10 dB higher) PSNR due to the superiority of IWT.

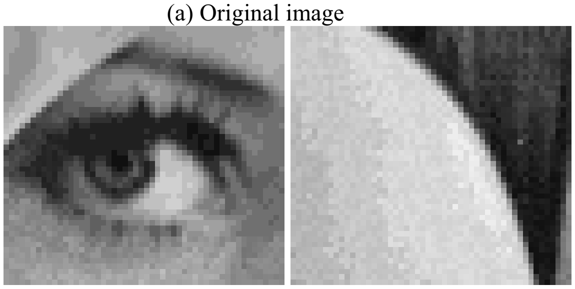
Table 5. Comparison of method C and method in spatial domain.

images	wavelet PSNR (db)	spatial PSNR (db)	images	wavelet PSNR (db)	spatial PSNR (db)
Lena	41.38	30.77	Baboon	38.78	31.50
Elaine	36.77	30.60	Barbara	41.38	30.83
Boat	41.46	30.87	Pepper	41.44	30.89
House	41.16	29.00	Tank	41.47	30.77
Goldhill	41.44	30.54	Milkdrop	41.14	30.46
Sailboat	41.43	31.18	Fingerprint	41.32	30.69
Airplane	41.14	30.89			

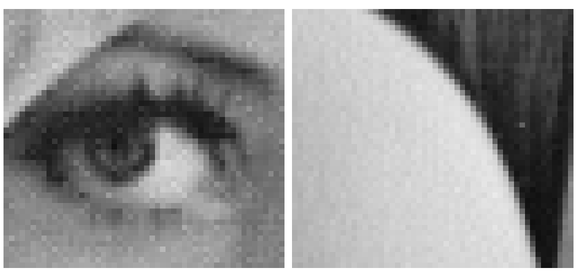
Figure 8 contains two detailed parts, i.e., right eye and shoulder, of marked Lena image. It is clearly shown that Methods B and C have achieved not only 6-10 dB higher PSNR as shown in Table 5, but also better visual quality than the spatial method (applying the LSB data hiding, followed by the next LSB embedding and so on).



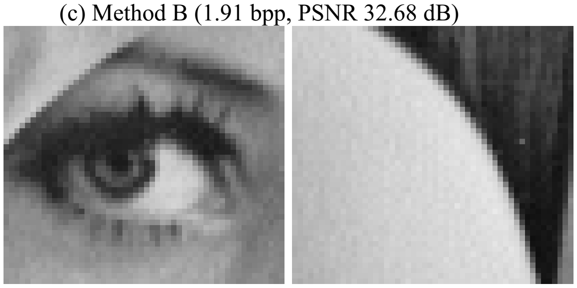
(a) Original image



(b) Spatial domain method (1.91 bpp, PSNR 30.77 dB)



(c) Method B (1.91 bpp, PSNR 32.68 dB)



(d) Method C (1.91 bpp, PSNR 41.39 dB)

Figure 8. Part of Lena image (right eye and shoulder).

We have successfully tested three methods on all of 1096 gray images (512 x768) of CorelDraw database.

5. APPLICATIONS

We have applied Method B in hiding traffic images. As shown in Figure 9, we embed five color traffic images (352x288) (a) into a pre-processed image (1024x768) (b) and produced a marked image (1024x768) (c). From these figures, it is difficult to distinguish image (c) from (b).

(a)

(b) (c)

Figure 9. An example of applying Method B.

6. CONCLUSION

This paper has proposed three high capacity data hiding techniques based on the integer wavelet transform. The performance of them is better than that in the spatial domain, especially the visual quality of marked images is much higher. Method A can losslessly recover the original image with higher capacity and better visual quality compared with other methods. Method B can losslessly recover the pre-processed image. Method C can only losslessly recover the hidden data. However, both of them have high capacity and good visual quality. These three methods have been applied to 1096 gray images in CorelDraw database and all have passed the test. These methods are appropriate to the fields of E-government, network bank, and have obtained quite good performance.

7. REFERENCES

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