Reversible Image Watermarking using Bit Plane Coding and Lifting Wavelet Transform

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Summary
This paper proposes a distortionless image data hiding algorithm based on integer wavelet transform that can hide data into the original image .The data can be retrieved and the original image can be recovered without any distortion after the hidden data are extracted. This algorithm hides data into one or more middle bit-plane(s) of the integer wavelet transform coefficients in the LH, HL and HH frequency sub bands. It can embed more data into the bit planes and also has the necessary imperceptibility requirement. The image histogram modification may be used to prevent grayscales from possible overflow or underflow. Experimental results have demonstrated the performance of the algorithm.
Key words:
Reversible image data hiding, bit plane, compression, integer wavelet transform, lifting scheme.

1. Introduction

Many data embedding methods use procedures that in which the original image is distorted by quite a small amount of noise due to data embedding itself.
This distortion cannot be removed completely due to quantization, bit-replacement, or truncation at the grayscale ends. Even though the distortion is often quite small, it may not be acceptable for medical imaging for legal reasons or for military images inspected under altered viewing conditions like filtering or zooming. In this paper, we introduce a approach for high-capacity data embedding that is lossless without any distortion. After the embedded information is extracted from the stego-image, we can revert to the exact copy of the original image before the embedding occurred. The new method can be used as a powerful tool to achieve a variety of tasks that needs distortion-free image after watermark embedding and extraction of watermarks. The proposed concept can be extended to commonly used image formats. Two techniques proposed in [1] is based on robust spatial additive watermarks combined with modulo addition and the second one on lossless compression and encryption of bit-planes The first technique embeds the hash of the whole image as a payload for a robust watermark and the second method for invertible authentication based on lossless compression of bit-planes and encryption is much more transparent for analysis. A high capacity distortionless data embedding method is presented which has opened many lossless data embedding methods [2].
A method for reversible data-embedding in digital images using a technique called difference expansion is discussed. Location map is used to locate the marked coefficients. The redundancy in the digital content to achieve reversibility is used. The payload capacity limit and the visual quality of embedded image are considered [3].
Reversible data hiding, in which the watermarked image can be reversed to the original cover media exactly, has attracted increasing interests from the data hiding community. The existing reversible data hiding algorithms, have been classified as those developed for fragile authentication, for achieving high data embedding capacity, for semi-fragile authentication. In each category the principles, merits, drawbacks and applications of these algorithms are analyzed and addressed [4].
A reversible Data Hiding method based on wavelet spread spectrum and histogram modification. Using spread spectrum scheme data is embedded in the coefficients of the integer wavelet transform in high frequency bands [5].A lossless data hiding method for digital images using IWT and embedding based on threshold is done. Data are embedded into the LSB planes of high frequency integer wavelet coefficients whose magnitude are lesser than a chosen threshold [6].
Data is embedded in the bit planes of color component of the Integer wavelet transformed image. Bit plane complexity segmentation is used. To estimate the complexity a particular criteria is used and the IWT coefficient areas which can be replaced to maintain imperceptibility is used[7].Reversible data Hiding Scheme for binary images is suggested. JPEG2000 compressed data is used and the bit-depth of the quantized coefficients are also embedded in code-blocks [8].

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2. Integer-To-Integer Wavelet Transforms

In conventional wavelet transform reversibility is not achieved due to the floating point wavelet coefficients, we get after transformation. When we take the inverse transform the original pixel values will get altered.

When we transform an image block consisting of integer-valued pixels into wavelet domain using a floating-point wavelet transform and the values of the wavelet coefficients are changed during watermark embedding, the corresponding watermarked image block will not have integer values. When we truncate the floating point values of the pixels, it may result in loss of information and reversibility is lost. The original image cannot be reconstructed from the watermarked image. In conventional method wavelet transform is done as a floating-point transform followed by a truncation or rounding and it is impossible to represent transform coefficients accurately. Information will be potentially lost through forward and inverse transforms.

In view of the above problems, an invertible integer-to-integer wavelet transform based on lifting is used in the proposed scheme. It maps integers to integers which are preserved in both forward and reverse transforms. There is no loss of information.Wavelet or subband decomposition associated with finite length filters is obtained by a finite number of primal and dual lifting followed by scaling.In the discussion, we consider eight-bit grayscale images and denote the least significant bit-planeas the 1st bit-plane, the most significant bit-plane the 8th bit-plane. In the commonly used grayscale images the study shows binary 0s and 1s are almost equally distributed in the lower bit-planes. The bias between 0s and 1s starts gradually increasing in the higher bit-planes. This kind of bias indicates redundancy, implying that we can compress bits in a particular bit-plane or more than one bit-plane to leave space to hide other data like text or image as watermark. Image transforms offer a larger bias between 0s and 1s in the wavelet domain than in the spatial domain. To eliminate more redundancy to embed data and to avoid round-off error, we propose to use the second generation wavelet transform such as IDWT which maps integer to integer. This technique is based on the lifting scheme.

2.1 Bit-plane Embedding Using Arithmetic Coding

Study has revealed that bias between binary 0s and 1s starting from the 2^{nd} bit- plane of the IDWT coefficients increases than in the spatial domain. The higher the bit-plane, the larger the bias. But alterations made in higher bit-plane will lead to degradation of image quality. In order to have the watermarked image perceptually the same as the original image, we choose to hide data in one or more middle bit planes in the IDWT domain. The approximate coefficients in the LL subband contribute to visual perception. So specifically the LH, HL and HH subbands are used for watermark embedding.

In the chosen bit-plane of the middle and high frequency subbands, the arithmetic coding is used to losslessly compress binary 0s and 1s because of its high coding efficiency.

3. Proposed Scheme:

The given image is decomposed into its frequency components using suitable wavelet transform. We have used the integer discrete wavelet transform IDWT and the pixel values are transformed in the forward and reverse directions losslessly.

In the proposed scheme the watermarked bits are embedded into bit planes.

The original image is preprocessed by performing lifting scheme. Now integer to integer wavelet transform is performed to decompose the image into its components namely, Approximate coefficients, horizontal, vertical coefficients and diagonal coefficients.

We use the horizontal vertical as well as the diagonal detailed bands to embed the watermark. We chose a bit plane of the detailed bands. The original bits in the selected plane are compressed losslessely to create space for embedding the payload bits.

The compression exploits the fact that ‘0’sand ‘1’s are nonuniformly distributed as we move from least significant bit plane to higher ones After compression necessary headers are generated reflecting the original bit distribution in the chosen plane of the quadrants.

3.1Embedding Process:

For a given image of size M x N in which the gray scale set {1,2…..255} indicate the pixel values and the wavelet coefficients are represented using eight bits. All the LSBs in a block represent the lowest bit plane, the next significant bits form the next plane and so on till the most significant bits form the most significant plane. Watermark bits are embedded in the chosen bit plane. Let B represent original bits in the chosen plane and CB the compressed bits. Let W be the watermark bits.

16 Bits	16 Bits	16 Bits	16 Bits	16 Bits	16 Bits	32 Bits
CH Header	CV Header	CD Header	CH Length	CV Length	CD Length	Watermark Length

CH, CV, CD headers represents the bit distribution needed for arithmetic encoder and decoder used for compression. CH, CV and CD Length represent the length of compressed bit stream in the chosen plane of the LH, HL and HH components. Bit Plane Identification shows

[8^{th} 7^{th} 6^{th} 5^{th} 4^{th} 3^{rd} 2^{nd} 1^{st}] are the plane identifiers.1^{st} plane represents the least significant plane and 8^{th} plane represents the most significant plane.

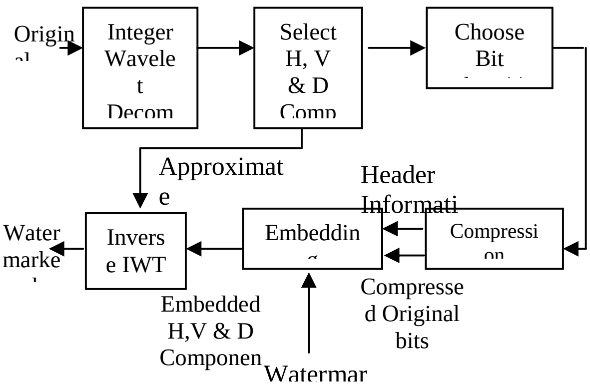

Fig 1. Embedding Process

3.2Embedding Algorithm

1. Read the original Image and decompose it into its sub bands.
2. Separate the H, V and D detailed bands for watermarking.
3. Construct binary images of H,V and D of the chosen bit plane.
4. Compress the original bits in the chosen plane of these bands and derive the necessary headers needed for the arithmetic encoder and decoder.
5. Read the water mark and convert it in to a bit string.
6. Now concatenate the header length, header, compressed bit stream CH, CV, CD and the watermark bits to a single bit stream.
7. Start embedding bit stream in to the bit plane of H. If not over continue in V and then in D and get the marked components of the image.
8. Now compute the inverse integer wavelet transform of the watermarked image from A and the embedded H,Vand D components to get the watermarked image.

3.3Extraction Algorithm

1. Read the watermarked image and take the integer wavelet transform to get the embedded H, V and D sub bands and the unmarked approximate coefficients.
2. Separate the header , compressed H, V and D sub bands and the watermark bits.
3. Remove the watermark bits and decompress the planes of the H, V and D sub bands to get the reconstructed sub bands.
4. Take inverse integer transform of the reconstructed H, V and D sub bands after decompression along with the unmarked approximate component to get the original image.

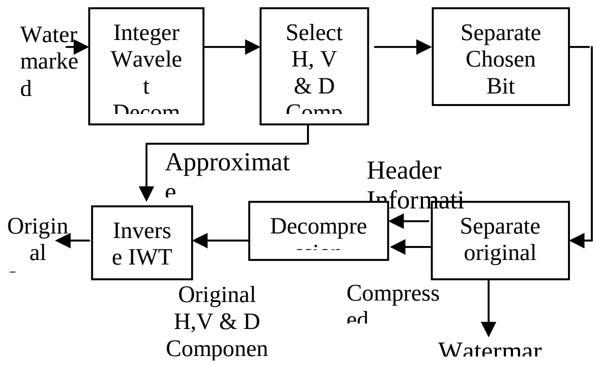

Fig 2. Extraction Process

4. Experimental Results and Discussions:

4.1 Watermarked Image Quality Performance measure

Watermarking the original image slightly degrades the original images as far as peak signal to noise ratio (PSNR) is concerned. But it is well within the visual perception and we do not readily visualize the watermark and the degradation. The visual quality of the marked image is measured in PSNR. The mean square error (MSE)

Table 1 Image Quality Tested for different Gray Scale Images for each Payload using bior 3.3 wavelet

Watermark Image Size	Payload bpp	Lena	Baboon	Barbara
10	0.0003	32.81	28.61	31.28
50	0.01	32.78	28.60	31.22
100	0.04	32.67	28.57	31.10
150	0.09	32.46	28.53	30.74
200	0.15	32.10	28.47	30.29
250	0.24	31.69	x	31.01
300	0.34	31.28	x	29.94
350	0.47	31.18	x	x
400	0.61	x	x	x
450	0.77	x	x	x

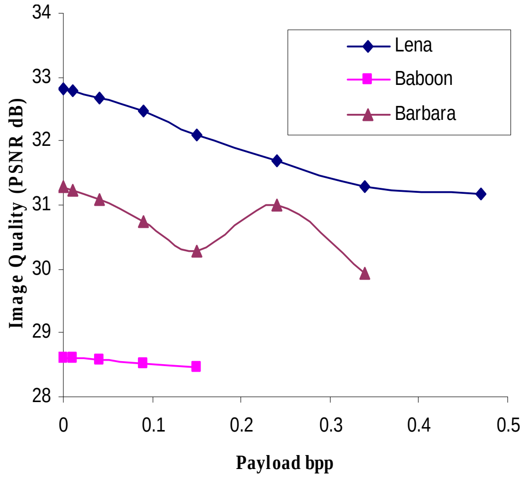

Fig 3 Comparison of embedding Capacity in bpp versus distortion in PSNR for different Grayscale Images

Table 2 Embedding Capacity of bit plane 4 and bit plane 5

Embedded Bits	PSNR	
	Bit Plane 5	Bit Plane 4
100	34.50	35.18
2500	34.45	35.14
22500	33.92	34.87
40000	34.86	34.72
50625	33.83	34.64
62500	33.07	34.59
90000	32.36	x
122500	32.13	x

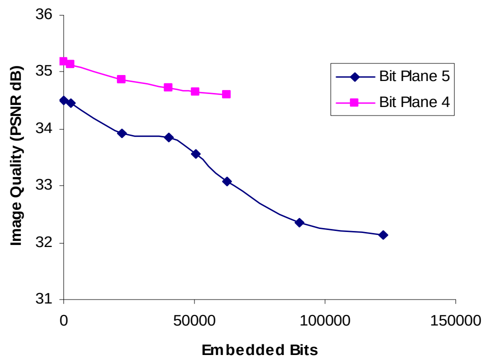

Fig 4 Comparison of embedding Capacity and Image Quality in different bit planes.

a b

c d e f

Fig 5 Original Image and Watermarked Image. a. Original Image, b. 30.01 dB with 129600 bits c. 30.36dB with 105625 bits, d. 30.62 dB with 78400 bits, e. 30.93 dB with 55225 bits, f. 31.36 dB with 22500 bits

indicate the difference between the original image and the watermarked image.

$$PSNR = 10\log_{10}\frac{255^2}{MSE} \tag{1}$$

$$MSE = \frac{1}{n}\sum_{i=1}^{n}\left(I(i) - I'(i)\right)^2 \tag{2}$$

Where I and I' are the original and watermarked Images respectively, n is the total number of pixels. 255 refer to the maximum possible pixel value in an eight bit image. Higher PSNR represents better signal quality.

Table 1 shows the Image Quality of different Gray scale images for each payload. The embedding capacity is image dependent and is also based on the bit distribution of the chosen bit plane. The table shows Lena has better embedding capacity than Baboon and Barbara. Figure 4 indicates the comparison of the images for different payloads.

Table 2 shows the embedding capacity of lower bit planes is lesser than the higher bit planes. Experiment is conducted on bit plane 4 and bit plane 5.results show bit plane 5 has more embedding capacity but since it is more significant plane, the PSNR is slightly lesser in this plane, than in Plane 4.

Figure 5 indicates these results.

Table 3 shows the performance of different wavelets on Lena , Baboon and Barbara images. The PSNR for the payload of 10000 bits is shown along with the mean square error between the original and the water marked image.

Table 3. Performance of various wavelets and their Image Quality in PSNR for a fixed payload of 10000 bits

Wavelet Type	Images					
	Lena		Baboon		Barbara	
	PSNR	MSE	PSNR	MSE	PSNR	MSE
coif1	30.81	51.41	29.23	72.27	30.64	59.61
9.7	34.81	20.14	29.70	64.27	32.06	37.28
cdf 2.2	34.92	20.09	29.35	67039	31.83	41.61
db2	31.77	41.52	29.40	63.37	30.85	50.91
sym 2	31.77	41.5	29.40	63.37	30.86	50.91
bior 1.1	32.56	34.09	29.26	64.78	30.88	51.08
bior 3.3	32.87	33.48	28.61	82.67	31.257	46.79
bior 6.8	X	X	30.25	67.67	32.475	41.52
rbio 1.1	X	X	30.01	54.68	31.873	39.31
rbio 3.3	X	X	28.65	78.679	31.125	47.84
rbio 6.8	34.50	22.162	29.37	71.65	31.98	40.53

X – indicates capacity is insufficient for embedding.

a b c d

Fig 6. Original and watermarked images: (a) Original Image (b) Watermarked with 10,000 bits at-34.92 dB (c) 62,500 bits error 16 PSNR 33.4623 (d)122500 bits error 16 PSNR 32.4736

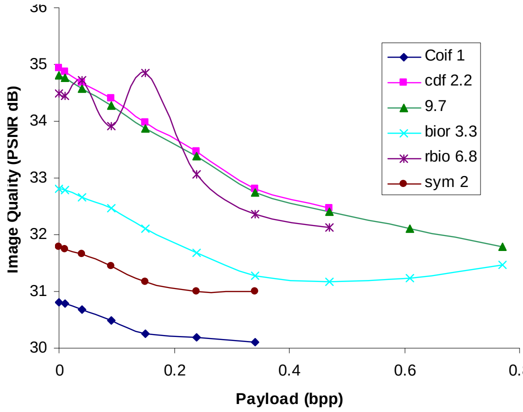

Fig 7. Performance of different Wavelets tested on Lena Image for Image Quality (PSNR) vs Payload (bpp).

5. Conclusion

Lossless image watermarking is done and is completely reversible. Arithmetic coding used for compression guarantees complete reversibility. Lower bit planes have lower embedding capacity but since they are less significant for visual perception image quality is better than in higher bit planes. Performance of various wavelet families are shown.

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