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Reversible Watermarking for Image Authentication using IWT

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Abstract

This paper proposes a 'Reversible Watermarking scheme for Image Authentication' (RWIA) using Integer Wavelet Transform that satisfies the requirements of imperceptibility, capacity, and robustness. The proposed algorithm hides the data and the bookkeeping information in the high frequency subbands of CDF (2,2) integer wavelet coefficients whose magnitudes are similar to a certain predefined threshold. Histogram modification is applied as a preprocessing to prevent overflow/underflow. The embedding technique is based on the parent-child structure of the transformed coefficients called "quadruple wavelet tree" (QWT). The paper provides a comprehensive analysis of the existing methods. The experimental results evaluated by the proposed technique on different grayscale images and a comparison with existing methods is found better. The watermark is extracted to an acceptable degree of normalized cross correlation even in the presence of attacks like geometric transformations and JPEG compression.

Keywords: *Reversible Data Hiding, Lifting Wavelet Scheme, Integer Wavelet Transform, Wavelet Tree*

1. Introduction

Reversible watermarking also called lossless data hiding is a method of hiding secret data into cover media, such as digital images, videos, audios, etc. and it enables marked media to be restored to their original form without any distortion. Several reversible watermarking methods have been proposed in Spatial Domain [1-5] and Transform Domain [6-9] for grayscale images. Tian [6] method is based on difference expansion (DE) of high-frequency coefficients of an image transformed by integer Haar wavelet transform. Xuan, *et al.*, [20-22] performs histogram shifting of high frequency coefficients and reversibly embeds the watermark bits into the middle and high frequency integer wavelet coefficients. Wu, *et al.*, [23] used parameterized integer wavelet transform using lifting scheme to improve the accuracy in tamper detection Lee, *et al.*, [13] proposed a high capacity reversible image watermarking scheme based on integer-to-integer wavelet transforms in which a watermark is embedded into the high-frequency wavelet coefficients of each image block. Yousefi, *et al.*, [24] explains a lossless data hiding method using integer wavelet transform in which small coefficients of the high frequency subband are modified to embed data. The histogram modification is done to prepare enough space for data hiding. Zou, *et al.*, [14] introduced a robust lossless data hiding scheme in Integer Wavelet Transform (IWT), which classified the IWT coefficients of an image blocks into special categories for data embedding and hence does not suffer from annoying salt-and-pepper noise. Kwon and Tewfik [25] method embeds a Gaussian random sequence with unit variance as watermark in the discrete multi wavelet transform (DMT) domain using successive subband quantization and a perceptual modeling. Ghouti, *et al.*, [15] embedding method is based on the principles of Spread-spectrum communications using balanced multiwavelet transform. Wang and Lin [16] groups the transformed ccoefficients into a structure called super tree. The Watermark bits are embedded by quantizing super tree and the resulting difference between quantized and unquantized trees is used for watermark extraction. Kumsawat, *et al.*, [26] embeds the watermark into the DMT coefficients using multiwavelet tree techniques. Maruthu Perumal and Vijaya Kumar [18] proposed a wavelet based Digital Watermarking (DW) approach in which a threshold, based on Intermediate Bit Values (TIBV) of image pixels for selecting the image pixels for inserting the watermark. In [19], Sumalatha et al. presented an image watermarking scheme based on the Simplified Significant Wavelet Tree (SSWT) and each watermark bit is embedded into the trees. The trees are quantized so that they exhibit a large enough statistical difference, which are later, used for watermark extraction. However the method is not reversible and the recovery of the embedded data is based on the quantization of the trees. The present paper extends the concept of super trees by proposing a reversible watermarking method which embeds the watermark into the wavelet trees.

The rest of this paper is organized as follows. Section 2 describes the Integer Wavelet Transform using lifting scheme. Section 3 illustrates the wavelet decomposition. In Section 4, describes about histogram modification, the proposed watermark embedding and extraction methods are described in Section 5. The experimental results and discussions are presented in Section 6. Finally, conclusions of this paper are given in Section 7.

2. Integer Wavelet Transform (IWT) using Lifting Scheme

Lifting scheme is an effective implementation of the wavelet filtering operations and improves the processing speed of WT. The lifting scheme allows designing second-generation wavelets that are non-separable. The present paper uses the lifting scheme on the Cohen, Daubechies and Feauveau classical biorthogonal wavelet with two vanishing moments (CDF (2, 2)) for both the primal and dual wavelet. For one dimensional signal $x_1 \ldots\ldots x_n$ the lifting scheme looks like:

- Splitting: The signal x is split into even and odd samples,

$$S_i \leftarrow x_{2i} \text{ and } d_i \leftarrow x_{2i+1} \tag{1}$$

- Prediction: A dual lifting step can be seen as a prediction .The odd samples are predicted using linear interpolation

$$d_i \leftarrow d_i - \left\{\frac{(S_i+S_{i+1})}{2}\right\} \tag{2}$$

- Update: The even samples are updated to preserve the mean value of samples. To restore this property, one needs a primal lifting step

$$S_i \leftarrow S_i + \left\{\frac{(d_{i-1}+d_i)}{4}\right\} \tag{3}$$

These steps can be repeated by iteration on the Si, creating a multi-level transform or multi-resolution decomposition. The inversion rules are obvious: revert the order of the operations, invert the signs in the lifting steps, and replace the splitting step by a merging step:

- Inverse primal lifting:

$$S_i \leftarrow S_i - \left\{\frac{(d_{i-1}+d_i)}{4}\right\} \tag{4}$$

- Inverse dual lifting:

$$d_i \leftarrow \left\{\frac{(S_{2i}+S_{2i+1})}{2}\right\} \tag{5}$$

- Merging:

$$x_{2i} \leftarrow S_i, \quad x_{2i+1} \leftarrow d_i \tag{6}$$

In multimedia applications (images, video, and audio) the input data consists of integers only. Conventional wavelets use a floating-point wavelet transform to convert an image consisting of integer-valued pixels into a wavelet domain. The disadvantage of this is the truncation of the floating point values of the pixels during watermark embedding may result in a loss of information. From this the corresponding watermarked image is no longer guaranteed to have integer values [13]. Based on this the present study understands that conventional wavelets do not suit for reversible data hiding. Integer wavelet transform constructs lossless wavelet transform which is important for fragile watermarking. To address the above issues, the present study choose lifting scheme, to construct integer wavelet transform. Invertible integer-to-integer wavelets transform [10-12] based on lifting scheme do not cause any loss of information through forward and inverse transforms. Another advantage of this scheme is that it also retains the perfect reconstruction property and hence perfectly suitable for reversible data hiding.

3. Wavelet Tree Decomposition

The present paper extends the study on wavelet trees and developed new concepts based on wavelet tree data structures to address the problem of (1) obtaining the best image quality for a given bit rate, and (2) to render the watermark more resistant to frequency based attacks, *i.e.*, to achieve high robustness. The host image of size n×n is transformed into wavelet coefficients using the L level DWT. With L level decomposition, one can have L×3+1 frequency bands. For an N scale transform, the scan begins at the lowest frequency subband, denoted as LL_N, and scans subbands HL_N, LH_N and HH_N, at which point it moves onto the scale N-1, etc. Each coefficient within a given coarser subband is scanned before any coefficient in the next finer subband. The proposed scheme is experimented with four levels as shown in Figure 1(a), when L = 4, the lowest frequency subband is located in the top left (*i.e.*, the LL_4 subband), the highest frequency subband is at the bottom right (*i.e.*, the HH_1 subband). The relationship between these frequency bands from the blocks of variable size can be seen as a parent child relationship. With the exception of the lowest frequency subband LL_4, the parent can be connected between these sub nodes to form a wavelet tree. If the root consists of more than one node, then an image will have many wavelet trees.

(a) (b)

Figure 1. a) Wavelet Decomposition and its Subbands b) Tree Structure of Wavelet Coefficients and Parent Child Relationship of Wavelet Tree

A wavelet tree descending from a coefficient in subband LH_4, HL_4 and HH_4 is shown in Figure 1(b). With the exception of the lowest frequency subband, all parent nodes have four children. For the lowest frequency subband, the parent child relationship is defined such that each parent node has three children in the wavelet tree. In the proposed approach, the scanning of the coefficients is performed in such a way that no child node is scanned before its parent. A four level wavelet tree with this description is called ‘Quadruple Wavelet Tree’ (QWT), which is represented in Figure 2. By using a four level wavelet transform image of a 512×512, at the fourth level, the subbands, LH_4, HL_4, HH_4 contains 32^2 coefficients, and by this a total $3\times32^2=3072$ trees are formed in QWT. Each tree consists of 1+4+16+64 = 85 coefficients.

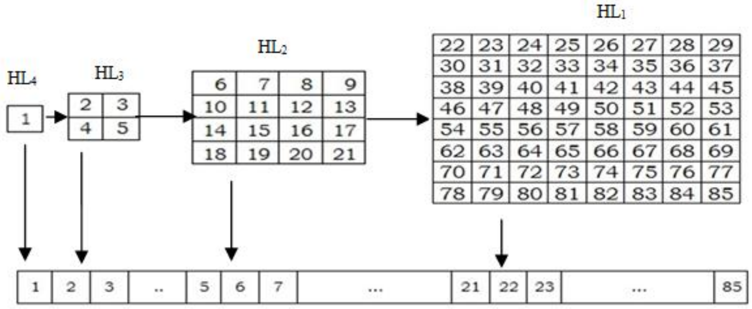
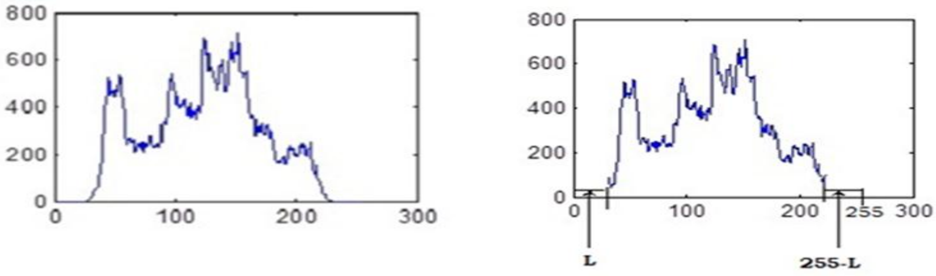


Figure 2. The 85 Wavelet Coefficients of a QWT for an Original Image of size 512 × 512 and Ordering of Coefficients from Coarser Scale to Finer Scale of QWT

4. Histogram Modification

The data embedding process may cause possible overflow and/or underflow in some IWT coefficients. This indicates that after inverse wavelet transforms the grayscale values of some pixels in the watermarked 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). To prevent the overflow and underflow the proposed method adopted histogram modification. The histogram of Lena image is shown in Figure 3(a). Histogram modification narrows the histogram from both sides as shown in Figure 3(b). In narrowing down a histogram to the range [L, 255-L], the present approach records the histogram modification information, as part of the embedded data. The modified information by histogram is called as bookkeeping information. By this the embedded data contains two parts: 1) watermark data, 2) bookkeeping information. The amount of bookkeeping information is small. The proposed approach restores efficiently the original image by using the bookkeeping information.



(a) (b)

Figure 3. Histogram Modification: a) Original Image Histogram; b) Modified Image Histogram

5. Watermark Embedding and Extraction

5.1 Embedding Algorithm

Step1: Transform the original image into using 4-level CDF(2,2) using lifting scheme. Then, create the wavelet trees and rearrange them into 3072 groups as discussed in Section 3.

Step2: Group these in a pseudorandom manner controlled by a secret key. Combine the Coefficients of the subbands LH_4, LH_3, LH_2 and LH_1 to form a QWT as represented in Figure 2.

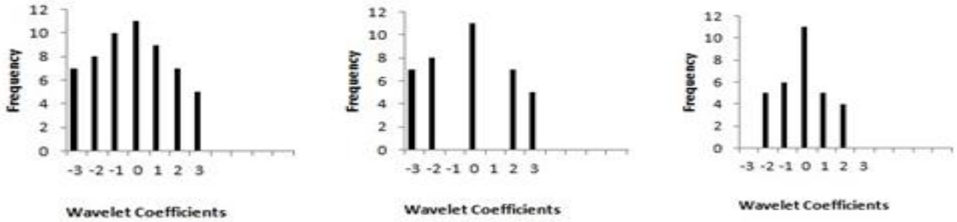
Step3: Before data embedding, the coefficients are modified by the proposed approach to obtain extra space for embedding using histogram shifting of the wavelet coefficients. For this purpose, a threshold ‘τ’ which is a nonnegative integer is selected by the proposed approach. Then the histogram shifting process aims at making zero points beside the coefficients whose value is equal to $\pm\tau$ based on equation (7). After the modification there are no coefficients that are equal to $(\tau+1)$ or $-(\tau+1)$.

$$y' = \begin{cases} y+\tau & \text{if } y \geq \tau \\ y-\tau & \text{if } y \leq -\tau \\ y & \text{otherwise} \end{cases} \tag{7}$$

This process is illustrated in Figure 4 by considering $\tau = 1$.

Step4: Embed a watermark bit into the coefficients that are equal to τ based on equation (8). The data is embedded by using the modified coefficients obtained in the previous step. For this the proposed method scans all the coefficients from left to right and when a coefficient which is equivalent to τ is met, and the embedded bit is "1", the coefficient is increased by 1. Otherwise, the coefficient value is kept intact.

$$y' = \begin{cases} y+b & \text{if } y = \tau \\ y-b & \text{if } y = -\tau \\ y & \text{otherwise} \end{cases} \tag{8}$$



(a) (b) (c)

Figure 4. Histogram Shifting of the Wavelet Coefficients with τ=1: a) Before Shifting; b) After Shifting; c) After Embedding

Step5: Perform the inverse quantization in each group of all quadruple trees and pass the modified QWT coefficients through the inverse IWT to obtain the watermarked image.

The selection τ is a critical issue because low valued high frequency IWT coefficients do not require any compression due to rare chances of overflow and underflow. Smaller value of τ significantly reduces the coefficients alteration and hence results in a good visual quality of a marked image. And also the variation of the signal after watermark embedding is small and can hardly be perceived. The value of L discussed in the Section 4 is equal to τ . The histogram is shifted from both sides by τ units which enable to avoid occurring overflow and underflow.

5.2 Extraction Algorithm

The extraction algorithm consists of six steps,

Step1: Transform the received image by four level decomposition of IWT.

Step2: Then, create the wavelet trees and rearrange them into 3072 groups.

Step3: Group these in a pseudorandom manner controlled by a secret key. Combine the coefficients of the three subbands LH_4, LH_3, LH_2 and LH_1 to form a QWT.

Step4: Generate the histogram of the coefficients.

Step5: The threshold τ is used to find the watermarked coefficients. From the watermarked coefficients extract a bit of information by (9),

$$b = \begin{cases} 0 & \text{if } y = \tau \\ 1 & \text{if } y = \tau + 1 \ \text{ or-}(\tau + 1) \end{cases} \tag{9}$$

Step6: Recover the original coefficients by (10),

$$y = \begin{cases} y' - \tau & \text{if } y' \geq (\tau + 1) \\ y' + \tau & \text{if } y' \leq -(\tau + 1) \\ y' - b & \text{if } y' = \tau \\ y' + b & \text{if } y' = -\tau \\ y & \text{otherwise} \end{cases} \tag{10}$$

6. Experimental Results

The efficiency of the proposed algorithm is tested using 10 test images given in Figure 5 by watermarking the binary logo shown in Figure 6. A 4-level IWT with CDF (2, 2) filtering kernel is implemented on the original images. The imperceptibility determines the alteration in the perceptual image quality after embedding the watermark. Image quality is measured using the Peak Signal to Noise Ratio (PSNR) value between the original and watermarked images given in (11).

$$\mathrm{PSNR} = 10\log 10 \ {}^{\mathrm{MxN}}/_{\mathrm{MSE}} \quad (11)$$

where M, N are height and width of the image, MSE is Mean Squared Error between original O(i,j) and watermarked images W(i,j), which is defined in (12)

$$\mathrm{MSE} = \sum_{\mathrm{i=0,j=0}}^{\mathrm{M,N}} \frac{(\mathrm{O(i,j)-WM(i,j)})^2}{\mathrm{M\times N}} \quad (12)$$

The correctness of the extracted watermark is judged by Normalized Correlation Coefficient (NCC). The equation for NCC is given in (13).

$$\mathrm{NCC} = \sum_{\mathrm{i=0,j=0}}^{\mathrm{M-1,N-1}} \mathrm{W(i,j)\ x\ W'(i,j)} \Big/ \sum_{\mathrm{i=0,j=0}}^{\mathrm{M-1,N-1}} \mathrm{W(i,j)\times W(i,j)} \quad (13)$$

where $\mathrm{W(i,j)}$ and $\mathrm{W'(i,j)}$ are original watermark and restored watermark.

Figure 5. Original Images: Lena, Barbara, Monalisa, Cameraman, House, Baboon, Peppers-1, Tiffany, Walk Bridge, Living Room

Figure 6. Binary Logo

Figure 7. Watermarked images: Lena, Barbara, Monalisa, Cameraman, House, Baboon, Peppers-1, Tiffany, Walk Bridge, Living Room

The watermarked images in Figure 7 show that the proposed technique ensures high degree of fidelity. The watermarking results in terms of the PSNR and the correlation values are summarized in Table 1. The PSNR of each watermarked image is ≥ 48dB, which is the empirical value for the image without any perceivable degradation. The high NCC values of Table 1 clearly indicate that there is no degradation in the image.

Table 1. Quality Measures of the Proposed Method using CDF (2, 2) Wavelet

S.No	Image	PSNR(dB)	NCC
1	Lena	49.23	0.987
2	Barbara	48.7	0.967
3	Monalisa	49.15	0.967
4	Cameraman	49.98	0.957
5	House	48.71	0.987
6	Baboon	48.68	0.967
7	Peppers-1	49.85	0.957
8	Tiffany	48.75	0.977
9	Walk bridge	48.62	0.925
10	Living room	48.55	0.955

6.1 Comparison of the Proposed Method with Other Existing Methods

The performance of the proposed scheme is evaluated, in Table 2 and graphically in Figure 6 by comparing with Wang, *et al.*, [16] which are based on wavelet tree quantization, Kumsawat, *et al.*, [26] method which is based on Discrete Multi wavelet Transform tree and Li, *et al.*, [27]methods. From the Table 2 and Figure 8, is clearly evident that the proposed method shows high efficiency in robustness and in NCC when compared to other methods.

Table 2. Performance of the Proposed Method Compared with Other Methods

S.No	Images	Wang et al. method		Li et al. method		Kumsawat et al. method		Proposed method	
		PSNR	NCC	PSNR	NCC	PSNR	NCC	PSNR	NCC
1	Lena	38.2	0.873	41.2	0.886	38.5	0.973	49.23	0.98
2	Baboon	38.9	0.853	40.7	0.866	37.9	0.953	48.68	0.96
3	Barbara	37.9	0.853	39.5	0.867	38.16	0.953	48.7	0.96
4	Cameraman	38	0.84	40.9	0.857	39.02	0.94	49.98	0.95
5	Tiffany	38.33	0.87	41.33	0.882	38.63	0.97	49.36	0.97
6	Living room	39.03	0.848	40.83	0.862	38.03	0.948	48.81	0.95
7	Peppers-1	38.03	0.838	39.63	0.85	38.29	0.938	48.83	0.95
8	Jet Plane	38.13	0.858	41.03	0.87	38.15	0.958	49.11	0.95

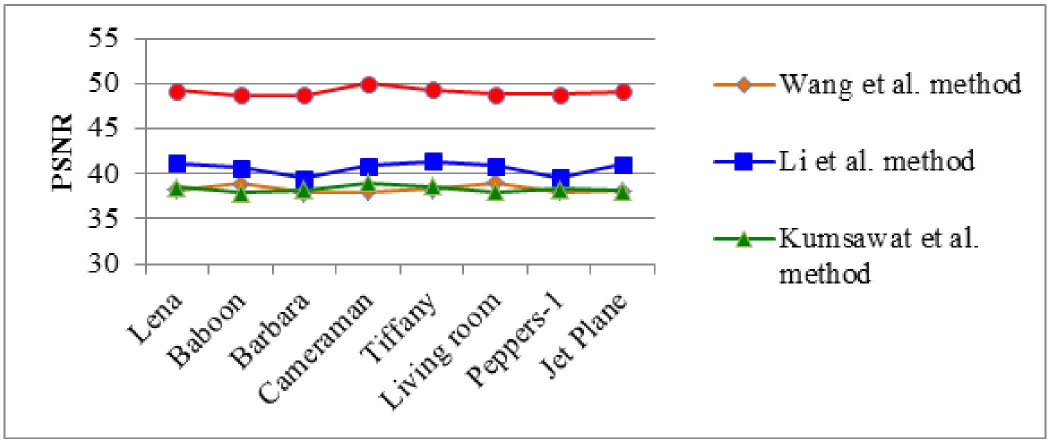


Figure 8. Comparison of PSNR Values of Proposed Method Other Methods

The performance of the proposed method is also compared with the above stated existing methods even in the presence of various attacks and the results are displayed in Table 3. From Table 3, is evident that the proposed method is significantly more robust than the other methods even in the presence of attacks. This is due to the random selection of the wavelet trees and also the process of embedding the watermark bits which are spread all over the image. As a result the watermark is robust against any attacks.

Table 3. Comparison of NCC Values with Various Attacks by the Proposed Method with Other Methods for the Lena Image

S.No	Attacks	Wang et al. method	Li et al. method	Kumsawat et al. method	Proposed method
1	3×3 Median Filtering	0.51	035	0.64	0.87
2	4×4 Median Filtering	0.23	0.26	0.44	0.83
3	3×3 Gaussian Filter	0.64	0.70	0.66	0.85
4	Rotation 0.25°	0.37	0.46	0.64	0.56
5	JPEG(QF=30)	0.15	0.52	0.53	0.79
6	JPEG(QF=50)	0.28	0.52	0.90	0.93
7	JPEG(QF=90)	1	0.78	1	0.99
8	Sharpening	0.46	0.38	NA	0.94
9	Salt and Pepper Noise	NA	NA	NA	0.95
10	10% Cropping of the image borders	NA	0.61	0.17	0.85

7. Conclusion

The present paper presented a reversible watermarking method for authenticating of digital images which exhibits high embedding capacity and high visual quality of marked images. The data embedding is based on the parent-child structure of the transform coefficient arranged as a quadruple tree and histogram modifications. The wavelet tree selection for embedding is random and hence it provides adequate security against unauthorized attempts to extract or remove the watermark. By histogram modification the overflow and underflow are prevented. Consequently, the lossless recovery of original image is achieved. Therefore the proposed approach can be easily incorporated into in the medical field, law enforcement and other fields. The experimental results show that the watermark survives to most of the attacks which are included in this paper. The proposed method is quite effective and easy to implement. It is capable of providing better imperceptibility for an image at a given effective payload compared to existing reversible watermarking approaches.

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