# VLSI Architecture of Invisible Watermarking using Lsb and Lifting Scheme for Real time Copyright Protection

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**Abstract** – This paper proposes an improved blind image watermarking scheme based on wavelet tree quantization. The wavelet coefficients of the original image are grouped into wavelet super trees. Each watermark bit is embedded using two wavelet super trees. The watermark is extracted according to the statistical difference between two wavelet super trees. In order to better provide a trade-off between the strength of the watermark and quality of the watermarked image, the knowledge of the relation between Discrete Wavelet Transform (DWT) coefficients and Human Visual System (HVS) is applied to the watermarking algorithm. Simulation results show that the proposed algorithm is robust to both common image processing operations and geometric attacks such as rotation, scaling, cropping.

*Index Terms - Blind watermarking, wavelet transform, quantization, geometric attacks*

## I. INTRODUCTION

With the rapid development of the digital multimedia technique, the need for the copyright protection of multimedia data becomes more crucial. In order to meet the requirement for multimedia data security, various kinds of watermarking techniques have been proposed.

Generally, we can classify current watermarking techniques as two classes: algorithms processed in spatial domain and algorithms processed in frequency domain, such as DCT and DWT. As the current image compression standard JPEG 2000 is based on DWT, much more attention has been paid to the wavelet-based watermarking algorithms.

There are three key requirements that should be satisfied by all effective watermarking methods: invisibility, robustness, and the ability of watermarking detection. Robustness includes the ability to resist the attacks of common image processing (filtering, compression, etc) and the ability to resist geometric attacks (rotation, scaling, cropping, etc). For most of the watermarking methods the robustness against geometric attacks is vital for the detection of watermark. Although geometric attacks do not cause serious visual distortions, they can severely affect the watermark detection by changing the detected position of the embedded watermark. So robustness against geometric attacks is a pressing necessity for the watermarking technique. Wavelet-based watermarking methods differ in many ways. In [1], the perceptually significant coefficients for each subband are selected to embed the watermark. These perceptually significant coefficients are chosen by using different scale factors depending onthe level of decomposition

. In [2], a different number of watermarks are embedded into each band in proportion to the energy contained in the band. In [4], the wavelet coefficients are grouped into so-called wavelet trees. Quantizing one of two certain wavelet trees embeds one watermark bit. In [6], the watermark is embedded by combining the rotation-invariant log-polar mapping (LPM) with the wavelet transform. The method is resilient to geometric attacks.

This paper proposes an improved blind wavelet-based watermarking scheme, which integrates the wavelet super tree quantization with the pixel-wise masking. The wavelet coefficients are ordered into so-called wavelet super trees, similar to [7]. Each of the watermark bits is embedded by quantizing one of two certain wavelet super trees by means of quantization illustrated in [3]. The disparity between super tree pairs is used to extract the watermark, which is similar to [8]. In order to obtain a better tradeoff between the robustness and the imperceptibility, the pixel-wise masking in [5], which is later modified to adapt for watermarking embedding by [9], is combined with the wavelet super tree quantization. The pixel-wise masking used in this paper is adjusted according to the characteristics of the super tree quantization. Moreover, the watermark is embedded into the bands in the three different orientations redundantly to deduce the false positive probability. Comparing with the method in [6], the proposed algorithm is much easier and suitable for the real time application. From the experiment results shown in section 4, we can see that while the PSNR of the watermarked image is higher, the robustness is stronger than the method in [7].

This paper is organized as follows. SectionĊ illustrates the proposed watermarking scheme in detail. In sectionč, the simulation results are presented, including geometric attacks and common image processing. Finally the conclusion is given in section Č.

## II. THE PROPOSED WATERMARKING SCHEME

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The original image is transformed into wavelet coefficients. We use 4-level wavelet transform of a 512x512 image as example. We have 13 frequency subbands as shown in Fig 1.

*A. Watermark Embedding*

*1) Wavelet trees*

As the high-frequency bands at the forth level contain little energy and HVS is much sensitive to the noise in the low-frequency band at the first level. So we only use the coefficients in subbands HL4, HH4, LH4, HL3, HH3, LH3, HL2, HH2, LH2 to form wavelet trees.

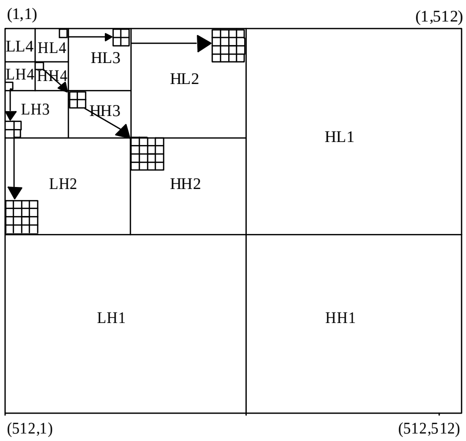


Fig. 1 Tree structure of wavelet coefficients.

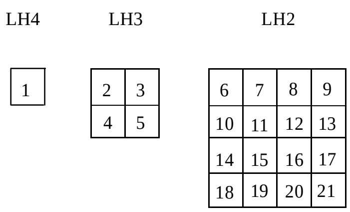


Fig. 2 Ordered coefficients of a wavelet tree.

As shown in Fig 1, the subbands HL4, HH4, LH4 is used as roots to form wavelet trees. Each wavelet tree consists of 1+4+16=21 coefficients, shown in Fig. 2. As the total number of trees is equal to the number of coefficients in subbands HL4 HH4 and LH4 so there are a total of 3x32^2=3072 Wav tree

*2) Super trees*

Two wavelet trees form one super tree with the length of L=42 as shown in Fig. 3. So there are totally 3072/2=1536 wavelet super trees $T_n$ , for n=1,…,1536.

*3) Quantization of super trees* [3-4]**:**

Every two super trees are used when one watermark bit is embedded. So the watermark bit capacity of the image is 1536/2=768 bits. In order to improve the robustness of the watermarked image, the watermark is repeatedly embedded into the bands in the three different orientations for three times. Here we generate a PN sequence of length $N_w$*=256* as the watermark $W$ with a certain key.

Let the *j*th coefficient of the nth super tree be denoted by Firstly, all the wavelet coefficients are quantized to integers, and then these coefficients are described in binary representation as shown in Fig 4.

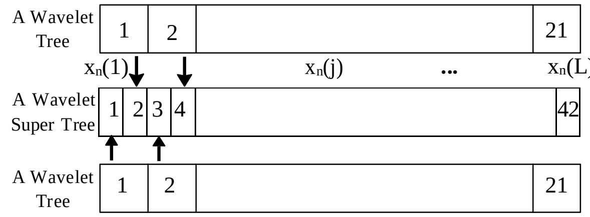


Fig. 3 A wavelet super tree built up by two wavelet trees.

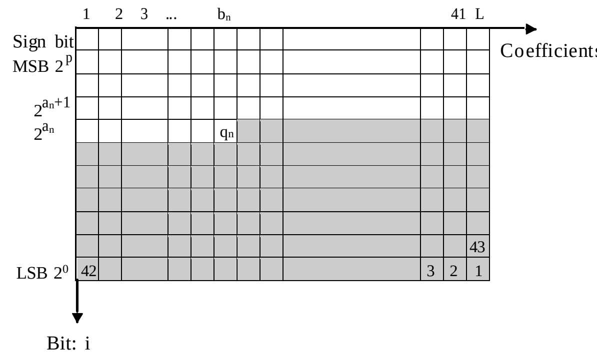


Fig. 4 Quantization of the nth wavelet super tree respect to $q_n$

The sign of every coefficient in the super tree is stored in the first row so called sign bit. The least significant bit (LSB) is $2^0$ , and the most significant bit (MSB) is denoted by $2^P$ .

The total number of the bits is $N_p \quad L(p \quad 1)$ .

Quantization index $q_n$ is a factor to control the strength of quantizing the *n*th tree. The index $q_n$ decides the number of bits discarded after the quantization. The larger $q_n$ is, the more bits will be discarded. The coordinate of $q_n$ in the array is $a_n, b_n$ as shown in Fig 4. All the bits below the quantization index $q_n$ which are shown as shaded area will be discarded. Thus, the coefficients will be changed by the following equation

$$Q[x_n(j)]_{q_n} = \begin{cases} round(x_n(j))_{a_n} & j \le b_n \\ round(x_n(j))_{a_n+1} & otherwise \end{cases} \quad (2)$$

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$n$

Let $round(x_n(j))_{a_n}$ denote the rounding of th coefficient $x_n(j)$ to the $a_n$th bit. The quantization of xn(j) with respect to qn is denoted by Q[xn(j)]qn

· The quantization step size $\Lambda_n(j)$ is denoted by

**(3)**

$$\Lambda_n(j) = \begin{cases} 2^{a_n} & j \le b_n \\ 2^{a_n+1} & otherwise \end{cases}$$

The quantization error of the *j*th coefficient with respect to $q_n$ is given by

The total quantization error of the $n$th tree with respect to $q_n$ is

$$\xi_n(q_n) = \sum_{j=1}^{L} |e_n(j)| \qquad (5)$$

*4) Watermark Insertion*

Two trees $T_{2n-1}$ and $T_{2n}$ are used to embed one watermark bit $w_n$. If $w_n = 1$, $T_{2n-1}$ is quantized according to $q_n$. If $w_n = -1$, $T_{2n}$ is quantized according to $q_n$. During the quantization procedure we need find the largest quantization index $q_n$ to satisfy the following inequation

$$\xi_{2n-1}(q_n) \geq \xi \qquad \xi_{2n}(q_n) \geq \xi \qquad (6)$$

$\xi$ is the reference error which can control the strength of the quantization. If there is no largest $q_n$ to satisfy (6), we will let $q_n = q_{\max}$. $q_{\max}$ is a pre-determined value.

*5) Design of the weighted factor*

We use the method in [9] for reference to make the pixel-wise masking of the proposed algorithm. In [9], the following consideration about human eye's sensibility to noise is taken into account.

• The eye is less sensitive to noise in high resolution bands and in those bands having orientation of $45^0$.

Based on this consideration, we modify the weighted product $\Theta$ for each wavelet coefficient in [9] to combine with The wavelet tree quantation as(7)

$$\Theta(l,\theta) = \begin{Bmatrix} 1.2, & if \quad \theta = 1 \\ 1, & otherwise \end{Bmatrix} \bullet \begin{Bmatrix} 0 & if\ l = 1 \\ 1 & if\ l = 2 \\ 1 & if\ l = 3 \\ 1 & if\ l = 4 \end{Bmatrix} \qquad (7)$$

This term refers from the sensibility to the noise according to the change of bands and particularly according to the orientation. The parameter $l$ denote the resolution level of the band and the parameter $\theta$ denote the orientation of the band ($\theta$=0 means vertical orientation; $\theta$=1 means diagonal orientation; $\theta$=2 means horizontal orientation). Equation (7) means the biggest of $\Theta$ is achieved by the diagonal high-frequency bands in the second, third and fourth resolutation levels(o=1;,l=2,l=3,l=-4).

Then we design the reference error $\xi$ renewedly as (8)

$$\xi' = \xi \bullet \Theta(l,\theta) \qquad (8)$$

Therefore, the energy of the watermark embedded in the diagonal high-frequency bands is stronger than the watermark embedded in other two high-frequency bands. In this way, we can strengthen the energy of the embedded watermark with respect to the invisibility of the watermark. According to the

*Step 2:* Achieve a PN sequence $W$ of length $N_w$ using a key $K$. To guarantee the security, the key $K$ also can be used to order the wavelet super trees in pseudorandom manner. *Set* $q_n = 1$, $n = 1$, $m = 0$;

*Step 3: Set* $q_n = q_n + 1$ to find the largest $q_n$ that satisfies (6), if there is no such $q_n$, let $q_n = q_{\max}$. And quantize the super trees $T_n$ with respect to $q_n$. Thus we get the quantized super trees $T1_n$;

*Step 4: If* $w_n = -1$, let $T2_{2n-1} = T1_{2n-1}$, $T2_{2n} = T_{2n}$; If $w_n = 1$, let $T2_{2n-1} = T_{2n-1}$, $T2_{2n} = T1_{2n}$. *Set n=n+1. If $n<N_w$, go to step 3;*

*Step 5: Set $m = m+1$, if $m < 3$, set $n = 256 \times m + 1$, and go to step 3. m help to embed the watermark bits into the bands in the three different orientations for three times;*

*Step 6: R*egroup the modified super trees $T2_n$ to form the modified wavelet coefficients. It is an adverse process of grouping wavelet coefficients to super trees;

*Step 7:* The IDWT is applied on the modified wavelet coefficients. Quantize the output of IDWT to integers. Then the watermarked image is obtained.

. *Watermarking Extraction*

*1) Designs of the watermark decoder*

Let $N_{2n-1}$ is the number of coefficients in $T'_{2n-1}$ which satisfy the following equation

$$\left| e'_{2n-1}(j) / \Lambda'_{2n-1}(j) \right| < \varepsilon \qquad (9)$$

Let $N_{2n}$ is the number of coefficients in $T'_{2n}$ which satisfy the following equation

$$\left| e'_{2n}(j) / \Lambda'_{2n}(j) \right| < \varepsilon \qquad (10)$$

$T'_n$ is the super trees of the watermarked image, $e'_n(j)$ and $\Lambda'_n(j)$ is respectively the quantization error and the quantization step size of the $j$th coefficient in super tree $T'_n$. $\varepsilon$ is a constant. Based on the literature [7], we let $\varepsilon = 0.1$. And we get the watermark decoder corresponding with the watermark insertion method as below

$$w'_n = \begin{cases} -1 & if\ N_{2n-1} > N_{2n} \\ 1 & otherwise \end{cases}$$

*2) Detection of watermark bit*

To extract the watermark $W'$, the DWT is realized watermarked image. Just as what we have discussed above, we obtain three versions $W_1'$, $W_2'$, $W_3'$ through extracting watermark from the bands in the three different orientations. By (12), then the final watermark $W'$ is achieved.

$$W' = W_1' + W_2' + W_3' \qquad (12)$$

experiment results shown later we can see that the robustness of the watermarked image is improved apparently.

*6) Embedding procedure*

The result is compared with a threshold $\rho_T$. If $\rho(W, W') \geq \rho_T$, the image is marked by the watermark $W$; otherwise, the image is not marked by the watermark $W$.

The probability of the false positive error $P_{fp}$ can be computed as follows based on [3]

$$P_{fp} = \sum_{k=E}^{N_w} \binom{N_w}{k} P_E^{N_w-k}(1-P_E)^k \qquad (14)$$

$E = ((\rho_T + 1)/2)N_w$, $P_E = \Pr ob(w_n \neq w'_n)$, it is reasonable to assume $P_E = 0.5$. We can choose the value of $\rho_T$ according to the requirement of the false positive probability.

*3) Extraction procedure*

*Step 1: Apply a 4-level DWT decomposition on the $512 \times 512$ watermarked image, and form super trees $T'_n$ (n=1,…,6$N_w$ )using the wavelet coefficients except the coefficients of bands LL4, HL1, HH1, LH1;*

*Step 2: Use the key K to order the wavelet super trees in pseudorandom manner. Set $q_n' = 1, n = 1, m = 0$;*

*Step 3: Set* $q_n' = q_n' + 1$ to find the largest $q_n'$ that satisfies (6), *if there is no such* $q_n'$, *let* $q_n' = q_{\max}$. *And quantize the super trees $T'_n$ with respect to $q_n'$, thus we get the quantized super trees $T1'_n$;*

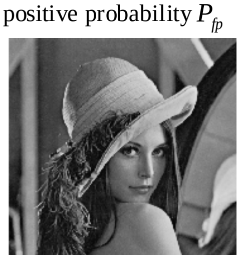
*Step 4: Compute $N_{2n}$ and $N_{2n-1}$ using (9) and (10). Set n=n+1. If n<$N_w$, go to step 3;*

*Step 5: Set $m = m+1$, if $m = 3$, set $n = 256 \times m + 1$, and go to step 3. m help to embed the watermark bits into the bands in the three different orientations for three times;*

*Step 6: Then use (12) to get the extracted watermark $W'$. Use (13) to compute $\rho(W, W')$. If $\rho(W, W') \geq \rho_T$, the image is marked by the watermark W; if $\rho(W, W') < \rho_T$, the image is not marked by the watermark W.*

## III. SIMULATION RESULTS

The $512 \times 512$ image "LENA" is used for our experiments. The original image and the watermarked image are shown in Fig.5. A 4-level DWT decomposition is performed using Daubechies-8 filters. Here we choose the value of the pre-determined parameters as follows $\varepsilon = 0.1$, $\xi = 215$, $q_{\max} = 336$, $N_w = 256$, $\rho_T = 0.26$. So the false positive probability $P_{fp} = 2.22 \times 10^{-5}$.



Original Image

Watermarked Image (PSNR=40.6.)

Fig. 5 Original Image and Watermarked Image

### A. Imperceptibility

The watermarked image has PSNR=40.6db which means that the watermark is almost imperceptible. Also from the original image and the watermarked image shown in Fig.5, we can see that the watermark is imperceptible.

For better comparison, we respectively detect the watermark from the original image and the watermarked image without any attack. The $\rho$ for original image $\rho_o = 0.03$ and the $\rho$ for watermarked image $\rho_w = 0.80$.

### B. Robustness

*1) Rotation*

The watermarked image is rotated by a small angle with the step of $0.25^0$. TABLE I reports the obtained results against rotation attacks. It can be seen that the proposed algorithm can resist a rotation of up to $2.25^0$

TABLE I.
WATERMARK EXISTENCE IN APPLYING ROTATION ATTACKS TO THE WATERMARKED IMAGE "LENA" (ROTATION UNIT: DEGREE ; +: CLOCKWISE; -:COUNTERCLOCKWISE)

| Rotation | 0.25 | 0.50 | 0.75 | 1.00 | 1.25 |
|---|---|---|---|---|---|
| $\rho$ | 0.46 | 0.38 | 0.36 | 0.33 | 0.30 |
| Existence | Y | Y | Y | Y | Y |
| Rotation | 1.50 | 1.75 | 2.00 | 2.25 | 2.50 |
| $\rho$ | 0.28 | 0.26 | 0.30 | 0.26 | 0.27 |
| Existence | Y | Y | Y | Y | Y |
| Rotation | -0.25 | -0.50 | -0.75 | -1.00 | -1.25 |
| $\rho$ | 0.50 | 0.40 | 0.29 | 0.33 | 0.27 |
| Existence | Y | Y | Y | Y | Y |
| Rotation | -1.50 | -1.75 | -2.00 | -2.25 | -2.50 |
| $\rho$ | 0.30 | 0.33 | 0.30 | 0.26 | 0.17 |
| Existence | Y | Y | Y | Y | N |

TABLE II.
WATERMARK EXISTENCE IN APPLYING CROPPING ATTACKS TO THE WATERMARKED IMAGE "LENA" (CROPPING FACTOR IS THE RATIO OF THE REMAINED CENTER PART TO THE WHOLE WATERMARKED IMAGE)

| Cropping Factor | 0.75 | 0.50 | 0.25 |
|---|---|---|---|
| $\rho$ | 0.61 | 0.48 | 0.26 |
| Existence | Y | Y | Y |

TABLE III.
WATERMARK EXISTENCE IN APPLYING SCALING ATTACKS TO THE WATERMARKED IMAGE "LENA" (SCALING FACTOR IS THE RATIO OF THE SCALED UP/DOWN WATERMARKED IMAGE SIZE TO THE ORIGINAL WATERMARKED IMAGE)

| Scaling Factor | 0.75 | 0.50 | 0.25 | 10 | 20. | 30. | 40. |
|---|---|---|---|---|---|---|---|
| $\rho$ | 0.48 | 0.35 | 0.32 | 0.80 | 0.80 | 0.80 | 0.80 |
| Existence | Y | Y | Y | Y | Y | Y | Y |

TABLE IV.
WATERMARK EXISTENCE OF APPLYING JPEG COMPRESSION ATTACKS TO THE WATERMARKED IMAGE "LENA"

| JPEG | 90 | 70 | 50 | 30 | 20 | 10 |
|---|---|---|---|---|---|---|
| $\rho$ | 0.78 | 0.63 | 0.52 | 0.52 | 0.34 | 0.15 |
| Existence | Y | Y | Y | Y | Y | N |

TABLE V
WATERMARK EXISTENCE OF APPLYING COMMON IMAGE PROCESSING ATTACKS TO THE WATERMARKED IMAGE "LENA"

| Image Processing Attacks | U | Existence |
|---|---|---|
| Median Filter (size 3x3) | 0.35 | Y |
| Median Filter (size 4x4) | 0.26 | Y |
| Sharpening | 0.38 | Y |
| Gaussian Filter (size 3x3) | 0.70 | Y |

TABLE IV
WATERMARK EXISTENCE COMPARISON OF THE PROPOSED METHOD AND THE METHOD IN [7] WITH THE SAME ATTACKS

| Different Attacks | Watermark Existence | |
|---|---|---|
| | Ref [7] (PSNR=38.2db) | Proposed (PSNR=40.6db) |
| Rotation (degree : 1.00) | No | Yes |
| Rotation (degree : 2.25) | No | Yes |
| JPEG (QF=30) | No | Yes |
| JPEG (QF=20) | No | Yes |
| Median Filter (4x4) | Yes | Yes |
| Gaussian Filter | Yes | Yes |
| Sharpening | Yes | Yes |

*2) Cropping*

The circumference of the original watermarked image is cropped and the remained center part of the watermarked image is used to extract the watermark. The results are shown in TABLE Ċ. The watermark can still be detected when the cropping factor is 0.25.

*3) Scaling*

The watermarked image is scaled up or down to examine the algorithm robustness. The results given in TABLE ĉ show that the proposed method is still effective when the scaling factor is down to 0.25 or up to 40.

*4) Compression*

For JPEG compression, the quality factor from 90 to 10 is used, and the results are shown in TABLE Й. From Tabled 4 we can see that even with quality factor low to 20, the proposed scheme can detect the existence of the watermark.

*5) Common image processing*

Median filter, Gaussian filter, and sharpening are applied to the watermarked image to test the algorithm robustness against common image processing. The results are shown in TABLE V. The proposed algorithm can resist median filter of window size 4x4, Gaussian filter of window size 3x3 and also sharpening.

Additionally, we compare the proposed scheme with the method in [7] using the image "LENA". The results are shown in TABLE Ď. We can see that as to the common image processing attacks the performance of the two methods is similar. However, with respect to rotation and JPEG compression, the proposed method is notably more robust.

## IV. CONCLUSIONS

In this paper, a blind wavelet-based watermarking method using the HVS and the quantization of wavelet super trees is presented. The wavelet coefficients are ordered in a certain manner to form the wavelet super trees. The energy of the inserted watermark is modified by the adjusted pixel-wise masking depending on the human eye's sensibility to the noise. The watermark bits are embedded repeatedly into bands in the three different orientations. The proposed method apparently improves the performance of robustness against the common image processing, especially against the geometric attacks and JPEG compression.

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