An Improved Wavelet based Image Compression Scheme and Oblivious Watermarking

K.Veeraswamy[†] and S.SrinivasKumar[††],

[†] Research Scholar [††]Professor
JNTU College of Engineering, Kakinada, A.P,India

Summary
This paper presents a novel procedure to improve the performance of a Wavelet based image compression in terms of entropy. All the subbands of wavelet decomposed image are quantized based on the energy of the subband. The quantized and rounded coefficients in the LL subband are re-ordered in a pre-determined manner. A prediction algorithm is used to reduce the entropy (bits/pixel). In addition, an oblivious image watermarking algorithm is proposed using compressed LL subband. The performance of the proposed watermarking algorithm is measured in terms of Peak Signal to Noise Ratio (PSNR) and Normalized Cross Correlation (NCC). Further, this algorithm is robust for various attacks including JPEG and JPEG2000 compression on watermarked image.

Key words:
Image compression, Topological re-ordering, Wavelet transform, Image watermarking.

1. Introduction

There are many applications requiring image compression, such as multimedia, internet, satellite imaging, remote sensing, and preservation of art work, etc. Discrete Wavelet Transform (DWT) has attracted widespread interest as a method of information coding [1, 2]. The ISO/CCITT Joint Photographic Experts Group (JPEG-2000) has selected the WT for its baseline coding technique [3]. Lossless image compression algorithms using prediction [4, 5] are available in the literature. In this work, the coefficients of all the subbands of wavelet decomposed image are quantized based on the energy in the particular subband. The redundant information available in the LL subband of wavelet decomposed image [6] is explored for further compression. Prediction algorithm is used and residues are calculated in the LL subband, thereby reducing entropy over a generic wavelet based compression.

Image watermarking algorithms using Discrete Cosine Transform (DCT), Discrete Wavelet Transform (DWT) and Singular Value Decomposition (SVD) are available in the literature [7, 8, 9]. The basic philosophy in majority of the transform domain watermarking schemes is to modify transform coefficients based on the bits in the watermark image. Quantized LL subband is used for watermarking.

This paper is organized as follows. A generic wavelet transform based image compression scheme is reviewed in section 2. The proposed compression and reconstruction algorithm is presented in section 3. Proposed image watermark algorithm in the compressed domain is discussed in section 4. Experimental results are given in section 5. Concluding remarks are given in section 6.

2. Wavelet transform based image compression

In DWT, an image can be processed by passing it through an analysis filter bank followed by a decimation operation [10]. This analysis filter bank, which consists of a low pass and a high pass filter at each decomposition stage, is commonly used in image compression. When a signal passes through these filters, it is split into two bands. The low pass filter, which corresponds to an averaging operation, extracts the coarse information of the image. The high pass filter, which corresponds to a differencing operation, extracts the detail information of the image. The output of the filtering operations is then decimated by two.

A 2D-DWT can be accomplished by performing two separate one-dimensional transforms. First, the image is filtered along the x-dimension using low pass and high pass analysis filters and decimated by two. Low pass filtered coefficients are stored on the left part of the matrix and high pass filtered on the right. Because of the decimation, the total size of the transformed image is same as the original image. Then, it is followed by filtering the sub-image along the y-dimension and decimated by two. Finally, the image is split into four bands denoted by LL, HL, LH and HH after one level decomposition and as shown in Fig 1. In the diagram, '*L*' indicates low pass filter and '*H*' indicates high pass filter. In the second level, the LL band is further decomposed into four bands. The same procedure is continued for further decomposition levels. This process of filtering the image is called pyramidal decomposition of image. Wavelet transform

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represents an image as a sum of wavelet functions with different shifts and scales. DWT performs multiresolution image analysis [11].

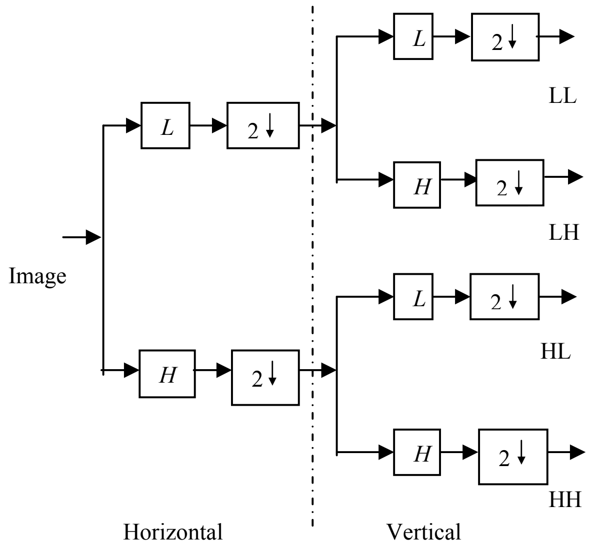


Fig. 1 Pyramidal decomposition.

After decomposing the image and representing it with wavelet coefficients $C\ (u,v)$, compression can be achieved by using quantization. Two popular quantization techniques are as follows:

1. Threshold based quantization [12]: Consider the threshold (Th) and quantize the coefficients as given in equation (1).

$$\begin{array}{ll} C(u,v) > Th & \text{Re}tain \\ C(u,v) \le Th & Discard \end{array} \quad (1)$$

2. JPEG2000 quantization [13]: Each of the transform coefficients $C_{sb}(u,v)$ of the subband '*sb'* quantized to the value $Q_{sb}(u,v)$ according to the formula given in equation (2).

$$Q_{sb}(u,v) = sign(C_{sb}(u,v))\left\lfloor \frac{|C_{sb}(u,v)|}{\Delta_{sb}} \right\rfloor \quad (2)$$

The quantization step-size Δ_{sb} is a function of the dynamic range of the subband. This quantization scheme gives better compression ratio. However, the computational complexity is more.

3. Proposed compression algorithm

In a general wavelet compression algorithm, an image is decomposed using wavelet transform to obtain LL, HL, LH and HH subbands. At first, all the subbands are quantized and then rounded. The rounded coefficients in the LL subband are further compressed by using a lossles procedure, viz., topological re-ordering of coefficients, scanning, prediction and calculation of residues. The basis for the quantization is the energy of the subband.

3.1 2D-DWT

The mother wavelet is defined as

$$\psi_{a,b}(x) = \frac{1}{\sqrt{a}}\psi\left(\frac{x-b}{a}\right) \quad (3)$$

where a is scale coefficient and b is shift coefficient. All other basis functions are variations of the mother wavelet. The image is decomposed using this mother wavelet and its variants with appropriate filter banks. The quality of the compressed image depends on the number of decompositions (*D*). The number of decompositions determines the resolution of the lowest level in the wavelet domain.

3.2 Quantization

Energy (ξ) of a subband is computed by

$$\xi = \sum_u \sum_v |C_{sb}(u,v)|^2 \quad (4)$$

Quantization is based on the energy in each subband of the decomposed image. The coefficients of the subband with higher energy are divided with small value and vice versa. These quantized coefficients are rounded off to get better compression.

3.2 Topological re-ordering

All the quantized and rounded coefficients of the LL subband are re-ordered using topological re-ordering. The rearrangement of coefficients is based purely upon coefficient position, rather than a function of coefficient value, hence it is designated as topological re-ordering. The advantage of re-ordering is better accessibility of the successive coefficients for the estimation of current coefficient value. Due to re-ordering, the size of a particular sub band is altered. This is due to scan path considered for reordering the coefficients in the LL subband. Various re-ordering possibilities are given in our earlier work [14, 15]. Two typical re-ordering schemes used in this work are illustrated in Figs.2 and 3 respectively. It is suggested to use the re-ordering scheme of Fig.3 in the case of number of decompositions exceeds four. This could be attributed to the close proximity of the LL subband coefficient values, as *D* increases. For all other decompositions, Fig.2 may be used.

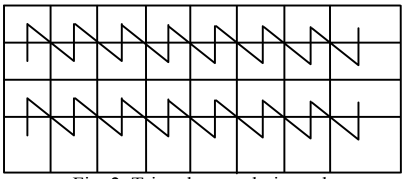


Fig. 2 Triangle re-ordering scheme.

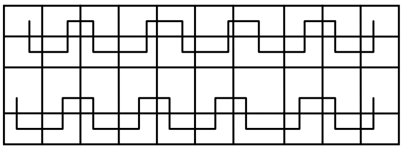


Fig. 3 Square re-ordering scheme.

3.3 Scanning, prediction and residues

The re-order LL subband coefficients can be processed by different scanning techniques [16]. The raster scan consists of scanning the re-ordered LL subband from left to right within each row and top to bottom. A prediction algorithm is applied to the LL subband. Ideally, the value estimated for the current coefficient 'P' should depend on its neighbors. Prediction [17, 18, 19] is based on one or combination of the neighboring coefficients.

NW	N	NE
W	*P*	E

Fig. 4 Notation of neighboring coefficients of 'P'.

A prediction algorithm applicable for topological re-ordering shown in Fig.3 is given below.

■

```
Y= Leasterror (I)
Input(I): LL subband
Output(Y): Error (current coefficient - predicted value)
m: rows, n: columns
  {
  Let Y=Ø
  R=Re-order using Square(I)
  Scan R using scan path and at each coefficient P do
  {
  for the first coefficient in every row predicted value
            (Q)=0
             Y=P-Q
       else predicted value (Q) = W
            Y=P-W
  }
      Return Y
        }
```

■

A prediction algorithm applicable for topological re-ordering shown in Fig.2 is given below.

■

```
Y= Leasterror (I);
Input(I): LL subband
Output(Y): Error (current coefficient - predicted value)
m: rows, n: columns
  { Let Y=Ø
  R=Re-order using Triangle(I)
  Scan I using scan path and at each coefficient P do
    {
      for the first row if W, WW are already scanned
      predicted value (Q)= (W + WW)/2
              Y=P-Q
      else
              Y=P-W
     for the first two columns if N, W are already
     scanned
     predicted value (Q)= (N + W)/2
              Y=P-Q
     else
              Y=P-N
     for all other rows and columns
     If Column is even
              Y=P-(W + NW)/2
     else
              Y=P-(W + WW + N)/3
      }
     Return Y
  }
```

■

The reverse of the above procedures are considered to reconstruct the original re-ordered matrix. In both the cases, if 'P' is the first coefficient to be scanned in the beginning of the matrix then the error at 'P' is defined to be of same value. The reverse process of topological re-ordering schemes is used to reconstruct the quantized matrix of the LL subband. In this process, each subband is multiplied with corresponding number used in the quantization of that subband to reconstruct the image.

4. Proposed watermarking technique

This section describes the proposed watermarking technique. The watermark is embedded in the quantized and rounded LL subband. The embedding algorithm consists of five main steps. These are

- Topological re-ordering (square) of compressed LL subband
- Identification of positions to embed the watermark
- Topological re-ordering (square) of bits in watermark image
- Embedding of re-ordered watermark image bits into rearranged coefficients of compressed LL subband
- Reversing the process of topological re-ordering to get the watermarked image.

By using topological re-ordering of LL subband, secrecy of the watermark image is assured. This topological re-ordering should be known at the receiver. The algorithm for embedding watermark image in the compressed LL subband is given below

■

Y= Bit embedding (*I,* W*,* B)
Inputs: LL subband (*I*), Secret data bit stream(W), and Number of blocks (B)
Output: Watermarked LL band (*Y*)
{
R=re-order Square(*I*), *S*=re-order Square (W)
Partition R into *n* x *n* size blocks and coefficients in this block are $C_1, C_2, \ldots, C_{nxn}$
For each block do
{

$$Avg = \frac{1}{(nxn)-1}\left[C_1 + C_2 + \ldots + C_{(nxn)-1}\right]$$

If watermark bit=1, $C_{nxn} = \alpha * Avg$

else $C_{nxn} = \gamma * Avg$

Y_B=append (*C*)
}
Return *Y*
}

■

where α and γ are constants. The reverse process of topological re-ordering is used to retrieve the watermark. The average value (Avg) is compared with last coefficient of particular block. Based on the comparison, watermark is extracted.

5. Experimental results

Experiments are performed on five grey images [20] to verify the proposed method. These five images are represented by 8 bits/pixel and size is 512x512. The entropy (*E*) [21] is defined as

$$E=-\sum_{e\in s} p(e)\log_2 p(e) \qquad (3)$$

Where, *s* is the set of prediction errors and *p(e)* is the probability of error ***(e)*** between actual and predicted values. An often used global objective quality measure is the mean square error (MSE) defined as

$$MSE = \frac{1}{(n)(m)}\sum_{i=1}^{n}\sum_{j=1}^{m}\left[X_{ij} - X_{ij}'\right]^2 \qquad (4)$$

Where, nxm is the number of total pixels. X_{ij} and X_{ij}' are the pixel values in the original and reconstructed image. The peak to peak signal to noise ratio ($PSNR$ in dB) [22] is calculated as

$$PSNR = 10\log_{10}\frac{255^2}{MSE} \qquad (5)$$

Usable grey level values range from 0 to 255. The other metric used to test the quality of the reconstructed image is Normalized Cross Correlation (NCC). It is defined as

$$NCC=\frac{\sum_i\sum_j\left(X_{ij}-\bar{X}\right)\left(X_{ij}'-\bar{X}'\right)}{\sqrt{\left[\sum_i\sum_j\left(X_{ij}-\bar{X}\right)^2\right]\left[\sum_i\sum_j\left(X_{ij}'-\bar{X}'\right)^2\right]}} \qquad (6)$$

where, $\bar{X}$ indicates the mean of the original image and $\bar{X}'$ indicates the mean of the reconstructed image. Experiments are compared with wavelet method using JPEG2000 quantization [13] and the proposed method. The original image pixels are level shifted by subtracting from 128. For 'Lena', ξ =17462, 14.7, 39.0 and 30.57 for LL, LH, HL and HH respectively. Based on ξ value, the subbands LL, LH, HL and HH are quantized independently with values 2, 7, 5, and 5 respectively. In the second level, LL band is further decomposed into four sub bands and quantization step is repeated. Several wavelet filters (haar, DB2 and JPEG9.7) are available. The wavelet filter selected for the experimentation is 'jpeg9.7'.

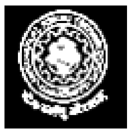
Proposed quantization is a simple technique than JPEG2000 quantization with less complexity. Results are summarized and given in Table 1.

Table 1: Entropy of compressed matrix

Image	***D***	**Wave let transform considering JPEG2000 quantization without considering prediction in LL subband**		**Wavelet transform considering proposed quantization with prediction in LL subband**	
		Entropy	PSNR(dB)	Entropy	PSNR(dB)
Lena	1	3.1061	40.3465	2.0454	41.0488
	2	1.3340	37.2295	1.0388	37.6467
	4	0.3198	31.4135	0.2968	31.5074
Barbara	1	3.5768	40.1964	2.7157	41.0958
	2	1.9726	36.7098	1.6841	37.1092
	4	0.5869	29.0497	0.5702	29.1927
Mandrill	1	4.4859	39.6322	3.9842	39.4048
	2	2.9946	34.8871	2.8293	34.9707
	4	0.9203	26.0576	0.9095	26.1605
Peppers	1	3.4839	39.6557	2.3510	40.1800
	2	1.4832	36.3668	1.1826	36.1509
	4	0.3758	31.1268	0.3532	31.2821
Goldhill	1	3.5960	39.8759	2.6380	40.1800
	2	1.7917	36.0531	1.5053	36.1509
	4	0.3838	29.4494	0.3533	29.4900

Results in Table 1 indicating that the proposed method (energy based quantization and prediction) is superior to general wavelet transform compression (JPEG2000 quantization). A higher compression gain is obtained by processing the LL subband with re-ordering. The entropy value of 'Lena' is 0.3019 bits per pixel without re-ordering of LL subband of compressed image at level 4 using prediction. With re-ordering, this is 0.2968 bits per pixel. Hence, the topological re-ordering of LL subband gives better compression. Prediction algorithm proposed in this work is very simple. This prediction algorithm can be extended to approximate subband of any transform technique like contourlet transform.

Experimental results have been obtained with an implementation of the proposed watermarking scheme in the compressed domain using 'Lena' image. Binary logo of size 64x64 is used in the experiments. 'Lena' is initially compressed using the quantization method at level 1. Re-ordered watermark is embedded in the re-ordered LL subband. Watermark bit is embedded at the location (2,2) of every 4x4 block. Due to 'logo' embedding, entropy is increased from 2.1923 to 2.9560 bits per pixel. Watermark can be embedded in level 2 decomposition also. The embedding capacity is now reduced. However, compression ratio is high. By applying the reverse process of compression, watermarked image is obtained. Original, watermark image ('logo') and watermarked image are shown in Fig.5.



(a)

(b) (c)

Fig.5. (a) Watermark image ('logo') (b) Watermarked error image (c) Watermarked image

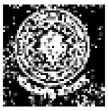
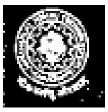
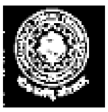
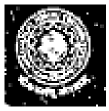
Experiments are conducted using α =1.03, γ =0.97 and 'jpeg9.7' filter. Visual quality of the watermarked images are good with a PSNR of 38.5076dB, showing no significant artifacts or distortions. Wong et al. [23] proposed a watermarking scheme in the JPEG compressed domain. For a 44x30 binary logo, PSNR of the watermarked Lena reported in their work is 36 dB. An improvement of more than 2 dB can be achieved with the proposed method with a binary logo (64x64). Hence, the proposed method is superior to Wong et al. Both the methods are able to survive with JPEG compression attack. Performance comparison is given in Table 2.

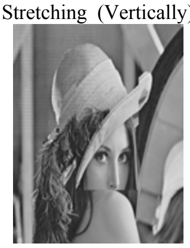
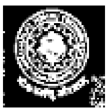
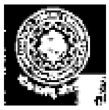
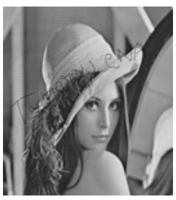
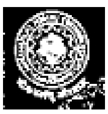
Table 2: Performance of watermarking with other methods

Method	PSNR	Capacity	Robustness	Embedding domain
Wong et al.	35.81	44x30 (binary)	Robust	Transform
Proposed	38.50	64x64 (binary)	Robust	Transform

Proposed method is able to survive for different attacks as shown in Table 3. The watermarked image is compressed using lossy JPEG and JPEG2000 compression ranges from 0 to 100, where 0 is best compression and 100 is best quality. Almost error free extraction of watermark is possible even after JPEG and JPEG-2000 compression attacks. The proposed method is robust to various noise and filtering attacks. Watermark is extracted even after tampering. The other attacks, where the watermark is successfully retrieved are bit plane removal, rotation, row column blanking, sharpening, stretching and skewing.

Table 3: Results with different attacks

S.No	Attack	NCC and Retrieved watermark
1.	JPEG compression (quality 80)	0.8411 
2.	JPEG2000 compression (quality 20%)	0.9918 
3.	Cropping (50%)	0.9951 
4.	Salt and Pepper noise (noise density of 0.01)	0.9622 
5.	Speckle Noise (noise density of 0.01)	0.8600 
6.	Median filtering (3x3 mask)	0.7092 
7.	Average Filtering (3x3 mask)	0.7034 
8.	Rotation (5^0 to right and then rotated back)	0.7756 
9.	Bit plane Removal (4^{th} bit plane values are set to 0)	0.7006 
10.	Row-Column blanking 10,25,50,100,150 columns and rows are blanked.	0.7236

		
11.	Sharpening (3x3 mask)	0.6076 
12.	Stretching (Vertically) 	0.9559 
13.	Skewing (Horizontal ,20 degrees) 	0.8575 
14.	Tampering 	0.9487 

6. Conclusions

In this paper, two schemes, one for image compression and another for watermarking are proposed in the wavelet domain. A higher compression ratio can be obtained by applying the quantization and prediction. Further, an oblivious watermarking algorithm in the compressed domain is proposed. The proposed watermarking algorithm is highly robust and can survive many image processing attacks. Quality of the watermarked image is good in terms of perceptibility and $PSNR$. Topological re-ordering gives more protection to the watermark. The proposed algorithm is shown to be robust to several attacks including JPEG2000 compression and JPEG compression. Future work will focus on further compression of other subbands using lossless procedure and watermarking in the compressed domain. Further compression can be obtained by applying various coding techniques on residue image.

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K.Veeraswamy is currently working as Assistant Professor in ECE Department, Bapatla Engineering College, Bapatla, India. He is working towards his Ph.D. at JNTU College of Engineering, Kakinada, India. He received his M.Tech. from the same institute. He has ten years experience of teaching undergraduate students and post graduate students. He has published one research papers in National journal and one research paper in International journal. His research interests are in the areas of image compression, image watermarking and networking protocols.

S.Srinivas Kumar is currently Professor and HOD in ECE Department, JNTU College of Engineering, Kakinada, India. He received his M.Tech. from Jawaharlal Nehru Technological University, Hyderabad, India. He received his Ph.D. from E&ECE Department IIT, Kharagpur. He has twenty years experience of teaching undergraduate and post-graduate students and guided number of post-graduate theses. He has published 20 research papers in National , International journals and presented in reputed conferences. Presently he is guiding five research scholors in the area of Image processing. His research interests are in the areas of digital image processing, computer vision, and application of artificial neural networks and fuzzy logic to engineering problems.