A Novel non-Redundant Contourlet Transform for Robust Image Watermarking against non-Geometrical and Geometrical Attacks

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Abstract

In contrast to conventional methods operating in the wavelet domain, a new robust watermarking algorithm using non-redundant contourlet transform is presented in this paper. We explore the high degree of directionality and anisotropy of this transform to obtain a sparser image representation. Through experiments, we find that most of the energy relations between parent and children non-redundant contourlet coefficients maintain invariant before and after JPEG compression. Performance improvement is obtained by means of embedding a watermark exploiting the modulation of the energy relations. Test results based on 16 set of attacks using 6 images are obtained. The results show that our non-redundant contourlet method is highly robust to different kinds of attacks including non-geometrical and geometrical attacks. These include JPEG 2000 compression (as low as QF=10), 400 pixels circular shifting, and contrast stretching, (as low as 20%). Comparisons with two other wavelet methods further demonstrate the potential of the non-redundant contourlet in digital watermarking applications.

1 Introduction

One of the important applications of digital watermarking technology is copyright protection and ownership identification for digital images. To achieve this goal, robust watermarking has been rapidly developed in the past ten years. Robust watermarking is designed to survive various manipulations, such as JPEG compression, additive noise, filtering and geometric distortions. A well design digital watermarking algorithm should satisfy three requirements: imperceptibility, robustness and security. DCT-based [1, 2], and DWT-based algorithms [3, 4, 5] have been used commonly in robust watermarking.

However, wavelet transforms constructed by the tensor product method are not optimal in capturing the contours, which are linear singularities in two dimensions [6]. These contours are significant for robust watermarking as they are frequently used for encoding and embedding in the frequencies of the wavelet decomposition. To overcome this drawback, several multiscale and directional transforms, which can capture the intrinsic geometrical structures, such as smooth contours in natural images have recently been proposed [7-11]. Some examples include steerable pyramid [7], ridgelet [8], curvelet [9], bandlet [10] and contourlet [11].

In particular, the contourlet transform developed by Do and Vetterli [11] provided different and flexible number of directions at each scale. It was shown to effectively deal with images having smooth contours. However, the contourlet transform has a redundancy rate of up to 33%. Subsequently, Eslami and Radha developed a non-redundant contourlet transform known as wavelet-based contourlet transform (WBCT) [12]. WBCT has been successfully applied in image fusion and image coding but it has not been applied in robust watermarking of images.

In this paper, we propose a novel robust watermarking algorithm adapting the wavelet-based contourlet transform. The motivation for developing a robust watermarking based on WBCT is due to the observation as follows. (1) This transform provides an effective sparse image representation where the most significant coefficients represent the most energetic direction of an image with edges. Thus, embedding a watermark in these significant coefficients would in principle contributing to improving robustness. (2) From experiments, most of the energy relations between the absolute value of parent-coefficients and the averages of its children-coefficients in WBCT domain maintain invariant before and after attacks, such as JPEG compression (parent-children relationship is seen in Fig.2). Based on this important property, we embed a watermark by modulating the relations. The modulation is performed by modifying the parent coefficients in relation with children coefficients. (3) This non-redundancy contourlet transform is relatively simple to implement as it starts with a discrete-domain construction, as compared to the ridgelet and curvelet transform [11].

In this paper, a brief review of the WBCT is presented in Section 2. Section 3 describes the analysis of the changes of its coefficient relations before and after attack, as well as the proposed watermark embedding. The watermark detection algorithm is discussed in Section 4. Results are presented in

Section 5, demonstrating the robustness of our method against different attacks such as compression, filtering, noise addition, pixels shifting, histogram equalization and scale and rotation.

2 Non-redundant Contourlet Transform

It is commonly known that the redundancy of contourlet is achieved through the Laplacian pyramid (LP) [11]. Eslami and Radha [12] developed the wavelet-based contourlet transform (WBCT) by replacing the LP with a wavelet and then applied a directional filter bank (DFB) into the wavelet coefficients to extract the directional information. The main advantage of WBCT is that it can achieve a non-redundant multiresolution and multidirectional expansion of images.

At each level in the wavelet transform, the three highpass bands corresponding to the LH, HL, and HH bands are obtained. DFB is applied with the same numbers of direction to each band in a given level. The framework of the WBCT is shown in Fig.1.

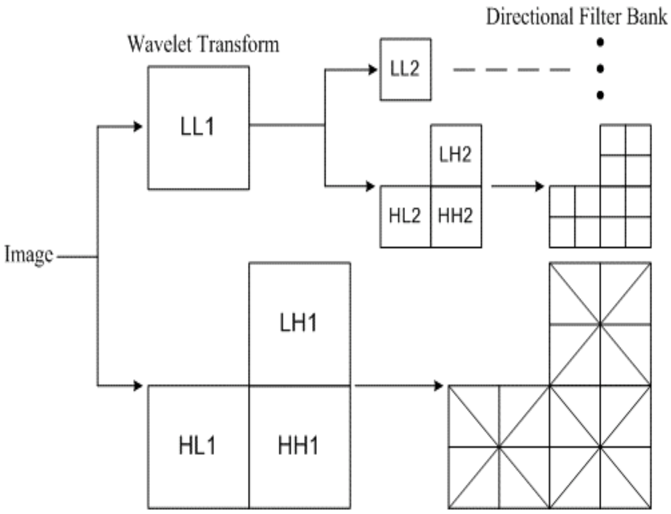
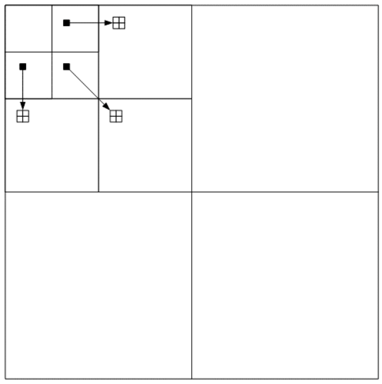


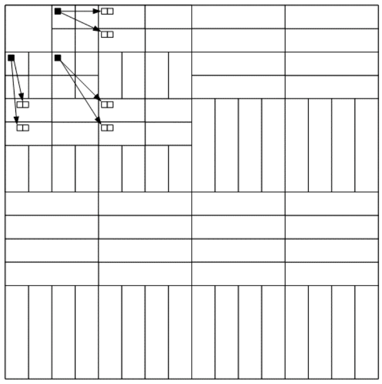
Figure 1: The framework of the WBCT. An image is first decomposed into wavelet levels, and then a DFB is applied into each high-pass bands.

Eslami and Radha [12] reported that the WBCT parent-children relationships were different from those relationships existed in conventional wavelet domains. In a conventional wavelet-domain, the parent-children links are always in the same direction among the three wavelet directions (Fig.2a). Whereas, WBCT coefficients comprise four children in two separate directional subbands for each LH, HL and HH subband (Fig.2b). One parent-children relationship corresponds to one tree structure. Each tree has one parent and four children.

Based on these relationship characteristics, the proposed watermarking embedding process attempts to achieve an optimum trade-off between greater robustness and imperceptibility.



(a) Wavelet



(b) WBCT

Figure 2: Parent-children relationship for (a) wavelets and (b) WBCT. The blank square is the parent coefficient with the white as their children. In WBCT domain, one parent has four children in two separate directional subbands which are quite different from the situation in wavelet domain. In our algorithm, the image is first decomposed into three wavelet levels, which are then decomposed into four, eight and sixteen directional subbands.

3 Watermarking embedding

3.1 Coefficient relations before and after attacks

Wang and Lin [4] proposed a watermarking method based on a wavelet tree quantization and obtained stronger robustness against different attacks. Subsequently, Tsai and Lin [5] presented an improved vision and achieved more robustness. In this paper, the WBCT coefficient relationships are used to determine the effectiveness of our algorithm. We first investigate the characteristics of the energy relations between the parent and the children coefficients before and after JPEG compression. The JPEG compression attack is one of the most common attacks in robust watermarking.

The original image and its JPEG compressed image are initially decomposed by 3-scale WBCT. The parent-children relationship is illustrated in Figure.2. We then compute the percentage of invariant energy relations between parent and children non-redundant contourlet coefficients before and after JPEG compression.

Suppose a parent coefficient in original image and JPEG compressed image are denoted as P_1 *and* P_2 , respectively, and its corresponding four children as $C_{1i}, C_{2i} (i = 1,2,3,4)$.

If $|P_1| \geq mean(|C_{1i}|)$ *and* $|P_2| \geq mean(|C_{2i}|)$

Or $|P_1| < mean(|C_{1i}|)$ *and* $|P_2| < mean(|C_{2i}|)$

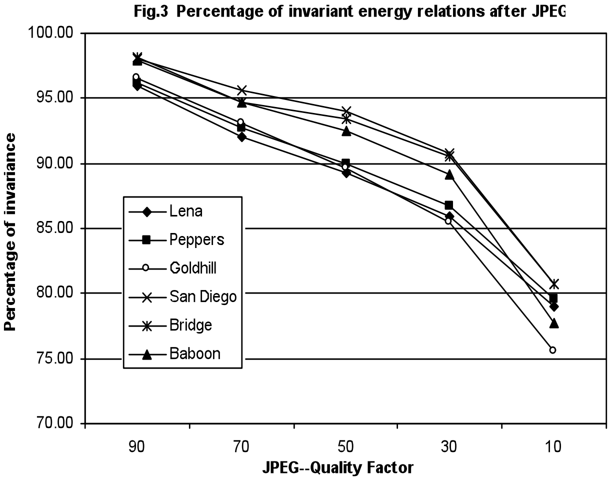
Then we assume this energy relation is invariant before and after compression.

In Fig. 3, the percentage is defined as follows:

$$P_{AV} = \frac{P_{LH} + P_{HL} + P_{HH}}{3}$$

where $P_i (i = LH, HL, HH)$ represents the percentages of the numbers of invariant relations to the total numbers of relations in the different bands. P_{AV} is the average of the P_i.

Fig.3 Percentage of invariant energy relations after JPEG



Six standard test images are used in this experiment to determine the invariant energy relationship as shown in Figure.3. As the quality factor (QF) decreases from 90 to 10, the average percentages of invariant relations also gradually decrease. For QF=90, it reaches above 95%, and for QF=10, although the image is distorted significantly, it still maintains above 75%. From Figure 3, it can also be observed that highly textured images such as 'San Diego', 'Bridge' and 'Baboon' all performed relatively better than the other images. Overall, for all images, improved performance can be achieved by exploiting the modulation of their energy relationship.

3.2 Watermarking embedding process

In this section, we describe the watermark embedding process as follows: the image is first decomposed into three wavelet levels which are then decomposed into four, eight, and sixteen directional subbands. We then randomly select the tree structures using a key .The total numbers of tree structures is equal to the length of the watermark and it is a pseudo-random binary values {-1, 1} sequence. After that, for each tree structure, we calculate the average of the absolute values of the children, and embed the watermark bits by modulation, as follows:

For watermark bit =1

If $|parent| \geq |average|$,

Then no operation;

Else

Increase the parent to make the $|parent| \geq |average|$,

Modulation process:

If parent >=0

Then parent=parent + (K1)(*$|average|$ *-parent);*

Else if parent<0

Then parent=parent - (K1)(*$|average| - |parent|$*);*

For watermark bit =0

If $|parent| < |average|$

Then no operation;

Else

Decrease the parent to make the $|parent| < |average|$;

Modulation process:

If parent >=0

Then parent=parent + (K2)(parent -* $|average|$*);*

Else if parent<0

Then parent=parent - (K2)(*$|parent| - |average|$*);*

where *K1* and *K2* are thresholds to determine the trade-off between imperceptibility and robustness. After the embedding steps, the watermarked image is reconstructed by the inverse WBCT transform.

4 Watermarking detection

In this section we present our proposed algorithm For watermarking detection. The WBCT transform is first preformed on the watermarked image. The tree structures are selected using the key. Comparing the absolute value of the parent with the absolute value of the average of the children, if the former is greater or equal to the latter, then the watermark bit '1' is obtained, otherwise, '- 1' is obtained. The process is repeated for every tree structure to retrieve the entire watermark bit.

A normalized correlation is used to determine whether a watermark is present or not, by comparing it to a prespecified threshold T. The normalized correlation is computed as follows:

$$NC(w,\tilde{w}) = \frac{\sum w(n)\tilde{w}(n)}{\sqrt{(\sum w(n)\sum \tilde{w}(n)}}$$

where w is the given watermark, and $\tilde{w}$ is the extracted watermark. If $NC >= T$, then the watermark is present in the image. We adapt the threshold T based on the false positive probability [3]:

$$P_{fp} = \sum_{m=\lceil N_w(T+1)/2 \rceil}^{N_w} \binom{N_w}{m} 0.5^{N_w}$$

Based on empirical results for our algorithm, $N_w = 512$, T is chosen to be 0.23 for a false positive probability of 1.03×10^{-7}.

5 Experimental results

In this section, six grayscale images 'Lena', 'Peppers', 'Goldhill', 'San Diego', 'Bridge', and 'Baboon' with size 512*512 are used for our experiments to evaluate our proposed WBCT watermarking method.

A. Imperceptibility

In Table 1, the PSNR are used to evaluate the perceptual distortion of these images before and after watermark embedding. The high PSNR values indicate the high imperceptibility quality of the watermarked images. We compare these results with Wang and Lin [4] and Tsai and Lin [5]. Our proposed contourlet method achieves higher PSNR values than the other two wavelet methods. Figure 4 illustrates the original and watermarked images for 'Goldhill 'and 'San Diego', with approximately 42dB and 39 dB, respectively.

Image	Our method	Wang's and Tsai's method [4][5]
Lena	41.46	38.2
Peppers	39.24	38.7
Goldhill	42.22	39.8
San Diego	38.81	Not Available(NA)
Bridge	39.43	NA
Baboon	40.22	NA

TABLE 1 Minimum PSNR of different images granting watermark invisibility

B. Robustness

The robustness of our proposed WBCT watermarking method has been tested against different attacks including non-geometrical and geometrical attacks. Furthermore, we compare these results with two conventional wavelet approaches based on Wang and Lin [4] and Tsai and Lin [5]. From the results, our method achieved better performance with a higher degree of robustness, proving the feasibility of

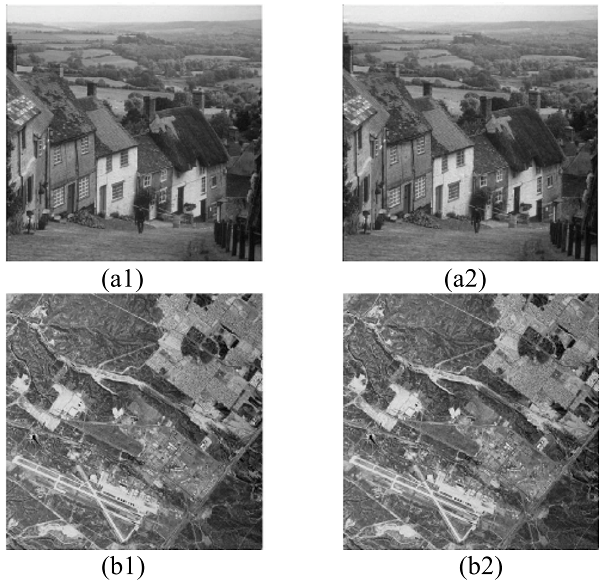


Figure 4: 'Goldhill' (a1) the original image (a2) the watermarked image; 'San Diego' (b1) the original image (b2) the watermarked image

robust digital watermarking using the WBCT domain. In our comparison, direct comparison with the two wavelet transforms were performed on images Lena, Peppers and Goldhill. These images were chosen because of their various degrees of image complexity.

Experiments on WBCT against different attacks are summarised in Table 2. Figures 5-10 illustrate detailed analysis of watermark robustness of WBCT against JPEG2000 compression, Gaussian noise, salt and pepper noise, contrast stretching, circular shifting and scaling, respectively. Comparative results between WBCT and the two wavelet transforms are shown in Table 3. The normalized correlation value below a threshold of approximately 0.23 means it has failed to detect the embedded watermark. The individual non-geometrical attacks are summarised as follows:

For JPEG and JPEG2000 compression attacks, different quality factors (QF) were used on watermarked images. Tables 2 and 3 show the effectiveness of our algorithm even when QF = 10, whereas [4] and [5] only showed results for QF=20 and QF=30. For the case of JPEG 2000 shown in Figure 5, our method achieved results even at QF=10. This has not been reported by other existing watermarking algorithms at this low compression end.

Figure 6 illustrates the images distorted under different Gaussian noise addition. Similarly, salt and pepper noise addition for different amount of noise densities is shown in Figure 7. Figure 8 shows the images under contrast stretching attack for different degrees. Tables 2 and 3 also highlighted the results achieved for mean filtering, histogram equalization, median Filter, Gaussian filtering, and sharpening. From the results, our method outperformed [4] and [5] in all cases with median filtering the only exception.

For geometrical attacks, we investigate the robustness of our proposed WBCT watermarking algorithm against different amounts of pixels circular shifting and scaling, as shown in Figures 9 and 10, respectively. Table 3 summarises the different non-geometrical and geometrical attacks used in comparing our method with [4] and [5]. In Table 3, shifting A indicates circular shifting and B indicates a deletion of lines followed by duplication of the adjacent lines. Overall, our method achieved relatively better performance than [4] and [5] except for the rotation and scaling attacks.

Attacks / Images	JPEG (QF=10)	Mean Filter (3by3)	Mean Filter (5by5)	Histogram Equalization
Lena	0.28	0.54	0.29	0.47
Peppers	0.26	0.60	0.23	0.45
Goldhill	0.34	0.60	0.32	0.55
San Diego	0.52	0.59	0.29	0.60
Bridge	0.48	0.63	0.33	0.67
Baboon	0.45	0.65	0.30	0.77

TABLE 2 Performance of our method under different attacks

Fig.5 Performance of our method after JPEG 2000 compression

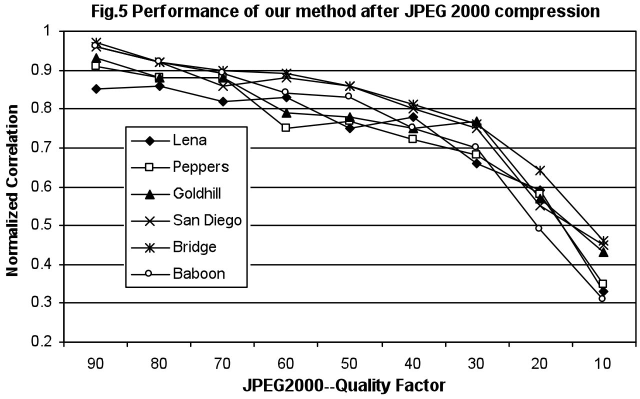


Fig.6 Performance of our method after gaussian white noise

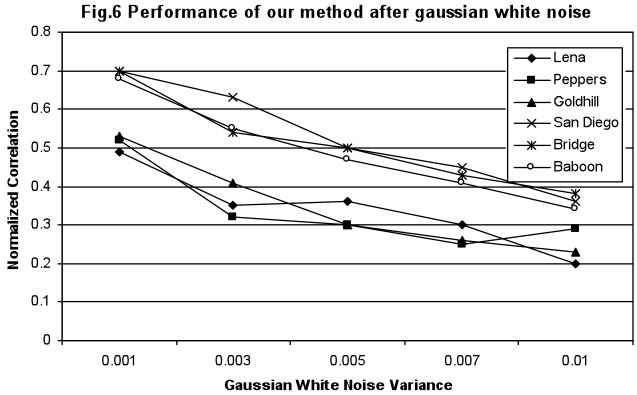


Fig.7 Performance of our method after salt & pepper noise

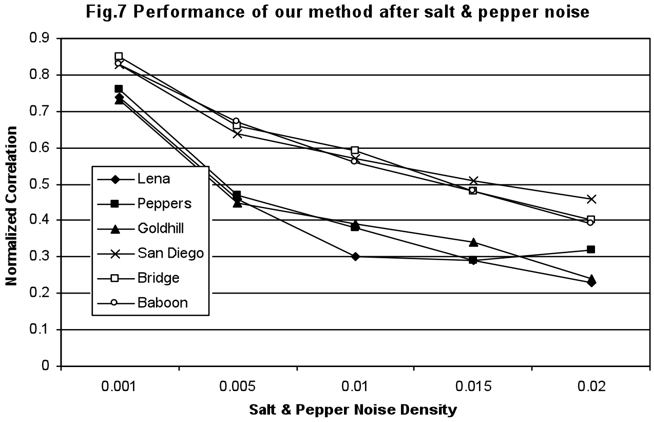


Fig.8 Performance of our method after contrast stretching

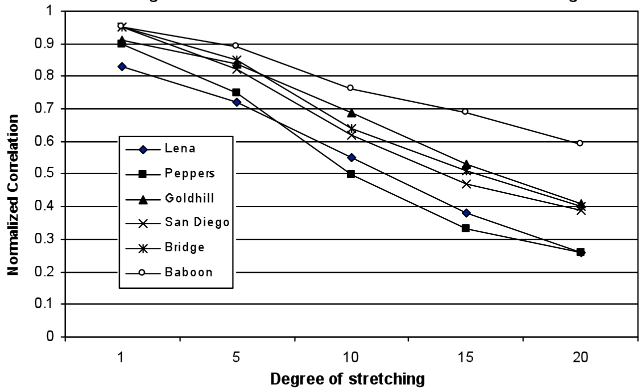


Fig.9 Performance of our method after pixcels circular shifting

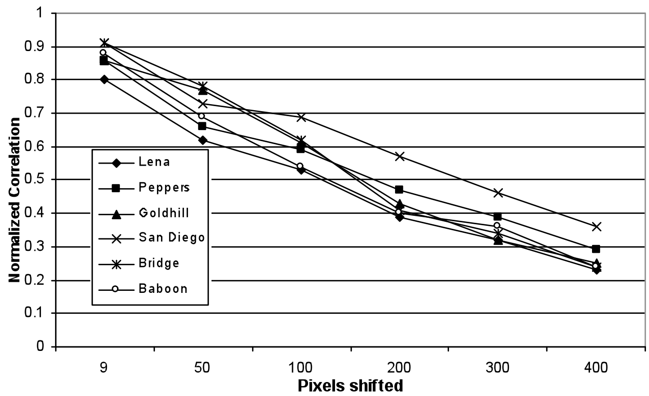
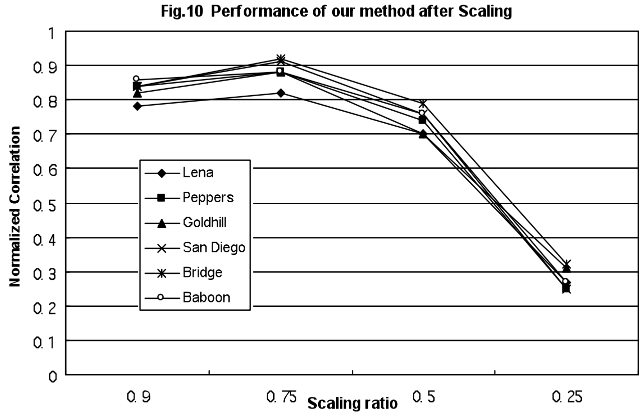


Fig.10 Performance of our method after Scaling



6 Conclusions

In this paper, we proposed a novel robust watermarking algorithm using the non-redundant contourlet transform that exploits the energy relations between parent and children coefficients. This special relationship provides an energy invariant before and after JPEG compression. Results showed that even for QF set as low as 10, the percentages of invariant energy relations of all test images were above 75%. In summary, the proposed method exhibited high degree of robustness against most non-geometrical and geometrical attacks, while maintaining an excellent perceptual invisibility. The use of WBCT for digital watermarking is still in its infancy and more research is needed to understand its potential and constraints. Future work includes the optimum selection of relation coefficients and robustness against rotation and scaling as well as print and scan processes.

.Attacks	Image	Wang et al Method [4]	Tsai et al Method [5]	**Our method**
JPEG(QF=30)	1	0.15	0.45	**0.55**
	2	0.23	0.44	**0.54**
	3	0.34	0.37	**0.63**
JPEG (QF=25)	1	NA	0.37	**0.45**
	2	NA	0.29	**0.56**
	3	NA	0.23	**0.50**
Median Filter (4*4)	1	0.23	0.38	**0.28**
	2	0.24	0.33	**0.27**
	3	0.25	0.36	**0.30**
Median Filter (5*5)	1	NA	0.43	**0.29**
	2	NA	0.32	**0.25**
	3	NA	0.41	**029**
Shifting A (9 pixels)	1	0.26	0.27	**0.79**
	2	0.29	0.35	**0.86**
	3	0.29	0.36	**0.90**
Shifting B(9 pixels)	1	0.25	0.29	**0.54**
	2	0.25	0.26	**0.56**
	3	0.28	0.31	**0.54**
Multiple watermarking	1	0.11	0.24	**0.93**
	2	0.18	0.29	**0.93**
	3	0.22	0.25	**0.91**
Scale& Rotation (1°)	1	0.24	0.25	**0.13**
	2	0.15	0.25	**0.04**
	3	0.17	0.26	**0.04**
Scale& Rotation (-0.75°)	1	0.24	0.30	**0.06**
	2	0.25	0.38	**0.03**
	3	0.25	0.30	**0**
Gaussian filtering	1	0.64	0.89	**0.83**
	2	0.56	0.91	**0.91**
	3	0.74	0.92	**0.90**
Sharpening	1	0.46	0.87	**0.90**
	2	0.39	0.63	**0.71**
	3	0.62	0.89	**0.91**

TABLE 3 Comparison of our method's performance with two Methods' in wavelet domain using (a) Lena (b) Peppers (c) Goldhill. Where '1' means image Lena, '1' means image Lena, '2' means Peppers, '3' means Goldhill

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