A Semi-blind Digital Watermarking Scheme Based on the Triplet of Significant Wavelet Coefficients

Hyung-Suk Chu†, Ariunzaya Batgerel* and Chong-Koo An**

Abstract – We proposed a semi-blind digital image watermarking technique for copyright protection. The proposed algorithm embedded a binary sequence watermark into significant wavelet coefficients by using a quantization method. The main idea of the quantization method was to quantize a middle coefficient of the triplet of a significant wavelet coefficient according to the watermark's value. Unlike an existing algorithm, which used a random location table to find a coefficient in which the watermark bit will be embedded: the proposed algorithm used quad-tree decomposition to find a significant wavelet coefficient for embedding. For watermark detection, an original host image was not required. Thanks to the usage of significant wavelet coefficients, the proposed algorithm improved the correlation value, up to 0.43, in comparison with the existing algorithm.

Keywords: Copyright protection, digital image watermarking, quad-tree algorithm, semi-blind watermarking

1. Introduction

Computer technology and the Internet are rapidly developing and are becoming more and more widely used as a means of distributing digital content.. Unfortunately, most of this information is distributed without the permission of its owner. In other words, the infringement of copyright by digital means is increasing exponentially due to the rapid development of the Internet and other digital media[1],[2]. To combat the rise in digital infringement there are preventative measures such as digital encryption and copyright laws which reduce and punish copyright infringement. The Digital Millennium Copyright Act (DMCA) was enacted in 1996 in the United States in order to combat the rise in digital piracy. Data encryption helps protect data from illegal attacks by scrambling digital information until such time as a secret code is used to decrypt this information. Only someone who has permission to access this data will know this code and thus can use the encrypted information[3]. Once data is decrypted, however, this approach cannot prevent further theft. If data is illegally accessed or stolen, it becomes necessary to prove ownership of it.. Therefore, techniques such as digital watermarking are essential to protect information ownership. Digital watermarking is a technique by which some form of extraneous information is hidden within the digital contents to prove ownership. If such proof is needed, the embedded data can be retrieved and ownership proven[4].

In recent years, an overwhelmingly large amount of research has been done in watermarking digital images for copyright protection. Digital watermarking schemes can be placed under three categories: non-blind watermarking, semi-blind watermarking, and blind watermarking. If the original host image and or a secret key are required to extract the embedded watermark, the scheme is non-blind [1]-[3]. The practicality of non-blind watermarking is limited, since it needs extra storage to maintain the host image and also the host image may not be available for detection. Semi-blind watermarking uses the embedded watermark or side information instead of the host image to extract the embedded watermark [5],[6]. In contrast, blind watermarking needs neither the host image nor the embedded watermark.

One of the simplest algorithms for semi-blind watermarking was introduced by D. Kundur and D. Hatzinakos in[7]. Their algorithm was based on the triplet of wavelet coefficients and the main idea was to quantize a middle coefficient of the triplet which is selected randomly. The advantages of the existing algorithm are its blind detection (does not require an original host image), and simple quantization method which is adjustable thanks to the Q parameter. But since the existing algorithm embeds a watermark everywhere due to a random table, the embedded watermark cannot be robust enough to ensure copyright protection.

We exploit the triplet based quantization method from the existing algorithm and improve it using quad-tree decomposition to find significant coefficients in order to ensure robustness of the watermark. Due to the robustness of the watermark, the proposed watermarking algorithm can to be used for copyright protection and ownership verification.

The rest of this paper is organized as follows: section 2 refers to related theories; in section 3, we describe the proposed algorithm; in section 4, the simulation results are

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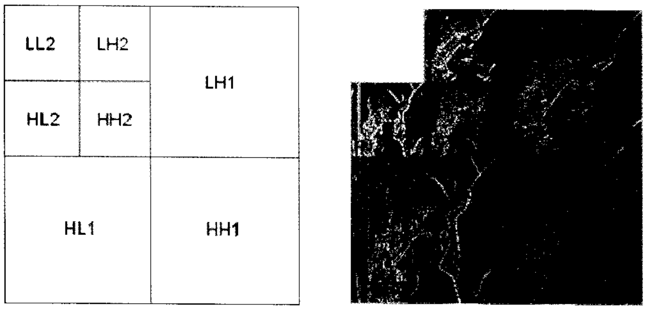
illustrated; and in the final section, a conclusion was formed.

2. Related theories

2.1 Discrete Wavelet Transform

Discrete Wavelet Transform (DWT) has been heavily studied and developed in signal processing. The 2D-DWT decomposes an image into four sub-bands, marked by LL, LH, HL and HH, as shown in Fig. 1(a). The sub-band LL shows the coefficients of the image signal consisting of the low frequency component. In addition, the remainder LH, HL, HH sub-bands can show the feature which expresses the boundary of the image in the horizontal, the vertical, and the diagonal directions, as shown in Fig. 1(b).

The reason why DWT is widely used for image analysis is that an image can be well differentiated into a smooth region and edges in the wavelet domain. |Due to the location information of the image edge, DWT is most widely used for image compression. Due to the assumption that the signal magnitudes dominate the magnitudes of the noise in a wavelet representation, DWT is used for image denoising. The knowledge of the significant coefficient as well as the insignificant coefficient of an image in the wavelet domain can be the reason for the usage of the DWT for image watermarking.

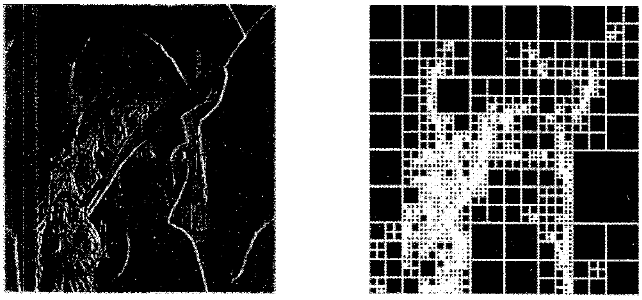


(a) (b)

Fig. 1. Representation of the 2D-DWT of image

2.2 The Quad-tree Decomposition

The quad-tree decomposition algorithm is used to show the position information of the significant coefficients. The quad-tree decomposition divides a square image into four equal-sized square blocks (sub-images) and then test each block to see if it meets the criterion of homogeneity (e.g., if all of the pixels in the block are within a specific dynamic range of gray levels). If a block meets the criterion, it is not divided any further, otherwise, it is subdivided again into four blocks, and the test criterion is applied to the smaller blocks. This process is repeated iteratively until either each block meets the criterion or we reach a block 1 pixel in size. The result may have blocks of several different sizes [8]. Fig. 2(b) shows a typical quad-tree representation for Fig. 2(a) which is a Lena image in the wavelet domain. In Fig. 2(b), the black regions represent larger blocks or similar homogenous regions, and white regions (such as edges) represent more decomposition and un-homogenous regions. Large regions mainly represent the background and are less valuable information and due to the absence of edges. Small regions represent the presence of critical information in an image and hence are a good place for watermark insertion.



(a) **(b)**

Fig. 2. Quad-tree representation of Lena image

2.3 Triplet of Wavelet Coefficient

The general method of a traditional frequency based watermarking algorithm is to add the watermark into perceptual significant DWT coefficients. The triplet of wavelet coefficients is defined as the three wavelet coefficients in the same location in the three detail orientation (HL, LH, HH) of a particular wavelet decomposition, as illustrated in Fig. 3. In the wavelet domain, the triplet coefficient has a correlation,and triplet coefficients provide an opportunity for quantization.

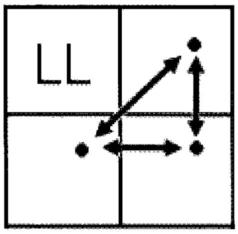


Fig. 3. Illustration of the triplet of a wavelet coefficient

3. Proposed Algorithm

The proposed algorithm exploited a triplet based quantization method first introduced by D.Kundur and D.Hatzinakos, and improved on by using a quad-tree decomposition algorithm. The main idea of the quantization method is to quantize a middle coefficient of the triplet of a wavelet coefficient according to the watermark's value. The existing algorithm finds a coefficient, in which a watermark bit will be embedded by creating a random table. The existing algorithm embeds a watermark randomly, although the position where watermark will be embedded is an important issue in watermarking schemes. In case of copyright protection, the watermark must be strong against various types of attack. In order to make a robust watermark, the watermark is usually embedded into the edge or texture of the host image. Because the edge contains important information about the image, most image processing algorithms will therefore try to keep the edge and texture the same as it was.

In the proposed algorithm, significant coefficients are tracked down using quad-tree decomposition algorithm in the HL bands at each level after 2D-DWT. In other words, the significant coefficients are obtained by picking a 1 x 1 block in the sparse metrics generated as a result of the quad-tree decomposition. For every significant coefficient, the triplet of the wavelet coefficients is computed by comparing the same position of the wavelet coefficient in LH, HL and HH sub-bands, and then the middle coefficient of the triplet is quantized according to a watermark value as an embedding process. In the watermark detection procedure, we perceive the knowledge of the location in which the watermark has been embedded. The watermarking procedures were described in detail as follows.

3.1 Embedding process

The proposed algorithm uses a binary sequence as a watermark that will be embedded into a host image. The watermark is denoted by W_n and contains values of 0 and 1. The host image is a gray-scale image and is denoted by $I_{m\times m}$. The embedding procedure is shown in Fig. 5 and is comprised as follows:

1. Transform the host image $I_{m\times m}$ into a wavelet domain using DWT.
2. Apply the quad-tree decomposition algorithm into HL sub-bands at each level to find a significant wavelet coefficient.
3. Pick all 1 x 1 blocks in the quad-tree decomposition and compute the triplet coefficients in the detail bands LH and HH. We denote the k^{th} detail image component at the l^{th} resolution level of the host image by $C_{k,l}(i,j)$ where $k = k1, k2, k3$ (which stands for "horizontal", "vertical", and "diagonal" detail coefficients).
4. Sort the triplet of the wavelet coefficients in ascending order:

$$C_{k1,l}(i,j) \le C_{k2,l}(i,j) \le C_{k3,l}(i,j) \qquad (1)$$

5. Compute the possible quantization values by dividing the range between the maximum triplet coefficient and the minimum triplet coefficient equally in order as in Eq. 4.

$$\Delta = \frac{C_{k3,l}(i,j) - C_{k1,l}(i,j)}{2*Q-1} \qquad (2)$$

Where Q is a user defined constant which helps to handle an appropriate trade-off between the visibility and the robustness of the watermark.

6. To embed the watermark bit with a value of one, the middle coefficient of the triplet $C_{k2,l}(i,j)$ is quantized to the nearest odd value. When the watermark value is zero, the middle coefficient is quantized to the nearest even value as shown in Fig. 4.
7. During the embedding process, a location table is created which should record the exact location of the embedded watermark.
8. Compute an inverse DWT to create a watermarked image in the watermarked bands.

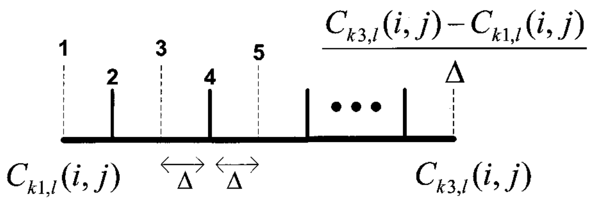


Fig. 4. Illustration of quantization process

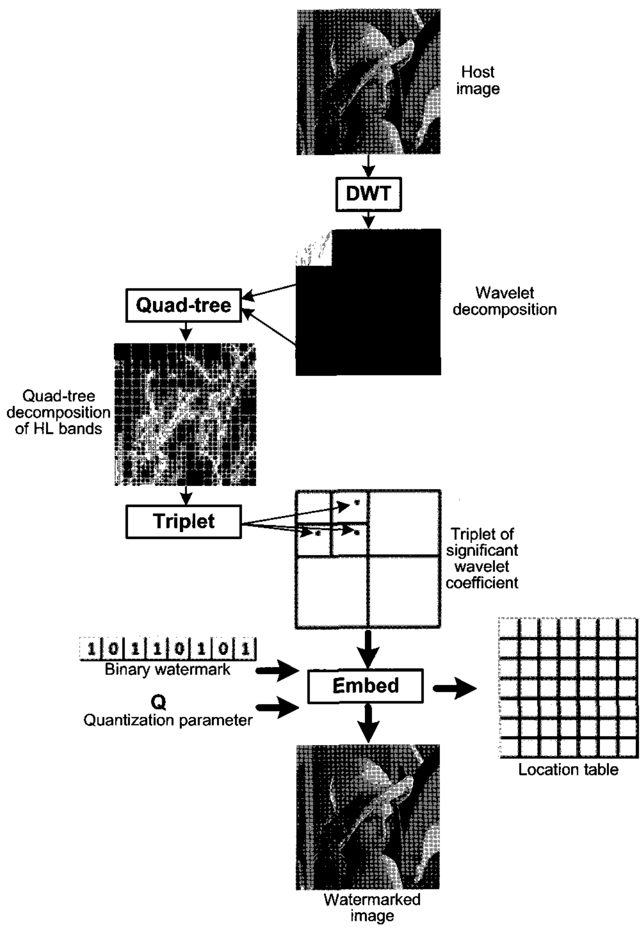


Fig. 5. The proposed watermark embedding algorithm

3.1 Extraction process

For watermark extraction, an original host image is not required. In return, the location table and quantization parameter are used as side information and also an original watermark is required to analyze subjectively. We assume that the watermarked image has been attacked by some interference, denoted by $I'_{m\times m}$. The idea of the watermark extraction process is to estimate the quantization value from the distorted image. The extraction stages are shown in Fig. 6 and are explained as follows:

1. Transform the distorted image $I'_{m\times m}$ into a wavelet domain using DWT.
2. By referring to the location table we can determine the location in which the watermark was embedded and the coefficient therein is denoted by $C'_{k2,l}(i,j)$.
3. Find the two other coefficients of the triplet corresponding to the coefficient $C'_{k2,l}(i,j)$ and sort them in ascending order.

$$C'_{k1,l}(i,j) \le C'_{k3,l}(i,j) \tag{3}$$

4. Find possible quantization values in the range between the minimum coefficient and the maximum coefficient using exactly the same constant Q as was used in the embedding process.

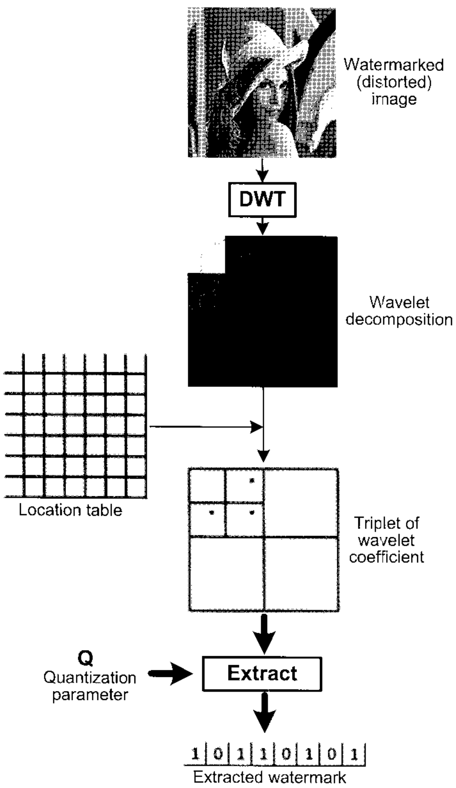


Fig. 6. The proposed watermark extraction algorithm

$$\Delta = \frac{C'_{k3,l}(i,j) - C'_{k1,l}(i,j)}{2*Q-1} \tag{4}$$

5. Estimate a watermark bit from the relative position of the value $C'_{k2,l}(i,j)$. A particular watermark bit is determined by finding the closest quantized value (shown in Fig. 4) to $C'_{k2,l}(i,j)$ and determining if this quantized value was used to embed a one or a zero. In other words, if the value $C'_{k2,l}(i,j)$ is close to the odd quantization value the watermark bit of a value of one is extracted. If the value $C'_{k2,l}(i,j)$ is close to the even quantization value the watermark bit of a value of zero is extracted.

4. Simulation Results

The proposed watermarking algorithm was tested on two gray-scale images of Lena (as a picture with low spatial frequency) and Barbara (as a picture with high spatial frequency) which were 512 x 512 in size. A binary watermark 1000 bits in length was used for the experiment. The general simulation scheme for testing is shown in Fig. 7. The binary watermark was embedded in the original host image using the proposed algorithm. The watermarked image was then distorted by three attacks such as salt and pepper noise, Gaussian noise and JPEG compression. The watermark was then extracted from the distorted image.

To analyze a result, the PSNR and correlation values were computed. In the image watermarking, PSNR (Peak Signal to Noise Ratio) is used to evaluate the quality of the watermarked image. For an $N_1 \times N_2$ pixels image with pixels' luminance values ranging from zero (black) to $L_{\max}$ (white), the PSNR is defined as:

$$PSNR = 10\log_{10}\frac{L_{\max}\times L_{\max}}{MSE} \tag{5}$$

Where MSE is a mean square error defined as:

$$MSE = \frac{\sum_{i=1}^{N_1}\sum_{j=1}^{N_2}[I(i,j)-I_w(i,j)]^2}{N_1\times N_2} \tag{6}$$

A higher PSNR tells us that the watermarked image has suffered a little from the embedding process.

The correlation value is used to measure the similarity between the extracted watermark and the original embedded watermark in order to show a reference for the robustness of the watermark. The normalized correlation between the original watermark $W(i,j)$ and the extracted watermark $W'(i,j)$ is computed by the following equation:

$$NC = \frac{\sum_{i=1}^{M_1}\sum_{j=1}^{M_2}[W(i,j)W'(i,j)]}{\sum_{i=1}^{M_1}\sum_{j=1}^{M_2}[W(i,j)]^2} \quad (7)$$

A higher correlation value tells us that the extracted watermark is much similar to the original watermark, meaning the watermark is robust to noise.

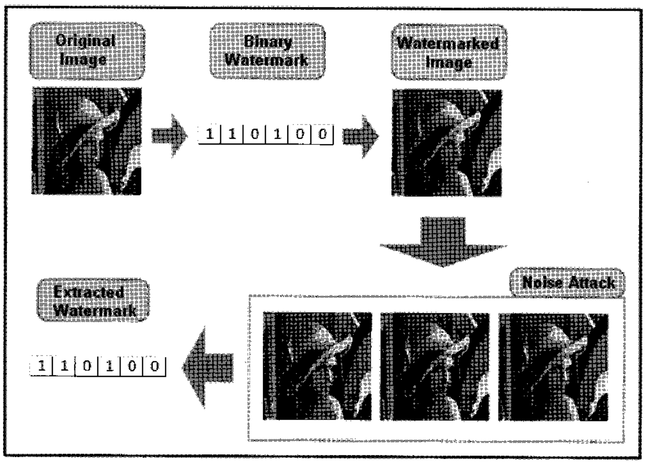


Fig. 7. Simulation configuration

Further, in order to demonstrate how the robustness of a watermark could be improved by quad-tree decomposition in the proposed algorithm, we compared the performance of the proposed algorithm with that of the existing algorithm. For comparison, both algorithms were implemented under the same conditions as the Lena image using a 232 bit binary watermark and the Barbara image using an 814 bit binary watermark.

The proposed algorithm is adjustable thanks to the Q parameter. Table 1(a) shows the effect of the Q parameter in both algorithms, existing and proposed, in terms of the PSNR. From the result shown in it, the PSNR of the proposed algorithm is less than that of the existing algorithm. This means that embedding a watermark into a significant coefficient degrades image quality.

Table 1(b) shows the effect of the Q parameter in the proposed algorithm when the watermark is extracted from the watermarked image, which is distorted by salt and pepper noise with a noise density of 0.0005. From this result, we can conclude that a small value of the Q parameter degrades the visual quality of the image more, but it can make the watermark stronger against the noise attack and vice versa.

Table 1. Effect of the Q parameter

(a) No noise attack

Quantization parameter Q	PSNR of Lena image [dB] (number of watermark=232)		PSNR of Barbara image [dB] (number of watermark=814)	
	Existing algorithm	Proposed algorithm	Existing algorithm	Proposed algorithm
Q = 1	57.49	40.96	41.37	36.62
Q = 2	66.22	50.38	51.63	46.66
Q = 3	74.13	54.23	55.93	51.12
Q = 4	73.85	56.86	59.05	54.04

(b) Salt and pepper noise, density: 0.0005
(Proposed algorithm, Lena image)

Value of Q parameter	PSNR [dB]	Correlation
Q = 1	36.8171	1
Q = 2	38.4402	1
Q = 3	38.5749	0.9983
Q = 4	38.4312	0.9974

The next measurements were performed where Q = 1 in order to show the robustness of the watermark more efficiently. Moreover, Cox's embedding method is experimented with and its performance is compared with the performance of the proposed algorithm.

By considering the PSNR performance of the proposed algorithm in Table 1, which shows that the PSNR = 40.96 dB in the case of the Lena image and the PSNR = 36.62 dB in the case of the Barbara image where Q = 1 and no noise attack, we decided to use Cox's embedding method with $\alpha = 0.8$ for the Lena image, $\alpha = 1$ for the Barbara image. And then, the same number of watermark bits as in the proposed algorithm was embedded into significant coefficient of the host image by using Cox's method. Results were shown in Tables 2, 3 and 4 and Figs. 8, 9 and 10.

In the case of salt and pepper noise with a noise density of 0.05, the correlation value of the proposed algorithm was 0.85, that of the existing algorithm was 0.43 and that of the Cox's algorithm with alpha 0.8 was 0.45, as shown in Table 2 and Fig 8. The correlation value of the proposed algorithm was improved, up to 0.42 as compared to the existing algorithm and up to 0.4 as compared to the Cox's algorithm. In case of the Gaussian noise with a noise density 0.001, the correlation value of the proposed algorithm was improved by up to 0.38 as compared to the existing algorithm and up to 0.02 compared to Cox's algorithm with alpha 1, as shown in Table 3 and Fig 9. When JPEG compression with a 70% compression rate was applied, the proposed algorithm improved the correlation value, up to 0.24, as compared to the existing algorithm and achieved the same result with the Cox's algorithm, as shown in Table 4 and Fig 10. In general, the proposed algorithm could achieve a higher correlation value than the existing algorithm. In comparison with Cox's algorithm, the proposed algorithm achieved a higher correlation value in the case of salt and pepper noise, a similar correlation value in the Gaussian noise case and a lower correlation value in the JPEG compression case. Finally, we can tell that our proposed algorithm could improve the existing algorithm in terms of its correlation value and it is comparable to the most common watermarking method Cox's.

Table 2. Test result on Lena image, Salt and pepper noise

Noise density	The existing algorithm	The proposed algorithm	Cox's method alpha = 0.8
0.0005	0.8	1	0.99
0.001	0.78	0.99	0.96
0.01	0.71	0.97	0.76
0.05	0.43	0.85	0.45
0.1	0.28	0.7	0.37

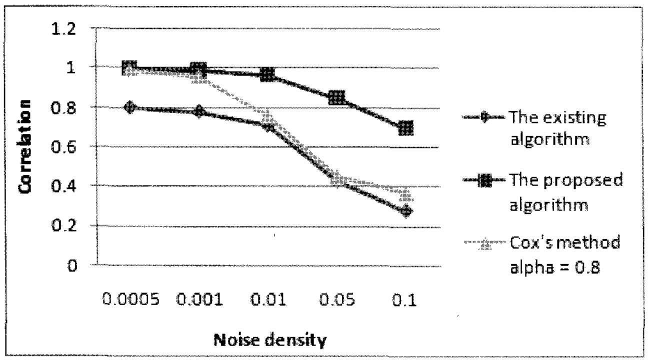


Fig. 8. Comparison of the proposed algorithm and Cox's algorithm (as salt and pepper noise, Lena image)

Table 3. Test result on Barbara image, Gaussian noise

Noise density	The existing algorithm	The proposed algorithm	Cox's method alpha = 1
0.00005	0.82	1	0.99
0.0001	0.77	1	0.99
0.0005	0.66	0.99	0.98
0.001	0.61	0.99	0.97
0.01	0.31	0.64	0.78

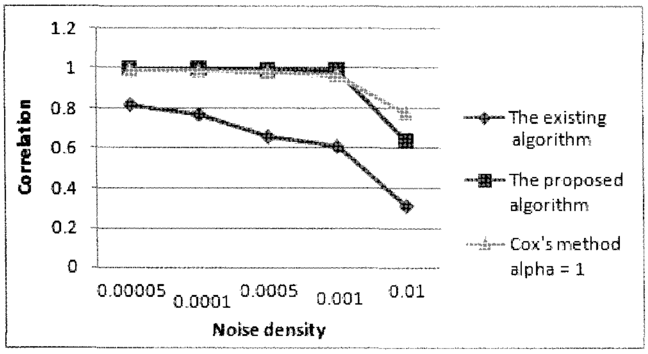


Fig. 9. Comparison of the proposed algorithm and Cox's algorithm (Gaussian noise, Barbara image)

Table 4. Test result on Barbara image, JPEG compression

Noise density	The existing algorithm	The proposed algorithm	Cox's method alpha = 1
90	0.86	1	0.99
70	0.71	0.95	0.95
50	0.63	0.74	0.92
30	0.56	0.61	0.83
20	0.47	0.51	0.72

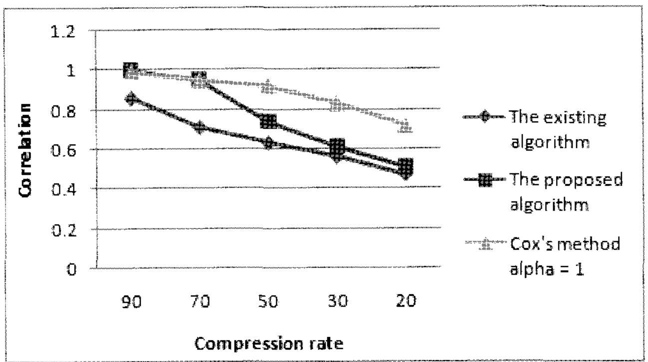


Fig. 10. Comparison of the proposed algorithm and Cox's algorithm (JPEG compression, Barbara image)

5. Conclusion

A digital image watermarking technique based on the triplet of significant wavelet coefficients, was proposed in this paper. The proposed algorithm selected significant coefficients using the quad-tree decomposition. As an embedding process, the middle coefficient of the triplet is quantized according to a watermark value. For detection of the watermark, an original host image is not required. As a simulation result, the proposed semi-blind digital watermarking algorithm improved the correlation value, up to 0.43, in comparison with the existing algorithm and achieved a similar result with Cox's algorithm, a powerful watermark embedding technique when the parameter alpha is higher. The robustness of the proposed algorithm was improved thanks to the usage of the significant triplet coefficients.

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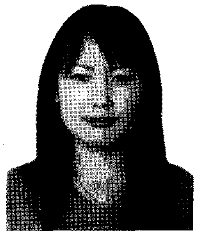

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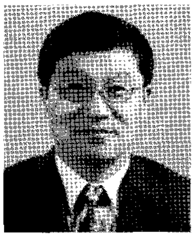

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