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## Quantum Image Watermarking Based on Wavelet and Geometric Transformation

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### Abstract

Like the digital watermark, which has been highlighted in previous studies, the quantum watermark aims to protect the copyright of any image and to validate its ownership using visible or invisible logos embedded in the cover image. In this paper, we propose a method to include an image logo in a cover image based on quantum fields, where a certain amount of texture is encapsulated to encode the logo image before it is included in the cover image. The method also involves transforming wavelets such as Haar base transformation and geometric transformation. These combination methods achieve a high degree of security and robustness for watermarking technology. The digital results obtained from the experiment show that the values of Peak Signal Noise Ratio (PSNR) and Mean Squared Error (MSE) that apply to one of the set cover images were 68.74 and 0.093, respectively.

**Keywords:** Quantum watermarking, quantum entanglement, bell state, image watermarking, discrete Wavelet Transform (DWT).

### العلامة المائية للصور الكمومية على أساس الموجات والتحول الهندسي

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### الخلاصة

مثل العلامة المائية الرقمية ، والتي تم تسليط الضوء عليها في الدراسات السابقة ، تهدف العلامة المائية الكمومية إلى حماية حقوق الطبع والنشر لأي صورة والتحقق من ملكيتها باستخدام الشعارات المرئية أو غير المرئية المضمنة في صورة الغلاف. في هذه الورقة ، نقترح طريقة لتضمين شعار صورة في صورة غلاف استنادًا إلى الحقول الكمومية ، حيث يتم تغليف كمية معينة من النسيج لتشفير صورة الشعار قبل تضمينها في صورة الغلاف. تتضمن الطريقة أيضًا تحويل الموجات مثل تحويل قاعدة Haar والتحول الهندسي. تحقق طرق الجمع هذه درجة عالية من الأمان والمتانة لتكنولوجيا العلامات المائية. أظهرت النتائج الرقمية التي تم الحصول عليها من التجربة أن قيم **Peak Signal Noise Ratio (PSNR)** و **Mean Squared Error (MSE)** التي تنطبق على إحدى صور الغلاف المحددة كانت 68.74 و 0.093 على التوالي.

### Introduction

Quantum computation has significantly evolved in the last period since the development of quantum computing. The quantum entanglement is important to the field of quantum computation. To achieve entanglement, bell states, that are four states of “0” and “1”, must be used. The possibility of a

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watermark is to make safe verification of multimedia information or visual work of art [1]. Wavelet, geometric transformations, and Least Significant Bit (LSB) technique are used to achieve watermarking the logo in the cover image. Proposed approaches were used for the quantum watermarking algorithm to achieve a high level of security. XU ShuJiang *et al.* [2] proposed a shrouded rule among the safe message, the underlying tensor product of two bell states and the last tensor item when individually applying nearby unitary changes to the principal molecule of the two introductory bell states. Chia-Hung *et al.* [3] presented a new technique to exchange the quantum message among the sharing parties using entanglement swapping. This technique has the advantage of the capability to safely identify each other under an unsafe routing way Heidari *et al.* [4] proposed a method of watermarking with a view LSB based quantum watermarking protocol, where the Novel Enhanced Quantum Image Representation (NEQR) strategy for quantum images representation is utilized to represent the quantum images. Fatahi and Naseri [5] suggested a method for quantum watermarking using entanglement swapping. The entanglement swapping is utilized to build up a hidden layer of secure message under the first layer of secure data arrangement. Another study [6] presented an enhancement of that quantum steganography protocol to transmit 8-bit secret message per round. The rest of this paper is organized as follows; the quantum computation in section 2, Discrete Wavelet Transform (DWT) in section 3, geometric transformation in section 4, the proposed algorithm in section 5, experimental results in section 6 and the conclusions are introduced in section 7.

### Quantum Computation

Quantum computing theory started in the beginning of 1982 by the famous physicist Richard P. Feynman who had interest in this topic and won Nobel Prize in his specialty [7]. Quantum computations utilize quantum phenomena that can collaborate to permit the amount of processed data to scale exponentially in the quantity of ‘quantum bits’ in the system [8]. Some information in quantum computation and a theoretical background are introduced in this article.

#### A. Introduction to Quantum Topics

In a classical computer, the bit is considered as the fundamental unit of computation, and it may be “0” or “1” to represent the information. The quantum bit (qubit), in contrast, is the basic unit to represent information in the quantum computer, being of two possible states which are  $|0\rangle$  and  $|1\rangle$ . A notation like ‘ $| \rangle$ ’ is named the Dirac notation. The qubit must be in a basic state which is  $|0\rangle$  or  $|1\rangle$  and it may construct a linear combination of  $|0\rangle$  and  $|1\rangle$  typically called superposition states according to equation (1):

$$|\psi\rangle = \alpha |0\rangle + \beta |1\rangle \quad (1)$$

The numbers  $\alpha$  and  $\beta$  are complex numbers where  $|\alpha|^2 + |\beta|^2 = 1$ . The bit in a classical computer can be determined either as zero or one. In contrast, we must use the measure operation to get 0 with probability of  $|\alpha|^2$  or get 1 with probability [9].

The states  $|0\rangle$  and  $|1\rangle$  are known as basis states, and form vector space,  $|\beta|^2$ :

$$|0\rangle = \begin{bmatrix} 1 \\ 0 \end{bmatrix} \quad (2)$$

$$|1\rangle = \begin{bmatrix} 0 \\ 1 \end{bmatrix} \quad (3)$$

#### B. Computation Operation on Qubit

A practical equivalent to the manner in a classical computer works by an electrical circuit containing logic gates and wires. A quantum computer works by a quantum circuit containing wires and basic quantum gates that convey and control the quantum information. The quantum gate may take one qubit, such as the NOT gate which takes the state  $|0\rangle$  to the state  $|1\rangle$ , and vice versa. The quantum NOT gate can be represented in the matrix form [9],

$$X \equiv \begin{bmatrix} 0 & 1 \\ 1 & 0 \end{bmatrix} \quad (4)$$

The other important gates that take one qubit are  $Z$ \_gate which is represented in the matrix form as:

$$Z \equiv \begin{bmatrix} 1 & 0 \\ 0 & -1 \end{bmatrix} \quad (5)$$

Also, Hadamard gate is represented in the matrix form as:

$$H \equiv \frac{1}{\sqrt{2}} \begin{bmatrix} 1 & 1 \\ 1 & -1 \end{bmatrix}. \quad (6)$$

The quantum gate also takes a multiple qubit, as in controlled-NOT gate (CNOT) which owns two input qubits called the control qubit and the objective qubit, as represented in the matrix form in equation (7) and Figure-1.

$$U_{CN} = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 1 \\ 0 & 0 & 1 & 0 \end{bmatrix} \quad (7)$$

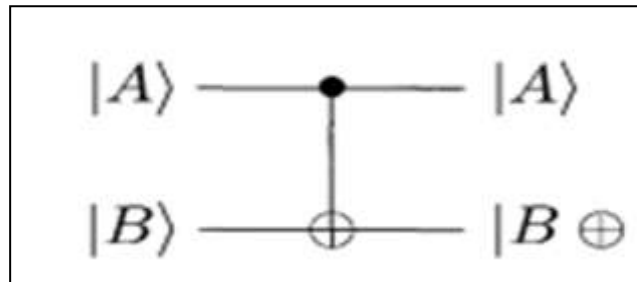


Figure 1- The controlled gate circuit [10].

### C. Quantum Entanglement

Entangled states are extremely fascinating states since they show correlations that have no traditional. They are of specific significance in quantum computation [9]. The bell states are used to apply the entangle concept in this paper. This topic will be explained later.

Bell states represent the simplest example of quantum entanglement, which are four basic two-qubit inputs,  $|00\rangle, |01\rangle, |10\rangle, |11\rangle$ . The circuit outputs and the final bell state are in accordance with equations (8) and (9) [6].

$$|\Psi^\pm\rangle = \frac{1}{\sqrt{2}} (|10\rangle \pm |01\rangle) \quad (8)$$

$$|\Phi^\pm\rangle = \frac{1}{\sqrt{2}} (|11\rangle \pm |00\rangle) \quad (9)$$

### Discrete Wavelet Transform (DWT)

DWT is a technique of transforming images from spatial domain to frequency domain. This technique has become important in the recent times, since it provides frequency decomposition of images, compacts the energy at low frequency, and displays the edges at high frequency sub band [6]. The simplest method of DWT is the Haar wavelet. When applying the Haar wavelet on an image, the result will be of four coefficients (horizontal band (HL), vertical band (LH), diagonal band (HH), and approximate band (LL)). The LL part comprises the main feature of the image. In LL, the sub band can embed the logo image [11]. More details are shown in Figure-2.

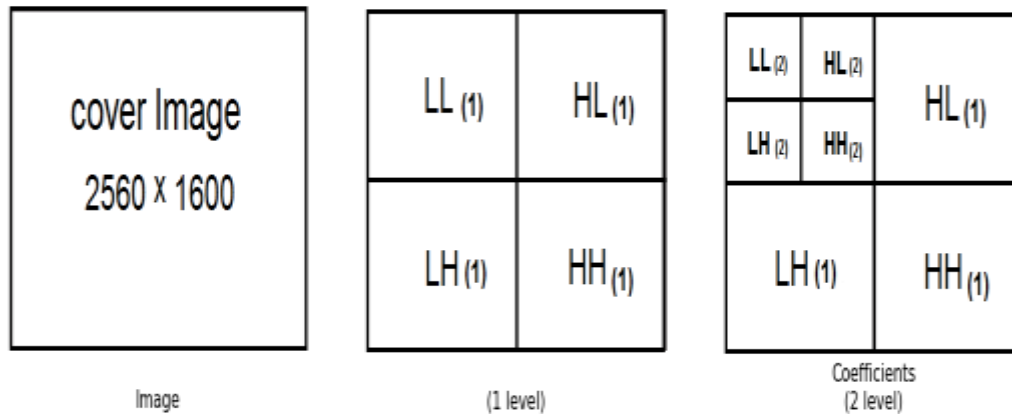


Figure 2- DWT for two levels of decomposing [7].

### Geometric transformations

A geometric transformation is an operation that adjusts shape, size, position, orientation etc, with respect to current setup working on the vertices (position vectors). Such geometric transforms are translation, rotation, scaling etc. In this paper, the rotation translation is used, in which the object of an image is rotated around a fixed point. The direction of rotation can be clockwise or anticlockwise and the fixed point in which the rotation takes place is known as the center of rotation. The measure of the turn made is called the angle of rotation, as shown in Figure-3 [9].

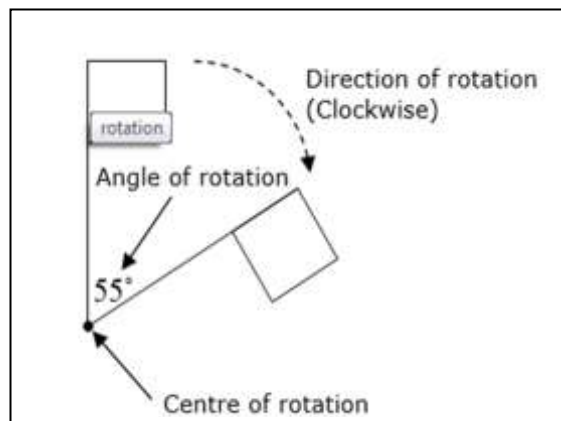


Figure 3- Rotation transformation.

### The proposed watermarking algorithm

To accomplish the watermarking, we need the cover image and the logo image to be embedded in it. There are some processes which are applied in the cover image and others applied in the logo image, with two main processes that are explained in the following sub sections.

#### A. Embedding the logo in the cover image

Before apply the embedding process, a pre-processing strategy was used in the cover image and the logo image to be embedded. Pre-processing is important to prepare the cover and logo images for the embedding process as in algorithms (1) and (2).

**Algorithm (1):** Convert cover image from spatial to frequency domain.

**Input:** Cover image.

**Output:** Cover image after applying DWT on it and four coefficients (HH, HL, LH, and LL).

**Processes:**

**Begin**

**Step (1):** Convert image from spatial domain to frequency domain. The Discrete Wavelet Transform (DWT) must be applied.

**Step (2):** Apply Haar Wavelet. The (HH, HL, LH, LL) coefficients are the results, and only the HH coefficient is used to hide the bits value of the logo image.

**Step (3):** Convert the integer part value of the approximation sub-band HH part into a binary system to achieve LSB technique later.

**End.**

In the logo image, algorithm (2) represents the important steps.

**Algorithm (2):** Rotate logo image.

**Input:** Logo image

**Output:** Bits vector rotated logo image

**Processes:**

**Begin**

**Step (1):** Input number of angles randomly as [360, 100, 180, 90, 180] or any numbers.

**Step (2):** Apply the rotate in the logo image according to these angles. The result of rotation being unexpected because the angles were chosen arbitrary.

**Step (3):** Convert pixels values into binary representation vector.

**End.**

Apply quantum entanglement to get a pair of qubits and bit pixel value of the logo image according to algorithm (3), as shown in Figure -4.

**Algorithm (3):** Embedding technique.

**Input:** Quantum engine, logo image, cover image.

**Output:** Embedded image.

**Processes:**

**Begin**

**Step (1):** Apply algorithm (1) on the cover image to produce four coefficients (HH, HL, LH, and LL).

**Step (2):** Apply algorithm (2) on the logo image which gives vector bits of rotated logo image.

**Step (3):** Allocate encode quantum register being  $E [q_1, q_2, q_3, \dots, q_n]$ , and in the same method create decoding quantum register  $D [q_1, q_2, q_3, \dots, q_n]$ . These two registers must be created from the same engine.

**Step (4):** Apply Hadamard gate on each qubit in the encode register.

**Step (5):** For ( $i=0$  to vector bits).

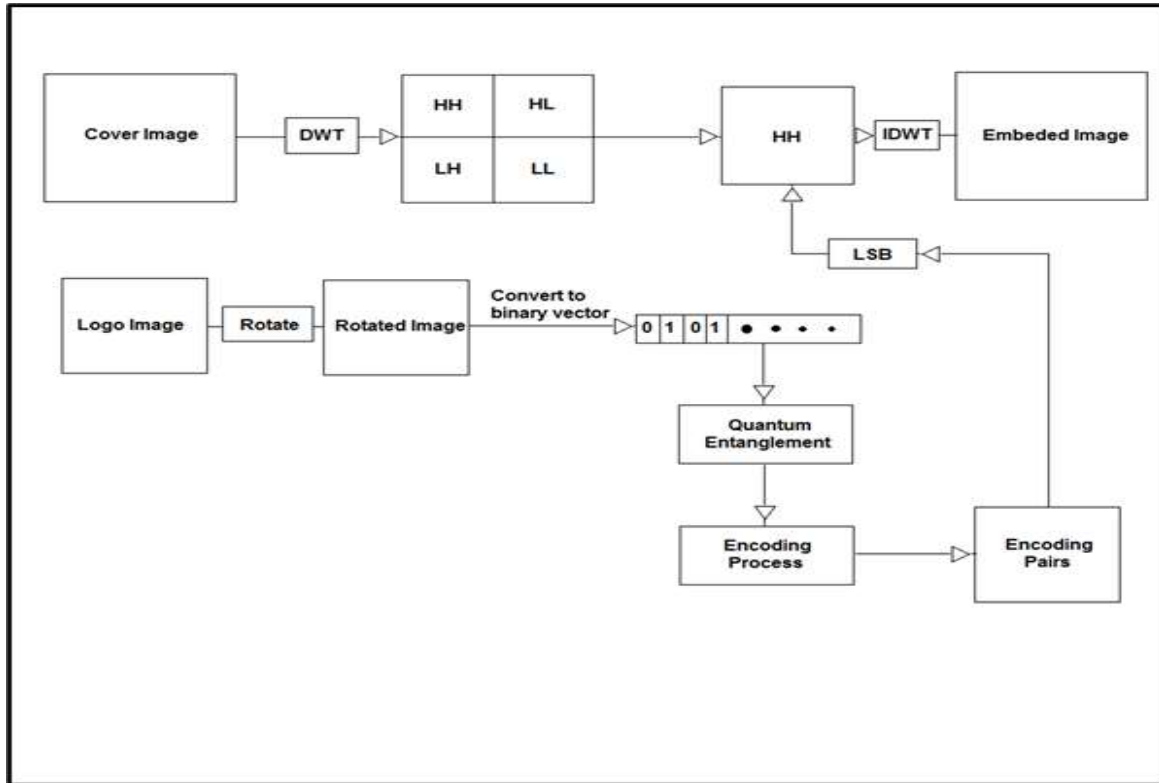
(5.1) Create new qubit ( $Q\_new[i]$ ) used for checking when decoding the pairs.

(5.2) If (vector\_bits [ $i$ ] = 1) then apply X gate on the new qubit ( $Q\_new[i]$ ).

(5.3) Apply CNOT gate on ( $Q\_new[i]$ ,  $E[i]$ ).

(5.4) Apply Hadamard gate on  $Q\_new$ .

(5.5) Apply the measure process on the two qubits  $Q\_new[i]$ , and  $E[i]$ .



**Figure 4-** Embedding process.

### B. Extracting the embedded logo image

The result of the embedding process is the logo image embedded in the cover image. In this step, extracting this logo from the cover image is as in the algorithm (4), while the steps of the extraction process are shown in Figure-5.

#### **Algorithm (4):** Extracting technique

**Input:** Quantum engine, embedded image, decode register  $D [q_1, q_2, q_3, \dots, q(n)]$ .

**Output:** Logo image.

**Processes:**

**Begin**

**Step (1):** Apply algorithm (1) on the cover image to produce four coefficients (HH, HL, LH, and LL).

**Step (2):** Use the Inverse Least Significant Bit (ILSB) technique for getting pairs of encoding values from the (HH) coefficient part.

**Step (3):** For ( $i=0$  to encoding pairs).

(3.1) If (encoding pairs  $[i, 1] == 1$ ) then apply X gate on the decode register  $D[i]$ .

(3.2) If (encoding pairs  $[i, 0] == 1$ ) then apply Z gate on the decode register  $D[i]$ .

(3.3) Apply the measure process on the decode register  $D[i]$  to get classical value.

**Step (4):** The decoding result is saved in  $D[i]$  after applying the measure.

**Step (5):** Convert binary representation of decode pairs to decimal to show the extracted rotation logo image as image.

**Step (6):** Apply inverse rotation on extracting rotation logo image to get finally logo image.

**End.**

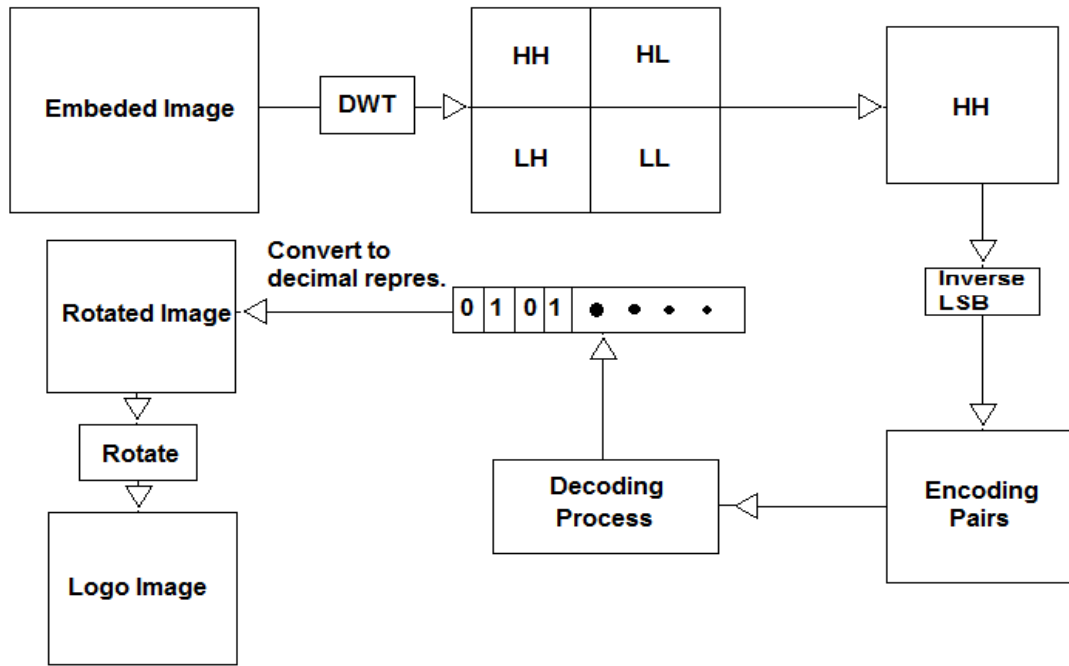


Figure 5- Extracting process.

**Experimental Results**

This experiment needs a high-quality CPU such as that of the super computer to complete its implementation, or the use of IBM company chips, which are specially made for some quantum processors because the quantum simulation needs more times in classical resources.

The results were measured by taking the quality image factor using two measures; the first is Peak Signal Noise Ratio (PSNR), as shown equation (10), and the second is Mean Squared Error (MSE), as shown equation (11). This was associated with the use of two other measures to know the robustness of the watermarking and the resistance to various attacks; the first is the Bit Error Rate (BER), as shown equation (13), and the second is the Normalized Correlation (NC) as, shown equation (12). The results of embedding watermark are shown in Figure-7 and described Table-1 and Figure-6. The test images are of a grey level, jpeg type and have different sizes.

$$PSNR = 20 \log_{10} \left( \frac{MAX_w}{\sqrt{MSE}} \right) \tag{10}$$

$$MSE = \frac{1}{MN} \sum_{i=1}^M \sum_{j=1}^N ||W(i,j) - W'(i,j)||^2 \tag{11}$$

Where  $x(i,j)$  represents the original image,  $y(i,j)$  represents the distorted image. and  $i$  and  $j$  are the pixel positions of the  $M \times N$  image.

$$NC(W, W') = \frac{\sum_{i=1}^M \sum_{j=1}^N W(i,j) * W'(i,j)}{\sqrt{\sum_{i=1}^M \sum_{j=1}^N W^2(i,j)} \sqrt{\sum_{i=1}^M \sum_{j=1}^N W'^2(i,j)}} \tag{12}$$

Where  $w$  and  $w'$  are the original watermarking and extracting watermarking, respectively.

$$BER(W, W') = \frac{\sum_{i=1}^M \sum_{j=1}^N W(i,j) \oplus W'(i,j)}{M * N} \tag{13}$$

Where  $w$  and  $w'$  are the original watermarking and extracting watermarking, respectively. A comparison of the visual quality between the proposed system and the system that has used the traditional LSB technique for watermarking is shown Table-1.

**Table 1-** Result of the measures by using proposed system.

Image name	Proposed system		LSB Technique system	
	PSNR	MSE	PSNR	MSE
(a1)	68.7402	0.0932	51.3598	0.6992
(a2)	67.1713	0.1116	51.3512	0.6895
(a3)	61.7496	0.2084	50.8471	0.7314
(a4)	76.7001	0.0372	51.3990	0.6864

The values of two measures are good and represent high quality for images test. This implies that there is a little effect of the original image on the final image onto which the logo was added. As it is known, the best value of PSNR measure was 100 dB and the best value of MSE was 0. It was clear that the values of the two measures, PSNR and MSE, were better in the proposed system over the traditional LSB.

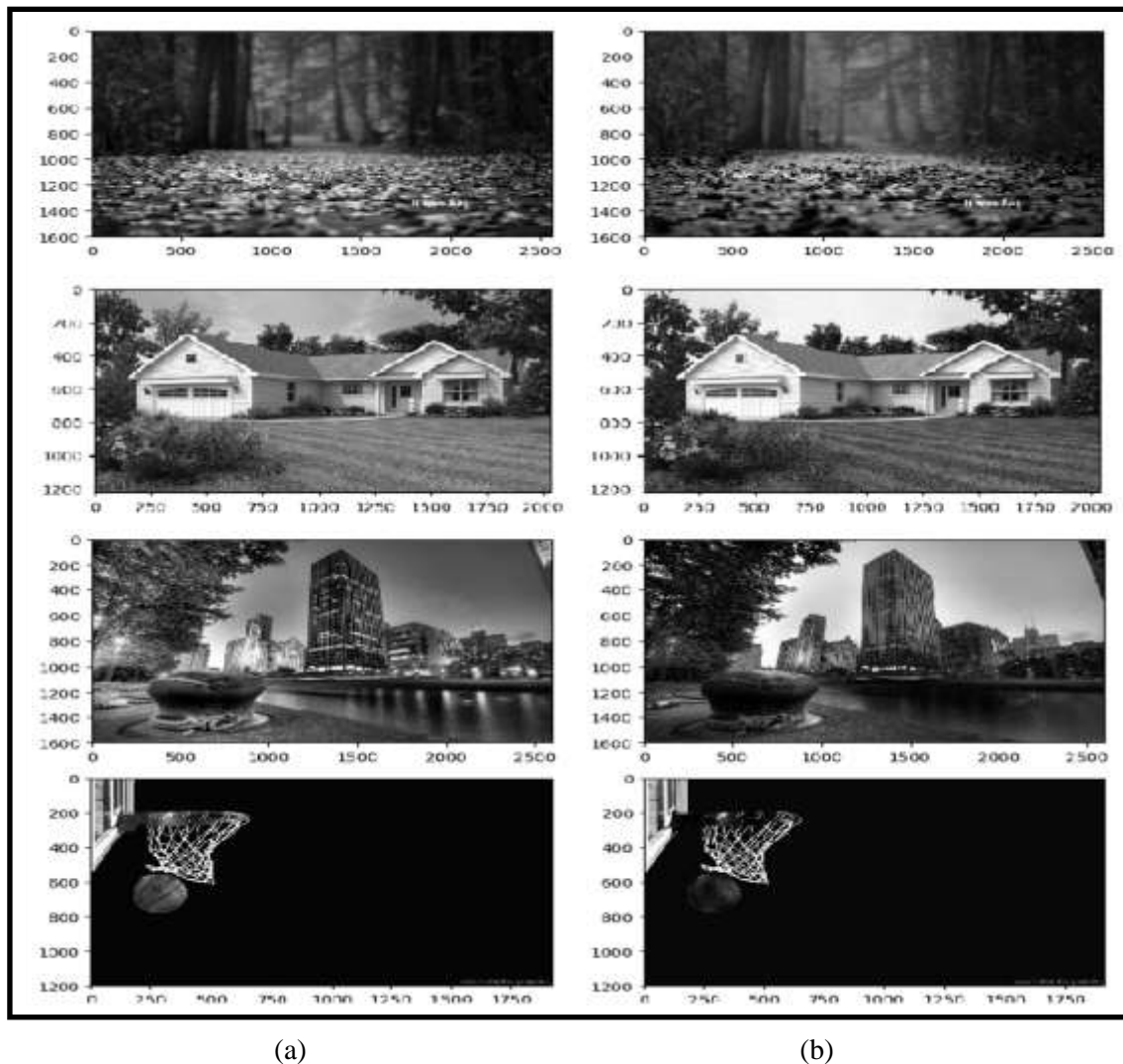
**Figure 6-** Test images using proposed system. (a) Original set image and (b) Watermarked set image.





Figure 7- Logo image.

Some types of attacks are tested to know the robustness of this system. The first type is the Gaussian noise attack. Two parameter values were applied, the first is for mean which is equal to "0", and the second parameter is called the variance value which is equal to  $(0.05)^2$ . The results are shown in Figure-8, using both measurements of robustness (NC and BER) between the original logo and the logo after applying the Gaussian noise attack (2.2068 and 1.4888), respectively.

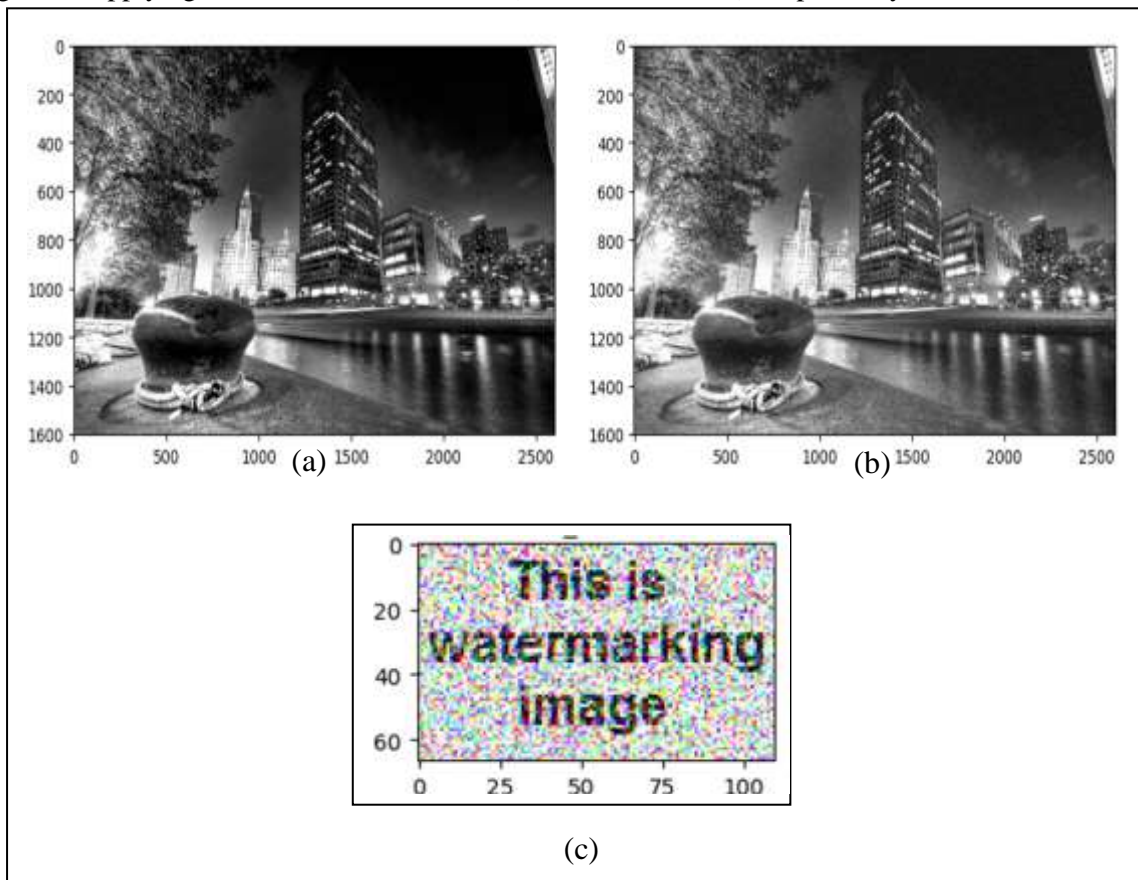
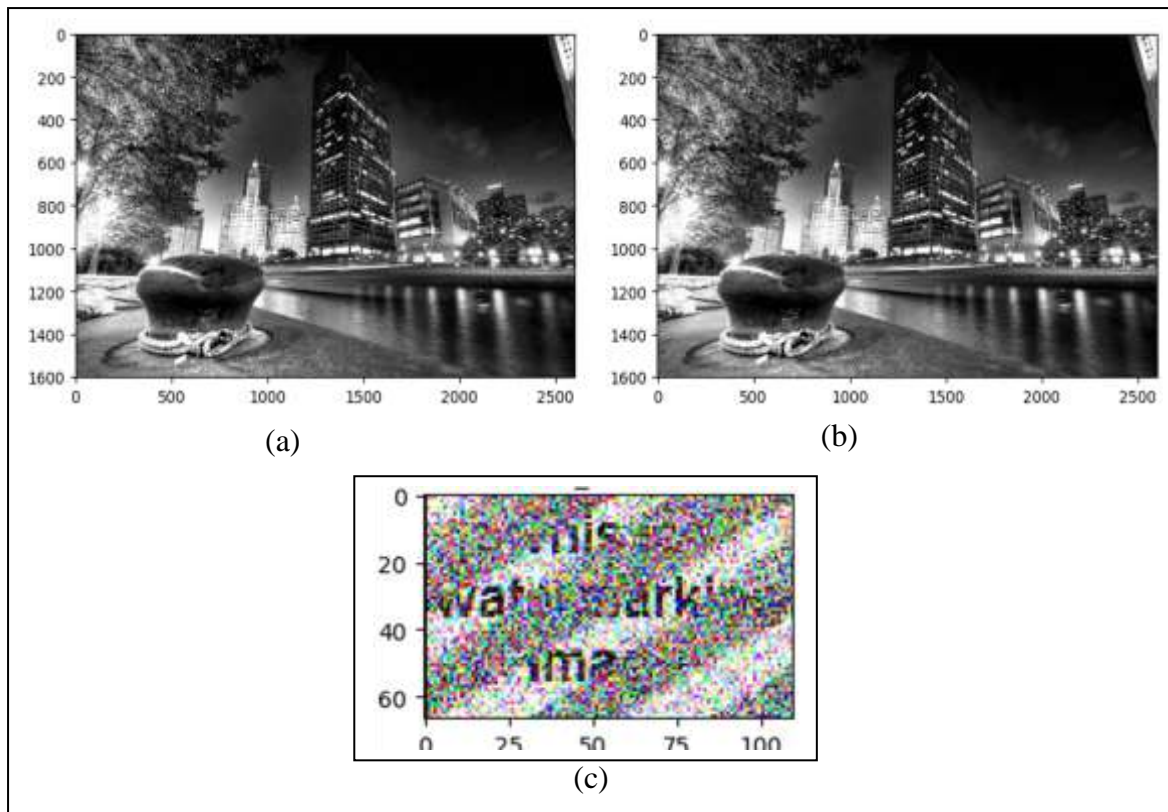


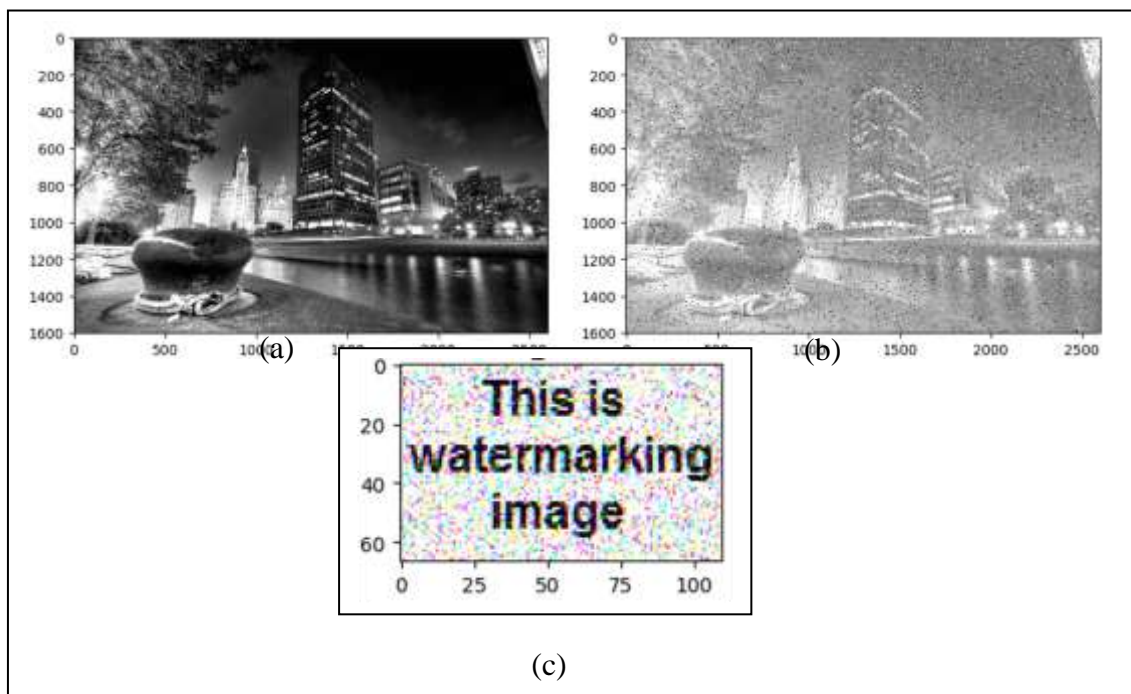
Figure 8- Building image under Gaussian noise attack. (a) Watermarking image (b) Watermarking image after adding noise (c) Extracting logo image.

Another type of attack is the median filter attack. The results of NC and BER measures were 3.1681 and 2.7177, respectively, as shown in Figure-9.



**Figure 9-** Building image under median filter attack. (a) Watermarking image (b) Watermarking image after adding noise (c) Extracting logo image

The third type of attack is the salt and pepper attack. The results of NC and BER measures were 1.6474 and 0.7069, respectively, as shown in Figure-10.



**Figure 10-** Building image under salt and pepper attack (a) Watermarking image (b) Watermarking image after adding noise (c) Extracting logo image.

## Conclusions

This work is designed for digital watermarking, using DWT, LSB and quantum techniques. In this paper, quantum entanglement of bell state was used to encode the logo image and embed it in the cover image for being secure from any detection. This paper used Haar Wavelet in DWT which was the simplest approach of the wavelet transform. When the proposed algorithm was used, the important factors employed to know the quality of the resulted image were the PSNR and MSE scores, which showed high and acceptable results, respectively. This will bring high security because of the use of the quantum entanglement for encoding the pixel of the logo image. The encoding method is considered secure for these reasons:

1. The qubits used in the quantum entanglement are random, with values between 0 and 1, when the measurement is applied to them. This helps to choose a random and changeable encoding and decoding keys every time it is measured and, therefore, the security of the watermarking image is high and unbreakable. During attacks, the attacker can only guess if he gets the middle key and the original encryption key and applies the quantum entanglement process to get the key for decoding and the hidden logo image bits.
2. In the embedded algorithm, the logo image is disguised as pairs of intermediate keys ( $Q_{new}$  [N of qubits]) which substitute the original bits in a particular manner. It is also entangled with the original key (encoding register E [N of qubits]), while another value of the pair is the encoding register. Each value in the pairs is embedded by the LSB technique on the last bit of the cover image byte. This process provides the difficulty of breaking and guessing the original values of the image because each bit of the logo image is converted into pair of bits and each bit of pair is hidden in one byte of the cover image.
3. Encoding by the use of quantum entanglement is considered as a new method for attacker to guess and breaks the encoding process.

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