A NEW WATERMARKING SCHEME FOR QUANTUM RGB DIGITAL IMAGES

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Abstract - In the present paper, a new watermarking scheme for quantum RGB digital images is proposed. Using the proposed scheme, the color channel of interest of each pixel is chosen according to the corresponding qubit pair of the generated randomized binary image. The security of our proposed scheme is insured through the randomization of the key image. Results of Simulations of real images show that not only the final watermarked images can't be recognized visually from the original ones, but also the histogram diagrams of these images are approximately similar. In addition, the average PSNR ratio calculated from the simulations is significantly higher than the PSNR ratios of previous proposed quantum image's watermarking methods.

Index Terms - Quantum image, Quantum watermarking, Quantum RGB images.

I. INTRODUCTION

In 1982, Richard Feynman [1] proposed his revolutionary computation method. This method was the first basis of the completely novel idea of quantum computers. Using the completely different properties of quantum physics, these computers are expected to solve many problems in a different, faster and more efficient way. Furthermore, some unsolvable problems in classical computers would be easily solved in quantum computers [2]. Recent researches show that a quantum computer is capable to act 100 million times faster than our classical computers [3].

Developing the main idea of a quantum computer, many interesting fields in quantum computation and quantum communications are developed, such as Quantum Key Distribution (QKD) [4-5], Quantum Teleportation [6], Quantum Data Hiding [7-8], Quantum Image Representation [9-12], Quantum Image Processing (QIP) and so on.

In the recent years, many QIP algorithms are proposed, such as quantum image scrambling [13-14], quantum geometric transformation [15], and quantum image watermarking [16-17].

In this work, a new method for quantum images watermarking is proposed. In the presented method, the color channel of interest of each pixel is chosen according to the corresponding qubit pair of the generated randomized binary image. This paper is organized as follows:

Some preliminaries are presented in the section 2. Proposed quantum images watermarking scheme is presented in section 3. In Section 4, using software simulations, the efficiency of the proposed scheme is evaluated. Finally, a short conclusion is given in section 5.

II. PRELIMINARIES

A. Quantum Gates

Quantum NOT Gate: This gate is the quantum equivalent of classical NOT gate[18]. A NOT gate maps $|1\rangle$ to $|0\rangle$ and $|0\rangle$ to $|1\rangle$.

Quantum Controlled Not Gate (CNOT gate): This gate is the quantum equivalent of classical XOR gate. It acts on two qubits. The first qubit is called "control qubit" and the second one is called "target qubit". This gate applies a NOT gate on the target qubit if the control qubit is $|1\rangle$, otherwise nothing happens[18].

Quantum Swap Gate: Swap gate doesn't have any classical equivalent. It acts on two qubits and swaps their values together[18].

Fig.1 shows the circuit diagram of these quantum gates.

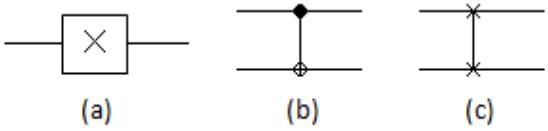


Fig.1. The circuit diagram of (a) Not gate, (b) CNOT gate, and (c) swap gate[18].

B. NEQR quantum gray-scale image representation model

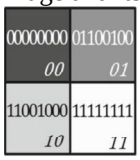
A novel enhanced quantum representation (NEQR) for quantum gray-scale digital images was proposed in 2013 [11]. Using this representation model, two entangled qubit sequences are used to keep the gray-scale value and position information of all the pixels of an image.

The representation of a $2^N \times 2^N$ image with the gray-scale range of 2^q using NEQR model can be given as:

$$|I\rangle = \frac{1}{2^N}\sum_{y=0}^{2^N-1}\sum_{x=0}^{2^N-1}|f(y,x)\rangle \otimes |yx\rangle$$

where, $f(y,x) = c_{yx}^{q-1}c_{yx}^{q-2}...c_{yx}^{0}$ is the gray-scale value of the (y,x) pixel. Fig.2 shows a simple 2×2 example

image and its NEQR quantum representation.



$$|I\rangle=\frac{1}{2}(|0\rangle\otimes|00\rangle+|100\rangle\otimes|01\rangle+|200\rangle\otimes|10\rangle+|255\rangle\otimes|11\rangle)$$

$$=\frac{1}{2}(|00000000\rangle\otimes|00\rangle+|01100100\rangle\otimes|01\rangle + |11001000\rangle\otimes|10\rangle+|01100100\rangle\otimes|01\rangle)$$

Fig.2. An example of a NEQR image [11]

C. QMCR quantum image representation model

Using the QMCR representation of quantum RGB images, two entangled qubit sequences are used to encode the information of the position and color of each pixel. Suppose that the gray range of each channel is 2^q. The presentation of a 2^N x 2^N RGB image can be given as [12]:

$$|I\rangle=\frac{1}{2^N}\sum_{y=0}^{2^N-1}\sum_{x=0}^{2^N-1}|C_{RGByx}\rangle\otimes|yx\rangle$$

where $\otimes$ represents the tensor product and the $|C_{RGByx}\rangle$ state is used to encode the R, G and B channels' information of the yx pixel, defined as follows:

$$|C_{RGByx}\rangle=|R_{yx}\rangle|G_{yx}\rangle|B_{yx}\rangle$$

Here, $|R_{yx}\rangle$, $|G_{yx}\rangle$ and $|B_{yx}\rangle$ are used to encode the information of Red, Green and Blue channels of the yx pixel, respectively, in the following fashion:

$$|R_{yx}\rangle=|r_{yx}^{q-1}r_{yx}^{q-2}...r_{yx}^{0}\rangle$$

$$|G_{yx}\rangle=|g_{yx}^{q-1}g_{yx}^{q-2}...g_{yx}^{0}\rangle$$

$$|B_{yx}\rangle=|b_{yx}^{q-1}b_{yx}^{q-2}...b_{yx}^{0}\rangle$$

$$r_{yx}^{k},g_{yx}^{k},b_{yx}^{k}\in\{0,1\}\text{, and}$$

$$|R_{yx}\rangle,|G_{yx}\rangle,|B_{yx}\rangle\in\{0,1,...,2^q-1\}$$

In RGB color image, we need to encode the information of the three color channels, therefore in order to represent a 2^N x 2^N RGB color image with 2^q gray range of each channel using QMCR, 3q+2n qubits are needed[12].

The general QMCR circuit is presented in Fig.3.

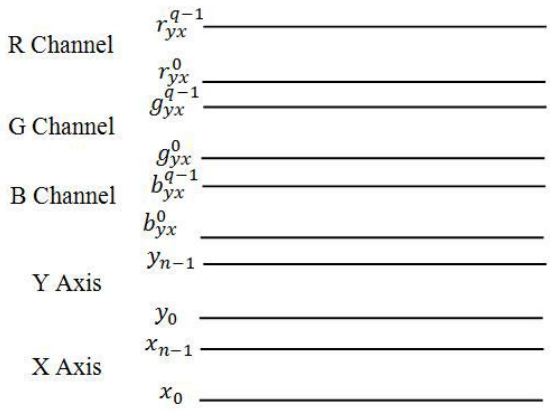
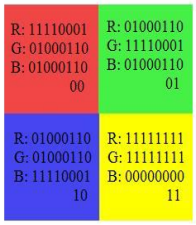


Fig.3. A general QMCR circuit[12]

A simple example of a 2 x 2 digital RGB image and its QMCR representation is shown in Fig.4.



$$|I\rangle=\frac{1}{2}[(|11110001\rangle|01000110\rangle|01000110\rangle)\otimes|00\rangle+$$
$$(|01000110\rangle|11110001\rangle|01000110\rangle)\otimes|01\rangle+$$
$$(|01000110\rangle|01000110\rangle|11110001\rangle)\otimes|10\rangle+$$
$$(|11111111\rangle|11111111\rangle|00000000\rangle)\otimes|11\rangle]$$

Fig.4. An example of a QMCR image [12].

III. PROPOSED SCHEME

In this section, we present our new scheme for quantum image watermarking. In our proposed scheme, a randomized black and white image is used as the binary key. This key will be used to choose the encoding color channel of each pixel and it will increase the security of the scheme. Based on the corresponding qubits of the key, one of three color channels of each pixel is chosen to carry the watermarked qubit of the authentication message. Having the binary key image, one can easily decode the secret watermarked message image.

Using the QMCR representation of quantum images, our proposed scheme can be summarized in the following simple formula:

$$WTR(|I\rangle)=\frac{1}{2^N}\sum_{y=0}^{2^N-1}\sum_{x=0}^{2^N-1}|C'_{RGByx}\rangle\otimes|yx\rangle$$

Where, WTR denotes the "watermarked", C'_{RGByx} is the RGB value of the yx pixel of the watermarked image, and $\otimes$ denotes the tensor product.

Fig.5 represents a schematic diagram of the proposed scheme.

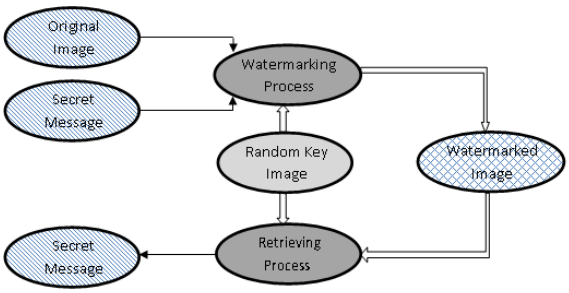


Fig.5. Schematic of the proposed watermarking scheme

In the proposed scheme, to watermark a $2^N\times2^N$ quantum image, a random binary key image is generated.

Since this key image is a black and white image, using NEQR representation, it would be formulated as:

$$BK(|I\rangle)=\frac{1}{2^N}\sum_{y=0}^{2^N-1}\sum_{x=0}^{2^N-1}|C_{yx}^{0}\rangle\otimes|yx\rangle$$

where, BK denotes the Binary Key, and $C_{yx}^{0}\in\{0,1\}$ is the binary value of the (y,x) pixel of the key.

A. Watermarking process

In the proposed scheme, the watermarking process is consisted of several steps as follows:

Step 1: Selecting the color channel based on the corresponding qubits of the binary key:
At first, based on the corresponding qubits of the binary key image, the process starts with selecting the color channel for every pixel of the original RGB image. Suppose that the P_{ij} pixel of the original image is going to be watermarked. According to the $|K_{ij}\rangle$ and $|K_{(2^N+1-i)(2^N+1-j)}\rangle$ qubits of the binary key image, and according to Table.1, one of the three color channels of pixel is selected.
To make it more clear, Fig.6 shows a simple example. As it can be seen, the values of the (1,1) and (2^N,2^N) pixels of the binary key image are $|0\rangle$ and $|0\rangle$, so according to Table.1, the selected color channel of the (1,1) pixel of the original RGB image would be the RED channel.

Table.1. Relations between qubits of the binary key and selected color channel

Qubits of the key	Selected color channel
$\|0\rangle\|0\rangle$	R
$\|0\rangle\|1\rangle$	G
$\|1\rangle\|0\rangle$	B
$\|1\rangle\|1\rangle$	B

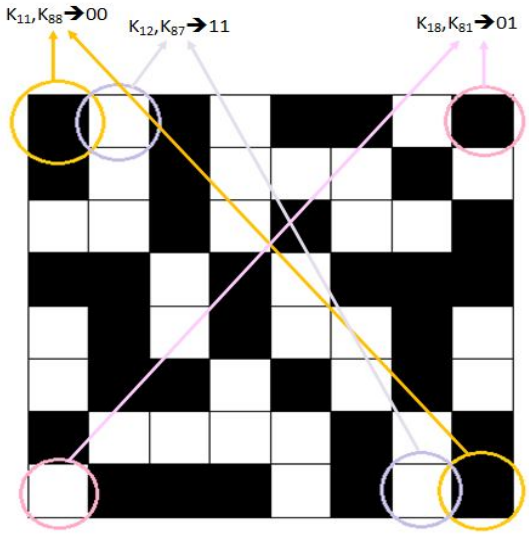


Fig.6. A simple example of corresponding qubits of binary key image and selected color channel

Fig.7 shows the quantum circuit of the corresponding binary key qubits and selected channel for each pixel of the original RGB image.

Step 2: Watermarking the corresponding qubit of the secret massage in the selected color channel:
In this step, based on the selected color channel of each pixel of the original RGB image, applying a SWAP gate, the corresponding qubit of the secret massage is watermarked in the LSB qubit of the channel of interest.
Fig.8 shows the quantum circuits of watermarking the secret massage's qubit in the original image's pixel.

B. Retrieving process
The retrieving process of the proposed scheme is also consisted of two steps as follows:

Step 1: Building a black image:
At first, a $2^N \times 2^N$ binary image is built. The gray-scale values of all pixels of this image should be $|0\rangle$, so this image is completely black. The NEQR representation of this image is as follows:

$$MSG(|I\rangle) = \frac{1}{2^N}\sum_{y=0}^{2^N-1}\sum_{x=0}^{2^N-1}|0\rangle\otimes|yx\rangle$$

where MSG denoted the binary massage image.

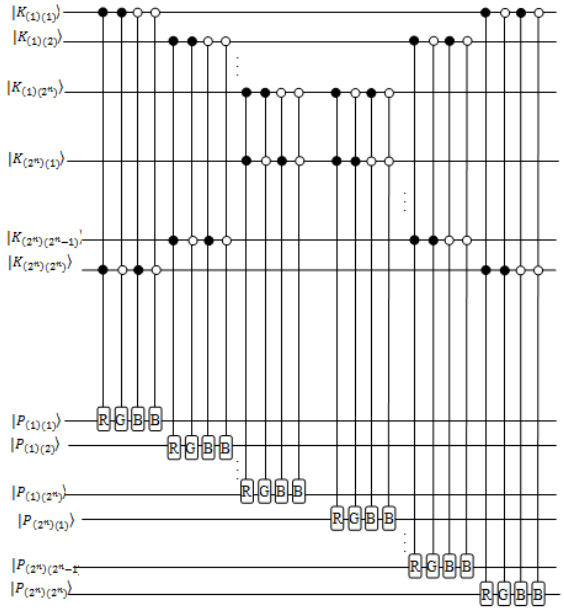


Fig.7. The quantum circuit of the corresponding binary key qubits and selected channel.

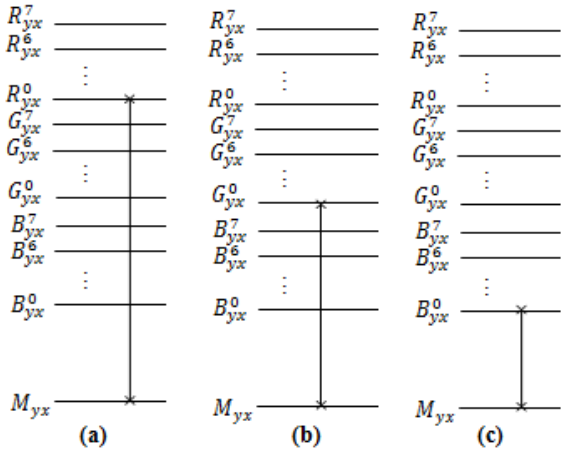


Fig.8. Quantum circuits of watermarking the secret massage's qubit, when the selected color channel is (a) Red channel, (b) Green channel, and (c) Blue channel.

Step 2: Detecting the color channel based on the corresponding qubits of the binary key:
In the second step of retrieving process, based on the corresponding qubits of the binary key image, the

selected color channel of each pixel is detected. The way of gathering the qubits of the key together to make the color channel code is completely similar to the first step of watermarking process. Here again, according to Table.1, the selected color channel is detected. The quantum circuit of this step is just like the Fig.7.

Step 3: Retrieving every qubit of the massage image:

In this step, which is the last step of the retrieving process, for each pixel of the watermarked image, based on the detected color channel, the qubit of the binary massage image is retrieved. For each pixel, the LSB qubit of the detected color channel is applied as the control qubit of a CNOT gate, and the target qubit of this gate is the corresponding $|0\rangle$ qubit of the binary massage image.

Since CNOT gate is the quantum equivalent of logical XOR gate, in the LSB qubit of detected color channel is $|0\rangle$, the target qubit stays unchanged, otherwise, the target qubit becomes $|1\rangle$.

Fig.9 shows the quantum circuits of retrieving the secret massage's qubit from the watermarked image's pixel.

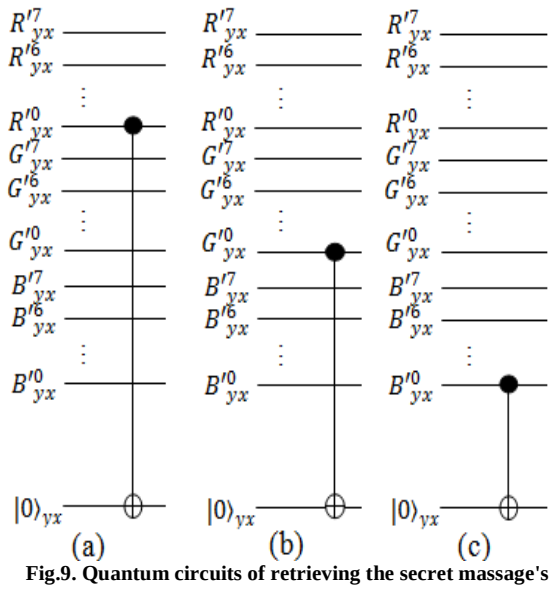


Fig.9. Quantum circuits of retrieving the secret massage's qubit, when the detected color channel is (a) Red channel, (b) Green channel, and (c) Blue channel.

IV. SIMULATIONS

Since the present quantum hardware currently cannot go beyond proof-of principle examples, to evaluate the proposed scheme, simulations are done, using a computer with Intel(R) Core(TM) i7-4500u CPU 2.40 GHz, 8.00 GB RAM equipped with the MATLAB R2015a environment.

A. A simple example

Fig. 10 shows a simple 8×8 RGB image, a binary random key image, and a secret binary massage .

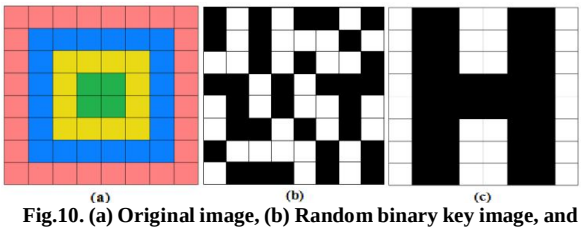


Fig.10. (a) Original image, (b) Random binary key image, and (c) Binary secret massage image.

Table.2 shows the color values of Red, Green and Blue channels of each color of the original image.

Table.2. The values of color channels of the original image

Color	R Channel	G Channel	B Channel
	11111111	10000000	10000000
	00001011	10000000	11111111
	11101010	11011010	00010101
	00100010	10110001	01001100

Fig.11 shows the selected color channels of every pixel of the original image, according to the corresponding qubits of the binary key image.

R	B	R	B	R	R	B	G
R	B	R	B	B	B	G	B
B	B	G	B	G	B	B	G
G	R	B	G	B	G	R	G
B	R	B	G	B	B	R	B
B	R	G	B	G	B	G	B
R	B	B	B	B	R	B	G
B	G	R	R	B	R	B	R

Fig.11. Selected color channel of each pixel.

Fig.12 shows the watermarked image of this simple simulation, and Table.3 shows the values of color channels of this image. As it can be seen, although the values of color channels are different from the original ones, but the watermarked and the original images still can't be recognized visually.

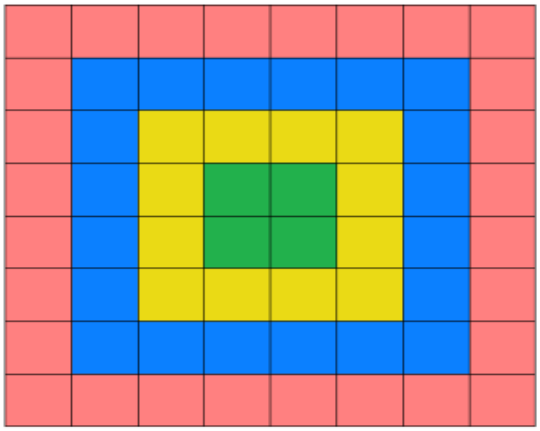


Fig.12. Watermarked image.

Table.3. The values of color channels of the watermarked image

Color	R Channel	G Channel	B Channel
	11111111	10000000	10000000
	11111110	10000000	10000000
	11111111	10000001	10000000
	11111111	10000000	10000001
	00001011	10000000	11111111
	00001010	10000000	11111111
	00001011	10000001	11111111
	00001011	10000000	11111110
	11101010	11011010	00010101
	11101011	11011010	00010101
	11101010	11011011	00010101
	11101010	11011010	00010100
	00100010	10110001	01001100
	00100011	10110001	01001100
	00100010	10110000	01001100
	00100010	10110001	01001101

B. Some real images

In our simulations, we evaluate the results of applying the proposed watermarking scheme on some real images by analyzing two essential properties: the histogram diagram (which shows the affluence of pixels with every color value in image) and the PSNR ratio (which is the Peak Signal to Noise Ratio of the image). In a watermarking scheme, our goal is to watermark our secret massage in an original image, with the minimum changes in it. So using an efficient watermarking scheme, the histogram diagram of the watermarked image should be similar to the original one's. In the other hand, applying the watermarking process, the watermarked secret massage acts like a noise to the original massage. So, the higher the PSNR ratio becomes, the watermarking scheme is more efficient. In Fig.13 to Fig.16, we have the original images, the binary secret massages, the watermarked images, and the histogram diagrams of original and watermarked images for four different simulated real images. Table.4 shows the PSNR ratio of these simulated images.



Fig.13. (a) the original Lena image, (b) the binary secret massage, (c) the watermarked Lena image, (d) histogram diagrams of original image, and (e) histogram diagrams of watermarked image.

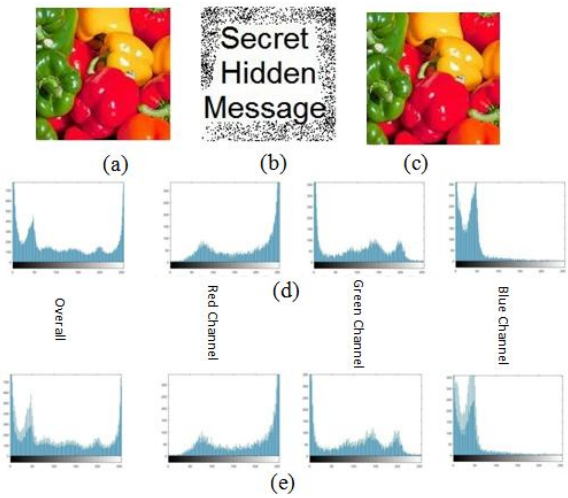


Fig.14. (a) the original Peppers image, (b) the binary secret massage, (c) the watermarked Peppers image, (d) histogram diagrams of original image, and (e) histogram diagrams of watermarked image.

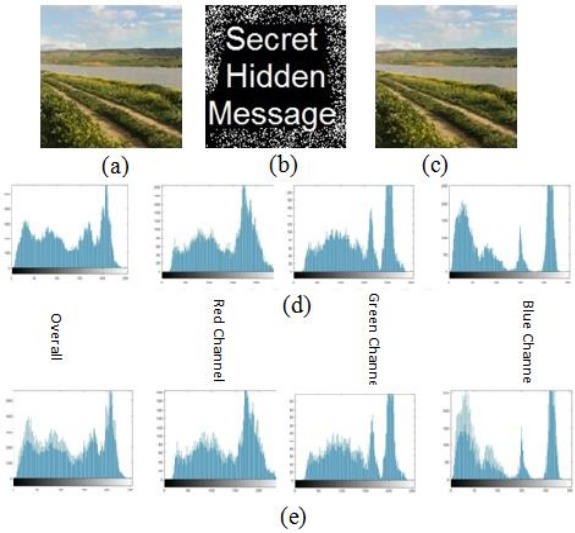


Fig.15. (a) the original First view image, (b) the binary secret massage, (c) the watermarked image, (d) histogram diagrams of original image, and (e) histogram diagrams of watermarked image.

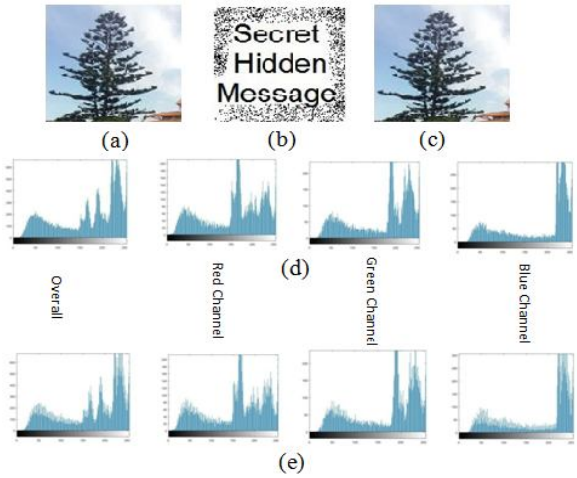


Fig.16. (a) the original Second view image, (b) the binary secret massage, (c) the watermarked image, (d) histogram diagrams of original image, and (e) histogram diagrams of watermarked image.

Table.4 The calculated PSNR ratio of the simulated images

Image	PSNR ratio
Lena image	55.9044%
Peppers image	55.7874%
First view image	55.9017%
Second view image	55.9389%
Average	55.8831%

It has been shown that comparing with previous watermarking schemes; our proposed scheme has a better PSNR ratio, which means that the proposed scheme watermarks the secret massage in a more efficient way than the previous schemes (Table.5).

Table.6. Comparing the average PSNR ratio with the previous watermarking schemes.

Reference	Quantum image representation model	Average PSNR ratio
Ghoshal et al[19]	SSCIA	33.2254%
Zhang et al[20]	FRQI	42.0788%
Yan et al[21]	MCQI	42.8266%
Miyake et al[22]	NEQR	44.55%
Present Work	MCQR	55.8831%

CONCLUSION

In this study, we proposed a new watermarking scheme for quantum RGB digital images. In our proposed scheme, a random binary key image is used to select one of three color channels of every pixel of the original image, and the corresponding qubit of the secret binary image is watermarked in the LSB qubit of the selected color channel.

The randomization of the key image insures the security of the proposed scheme. Simulations' results show that the final watermarked images can't be recognized visually from the original ones and the histogram diagrams of the watermarked images are similar to the histogram diagrams of the original images. Furthermore, the PSNR ratios of the final watermarked images are significantly higher than the previous proposed quantum image's watermarking methods.

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