July - August 2020
ISSN: 0193-4120 Page No. 3664 - 3673

Texture Feature Extraction for Quantum Images Using Local Binary Pattern

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Abstract

Local binary pattern (LBP) summarizes the local structure of image effectively, especially for digital image pre-processing. In this study, we propose a quantum approach to extract texture features using LBP. By encoding and storing the image information in quantum-mechanical system of the novel enhanced quantum representation (NEQR) of digital images, we demonstrate the frame work of quantum image feature extraction. Then we design concrete quantum realization circuit for the quantum version of LBP using some basic quantum gates. The proposed scheme can extract the texture feature in the computational complexity of $O(n^2+8q)$ for a NEQR quantum image with a size of $2^n \times 2^n$. Theoretical analysis and simulation-based experimental show both the feasibilities and capabilities of the proposed method, which is efficient, with low computational complexity and good robustness.

Keywords: *quantum image processing, feature extraction, local binary pattern, quantum circuit*

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1.INTRODUCTION

Recently, image information has been widely used in every field of society. The analysis of visual information becomes more and more important. However, some of these tasks can be performed very efficiently by classical computers, but others are still time-consuming [1]. The pre-processing of a large number of real-time images, such as feature extraction, has exceeded the capabilities of classical computers [2]. Obviously, effective image pre-processing methods are needed, especially with the application of emerging technologies [3].

As everyone knows, quantum computing is considered to be one of the most promising computing models in the future. It is an effective way to store and process information using some properties of quantum mechanics. When Feynman [4] proposed this concept in 1982, quantum computing first caught the attention of researchers. Since the research on quantum computing has been paid more and more attention, after decades of research, some reliable results have been achieved. In 1994, Shor [5] designed a polynomial-time quantum integer factorization algorithm; meanwhile, Grover [6] explored a database quantum search algorithm, which can reach quadratic speed. Quantum computing has undoubtedly become a new type of computing model to overcome the limitations of classical computation.

Because of its parallel computing ability and effectiveness, quantum image processing has been widely concerned in recent years. For quantum image processing, quantum image representation plays a key role. several quantum image representations have been discussed, such as flexible representation of quantum images (FRQI) [7] and novel enhanced quantum representation (NEQR) of digital images [8].

On the basis of quantum image representations, several quantum image processing algorithms have been proposed, such as quantum image feature extraction and segmentation. Due to its high efficiency of image processing and analysis, quantum image feature extraction techniques have been attracted considerable research interest recently.

Based on Qubit Lattice model, edge extraction algorithm was studied firstly [9]. Because the quantum image model does not use the unique properties of quantum mechanics, the proposed edge extraction scheme has high complexity. Then A novel edge extraction algorithm was put forward on the basis of FRQI and the famous edge extraction algorithm Sobel [10]. The proposed quantum Sobel can utilize quantum parallel computing to achieve a significant and exponential acceleration speedup. Similarly, based on the classical Sobel, quantum image edge extraction using NEQR was designed [11]. On the basis of NEQR, a quantum feature extraction framework was proposed, which can be used to extract feature points [12]. The algorithm to detect the quantum edge [13] was studied, which is the combination of the zero-crossing method and the classical Laplace operator. A new procedure to extract the texture from images, called the quantum local binary pattern (LBP), was investigated [14]. The proposed method was designed for and applied to medical images.

Previous works have focused on image feature extraction based on quantum computing. However, the related research on texture feature extraction for quantum images is still lacking. In classical digital image processing, LBP is a simple and effective method for describing local structure. In this paper, we propose a quantum image feature extraction algorithm based on LBP. However, we mainly focus on the feature extraction approach for quantum images using the NEQR model, which is different from Ref. [14]. Compared with the previous related quantum image extraction schemes, the proposed scheme has the following merits:

(1) The proposed scheme is utilized to extract the texture from quantum images using NEQR model.

(2) We have designed the reversible logic circuit for the proposed quantum version of LBP, which has a computational complexity $O\left(n^2+8q\right)$.

(3) The proposed scheme has good robustness.

The remainder of this paper is organized as follows. Section 2 gives the basic introduction of NEQR and LBP. Section 3 discusses the quantum module circuit which is used to construct the concrete quantum realization circuit of proposed algorithm. Section 4 describes the proposed algorithm. Section 5 discusses the computational complexity and experimental results. Finally, Section 6 concludes the paper.

2.PRELIMINARIES

2.1 NEQR

The image information, including pixel information and coordinate position, is integrated into two entangled qubit sequences in NEQR [8]. Suppose that the range of the grayscale value is 2^q, the representative expression of the normalized

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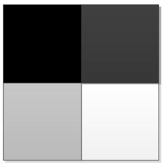
July - August 2020
ISSN: 0193-4120 Page No. 3664 - 3673

superimposed quantum state to realize the quantum expression of a digital image is as follows:

$$|I\rangle = \frac{1}{2^n}\sum_{i=0}^{2^{2n}-1}|C_i\rangle\otimes|i\rangle = \frac{1}{2^n}\sum_{Y=0}^{2^n-1}\sum_{X=0}^{2^n-1}\bigotimes_{k=0}^{q-1}|c_{YX}^k\rangle\otimes|YX\rangle, \quad (1)$$

Herein, the *q*-qubit sequence $|C_i\rangle = |c_i^{q-1}\cdots c_i^1 c_i^0\rangle$ and the two *n*-qubit sequences of $|Y\rangle = |y_{n-1}\cdots y_1 y_0\rangle$ and $|X\rangle = |x_{n-1}\cdots x_1 x_0\rangle$ is used to encode color information in position $|i\rangle$. Figure 1 shows an image with size 2×2 and its corresponding representation.



$$|I\rangle = \frac{1}{2}(|0\rangle\otimes|00\rangle + |100\rangle\otimes|10\rangle + |200\rangle\otimes|01\rangle + |255\rangle\otimes|11\rangle)$$
$$= \frac{1}{2}(|00000000\rangle\otimes|00\rangle + |01100100\rangle\otimes|10\rangle + |11001000\rangle\otimes|01\rangle + |11111111\rangle\otimes|11\rangle)$$

Figure 1. An image with size 2×2 and its representation

2.2 LBP

T. Ojala et al. [15] proposed LBP for the first time in 1996. LBP has been used for processing image as well as the computer vision [16-17]. For an image divided into 3×3 blocks, LBP is a local texture descriptor. We can effectively summarize the local structure of the image with the comparison of every pixel with its surrounding pixels. Figure 2 illustrates the LBP process. The original LBP is obtained by thresholding the pixel values in the neighborhood with the center pixel. All pixels are to make a comparison with the eight neighboring pixels with the subtraction of the central pixel value; the negative value and the other values are encoded as 0 and 1 accordingly. That is, if a neighborhood pixel value is less than the value of the central pixel, the result will be set to zero. Otherwise, it is set to one. For each specified pixel, the connection of all binary values in a clockwise direction can get a binary string, starting with its upper left neighbor. Then, the specified pixel can be marked with the generated binary string.

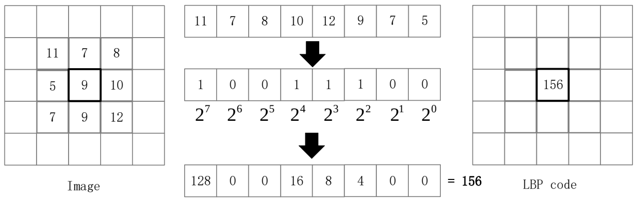


Figure 2. An example of the basic LBP operator

In order to handle various scales of texture, different sizes of neighborhood are used to extend the operator. Here, we introduce some extended LBP operators. The symbols (P, R) represent the P sampling points on the circle with radius R. Assume there is a given pixel (x_c, y_c), Eq. 2 shows how to express LBP in the format of decimal:

$$LBP_{P,R(x_c,y_c)} = \sum_{P=0}^{P-1} s(i_P - i_c)2^P \quad (2)$$

where i_c is the gray values of the center pixel , i_P is the gray value of the neighboring pixels P in the circle neighborhood of radius R, respectively, and the function $s(x)$ is defined as

$$s(x) = \begin{cases} 1, & if \ x \geq 0 \\ 0, & if \ x < 0. \end{cases} \quad (3)$$

LBP mode is very robust in gray level change and brightness conversion. In addition, LBP mode can be extended to rotation invariance. For example, if these binary sequences are rotated, many binary sequences can be obtained. The minimum value will be taken and used as the new LBP code, which is the only mode, regardless of how it rotates. For grayscale images, the basic LBP operators can provide better performance and application [14]. Therefore, for simplicity, the basic LBP with $P = 8$ and $R = 1$ is applied to the proposed scheme in this paper.

3.RELATED QUANTUM CIRCUIT DESIGN

3.1 Transformations of X-shift and Y-shift

Le et al. [18] gave a geometric transformation for FRQI images, which can also be used to move the

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July - August 2020
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entire image. Each pixel can simultaneously access information of its surrounding pixels. For instance, when moving up one unit for an image, the pixels are converted from C_{YX} to C_{Y-1X} . Location information in the NEQR model is stored with the same scheme. NEQR defines the X-shift and Y-shift of quantum images with size $2^n \times 2^n$. In this section, a cyclic shift operation will be described, which will be used in our proposed method. Quantum operations s_{y-} and s_{x+} are briefly discussed as follows.

s_{y-} moves all pixels to the up position and decreases one to its Y-axis coordinates. Note that the operation is circular for the edge pixels of an image. Subtraction is also a circular subtraction of modules 2^n . Then the transformation of the quantum image can be defined as

$$|I\rangle = \frac{1}{2^n}\sum_{Y=0}^{2^n-1}\sum_{X=0}^{2^n-1}|C_{YX}\rangle|Y\rangle|X\rangle$$
$$\underrightarrow{S_{y-}}\ |I'\rangle = \frac{1}{2^n}\sum_{Y=0}^{2^n-1}\sum_{X=0}^{2^n-1}|C_{YX}\rangle|(Y-1)\bmod 2^n\rangle|X\rangle \quad (4)$$

The transformation s_{y-} can be converted into quantum circuit by using multi-controlled-NOT gate. The corresponding circuit and the transformed result of an example image are shown in Figure 3.

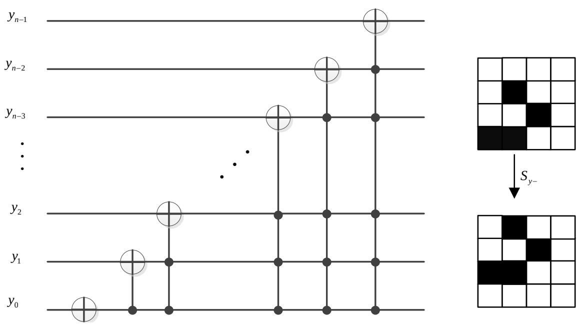

Figure 3. Quantum circuit of the Y-shift transformation and an example

The rotation operations for both coordinates are similar for the two-dimensional image. As a result, s_{x+} transformation can be described in the same way, that is, it can move all pixels to the right position. Then the value of X-axis coordinates is added one. Similarly, this operation is cyclic for the edge pixels. The addition is also a cyclic subtraction with modulus 2^n. The transformation can be defined as

$$|I\rangle = \frac{1}{2^n}\sum_{Y=0}^{2^n-1}\sum_{X=0}^{2^n-1}|C_{YX}\rangle|Y\rangle|X\rangle$$
$$\underrightarrow{S_{x+}}\ |I''\rangle = \frac{1}{2^n}\sum_{Y=0}^{2^n-1}\sum_{X=0}^{2^n-1}|C_{YX}\rangle|Y\rangle|(X+1)\bmod 2^n\rangle \quad (5)$$

Figure 4 shows the quantum circuit of s_{x+} and its transformed result for an example image.

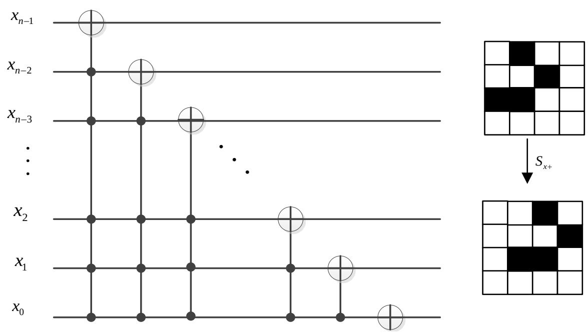

Figure 4. Quantum circuit of   and an example

By using the same method, s_{y+} and s_{x-} can be precisely defined according to the symmetry of coordinates. These X-shift and Y-shift transformations play an important role in the proposed method which will be presented in Section 4.

3.2 Quantum Comparator

Wang et al. have put forward the quantum comparator [19]. This comparator makes a comparison between a and b, where $|a\rangle = |a_{n-1}\ldots a_1 a_0\rangle$ and $|b\rangle = |b_{n-1}\ldots b_1 b_0\rangle$. $|c_1 c_0\rangle$ is the output. Figure 5 presents the specific quantum comparator circuit. The following are the results of this comparator.

- If $c_1c_0 = 00$, then $a = b$;
- If $c_1c_0 = 01$, then $a < b$;
- If $c_1c_0 = 10$, then $a > b$.

July - August 2020
ISSN: 0193-4120 Page No. 3664 - 3673

In our scheme, the qubit of c_1 is used to describe the LBP codes, while the qubit of c_0 is not used. It is not difficult to see that if $c_1 = 0$, the result of $b \geq a$ can be obtained through the above descriptions. Therefore, the qubit of c_1 can be used as the control qubit.

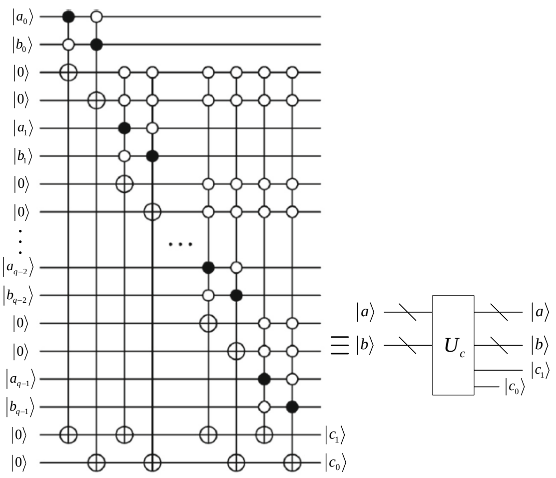

Figure 5. Quantum comparators

3.3 Quantum Unitary Operator

To obtain the new LBP image, the operator U_s is defined as follows:

$$U_S\left(|C\rangle|0\rangle^{\otimes n}\right) = |C_{YX}\rangle|C_{YX}\rangle. \quad (6)$$

The operator U_s can copy $|C\rangle = |c_{q-1}c_{q-2}\cdots c_0\rangle$ into the auxiliary qubits of $|0\rangle^{\otimes q}$. The corresponding circuit and its simplified diagram are shown in Figure 6.

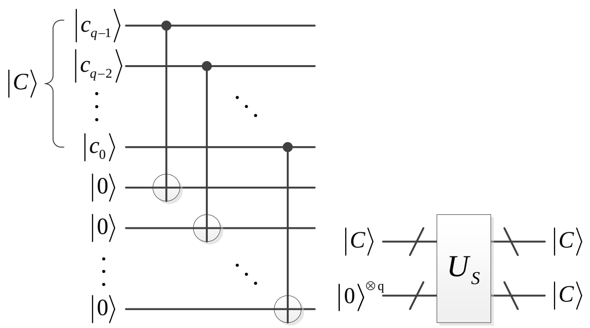

Figure 6. Quantum operation of U_S

4.PROPOSED SCHEME

In this part, we will describe the procedures of the proposed scheme. Firstly, we will discuss the relevant preparations. Then, the calculation of LBP code and the framework of texture feature extraction for quantum image will be analyzed in detail.

4.1 Preparations

Extracting the texture features of a quantum image using the classic LBP method can be divided into four procedures, as it is presented in Figure 7.

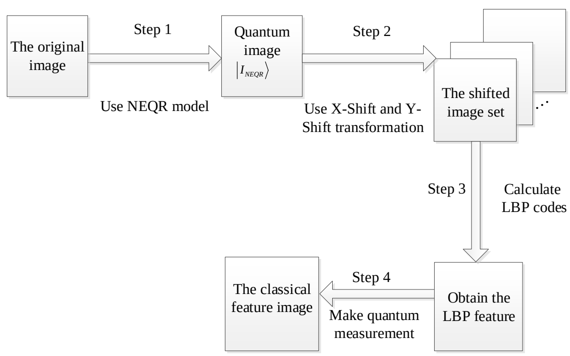

Figure 7. Workflow of the feature extraction for quantum images

As shown in Figure 8, there are 8 adjacent pixels for (Y, X). In order to obtain the LBP codes, the above two shift transformations are used to make a calculation about the LBP code of every pixel simultaneously. By using X-shift and Y-shift transformations as well as quantum operator U_s, the gray level information of each pixel in the 3×3 neighborhood windows can be obtained at the same time. The concrete steps for this algorithm are as below.

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July - August 2020
ISSN: 0193-4120 Page No. 3664 - 3673

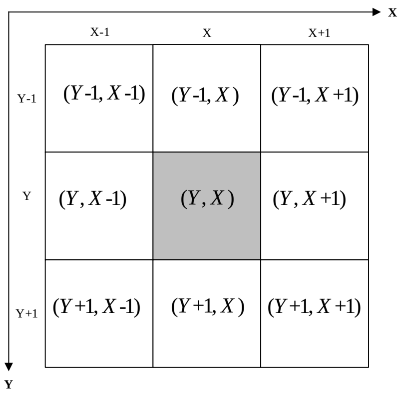

Figure 8. 3×3 neighborhood pixel of (Y, X)

Initialization: I_{yx} is defined in

$$|I\rangle = \frac{1}{2^n}\sum_{Y=0}^{2^n-1}\sum_{X=0}^{2^n-1}|C_{YX}\rangle|Y\rangle|X\rangle$$

Step1: $S(y-)$, shift I_{yx} one unit upwards,

$$I_{y-1x} = S(y-)I_{yx} = \frac{1}{2^n}\sum_{Y=0}^{2^n-1}\sum_{X=0}^{2^n-1}|C_{Y-1X}\rangle|Y\rangle|X\rangle$$

Step2: $S(x+)$, shift I_{y-1x} one unit rightwards,

$$I_{y-1x+1} = S(x+)I_{y-1x} = \frac{1}{2^n}\sum_{Y=0}^{2^n-1}\sum_{X=0}^{2^n-1}|I_{Y-1X+1}\rangle|Y\rangle|X\rangle$$

Step3: $S(y+)$, shift I_{y-1x+1} one unit downwards,

$$I_{yx+1} = S(y+)I_{y-1x+1} = \frac{1}{2^n}\sum_{Y=0}^{2^n-1}\sum_{X=0}^{2^n-1}|I_{YX+1}\rangle|Y\rangle|X\rangle$$

Step4: $S(y+)$, shift I_{yx+1} one unit downwards,

$$I_{y+1x+1} = S(y+)I_{yx+1} = \frac{1}{2^n}\sum_{Y=0}^{2^n-1}\sum_{X=0}^{2^n-1}|I_{Y+1X+1}\rangle|Y\rangle|X\rangle$$

Step5: $S(x-)$, shift I_{y+1x+1} one unit leftwards,

$$I_{y+1x} = S(x-)I_{y+1x+1} = \frac{1}{2^n}\sum_{Y=0}^{2^n-1}\sum_{X=0}^{2^n-1}|I_{Y+1X}\rangle|Y\rangle|X\rangle$$

Step6: $S(x-)$, shift I_{y+1x} one unit leftwards,

$$I_{y+1x-1} = S(x-)I_{y+1x} = \frac{1}{2^n}\sum_{Y=0}^{2^n-1}\sum_{X=0}^{2^n-1}|I_{Y+1X-1}\rangle|Y\rangle|X\rangle$$

Step7: $S(y\text{-})$: shift I_{y+1x-1} one unit upwards,

$$I_{yx-1} = S(y\text{-})I_{y+1x-1} = \frac{1}{2^n}\sum_{Y=0}^{2^n-1}\sum_{X=0}^{2^n-1}|I_{YX-1}\rangle|Y\rangle|X\rangle$$

Step8: $S(y\text{-})$: shift $I_{yx\text{-}1}$ one unit upwards,

$$I_{y-1x-1} = S(y\text{-})I_{yx-1} = \frac{1}{2^n}\sum_{Y=0}^{2^n-1}\sum_{X=0}^{2^n-1}|I_{Y-1X-1}\rangle|Y\rangle|X\rangle$$

4.2 The Procedures and its Reversible Logical Circuit

The procedures of texture feature extraction for quantum images based on LBP is given as follows.

Stage 1: Suppose that the image size is $2^n\times2^n$. This image is converted into quantum image. $2n+q$ qubits are needed to store all of the image information. In addition, the next operation requires eight additional qubits to store the neighboring pixels' color information, which is stored in

$$|0\rangle^{\otimes q}\otimes\ldots\otimes|0\rangle^{\otimes q} \qquad (7)$$

Stage 2: This stage will perform the X-Shift and Y-Shift, as well as the quantum operator. The relative color qubits of the entire image are obtained and stored in the auxiliary qubits. After executing the algorithm, the quantum image set can be defined in

$$\begin{Bmatrix} |C_{YX}\rangle, |C_{Y-1X}\rangle, |C_{Y-1X+1}\rangle, |C_{YX+1}\rangle, |C_{Y+1X+1}\rangle, \\ |C_{Y+1X}\rangle, |C_{Y+1X-1}\rangle, |C_{YX-1}\rangle, |C_{Y-1X-1}\rangle \end{Bmatrix} \qquad (8)$$

Obviously, eight shift images stored in quantum state are obtained by X-Shift and y-shift in a certain order.

Stage 3: Calculate the LBP code using the relevant image. To make the comparison between the values of C_{YX} and $C_{Y\text{-}1X\text{-}1}$, C_{YX} and $C_{YX\text{-}1}$, etc., the quantum comparator U_c can be utilized. When the value of the eight neighborhood pixels is equal or greater than C_{YX}, the auxiliary qubit with the basic quantum state $|1\rangle$ will be stored; otherwise, the basic quantum state $|0\rangle$ will be stored. After it, eight basic quantum states are obtained. In order to obtain the LBP codes of the image, eight basic quantum state sequences need to be selected. Here, the result of the above comparison (C_{YX} and $C_{Y\text{-}1X\text{-}1}$) is considered as the most significant bit C_{YX}^7. According to the clockwise direction, the binary sequence is obtained and defined in

$$\begin{aligned} |I'\rangle &= \frac{1}{2^n}\sum_{Y=0}^{2^n-1}\sum_{X=0}^{2^n-1}|C_{YX}\rangle|Y\rangle|X\rangle \\ |C_{YX}\rangle &= \bigotimes_{i=0}^{7}|C_{YX}^i\rangle = |C_{YX}^7\ldots C_{YX}^1C_{YX}^0\rangle,\ \ C_{YX}^i\in\{0,1\} \end{aligned} \qquad (9)$$

July - August 2020
ISSN: 0193-4120 Page No. 3664 - 3673

The concrete realization circuit is shown in Figure 9. It is worth noting that $|c_1\rangle = 0$ is used as the control qubit.

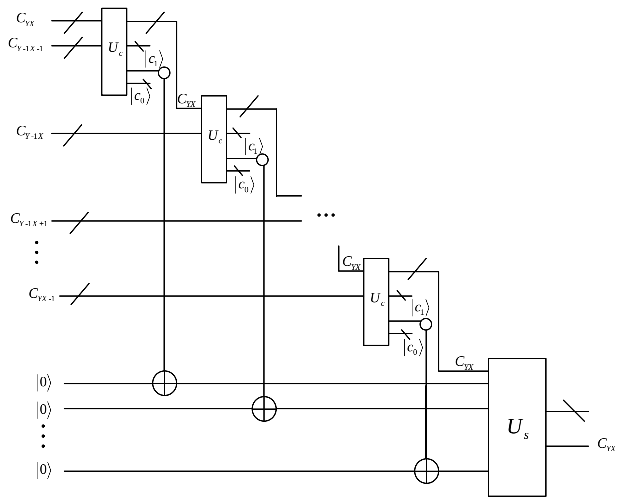

Figure 9. The concrete realization circuit

Stage 4: Obtain the gray information of every pixel in the new LBP quantum image. To achieve the classical information of a quantum image, quantum measurement can be used to regain classical information. Since all pixels are stored in the basic state of qubit sequence, the grayscale information can be recovered by using the quantum measurement. The entire measurement process can be divided into two parts. In the first part, the quantum measurement is utilized to extract the pixel information $|P_{YX}\rangle$ of (Y, X). The process is shown as follows:

$$\Gamma=\sum_{YX=0}^{2^{2n}-1} I'^{\otimes q}\otimes|YX\rangle\langle YX|,|P_{YX}\rangle=|C_{YX}\rangle|YX\rangle \qquad (10)$$

$$\begin{aligned} M &= \sum_{m=0}^{2^q-1} m|m\rangle\langle m| \\ \langle C_{YX}|M|C_{YX}\rangle &= \sum_{m=0}^{2^q-1} m\langle C_{YX}||m\rangle\langle m||C_{YX}\rangle = C_{YX} \end{aligned} \qquad (11)$$

In the second part, through these operations, the classic LBP gray value of the pixel can be restored. An accurate classic LBP image is obtained.

5.COMPLEXITY DISCUSSION AND EXPERIMENTAL ANALYSIS

In this section, the circuit complexity of the proposed quantum texture feature extraction algorithm is discussed firstly. Then, we use the peak signal to noise ratio (PSNR) to evaluate the performance and robustness of the proposed algorithm.

5.1 Computational Complexity

In general, the computational complexity depends on the number of basic quantum gates [20]. Here we consider a digital image with a size of $2^n \times 2^n$ as an example.

First, to obtain the feature images using quantum algorithm, the original image should be encoded in a pure quantum state. The preparation procedure for NEQR was described and the computational complexity for NEQR image preparation does not exceed $O(qn2^{2n})$ [8].

In stage 2, get the converted quantum image set with the quantum cyclic shift operations. The complexity is about $O(n^2)$. At the same time, eight quantum operations U_s are performed. The whole complexity is no more than $O(n^2+8q)$.

In stage 3, there are eight quantum comparators U_c and one quantum operation U_s in the quantum implementation circuits. The complexity of quantum comparator is $24n^2+6n$ [19]. The complexity of unitary operator is $O(q)$. Thus, it is clear that the complexity of this stage is about $O(n^2+q)$.

In stage 4, due to the collapse of quantum system and uncertainty principle, it is necessary to prepare some quantum images for measurement. The method is used to prepare quantum measurements. The texture features can be accurately retrieved from NEQR images instead of probabilistic ones.

Through the above analysis, the main cost of our scheme comes from the preparation of NEQR and quantum measurement. Generally, they should not be regarded as part of quantum image processing. If we ignore the complexity of quantum image preparation and measurement, the proposed algorithm can extract the texture features of quantum image with a complexity of $O(n^2+8q)$. Table 1 demonstrates the complexity comparisons between our proposed scheme and other existing quantum edge extraction algorithms. Obviously, the proposed algorithm has a lower computational complexity than the existing scheme using quantum image representation of Qubit lattic [9]. The complexity is equivalent with that of quantum image feature extraction using FRQI and NEQR. Both of these algorithms have achieved a low computational complexity. However, Due to the one-by-one processing pixel in classical counterpart, which the computational complexity is no less than $O(2^{2n})$. Hence, the proposed approach can achieve exponential speed in comparison with their classical counterparts.

Table 1. Comparison of computational complexity

Algorithm	Quantum image representation	Complexity of edge extraction
Ref. [9]	Qubit Lattic	$O(2^{2n})$
Ref. [10]	FRQI	$O(n^2)$
Ref. [13]	NEQR	$O(n^2+q^2)$
Ref. [11]	NEQR	$O(n^2+2^{q+4})$
Proposed algorithm	NEQR	$O(n^2+8q)$

5.2 Experimental analysis

As a practical and useful quantum computer was unavailable, the simulation experiments were performed on a laptop using MATLAB 2014b to test whether this method is effective or not. Four face images with a size of 256×256 were used as the original test images (Figure. 10). After extracting LBP features using the proposed method, the corresponding feature images are obtained shown in Figure 11.

Figure 10. Four test images

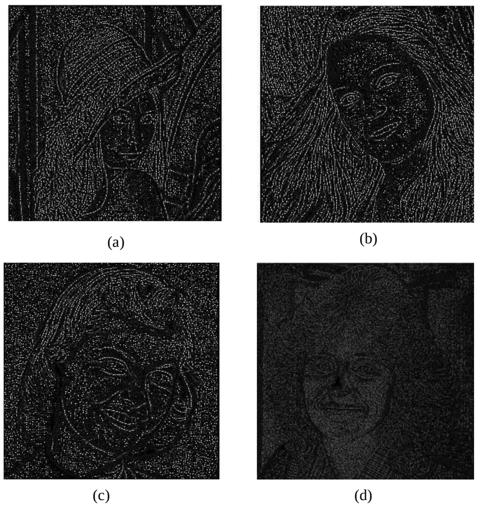

Figure 11. The LBP feature images

The performance of the proposed approach had been evaluated by using the peak signal to noise ratio (PSNR), which is one of the most used indicators to compare the fidelity of an extracted image with its original version. Here, PSNR is considered our extracted image evaluation indictor by transforming the quantum images into classical forms. The PSNR is defined as:

$$PSNR = 10\log_{10}\frac{MAX_I^2}{MSE} = 20\log\frac{MAX_I}{\sqrt{MSE}}, \quad (12)$$

therein, MAX_I is the maximum gray-level value of the image. MSE is the mean squared error for two $m\times n$ grayscale images: the original image I and its feature image version J, as defined in:

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July - August 2020
ISSN: 0193-4120 Page No. 3664 - 3673

$$MSE = \frac{1}{mn}\sum_{i=0}^{m-1}\sum_{j=0}^{n-1}\left[I(i,j)-J(i,j)\right]^2 \qquad (13)$$

In the experiment, all of the PSNR values between different face images and their corresponding feature images (Figs. 10 and 11) were calculated to be about 34dB. To test the performance of the proposed algorithm further, the robustness analysis in the noise environment is demonstrated for the classical cases. Here we consider the cases of face images affected by salt and pepper noise. First, salt and pepper noise were applied with density 0.05 to the original face images. After extracted, the PSNR values of corresponding feature image were also calculated to be about 33dB. That is, the simulated result shows the algorithm is robust against salt and pepper noise. Then, the images are affected by salt and pepper noise, and the density is set to 0.20. After the proposed algorithm was executed, the PSNR values of 32dB in this case were also obtained. Compared with existing schemes of quantum local binary pattern for medical edge detection [14], the proposed approach can achieve higher PSNR. It should be emphasized, however, the images used for testing are different. The standard test images were used in proposed scheme, while some medical grayscale image datasets were used in Lekehali's scheme [14].

6.CONCLUSION

We have proposed a novel quantum feature extraction scheme using local binary pattern on the basis of NEQR. The feature image extracting process can be realized by constructing quantum transformation operations. We have designed the corresponding reversible logic circuit for the proposed quantum algorithm, which has an algorithm complexity of $O(n^2+8q)$. Supported by detailed theoretical analysis and numerical simulation, the proposal has also clarified its computational complexity and robustness. Depending on the unique quantum properties, such as quantum superpositions and quantum parallelism, are used to speed up data processing, the proposed quantum algorithm may be used for further improving the efficiency of image feature extracting and analysis. However, due to the limitations of basic LBP methods and the difficulty of quantum operations, some extended methods will be considered to extract the texture features for quantum images in future work.

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