An Improvement of Remote Sensing Images Edge Extraction Algorithm Based on Quantum Derivation

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Abstract: Aiming at the problem that the edge connectivity is poor when the original quantum derived edge extraction algorithm detects the edge of remote sensing image, it is necessary to improve the original algorithm in this study. The remote sensing image is initially multi-threshold segmented globally by quantum genetic algorithm, and then the method of quantum probability statistic is used to extract the edge of images. The experiment results show that the proposed algorithm improves the edge connectivity under the premise of preserving the precise edge of the image edge.

1. Introduction

Because extracting the edge of an image is the preprocessing of image segmentation, target recognition, three-dimensional reconstruction and so on, it is particularly important to detect image edge precisely. Traditional edge extraction operators such as Sobel operator, Laplace operator and Canny operator are not ideal when processing the edge of remote sensing image, but in recent years, many researchers are trying to use new methods to process the edge of remote sensing image, such as wavelet transform\(^1\), morphological\(^2\) and neural network method\(^3\).

The method based on quantum derivation is a new method which borrows some basic principles of quantum mechanics to improve the traditional algorithm. In 2007, Kefu Xie\(^4\) proposed the quantum derived morphological edge detection, which has the advantages of detecting noise polluted images, but it is not superior to the ordinary image edge detection. In 2013, Jingen Ai et al.\(^5\) extracted the gray-scale image processing method based on quantum pointer. In 2016, S.Abdel-Khalek et al.\(^6\) proposed an image edge detection algorithm based on quantum entropy in which the image segmentation threshold is determined by calculating the quantum entropy of the image and then the image edge is extracted. In 2018, Prof.Siwen Bi\(^7\), who is from the Institute of remote sensing of the Chinese Academy of Sciences in Beijing, led his team to conduct quantum remote sensing image data processing research on which image edge extraction results was also quite fruitful.

Because the original quantum remote sensing image data edge extraction algorithm has the defects of poor edge connectivity and others, the algorithm is improved in the study in which original image is threshold segmented globally to sharpen the edge and then binary edge extraction is conducted. The results show that compared with the original algorithm, this one improves the poor edge connectivity, enhances the edge details of the image, and makes it more advantageous to extract edge of remote sensing image with the quantum method than the traditional method.

2. The basics of quantum theory

2.1 Quantum superposition

[^1]: Wavelet transform
[^2]: Morphological
[^3]: Neural network method
[^4]: Kefu Xie
[^5]: Jingen Ai et al.
[^6]: S.Abdel-Khalek et al.
[^7]: Prof.Siwen Bi
A qubit is a concept that distinguishes information bits in classic computer, and its state can be represented by a "linear combination" of two basic states of $|0\rangle$ or $|1\rangle$. It is called quantum superposition. The corresponding formula is given below:

$$|\phi\rangle = a|0\rangle + b|1\rangle$$

(1)

Where $a$ and $b$ are complex numbers representing the probability amplitude and satisfying the normalization condition $|a|^2 + |b|^2 = 1$. $|a|^2$ and $|b|^2$ represent the probability of occurrence of ground state $|0\rangle$ and $|1\rangle$ respectively.

2.2 Quantum system

A quantum system is a system like binary number that composed of one or more qubits (each bit is a qubit). The system is in a superposition state before observation or measurement and collapses into a quantum ground state in the expression after them. Assuming that a quantum system consists of $n$ qubits, and the state of the ith qubit is represented as quantum superposition, the state of the quantum system can be represented by the direct product of $n$ qubits:

$$|\psi\rangle = \otimes_{i=1}^{n} |i\rangle$$

(2)

Where "$\otimes$" represents tensor product; $i$ is the n-bit binary string corresponding to the decimal number $i$; $\omega_i$ represents the probability amplitude of the corresponding ground state, and $|\omega_i|^2$ is the probability of occurrence of the corresponding ground state, the sum of probabilities determined by the probability amplitude is 1.

2.3 Quantum bit representation of gray image

Suppose $f(x, y)$ represents a classic digital image, $(x, y) \in \mathbb{Z}^2$, $f(x, y) \in [0,255]$, $f(x, y)$ represents the normalized image, and the range of pixel values is $[0,1]$. According to Formula 1, the gray image can be expressed as follows:

$$|f(x, y)\rangle = \sqrt{1-f(x, y)}|0\rangle + \sqrt{f(x, y)}|1\rangle$$

(3)

Among them, $|0\rangle$ and $|1\rangle$ represent all black points and all white points in the classic image, $1-f(x, y)$ represents the probability that the pixel value of the image is taken as ‘0’ at the position $(x, y)$, and $f(x, y)$ represents the probability that the pixel value of the image is taken as ‘1’ at the position $(x, y)$. Obviously, they meet the normalization conditions.

3. Multi-threshold global segmentation of image

According to the method mentioned in [8], this study intends to use quantum genetic algorithm to experiment multi-threshold global segmentation of remote sensing image.

3.1 The quantum genetic algorithm (QGA)

3.1.1 Quantum chromosome

There is a biological population $Q$, and the quantity of population is pop_num. Now it is assumed that each individual in the population has only one chromosome:

$$\text{chrom} = \begin{bmatrix}
    a_1 & a_2 & \ldots & a_n \\
    b_1 & b_2 & \ldots & b_n
\end{bmatrix}$$

(4)

As mentioned above, it is called quantum chromosome coding, and each column is called a quantum bit gene. The ith quantum bit gene can be represented by quantum ground state $|0\rangle$ and $|1\rangle$ and their probability amplitude $|a_i|^2$ and $|b_i|^2$, $i = 1, 2, \ldots, n$. As $|a_i|^2$ approaches ‘0’ or $|b_i|^2$ approaches ‘1’, quantum chromosome will converge to a certain single state.
3.1.2 Quantum variation
In quantum genetic algorithm, chromosome mutation can be realized by quantum rotation gate\(^{(10)}\),
which uses the chromosome information of the optimal individual to guide chromosome evolution and
improve the convergence of the algorithm:
\[
\begin{bmatrix}
\alpha' \\
\beta'
\end{bmatrix} =
\begin{bmatrix}
\cos \theta & -\sin \theta \\
\sin \theta & -\cos \theta
\end{bmatrix}
\begin{bmatrix}
\alpha \\
\beta
\end{bmatrix}
\] (5)

Where \(\theta\) represents the rotational variation angle of quantum revolving gate,\([a \ b]'\) is a quantum bit
vector representation of gene.

3.2 The algorithm steps of multi-threshold global segmentation using QGA
(1) Initialize evolutionary algebra at \(t=0\) and population \(Q(t)\),
(2) Collect statistics regarding image data information entropy,
(3) Calculate the best fitness value of the function, and the corresponding entropy to obtain the
mean value,
(4) At \(t = t + 1\), update the population through quantum variation and quantum rotation gates;
(5) If the entropy mean value is the maximum, output the best result, otherwise return to step (2).

4. Quantum edge extraction algorithm
4.1 Superposition state correlation decomposition of image
Suppose there is a convolution window of 3*3 size. After normalization, the center pixel value is \(f(x, y)\), and the adjacent pixels are shown in the figure below:

| \(f_{x-1,y-1}\) | \(f_{x,y-1}\) | \(f_{x+1,y-1}\) |
| \(f_{x-1,y}\) | \(f_{x,y}\) | \(f_{x+1,y}\) |
| \(f_{x-1,y+1}\) | \(f_{x,y+1}\) | \(f_{x+1,y+1}\) |

Figure 1. Convolution window of 3*3

Suppose there is a quantum system with three qubits, and each qubit is a pixel bit, therefore the
following formula can be obtained as shown in Figure 1 above:
\[
|f_{x-1,y}\rangle = \sqrt{1-f_{x-1,y}}|f_{x-1,y}\rangle + \sqrt{f_{x-1,y}}|f_{x+1,y}\rangle
\]
\[
|f_{x-1,y}\rangle |f_{x,y}\rangle |f_{x+1,y}\rangle = \sqrt{1-f_{x-1,y}}|f_{x-1,y}\rangle \otimes \sqrt{f_{x-1,y}}|f_{x+1,y}\rangle
\] + \sqrt{1-f_{x-1,y}}|f_{x-1,y}\rangle \otimes \sqrt{f_{x-1,y}}|f_{x+1,y}\rangle
\]
\[
= \sum_{i=0}^{2} w_i |i\rangle
\] (6)

Now taking image lena for example, the state vector of figure(h) is \(\sqrt{1-f_{x-1,y}}\sqrt{f_{x,y}}\sqrt{f_{x+1,y}}\), it
represents the appearance probability of black dot and white dot of the image in the horizontal
direction , and this value can reflect the probability of the gray positive jump in the original position of the image.
4.2 Quantum derivative median filter

Because salt and pepper noises in the image has a great influence on the edge detection in this study, the median filter is necessary before the edge extraction. This study borrows the method of quantum derived median filter mentioned in reference [11].

\[
\frac{\sqrt{1-f_{x,y}} + \sqrt{f_{x,y}}}{\sqrt{2}} = \frac{1}{2} \ast \left(1 + 2 \ast \sqrt{1-f_{x,y} \sqrt{f_{x,y}}} \right)
\]  

(7)

4.3 Quantum derived edge detection detector

In Figure 2, four subgraphs (d), (h), (g) and (e) corresponding to the state vector |110>, |011>, |100> and |001> have gray edge changes. We define two state vectors |110> and |100> as the negative jump of image gray value, and two state vectors |011> and |001> as the positive jump of image gray value. The probability of the positive and negative jump of the four state vectors in the horizontal direction is shown below:

\[
|w_{m1}|^2 - |w_{m0}|^2 = (f_{x,y} - f_{x-1,y}) \ast f_{x+1,y}
\]

\[
|w_{m0}|^2 - |w_{m0}|^2 = (f_{x+1,y} - f_{x,y}) \ast (1 - f_{x-1,y})
\]

\[
|w_{m1}|^2 - |w_{m0}|^2 = (f_{x,y} - f_{x+1,y}) \ast f_{x-1,y}
\]

\[
|w_{m0}|^2 - |w_{m0}|^2 = (f_{x+1,y} - f_{x,y}) \ast (1 - f_{x+1,y})
\]

(8)

Here, the arithmetic mean value of two positive states vectors or negative states vectors can be used as the probability of dramatic change of image gray.

Considering the horizontal direction and the vertical direction, the horizontal direction are 0°, 45° and 135°, the vertical direction are 90°, 45° and 135, and the distance between the center pixel point and the adjacent pixel point which affect the center pixel value is also considered. The horizontal direction and the vertical direction are multiplied by the weight value \(\sqrt{2}\). Therefore, we can get the detection operator in the horizontal direction as follows:

\[
O^+_h = \frac{\sqrt{2}}{2} \left[(f_{x,y} - f_{x-1,y}) \ast f_{x+1,y} + (f_{x+1,y} - f_{x,y}) \ast (1 - f_{x-1,y})\right]
\]

\[
O^-_h = \frac{\sqrt{2}}{2} \left[(f_{x,y} - f_{x+1,y}) \ast f_{x-1,y} + (f_{x-1,y} - f_{x,y}) \ast (1 - f_{x+1,y})\right]
\]

(10)

There are 12 groups of operators in 6 directions, 6 horizontal templates of which form the edge
detection operator in the horizontal direction and 6 vertical templates of which form the edge detection operator in the vertical direction. In this study, the maximum value of the average value of the positive and negative operators in the horizontal direction is taken as the horizontal detection component $G_x$.

Similarly, we can get the expression of $G_y$, the formulas is shown below:

$$G_x = \max\{(0^\circ_h + 45^\circ_h + 135^\circ_h)^* \frac{1}{3}, (0^\circ_h + 45^\circ_h + 135^\circ_h)^* \frac{1}{3}\}$$

$$G_y = \max\{(90^\circ_h + 45^\circ_h + 135^\circ_h)^* \frac{1}{3}, (90^\circ_h + 45^\circ_h + 135^\circ_h)^* \frac{1}{3}\}$$

the sum of the gradient absolute values of the horizontal detection component and the vertical detection component is taken as the ultimate edge detection result, that is:

$$G(x, y) = |G_x| + |G_y|$$

Finally, the binary edge image can be obtained by binary extraction of the above gray edge image with the method of non-maximum suppression in Canny operator.

4.4 Quantum edge detection algorithm steps
(1) At first, the original image is denoised by the quantum derived median filter.
(2) Then the edge of the denoised image is detected by the quantum edge detection operator, and the edge gray image is obtained.
(3) Finally, do binary extraction of edge gray image.

5. Simulation experiment and the results
In order to verify the advantages of this algorithm compared with the original quantum derivative algorithm, I selected several groups of representative images in the test environment of visual studio 2013 for edge extraction simulation experiment, and compared these results with the traditional edge detection Canny operator and the original quantum derivative algorithm subjectively and objectively.

The subjective method is mainly to observe the quality of image edge extraction directly with the naked eye, which are showed in Figure 3 and Figure 4. The objective method is to measure the processed image with some typical edge extraction evaluation indicators, and then compare their values, which are summarized in Table 1 and Table 2. The edge evaluation method based on connected domain in reference [12] is adopted in the study. The smaller the ratio $C8 / C4$ is, the better the linear connectivity of the edge is, the less the probability of missing and wrong detection is.

5.1 Remote sensing geomorphic image

![Figure 3](image)

Figure 3. Results for four different edge extraction algorithm

Comparing the three pictures shown above, it can be seen that Figure 3 (c) and Figure 3 (d) which detect fine structure edge are more precise than Figure 3 (b), such as the houses and trees in the lower left corner of the land in the figure and the viaduct connected to the land in the right half of it. Figure 3 (b) is all stuck together, while Figure 3 (c) and Figure 3 (d) can also see the outline of some green vegetation and the edge of the bridge body. However, in terms of edge connectivity, Figure 3 (c) is
inferior to Figure 3 (b) and Figure 3 (d), such as the wharf and the speedboat sailing to the sea in the middle part of image, Figure 3 (c) is not well connected, while the edges of those in Figure 3 (b) and Figure 3 (d) are well connected. In general, this method is better than the traditional Canny algorithm and the original quantum derivation method.

| Table 1. Comparison of the edge extraction results for the four different methods |
|-----------------------------------|------------------|-------|-------|-------|
| Edge extraction algorithm        | Number of Edge points | C4    | C8    | C8/C4 |
| Canny algorithm                  | 36385             | 5310  | 1148  | 0.2162|
| Original quantum derived algorithm| 38322             | 16313 | 3672  | 0.2251|
| proposed algorithm               | 40382             | 18838 | 3815  | 0.2025|

It can be seen from Table 1 that the number of edge points of Canny algorithm is the least, followed by the original quantum derivation method, and the method in this study is the most of them, which shows that the algorithm here can detect the edge structure of the object more precisely, which is consistent with the visual effect of the naked eye. For the ratio of the number of two kinds of connected domains, this method decreases the value of parameter, which shows that this method improves the poor edge connectivity of the original method.

5.2 Street photography image

![Figure 4](image)

Figure 4. Results for four different edge extraction algorithm

It is not difficult to see that the method in the study and the original quantum derivative method are better than the traditional Canny algorithm. Canny algorithm shown in Figure 4 (b) does not detect the structure of some fine objects, such as the roof tiles in the upper right corner and the white clouds in the sky. Compared with the original quantum derivative method shown in Figure 4 (c), this method shown in Figure 4 (d) better connects the edges of some objects, such as the outline of a girl's hair at the bottom left and a beam of sunlight shining on the ground at the bottom right. However, the disadvantage of this method is that it is so sensitive to noise points that it can detect some edges which do not exist originally. For example, there are some scattered edges in the upper right corner of the image, which can be said to have a slight hollow powder effect.

| Table 2. Comparison of the edge extraction results for the four different methods |
|-----------------------------------|------------------|-------|-------|-------|
| Edge extraction algorithm        | Number of Edge points | C4    | C8    | C8/C4 |
| Canny algorithm                  | 25328             | 3264  | 775   | 0.2374|
| Original quantum derived algorithm| 27007             | 11106 | 2846  | 0.2563|
| proposed algorithm               | 32543             | 13742 | 3028  | 0.2203|
Table 2 further verifies that the algorithm in this study can not only detect the fine structure of the object edge, but also better connect the edge points, which is consistent with the experimental results of the first image.

6. Conclusion and prospects

Compared with the traditional Canny algorithm, the original quantum derived edge detection method can detect the edge structure of complex objects more precisely, but its connection to edge points is poor. The algorithm of this study focuses on improving this defect. Its method is to segment the original image with global multi-threshold, and then detect and extract the edge of the processed image. The experimental results show that the algorithm can connect the edges of objects better. However, this method also has its limitations, that is, it is easy to be affected by noise, so that it can detect some non-existent edges. In addition, the number of global thresholds is selected artificially, which needs to be converted into adaptive mode to better meet the requirements of universality. In the future research work, I need to do my further endeavor in the robustness and adaptability of the algorithm.

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