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Enhancement Algorithm for Quantum Remote Sensing Image Data

Bi, S. W.* Ke, Y. X.

State Key Laboratory of Remote Sensing Science, Institute of Remote Sensing and Digital Earth, Chinese Academy of Sciences, Beijing 100101, China

Abstract: Given the low contrast ratio and brightness as well as insufficient detail for a remote sensing (RS) image due to sensor properties and external factors, this paper proposed the use of a quantum algorithm based on the combination of a quantum inspired and unsharp masking to enhance the RS image data. Two sets of experiments were conducted on images of an RS aerial map of an airport on a misty day, an aerial photo of an airport, a non-RS image of a street setting with smog, and a digital picture of an X-ray film. In the study, a quantum enhancement operator based on quantum superposition state theory in a 3×3 window was first constructed to enhance the image contrast ratio, and then the quality of the processed image was improved by unsharp masking. The results for the four tests showed that the contrast ratio and brightness of the images processed by the quantum algorithm improved image entropy and peak signal to noise ratio.

Keywords: quantum remote sensing (QRS); image enhancement; unsharp masking; quantum inspired; quantum superposition state

1 Introduction

Following on from descriptions of quantum remote sensing (QRS) theory, QRS information, experimentation, imaging, quantum spectral imaging, QRS calculation, detection[1–3] and QRS image data denoising algorithm[4], Bi and Chen[4] proposed the QRS image data enhancement algorithm. This research includes theoretical algorithms for QRS image data denoising, enhancement and segmentation, as well as technical applications and experimental detection.

QRS image enhancement is a process of image preprocessing, and its enhancement effect plays a crucial role in the following image segmentation and classification recognition processes. Image enhancement technology can be divided into spatial domain techniques and transform domain techniques[5]. The spatial domain operates directly on image pixel points and pixel values. Classical spatial domain methods include histogram equalization and refinements, linear stretching, unsharp masking, etc.[6]. Histogram equalization is a global image enhancement method, but it ignores the local information and cannot maintain the aver-

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***Corresponding Author:** Bi, S. W. R-8205-2018, Institute of Remote Sensing and Digital Earth, Chinese Academy of Sciences, bisw@radi.ac.cn
Author ID: Bi, S. W. R-8205-2018; Ke, Y. X. Y-5344-2018
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age image brightness, which may result in over-saturation or under-saturation of the selected region[7]. The unsharp masking method enhances image noise given that it enhances the image detail. Converting the image to the frequency domain and processing the converted coefficients is called transform domain processing. The classical remote sensing (RS) image frequency domain enhancement algorithm can be based on the wavelet transform, on the non-subsampled shearlet-contrast transform (NSSCT), and homomorphic filtering[8], which, however, consume much time and are more complicated despite being an improvement over the spatial domain. Therefore, in order to solve these problems and improve image quality, it is necessary to improve on existing algorithms or propose a new algorithmic approach.

Inspired by artificial neural networks, genetic algorithms and other natural laws, a quantum inspired concept was proposed and used on computers after combining the concept with quantum mechanics theory and principles, and mathematical systems as a means to improve existing or develop new algorithms[9]. In 2007, Xie *et al*.[10] proposed a quantum inspired morphology edge detection method based on quantum mechanics and quantum information theories and other concepts. Zhou *et al*.[11] proposed in 2008 the quantum Hopfield neural network system whose storage and memory capacity were improved 2^n times. In 2010, Fu *et al*.[12] proposed a medical image enhancement algorithm based on quantum statistical probability, which combined the proprieties of medical images to construct quantum enhancement operators in 3×3 windows. In 2011, Gao *et al*.[13] applied the quantum enhancement algorithm to color images, which converted firstly the RGB (Red, Green, Blue) color model of the image into an HSV (Hue, Saturation, Value) model and conducted quantum enhancement of luminous components, and then converted the enhanced HSV image model to the RGB color image.

In 2014, Bi realized the QRS image denoising, enhancement, segmentation and other image processing techniques using Matlab simulation software[14]. To improve the image processing system, utilize the system with the prototype, and further improve RS image quality, this paper proposed a QRS image enhancement algorithm based on the combination of a quantum derivative and unsharp masking, which is realized in Visual Studio 2013 IDE through C++ and open CV.

2 Quantum Enhancement Algorithm

2.1 Quantum Bit Representation of Image

2.1.1 Quantum Bit and Quantum System

In quantum computing, a quantum state is represented by a quantum bit (or qubit), and a qubit is a two-state quantum system with two ground states. If a qubit in two ground states is expressed by $|\mathbf{0}\rangle$ and $|\mathbf{1}\rangle$, the qubit is in a linear superposition state, which is also a possible state of the system and is represented by the following equation:

$$|\phi\rangle = a|\mathbf{0}\rangle + b|\mathbf{1}\rangle \tag{1}$$

where *a* and *b* are complex numbers that satisfy the normalization condition $|a|^2 + |b|^2 = 1$, and $|a|^2$ and $|b|^2$ are the probability amplitudes, representing the occurrence probability of two ground states $|\mathbf{0}\rangle$ and $|\mathbf{1}\rangle$, respectively.

If a quantum system is in the superposition of the ground state, the quantum system is said to be coherent. When a coherent quantum system interacts with its environment in some way, the linear superposition will be destroyed, which is called decoherence or collapse. If a quantum system consists of *n* qubits, then the i_{th} qubit state is $|\phi_i\rangle = a_i|0\rangle + b_i|1\rangle$. The state of the quantum system can be represented by the direct product of the states of *n* single qubits:

$$\begin{aligned} |\phi\rangle &= |\phi_1\rangle \otimes |\phi_2\rangle \otimes \cdots \otimes |\phi_n\rangle \\ &= a_1 a_2 \cdots a_n |000\cdots 0\rangle + a_1 a_2 \cdots a_{n-1} b_n |00\cdots 1\rangle + b_1 b_2 \cdots b_n |11\cdots 1\rangle \\ &= \sum_{i=0}^{2^n-1} \omega_i |i_b\rangle \end{aligned} \quad (2)$$

where $\otimes$ represents the tensor product, the state vector $|i\rangle$ represents the i_{th} ground state of *n* qubit systems $|\phi\rangle$, i_b represents the *n*-bit binary number corresponding to the decimal number *i*, ω_i is the probability amplitude of the corresponding ground state, and $|\omega_i|^2$ is the probability of occurrence of the corresponding ground state. Given that the function describes a real physical system, it will inevitably collapse to a ground state, and the probability sum of the probability amplitude ω_i is 1 and it also satisfies the normalization condition $\sum_{i=0}^{2^n-1} |\omega_i|^2 = 1$.

2.1.2 Quantum Bit Representation of Image Gray Scale

Let us assume *g*(*m*, *n*) is a digital image in which $g(m,n) \in [0,1]$, $(m,n) \in Z^2$, represents the pixel gray value of the image at the position $(m,n) \in Z^2$ after the gray level normalization process. Clearly, *g*(*m*, *n*) and l−*g* (*m*, *n*) can be regarded as the probability of the pixel point (*m*, *n*) whose gray value is "1" and "0". If $|\mathbf{0}\rangle$ and $|\mathbf{1}\rangle$ represent the gray value "0" and "1" respectively, the qubit representation of the image *g*(*m*, *n*) is:

$$|g(m,n)\rangle = \sqrt{1-g(m,n)}\,|0\rangle + \sqrt{g(m,n)}\,|1\rangle \quad (3)$$

$$|g(m,n)\rangle = \cos\left[g(m,n) \times \pi/2\right]|0\rangle + \sin\left[g(m,n) \times \pi/2\right]|0\rangle \quad (4)$$

Let us introduce $|\mathbf{0}\rangle$ and $|\mathbf{1}\rangle$ in the quantum system to indicate the gray values "0" and "1", corresponding to the black and white points, respectively, in the binary image, and the probability amplitudes are represented as $\sqrt{g(m,n)}$ (or $\cos\left[g(m,n)\times\pi/2\right]$) and $\sqrt{1-g(m,n)}$ (or $\sin\left[g(m,n)\times\pi/2\right]$, respectively, when the gray values of the pixel points are "0" and "1", and where $|g(m,n)\rangle$ is the quantum bit representations of the image *g*(*m, n*).

Using the example of a 3×3 window, and assuming the middle pixel is (m,n), the neighboring pixel is $f_{i,j}$, $m-1 \leqslant i \leqslant m+1$, $n-1 \leqslant j \leqslant n+1$.

$f_{m-1,n-1}$	$f_{m-1,n}$	$f_{m-1,n+1}$
$f_{m,n-1}$	$f_{m,n}$	$f_{m,n+1}$
$f_{m+1,n-1}$	$f_{m+1,n}$	$f_{m+1,n+1}$

Figure 1 Image of 3×3 window (pixel relation graph)

From inspection of Figure 1:

In the horizontal direction, based on equations (2) and (3), we can get the complex system of three qubits:

$$\begin{aligned}\left| f_{m,n-1} f_{m,n} f_{m,n+1} \right\rangle &= \left| f_{m,n-1} \right\rangle \otimes \left| f_{m,n} \right\rangle \otimes \left| f_{m,n+1} \right\rangle = \sqrt{1-f_{m,n-1}}\sqrt{1-f_{m,n}}\sqrt{1-f_{m,n+1}}\left|000\right\rangle \\ &+ \sqrt{1-f_{m,n-1}}\sqrt{1-f_{m,n}}\sqrt{f_{m,n+1}}\left|001\right\rangle + \sqrt{1-f_{m,n-1}}\sqrt{f_{m,n}}\sqrt{1-f_{m,n+1}}\left|010\right\rangle \\ &+ \sqrt{f_{m,n-1}}\sqrt{1-f_{m,n}}\sqrt{1-f_{m,n+1}} > \left|100\right\rangle + \sqrt{f_{m,n-1}}\sqrt{f_{m,n}}\sqrt{1-f_{m,n+1}}\left|110\right\rangle \\ &+ \sqrt{1-f_{m,n-1}}\sqrt{f_{m,n}}\sqrt{f_{m,n+1}}\left|011\right\rangle + \sqrt{f_{m,n-1}}\sqrt{1-f_{m,n}}\sqrt{f_{m,n+1}} + \left|101\right\rangle \\ &+ \sqrt{f_{m,n-1}}\sqrt{f_{m,n}}\sqrt{f_{m,n+1}}\left|111\right\rangle = \sum_{i=0}^{7} w_i \left|i\right\rangle\end{aligned} \tag{5}$$

2.2 Enhancement Operator Construction based on Quantum Bit and Quantum Superposition State

In a 3×3 window, noise directivity and correlation is poor, while the edge pixels are strongly correlated and closely related to nearby pixels, so we use (5) to construct the quantum enhancement operator. The ground state $\left|1\times 0\right\rangle$ and $\left|0\times 1\right\rangle$ represents image edge pixel change information, and $\left|1\times 1\right\rangle$ represents the image smooth region. The occurrence probability sum S_i of six ground states in four directions 0°, 45°, 90°, and 135°, respectively, is calculated and the weighted average of these directions is taken as the final quantum enhancement operator E, which, considering the influence of the distance between the central pixel to the adjacent pixel on the central pixel value, 0° in the horizontal direction and 90° in the vertical direction, is multiplied by the weight value $\sqrt{2}$. In this paper, equation (4) represents grayscale images, and the enhancement operator expression is:

$$S_{0^\circ} = 1 - \cos^2(f_{m,n-1} \times \tfrac{\pi}{2}) \times \cos^2(f_{m,n+1} \times \tfrac{\pi}{2}) \tag{6}$$

$$S_{45^\circ} = 1 - \cos^2(f_{m+1,n-1} \times \tfrac{\pi}{2}) \times \cos^2(f_{m-1,n+1} \times \tfrac{\pi}{2}) \tag{7}$$

$$S_{90^\circ} = 1 - \cos^2(f_{m-1,n} \times \tfrac{\pi}{2}) \times \cos^2(f_{m+1,n} \times \tfrac{\pi}{2}) \tag{8}$$

$$S_{135^\circ} = 1 - \cos^2(f_{m+1,n+1} \times \tfrac{\pi}{2}) \times \cos^2(f_{m-1,n-1} \times \tfrac{\pi}{2}) \tag{9}$$

$$E(m,n) = \frac{\sqrt{2}}{4} \times (S_{0^\circ} + S_{90^\circ}) + \frac{1}{4} \times (S_{45^\circ} + S_{135^\circ}) \tag{10}$$

Before constructing the quantum enhancement operator, the image pixel value is normalized to the interval [0, 1]:

when $g(m,n) \leqslant T$,

$$f(m,n) = \frac{\lambda \times [g(m,n) - \min]}{T - \min} \tag{11}$$

when $g(m,n) \geqslant T$,

$$f(m,n) = \lambda + \frac{(1-\lambda) \times [g(m,n) - T]}{\max - T} \tag{12}$$

where $g(m,n)$ represents the original image, $f(m,n)$ represents the normalized image, the pixel value is in the range of [0, 1], min and max are, respectively, the minimum and maximum values of the original image pixel value, coefficient $\lambda \in [0,1]$, and the difference image normalized coefficient λ has different optimal values. Experiments show that $\lambda = 0.5$ is appropriate for most RS images, and T is the normalized threshold, $T \in [\min, \max]$. Here, we determine T based on the image entropy maximization principle. The image entropy equation is:

$$H(E) = -\sum_{i=0}^{255} p(i) \log p(i) \tag{13}$$

where $p(i)$ represents the occurrence probability for the grayscale i in the final quantum enhancement image.

2.3 Unsharp Masking Principle

The contrast ratio and brightness of the image processed by the quantum enhancement algorithm have been improved, while the edge remains fuzzy. Therefore, the linear unsharp masking method is used to enhance the edges details. The unsharp mask equations are:

$$y_{mask}(m,n) = f(m,n) - \overline{f}(m,n) \tag{14}$$

$$y(m,n) = f(m,n) + k \times y_{mask}(m,n) \tag{15}$$

where $f(m,n)$ is the original image, $\overline{f}(m,n)$ is an approximate image obtained by processing $f(m,n)$ through a low-pass filter. $y_{mask}(m,n)$, obtained through equation (14), is the detailed image of $f(m,n)$. Multiplication of the detailed image by the gain factor k is performed and the final enhanced image $y(m,n)$ is obtained by adding $f(m,n)$.

2.4 Algorithm and Steps:

The following steps are included:

(1) Sample the pixel points of the original image $g(m,n)$ and obtain the sampling map $\hat{g}(m,n)$.

(2) Normalize the image $\hat{g}(m,n)$ through equations (11) and (12) and obtain the normalized image $\hat{f}(m,n)$.

(3) Process the image $\hat{f}(m,n)$ by the quantum enhancement algorithm through equations (6)−(10), obtain the enhanced image $\hat{E}(m,n)$, calculate the image entropy H of $\hat{E}(m,n)$ by equation (13) to determine whether it is the largest.

(4) Update constantly the threshold $T, T = T+1$, and then repeat equations (2) and (3) until $T = \max$, thus obtaining the threshold corresponding to the maximum image entropy.

(5) Make $T = T_{opt}$, normalize $g(m,n)$ through equations (11) and (12) to obtain the normalized image $f(m,n)$, and obtain the enhanced image $E(m,n)$ by equations (6)−(10).

(6) Using the unsharp mask equations (14) and (15), combine with $g(m,n)$ and $E(m,n)$ to obtain the final enhanced image.

2.5 Evaluation of Function

To illustrate objectively the enhanced performance of the algorithm, the image entropy and the image quality measurement function[20] (calculate entry, CE) were deployed to analyze the image enhancement effect. Image entropy can represent the richness of image information. The better the image enhancement effect, the more information is displayed, and the larger the image entropy. The equation for image entropy has been introduced, and the image quality measurement function equation is:

$$CE = \frac{1}{MN}\sum_{i=1}^{M}\sum_{j=1}^{N} f^2(i,j) - \left[\frac{1}{MN}\sum_{i=1}^{M}\sum_{j=1}^{N} f(i,j)\right]^2 \tag{16}$$

Where M, N is the image resolution, and the image height and width; and $f(i,j)$ is the pixel value of the enhanced image.

3 Quantum Image Data Enhancement Algorithm: Simulation Experiment and Results

Simulation experiments were conducted using the quantum algorithm with C++ and open CV in Visual Studio 2013 IDE, and results were compared with wavelet transform, homomorphic filtering and quantum probability statistics. The experiments focused on an aerial RS map and non-RS pictures.

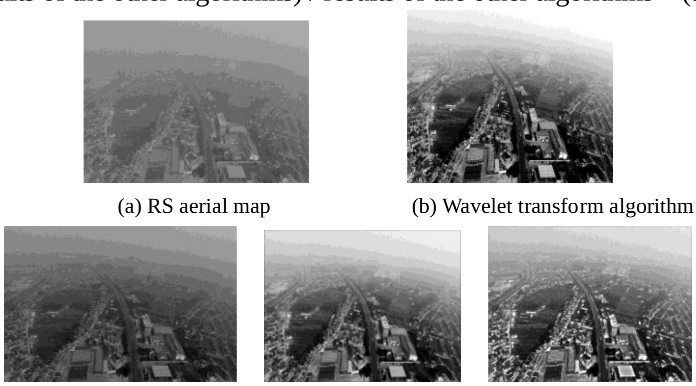
3.1 The First Simulation Experiment

The first study was an image enhancement experiment performed on a RS aerial map on a misty day (Figure 2a) and the second concerned a RS aerial photo of an airport (Figure 3a).

3.1.1 Image Enhancement of RS Aerial Map on a Misty Day

The results of four algorithms were compared: wavelet transform[15] (Figure 2b), homomorphic filtering (Figure 2c), quantum probability statistics (Figure 2d) and quantum enhancement (Figure 2e).

The respective image entropies and quality measurement functions are presented in Table 1. The results show that the image quality obtained using the quantum algorithm was superior to the other three having higher performance parameters, richer image information and a well-distributed gray scale. In the case of the quantum probably statistics method, the % improvement for the image entropy and quality measurement function were 3.72% and 15.26% (Table 1, Figure 2d, Figure 2e), respectively, this method giving the best performance of the other methods. Among them, improvement percentage = (results of Quantum algorithm − results of the other algorithms) / results of the other algorithms[4] (the same below).



(a) RS aerial map (b) Wavelet transform algorithm

(c) Homomorphic filtering (d) Quantum probability statistics (e) Quantum enhancement

Figure 2 Image enhancement results on a misty day

Table 1 Comparison of the four different enhancement processing results

Processing methods	Image entropy	Improvement percentage (%)	Quality measurement function	Improvement percentage (%)
Quantum methods	7.710,0	–	3,622.9	–
Wavelet transform	7.341,2	5.02	2,789.5	29.87
Quantum probability statistics	7.433,0	3.72	3,142.2	15.26
Homomorphic filtering	6.970,6	10.60	2,028.3	44.01

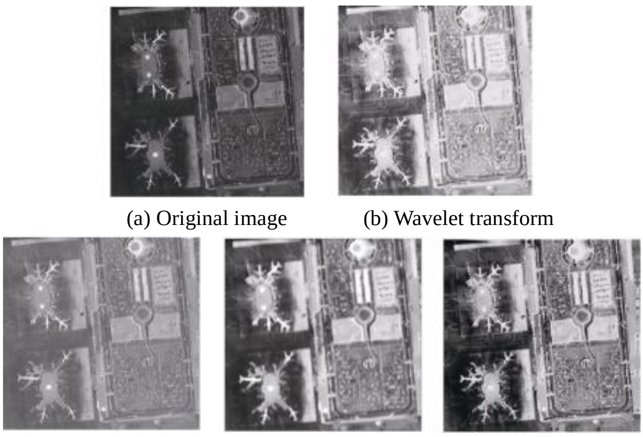
3.1.2 Image Enhancement of RS Aerial Photo of Airport

The results for the four algorithms were compared: wavelet transform (Figure 3b), homomorphic filtering (Figure 3c), quantum probability statistics (Figure 3d) and quantum enhancement (Figure 3e).

Table 2 presents the performance data for the respective algorithm enhancement effects and it can be seen that the image entropy and quality measurement function for the quantum algorithm are superior to the others, namely, the performance parameters are higher, the image information is richer and there is a well-distributed gray scale. The wavelet transform method performed the best among the other three, the % improvement in image entropy and quality measurement function being 1.48% (Figure 3b, Figure 3e) and 33.84% (Table 2, Figure 3b, Figure 3e), respectively.

3.2 The Second Simulation Experiment

The second experiment was undertaken to assess the enhancement effect for non-RS images, and included a street image taken in smog (Figure 4a) and an X-ray digital radiography (DR) image (Figure 5a).



(a) Original image (b) Wavelet transform

(c) Homomorphic filtering (d) Quantum probability statistics (e) Quantum enhancement

Figure 3 Image enhancement results of RS airport image

Table 2 Comparison of the four different enhancement processing results (from data of Figure 3)

Processing methods	Image entropy	Improvement percentage (%)	Quality measurement function	Improvement percentage (%)
Quantum methods	7.592,1	–	2,810.8	–
Wavelet transform	7.480,9	1.48	2,100.0	33.84
Quantum probability statistics	7.438,8	2.06	2,350.0	19.60
Homomorphic filtering	6.623,4	14.62	1,792.4	56.81

3.2.1 Enhancement Study on Street Image

The image with smog is quite typical for an urban center in China with high traffic density. In this image, the gray scale is centralized and uniform, so objects in the image are difficult to recognize. The four algorithms were compared: wavelet transform (Figure 4b), homomorphic filtering (Figure 4c), quantum probability statistics (Figure 4d) and quantum enhancement (Figure 4e).

Table 3 presents the results of the algorithm enhancement effects. The results show that the image entropy and quality measurement function for the quantum algorithm is superior to the other three. Specifically, the quantum algorithm has higher performance parameters, richer image information and content, as well as a well-distributed gray scale. The quantum probability statistics algorithm performed the best among the other three, the % improvement in image entropy and quality measurement function being 6.60% (Figure 4d, Figure 4e) and 8.48% (Table 3, Figure 4d, Figure 4e), respectively.

(a) Original image (b) Wavelet transform

(c) Homomorphic filtering (d) Quantum probability statistics (e) Quantum enhancement

Figure 4 Image enhancement results of street fog image

Table 3 Comparison of the four different enhancement processing results (from data of Figure 4)

Processing methods	Image entropy	Improvement percentage (%)	Quality measurement function	Improvement percentage (%)
Quantum methods	7.188,9	–	1,755.5	–
Wavelet transform	5.928,5	21.26	1,552.1	13.10
Quantum probability statistics	6.743,5	6.60	1,618.2	8.48
Homomorphic filtering	5.475,7	31.28	1,365.0	28.60

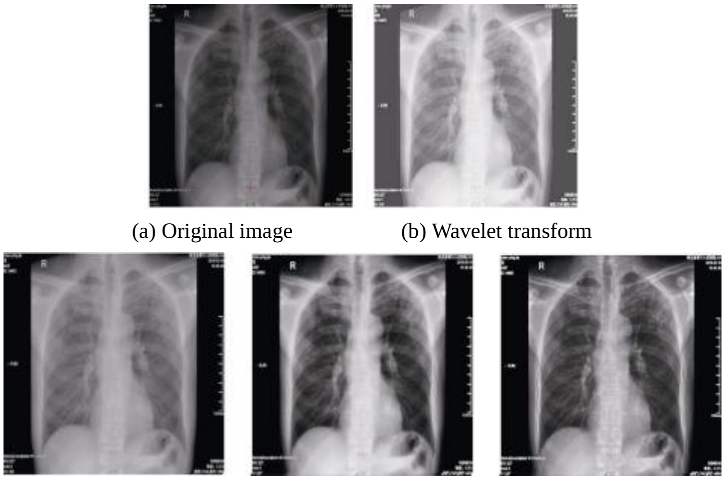
3.2.2 Enhancement Experiment on X-ray DR

The digital X-ray (DR) consisted of an electronic cassette, a scanning controller, a system controller, an image monitor, etc., which directly converted the X-ray photons into a digital image. Four algorithms were evaluated: wavelet transform (Figure 5b), homomorphic filtering (Figure 5c), quantum probability statistics (Figure 5d) and quantum enhancement (Figure 5e).

Table 4 presents the results of the algorithm enhancement effects and it can be seen that the image entropy and quality measurement function for the quantum algorithm were superior to the others, having higher performance parameters, richer image information and content, as well as a well-distributed gray scale. Its image entropy and quality measurement function is 0.67% (Table 4, Figure 5b, Figure 5e) and 21.22% (Table 4, Figure 5d, Figure 5e) respectively higher than wavelet transform and quantum probability statistics algorithm, the best among the other three.

3.3 Results of the Two Simulation Experiments

The experimental statistics show that the image entropy and quality measurement function for the quantum enhancement algorithm is higher than that of the histogram equalization, quantum probability statistics and the homomorphic filtering algorithm. Among them, the image entropy of the RS images was 3%–12% higher than the others and the image quality measurement function was 17%–68% (Table 5) higher than the others. The image entropy for the non-RS images was 3%–19% higher than the others and image quality measurement function was 17%–48% (Table 6) higher than the others.



(a) Original image (b) Wavelet transform

(c) Homomorphic filtering (d) Quantum probability statistics (e) Quantum enhancement

Figure 5 Image enhancement results on chest X-ray DR

Table 4 Comparison of the four different enhancement processing results (from data of Figure 5)

Processing methods	Image entropy	Improvement percentage (%)	Quality measurement function	Improvement percentage (%)
Quantum methods	7.730,4	–	4,801.3	–
Wavelet transform	7.678,6	0.67	3,345.6	43.51
Quantum probability statistics	7.634,0	1.26	4,265.7	21.22
Homomorphic filtering	6.970,6	10.90	3,053.7	57.22

4 Conclusion

It is clear that the proposed quantum enhancement algorithm performs better than the classical methods. Histogram equalization based on the wavelet transform lightens the enhanced image, but ignores local information. For instance, from Figure 2b, it can be seen that the upper right corner is over-bright which affects the recognition of ground objects. Over-bright situations are also apparent in Figure 4b, Figure 3b and Figure 5b. The enhancement result for homomorphic filtering is not so good and requires more time to select parameters. The quantum probability statistics method blurs the image edge during image contrast and brightness enhancement. The method based on quantum mechanics and unsharp masking does reduce the brighter pixel gray-

Table 5 Mean enhancement for quantum algorithm vs others for RS image processing (%)

Processing methods	Image entropy	Quality measurement function
Wavelet transform	3.23	31.58
Quantum probability statistics	2.92	17.14
Homomorphic filtering	12.56	68.39

Table 6 Mean enhancement for quantum algorithm vs others for non-RS image processing (%)

Processing methods	Image entropy	Quality measurement function
Wavelet transform	12.96	33.86
Quantum probability statistics	3.76	17.53
Homomorphic filtering	19.87	48.39

scale change, enhance the dark pixel grayscale transformation, and enhance the edges and detail, making the image outline clearer.

5 Prospects

An image data enhancement algorithm is required for RS and non-RS image processing, and algorithms for RS image enhancement is a key research field in RS image data analysis. The quantum enhancement algorithm proposed in this paper is superior to the current existing algorithms. This method can used for RS image (including aerial and space RS image) as well as non-RS image (such as camera and medical image) processing. Quantum computing has not yet arrived; hence our research is based on classical computing. We can, however, predict that QRS image data enhancement and visualization will be extensively used in the future when quantum computing occurs and when its strong calculation ability will be exploited.

References

[1] Bi, S. W. Research on the concept, framework and connotation of quantum remote sensing [J]. *Journal of Infrared and Millimeter Waves*, 2003, 22: 1−9.

[2] Bi, S. W., Han, J. X. The mid-far infrared experiment of quantum remote sensing [C]. Beijing: Proceedings of the 15th National Remote Sensing Conference, 2005: 8−15.

[3] Bi, S. W., Han, J. X. Research on quantum remote sensing information mechanism [J]. *Science* & *Technology Review*, 2006, 9(11): 38−42.

[4] Bi, S. W., Chen, H. Research on denoising algorithm of quantum remote sensing image data [J]. *Journal of Global Change Data* & *Discovery*, 2018, 2(3): 256−270. DOI: 10.3974/geodp.2018.03.03.

[5] Rafael, C. G. Digital Image Processing [M]. Translated by Ruan, Q. Q. Beijing: Publishing House of Electronics Industry, 2007.

[6] Jiang, B. J., Zhong, M. X. Application of improved Histogram Equalization on image enhancement [J]. *Laser* & *Infrared*, 2014, 44(6): 702−706.

[7] Suresh, S., Lal, S. Modified differential evolution algorithm for contrast and brightness enhancement of satellite images [J]. *Applied Soft Computing*, 2017, 61: 622−641.

[8] Sha, Y. H., Liu, F., Jiao, L. C. SAR image enhancement based on nonsubsampled contourlet transform [J]. *Journal of Electronics* & *Information Technology*, 2009, 31(7): 1716−1721.

[9] Xie, K. F. Research on quantum derivative image processing method [D]. Changsha: Central South University, 2007: 1−119.

[10] Xie, K. F, Luo, A., Zhou, X. Y. Edge detection method of quantum derived morphology [J]. *Computer Engineering and Applications*, 2007, 43(11): 87−90.

[11] Zhou, R. G., Jiang, N., Ding, Q. L. Quantum hopfield neural networks and image identification [J]. *Journal of Image and Graphic*, 2008, 13(1): 119−123.

[12] Fu, X. W., Ding, Y. M., Cai, C. Medical imaging enhancement algorithm based on quantum probability statistics [J]. *Acta Electronica Sinica*, 2010, 38(7): 1591−1596.

[13] Gao, J. B., Wu, C. M., Tian, X. P. Quantum enhancement algorithm for RGB images based on definition [J]. *Journal of Xi'an University of Posts and Telecommunications*, 2011, 16(2): 5−8.

[14] Zhang, Y. Research on remote sensing image processing based on quantum derivation [D]. Beijing: University of Chinese Academy of Sciences, 2015: 1−67.

[15] Wang, Z. H., Sun, L. J., Shao, X. An image enhancement algorithm based on wavelet domain [J]. *Packaging Journal*, 2017, 9(1): 22−25.