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The Application of Quantum Computing and Quantum Information in Ecology

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Abstract

With the development of technology, the quantum era is coming. There are many experts in various industries that have tried to practice the application of quantum computing and quantum information. In ecology, the timely, efficient and accurate ecological data processing is the prerequisite for analyzing the ecological protection mechanism, obtaining the greatest ecological economic benefits and making the ecological environment benign. While quantum computing and quantum information have the advantages of automation and real-time when storing and analyzing ecosystem data, people can improve work efficiency and save money to cope with ecological problems.

Keywords: quantum computing, quantum information, ecology

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INTRODUCTION

In recent decades, quantum computing and quantum information have risen rapidly. As representative in quantum computing, quantum machine learning has been widely used in ecology field. Quantum machine learning is derived from artificial intelligence and statistics. It can explore learning strategies based on existing ecosystem data and discover the potential structures in order to predict future generations and analyze gene conditions (Kohavi and Foster 1998). In addition, with the development of information technology, informatization closely links various industries, and industrial data becomes explosive growth. This growth not only involves the growth of data quantity, but also contains the growth of data type, structure and production rate (Hilbert and López 2011). The growth of data brings substantial profits and also technical challenges. Many traditional machine learning algorithms cannot cope with the processing and analysis of massive data in the age of big data, so they have to find new methods to solve problems. At the same time, the problem of ecological protection is becoming more and more serious. The environmental pollution issue has become the hot topic in major cities across the country, which can be eased by timely analysis and application of massive data. Therefore, the timely, efficient and accurate acquisition of ecological data is the premise of analyzing ecological management mechanism (Meng and Ci 2013).

Quantum computing itself has a good application prospect in ecology. Firstly, quantum computing can improve the efficiency of ecological management. Since the improvement and protection of the ecosystem will contain lots of works and covers many difficult computing problems, the unique feature of quantum computing can solve the operational efficiency trouble which traditional algorithms meet with. For example, traditional computer can only process one bit data at a time because of its low storage level. While quantum computer stores quantum bits which represent the superposition of the quantum state $|0>$and $|1>$, the information of these two states can be processed in one operation. In the same way, it takes 2^n operations to perform the same calculation on 2^n bits of data in a classical computer, while quantum computer only needs to perform one operation on n quantum bits. Therefore, quantum computing is far superior to classical computing in terms of both data storage and processing power. In addition, in the process of ecosystem management, the cost of using quantum computer will decrease with the aggregation of big data. This kind of efficient work can effectively reduce human and material resources, thus improving the work efficiency of ecological researchers. For instance, when monitoring large geographical area or ecological events in the long process, quantum computing extract vegetation index changing information in one area by using remote sensing data, and then put the vegetation

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index as input parameters of the ecological process model to save a lot of computing resources consumption and improve the work efficiency. Secondly, using quantum computers to manage ecological resources can save money. Considering serious destruction of ecological environment in recent decades, many countries have invested heavily in ecological aspects. Although the introduction and the maintenance of quantum computer need certain cost, the more economic benefits can be obtained under the intelligent ecological management in the long term. Without the quantum computer to manage grassland resource, the investigation mainly depends on artificial survey. However, the relevant information is distributed in the corners of the space and time, which may cost a lot of manpower, material and financial resources to be acquired. By introducing quantum computer management system, the coverage of processing information is broader, the information accuracy is higher and the cost of saving time is unmeasurable. Finally, quantum computers are more suitable to processing large amounts of data. Combined with the intelligent management system of big data and the quantum network coding technology, quantum computing can not only meet the requirements of mass data processing and real-time analysis, but also cover all networks. Mature quantum computers enable to collect, process and update massive data automatically in real time, while also using quantum machine learning to analyze and apply data intelligently. They are highly automatic, real-time and intelligent, which provides scientific decision-making consulting in the ecological field.

Quantum information also has many applications in ecology, mainly including quantum multimedia processing, pattern recognition and so on. During the storage of multiple flower and grass information, multiple kinds of information such as appearance, origin, flowering period and species are made specifically by means of quantum multimedia representation. With the progress of network technology, the application of quantum multimedia information (Qu et al. 2018) such as quantum image is more and more extensive. In the existing quantum storage protocols, most of them are based on quantum image representation (Heidari and Farzadnia 2017, Heidari et al. 2017, Li and Lu 2018), such as novel enhanced quantum representation (NEQR) (Heidari and Naseri 2016, Jiang et al. 2016, Wang et al. 2015, Zhou et al. 2018), flexible representation for quantum image (FRQI) (Ji et al. 2018, Li and Liu 2018), quantum representation of multi wavelength images (QRMW) (Sahin and Yilmaz 2018), the multi-channel representation for quantum images (MCQI) (Sun et al. 2011, 2013) and so on (Jiang and Wang 2015). Combined with Moire mode, the quantum image storage is realized by recursive loop operation (Wang et al. 2015). Using LSB, the Fourier transform was performed in the frequency domain to complete the embedding and extraction of important information. Then in 2016 Jiang et al. (2016) proposed to embed important information with two blind LSB algorithms. One is to substitute secret information directly for the lowest effective bit of pixel value. The other is to embed secret information into the lowest effective bit of pixel belonging to one block. The experimental results show that this protocol is not visible and can meet the required capacity and robustness. In the ecological field, by quantizing and storing important species information, the security of information during transmission can be greatly improved, while the following information processing will be more convenient.

In this paper, we propose an efficient and secure quantum storage protocol based on controlled quantum image representation (CFRQI). The new protocol can not only guarantee that the eavesdropper cannot get any useful ecological information in the transmission process but also make sure that others are not able to perceive the existence of secret important information such as the origin, flowering period and species information, which greatly improves the security of transmission. In addition, the corresponding performance analysis fully verifies the great performance of the new quantum storage for ecological species information.

QUANTUM REPRESENTATION OF BIOLOGICAL SAMPLES

Quantum Image Representation of Biological Samples

In the existing quantum image transmission protocols, the flexible representation of quantum images (FRQI) is usually used to describe grey image, which can be represented as follows:

$$I(\beta) = \frac{1}{2^n} \sum_{i=0}^{2^{2n}-1} |c_i > \otimes |i > \quad (1)$$

$$|c_i >= cos\beta_i |0 > + sin\beta_i |1 > \quad (2)$$

$$\theta_i \in [0, \frac{\pi}{2}], i = 0,1,\ldots, 2^{2n} - 1 \quad (3)$$

Here, $I(\beta)$ is the $2^n \times 2^n$ quantum grey image. $|c_i>$ and $|i>$ are used to encode color information and position information respectively, while β_i represents the grey values of the i-th pixel in the image.

CFRQI is a new secure controlled quantum image representation based on FRQI, which can be expressed as follows:

$$|F_n>=\frac{1}{2^n}\sum_{i=0}^{2^{2n}-1}|c_i>|i> \quad (4)$$

$$|c_i>=\frac{1}{\sqrt{2}}\begin{bmatrix}(sin(\alpha+\beta_i)|0>+cos(\alpha+\beta_i)|1>)_1(cos\alpha|0>+sin\alpha|1>)_2\\+(cos(\alpha+\beta_i)|0>-sin(\alpha+\beta_i)|1>)_1(sin\alpha|0>-cos\alpha|1>)_2\end{bmatrix} \quad (5)$$

$$\alpha,\beta_i\in[0,\frac{\pi}{2}], i=0,1,\dots,2^{2n}-1 \quad (6)$$

Here, particle 1 and particle 2 are color information particles. $|c_i>$ is used to encode color information of image, while α is the controlled color vector and β_i is the real color vector representing the color information at the i-th position of the image. Position information is encoded by $|i>$, which contains vertical and horizontal values of each pixel. Besides, the particle 1 is the control bit and the particle 2 is the target bit. Only if people perform an reasonable measurement on the particle 1, the 2 particle can carry real image color information in the controlled flexible representation for quantum image (CFRQI).

Bioinformatics Embedding

This paper proposes a new secure controlled quantum image encoding protocol for bioinformation storage.

The sender firstly prepares to embed secret bioinformatics $|S_n>$ into the species samples photo (the carrier image) $|F_n>$. $|S_n>$ can be represented as follows:

$$|S_n>=\otimes_{i=0}^{2^{2n}-1}(cos\gamma_i|0>+sin\gamma_i|1>) \quad (7)$$

The size of secret ecological information can be as the same as the species samples photo. Each ecological information such as the location has been encoding with $\gamma_i$which will be embedded by means of continued fraction.

Firstly, the sender and the receiver negotiate the value of the controlled color vector α in advance. This step is to ensure only the real receiver know the correct measurement basis when he wants to extract secret information. Then, the sender prepares the controlled quantum carrier image $|F_n>$. and share a series of random binary keys l_i.

When $l_i=0$, the sender will embed the secret information into the cosine part of each pixel on carrier image:

$$cos\beta_i'=\cfrac{1}{a_{i1}+\cfrac{1}{a_{i2}+\cfrac{1}{a_{i3}+\gamma_i}}} \quad (8)$$

When $l_i=1$, the sender will embed secret information into the sine part of each pixel on carrier image:

$$sin\beta_i'=\cfrac{1}{b_{i1}+\cfrac{1}{b_{i2}+\cfrac{1}{b_{i3}+\gamma_i}}} \quad (9)$$

Then the sender calculates the shift angle, $\beta_i^r=\beta_i'-\beta_i$. By performing unitary operation $R_y(2\theta_i^r)=\begin{pmatrix}\cos\theta_i^r & \sin\theta_i^r\\ -\sin\theta_i^r & \cos\theta_i^r\end{pmatrix}$ on particle 1, the sender embeds the secret image information into the controlled carrier image. After embedding process, the stego controlled carrier image will become:

$$|F_n'>=\frac{1}{2^n}\sum_{i=0}^{2^{2n}-1}|c_i'>|i> \quad (10)$$

$$|c_i'\geq\frac{1}{\sqrt{2}}\begin{bmatrix}(sin(\alpha+\beta_i')|0>+cos(\alpha+\beta_i')|1>)_1(cos\alpha|0>+sin\alpha|1>)_2\\+(cos(\alpha+\beta_i')|0>-sin(\alpha+\beta_i')|1>)_1(sin\alpha|0>-cos\alpha|1>)_2\end{bmatrix} \quad (11)$$

Finally, the sender sends all particles to the receiver.

Bioinformatics Extraction

After receiving the stego controlled carrier image, the receiver should measure the particle 1 under correct measure basis in order to restore the real stego carrier image $I(\beta')$:

$$I(\beta')=\frac{1}{2^n}\sum_{i=0}^{2^{2n}-1}(cos\beta'|0>+sin\beta'|1>)\otimes|i> \quad (12)$$

According to the controlled color vector α that the sender and the receiver negotiate in advance, the receiver know to use the correct measure basis $MB=\{|\varphi_0>,|\varphi_1>\}$ to measure on particle 1:

$$|\varphi_0>=sin2\alpha|0>+cos2\alpha|1> \quad (13)$$

$$|\varphi_1>=cos2\alpha|0>-sin2\alpha|1> \quad (14)$$

After the measurement, the stego controlled carrier image can be rewritten as:

$$|F_n'\geq\frac{1}{2^n}\sum_{i=0}^{2^{2n}-1}\left(\frac{1}{\sqrt{2}}[|\varphi_0>_1(cos\beta_i'|0>+sin\beta_i'|1>)_2+|\varphi_1>_1(sin\beta_i'|0>-cos\beta_i'|1>)_2]\right)\otimes|i> \quad (15)$$

According to the measurement result of the particle 1, the receiver performs corresponding unitary operation on the particle 2. To be specific, when the

(a)Human (b)Vegetable (c)Environment (d)Animal

Fig. 1. (a)-(d)The species samples photos(the carrier images)

result of particle 1 is $|\varphi_0>$, the receiver will do I operation on the particle 2. When the result of particle 1 is $|\varphi_1>$, the receiver will do iY operation on the particle 2. Finally, a stego image $I(\beta')$ can be obtained.

After obtaining the stego carrier image, the receiver prepare to extract the secret image information according to the key string l_i. If $l_i = 0$,

$$\gamma_i = \cfrac{1}{\cfrac{1}{\cfrac{1}{\cos\beta_i{}'} - a_{i1}} - a_{i2}} - a_{i3} \tag{16}$$

If $l_i = 1$,

$$\gamma_i = \cfrac{1}{\cfrac{1}{\cfrac{1}{\sin\beta_i{}'} - b_{i1}} - b_{i2}} - b_{i3} \tag{17}$$

After recursively implementing the above steps for every stego image's pixel and getting each pixel of the secret information, the receiver can obtain each ecological information $|S_n>=\otimes_{i=0}^{2^{2n}-1}(\cos\gamma_i|0>+\sin\gamma_i|1>)$.

Performance Analysis

We analysis the new storage protocol in ecology from its capacity, imperceptibility and security. In order to fully evaluate the performance of the new protocol, we use multiple methods, such as PSNR, theoretical analysis, simulation experiment or comparation to analysis the performance of the new protocol in this section.

Capacity

Capacity is the maximum amount of secret information that can be embedded into the carriers. In the existing quantum storage protocol, the largest embedding rate can reach that one quantum bit transfer one bit message. When it comes to the new protocol, the size of the ecological information is as the same as the species samples photo and the embed process manage to achieve the largest embedding rate. Compared with the previous binary algorithm (Jiang et al. 2016), the secret ecological information that can be embedded in this protocol has an eight-fold increase in capacity.

By comparing with other kinds of carrier, such as quantum video (Chen and Qu 2018, Qu et al. 2017), quantum image can reach the largest embedding rates. It means that people can improve the capacity by choosing reasonable size of quantum carrier image (the species samples photo). To be more specific, when people want to embed larger secret ecological information, they just need to select the same size of another samples' photo as the carrier. If they have already own a carrier image that is big enough, the sender can embed more secret information. Therefore, the capacity of the new protocol is controllable by the users.

Imperceptibility

The new protocol has excellent performance on imperceptibility. When the sender prepares the stego controlled carrier image and sends it to the receiver, the transmitted particles $|F_n{}'>$ are in a composite system, which is completely a mixed state. Without any measurement performed on the particle 1, eavesdroppers cannot know any useful information about the species samples photo, no matter to extract the correct secret the ecological information.

Here, we use the species samples photos as shown in **Fig. 1** for the simulation experiment. The size of all images is 512*512.

The sender firstly embeds each relevant ecological information into carrier image respectively according to the new quantum image storage protocol proposed in this paper. Then, he sends the controlled stego image to the receiver. In the transmission process, the controlled stego image is shown in **Fig. 2**.

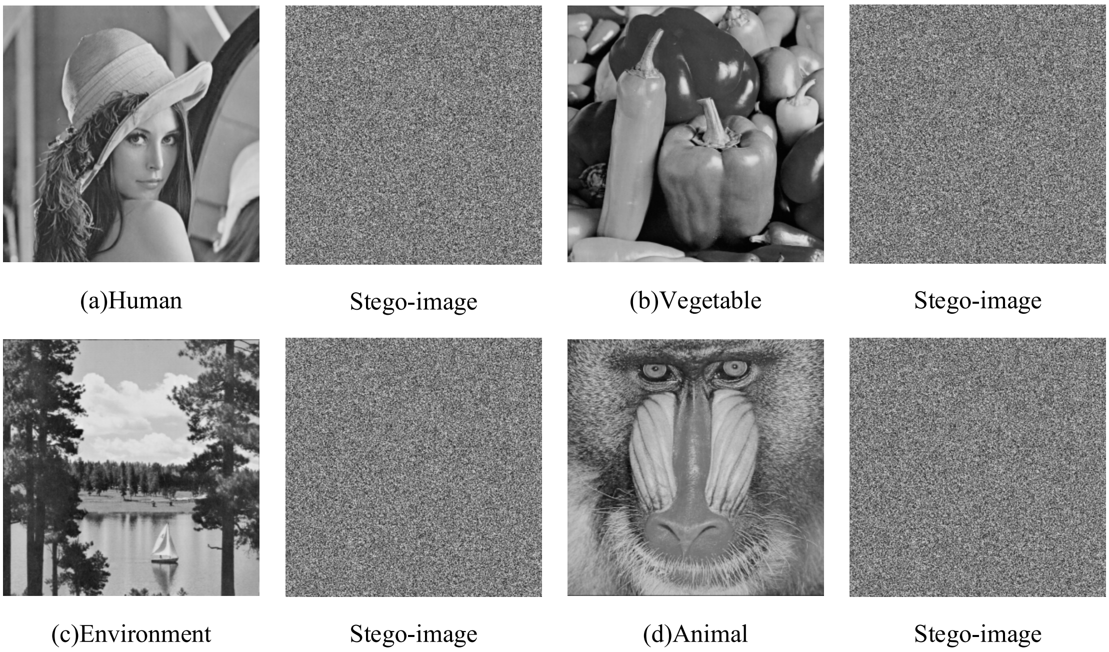

Fig. 2. The carrier images and controlled stego images

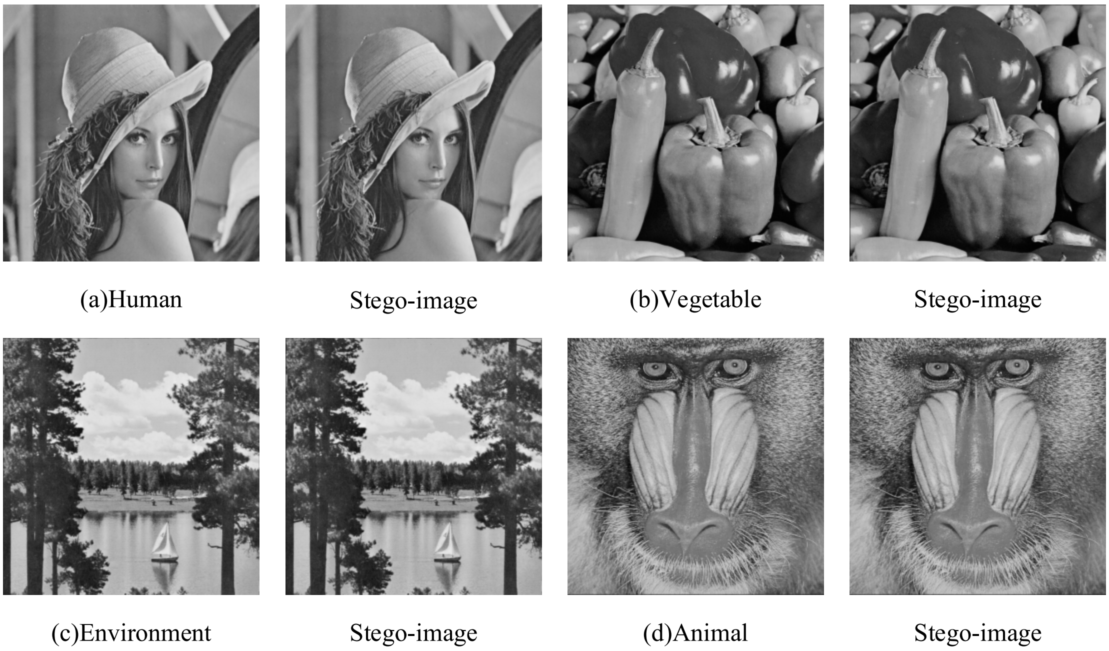

Fig. 3. The carrier images and controlled stego images

As shown in **Fig. 2**, the eavesdroppers can only learn some meaningless particles in the transmission process. It is impossible to know that the carrier image information is transmitted or detect the transmission of secret information.

Furthermore, when the controlled stego images has been transmitted to the real receiver, he will finish performing measurement on particle 1 under right measurement basis. In this case, the correct stego image are shown in **Fig. 3**.

As shown in **Fig. 3**, we can see that people can hardly find the difference between the original carrier image and stego image. Here we utilize PSNR method to value the differences of two images:

$$PSNR = 10log_{10}(\frac{255}{MSE}) \tag{18}$$

$$MSE = \frac{1}{mn}\sum_{i=0}^{m-1}\sum_{j=0}^{n-1}[I'(i,j) - I(i,j)]^2 \tag{19}$$

Table 1. The PSNR of each embedding group

Carrier image	PSNR
Human	60.0098
Vegetable	62.4586
Environment	61.3374
Animal	60.9621

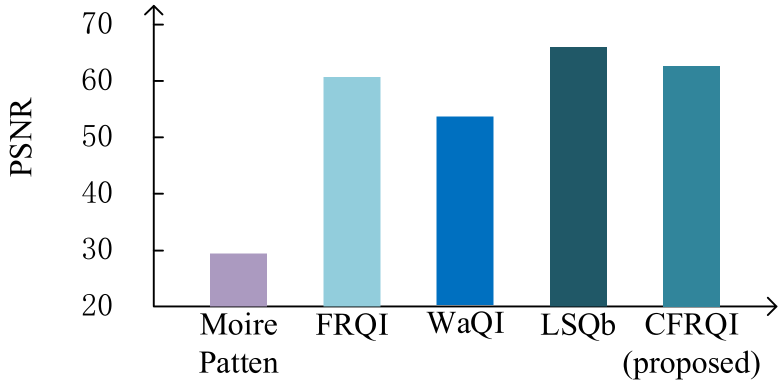

Fig. 4. The PSNR values in the relevant protocols

Here the tested images are I and I'. The size of them is $m \times n$, while MSE is the mean square error between them.

The PSNR of each embedding group in the new protocol are shown in **Table 1**.

From **Table 1**, we can find that the average of PSNR in the new protocol can reach 61.1919. These results can fully prove that the new protocol owns significant imperceptibility. Besides, we compare the average PSNR values with existing steganography protocols and give the corresponding line chart in **Fig. 4**.

According to **Fig. 4**, the average of PSNR in the new protocol is higher than that in existing protocols. It strongly proves that the great imperceptibility can be obtained in the new protocol.

In conclusion, the transmission process is quite covert that no one can detect the existence of the species sample photos or the ecological information. What is more, new protocol has significant imperceptibility based on the continuous fraction method, which just modifies a little in the the species sample photos.

Security

The security of storage protocol mainly means that the secret information can be protected from eavesdropping or attack during transmission. The proposed storage protocol can guarantee the security of secret ecologicalinformation transmission from two respects, including the characteristic of controlled flexible representation for quantum image and the design of the new storage protocol itself which involves encryption key as well as the random embedding position.

From the point of the characteristic of controlled flexible representation for quantum image, the quantum state of transmitted particles $|F_n' >$ is mixed so that eavesdroppers cannot identify species sample photo to extract the correct secret information even if he obtains the corresponding particles. Therefore, the security of the new protocol can be guaranteed.

From the point of the new protocol itself, on one hand, the embedded secretecological information position is random so that the eavesdropper cannot know the exact location of the secret information, which enhances the security of the protocol. On the other hand, only real receiver knows the correct measuring basis to perform on particle 1 to obtain stego image. When people want to extract the correct secretecological information, they must recover the right stego carrier image firstly. Therefore, the new protocol greatly improves the security because of the controlled color vector α.

In addition, the new protocol can also resist attack during transmission. For example, when other one wants to obtain information by performing measurements transmission particles, the receiver will detect this action and drop the communication because some particles in the $|F_n' >$ has been disentangled.

In conclusion, the new protocol enables to make sure the security of information.

CONCLUSION

In this paper, we analyze the application prospect of quantum computing and quantum information in ecology and produce a concrete application method, using quantum state to store ecological information. Compared with previous ways of storing ecological information, quantum state storage can reduce bit consumption, expand storage capacity, facilitate extraction, and improve security during transmission.

In general, the research on information storage and analysis of ecosystem using quantum technology is still in the initial stage. In terms of quantum machine learning, a considerable mature quantum machine learning system need to be improved, which can learn to recognize various institutions information system data from the Internet of things, find out the differences of time and space, and collect heterogeneous data. When it necessary, quantum computer need to compare data with historical research to verify credibility and value of data from multiple perspectives. In data processing, the complexity of ecology is not only reflected in the data sample, but also in the multi-source heterogeneous, multiple entities and space on the cross interaction. Workers find it difficult to use traditional methods to describe and measure ecology complexity so that some high-dimensional image or other multimedia data should be accomplished dimension reduction before measurement and processing. Totally speaking, the application of quantum computing and quantum information in ecology has a broad prospect and challenges.

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