Using quantum algorithms for Earth Observation data processing

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Abstract— **Big data is collected these days from various sources including sensors and cameras and contains important information about space, weather, medical application, industrial application, etc. Such information requires processing and storage memory, the limited ability of classical computers makes it hard to deal with such a huge amount of data. Quantum algorithms offer revolutionary solutions in various domains which require complex computational steps.**

In our paper, we introduce selected quantum algorithms that can be run on quantum computers soon to support the data handling process for images arriving from the Earth Observation satellite. We briefly present a potential application area named quantum image processing (QIP) which could be utilized to enhance the data processing operation while handling Earth Observation data. The novel idea of QIP is aimed to apply principles of quantum physics such as superposition, entanglement, and parallelism to image processing applications. instead of using classical algorithms. This will be able to solve many problems, reduce computational complexity, and exponentially speed up compared to the classical one, no matter how large the amount of data we deal with. Future's quantum computer will be able to perform the algorithms of QIP such as image representation, detection, etc., and break the classical limitation of calculation.

Keywords— quantum computers; quantum algorithm; image processing.

I. Introduction

Big data is collected these days from various sources including sensors and cameras and contains important information about space, weather, medical application, industrial application, etc. Such information requires processing and storage memory, the limited ability of classical computers makes it hard to deal with such a huge amount of data.

Quantum computers are powerful tools in big data-related data processing utilizing the phenomenon of quantum physics such as superposition, entanglement, and parallelism [1]. Due to these properties' quantum computers provided high-speed algorithms to process data and memory based on using quantum registers. From the viewpoint of quantum computing, we name the nowadays used techniques as classical (e.g., classical computers, classical algorithms, etc.).

In our survey paper, we introduce how quantum computers can help achieve higher performance in big data handling by utilizing the power of quantum parallelism. We are focusing on optical data processing which has an important role in Earth Observation (EO). We introduce quantum image processing algorithms which can outperform the classical image processing algorithm, offering faster response time in any service which is using data based on optical images.

Quantum image processing is an important branch of quantum information and computation theory, it is a promising technology that will come up with better images in terms of resolution, memory, and complexity. QIP has an exponential storage advantage if compared with the classical one, representing a square quantum image requires $(\lceil \log_2 N \rceil + \lceil \log_2 N \rceil + l)$ qubits, while classical needs (N x N x bit depth) bits [2]. Based on quantum Fourier transform and quantum image compression (QIC) different algorithms are introduced recently to represent, store, and retrieve images by using quantum computers.

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II. Quantum Algorithm

Feynman [3] was the first who suggested using quantum computers based on the principles of quantum physics in 1982. Quantum computers are more powerful than classical computers, where the processors of classical ones consist of a transistor (semiconductor material), which could reach its physical limitation in the next few years. According to Moore's law [4], we will reach the limit of classical transistors. To be able to further increase the calculation capacity, we need to apply the laws of quantum physics and build quantum computers. Quantum computers are based on quantum bit (or qubit in short). A qubit can be represented by any two-level quantum system such as the spin of an electron, trapped ion, photon, or atom. These qubits are represented in the bases of |0> and |1>, in a so-called superposition form:

$$|\psi\rangle = \alpha|0\rangle + \beta|1\rangle \quad (1)$$

where α and β are complex numbers and |α|^2+|β|^2=1.

Quantum bit is linked with two-dimensional Hilbert space which provided its ability to be in the superposition state of 0 and 1. The pure state of a qubit is described by a unit vector belonging to a two-dimensional complex Hilbert space as in equation 1.

In quantum computers, the qubit represents the basic information unit that meets the binary bit in the classical. A qubit can be in superposition in two states at the same time while the classical binary bit cannot be on both states simultaneously (i.e., if one entry has 1, then the other will be zero). Here the information bits are measured by the probability of the possible states, where the memory consist of n bits of information has 2n states represented by a probability vector. A qubit can be defined as a higher-dimensional quantum system that is described by a dimensional Hilbert space Hd and referred to as qudits.

Bloch sphere is a geometrical representation used to represent the quantum states, qubits can be represented at any point of the sphere surface while classical bits could be represented only by the north or south pole of the sphere. Quantum computers have applications in different fields such as cryptography, optimization problems, and image processing, because of their ability to solve the problems that face classical computers in such fields.

Deutsch [5] suggested using quantum algorithms instead of classical ones. Different quantum algorithms are suggested to deal with various trends such as machine learning, image processing, classification, factorization, and searching. The most important advantage of such algorithms is the required time complexity and storage memory lass than classical one such as quantum algorithm suggested by [6], which find larger Walsh coefficients with time query equal to $O\left(\frac{\log\frac{1}{\delta}}{\epsilon^4}\right)$ while classical one takes a $poly\left(n, \frac{1}{\epsilon}\log\frac{1}{\delta}\right)$.

Images are one the important sources of information because of their massive applications in various fields such as medical, industrial, weather, etc. Using of quantum mechanics for image reorganization was first suggested by [7] who focuses on the use of quantum mechanics to realize orthogonal images, but a major role of research in quantum image processing is assigned to [8], which suggests using quantum mechanics in images storage and retrieval, then compare with classical methods. Using quantum mechanics principles for image processing provided us with unique properties such as higher computing speed, ensuring security, and reduced memory requirement. These improvements are due to the quantum computers attribute illustrated above and using of qubit instead of classical bits. OIP could perform image processing such as image storage, retrieval, representation, encryption, segmentation, etc. better than the classical one.

In the classical representation of images, images are represented by using matrices, and each value is represented by a pixel. While for quantum representation there are two main representation methods state amplitude-based and basic state representation. In amplitude representation, the value of the pixel is represented by the amplitude of the qubit such as in the FRQI algorithm [2], while for base state representation pixels values are stored in the state of the qubit sequence such as in the NEQR algorithm [9]. There are different other methods to store and retrieve quantum images such as entangled quantum sequence [10] and others.

III. Quantum Image Processing

Quantum algorithms can be used to help the image processing which is a typical step in Earth Observation. Image processing based on quantum physics is named Quantum Image Processing (QIP), which deals with image storage, retrieval, security, etc., by using quantum computing instead of the classical one. The pictures are two-dimensional matrices that are represented in the memory by a quantum bit called grid qubit. In the next subsections, we introduce selected algorithms which are compared in Table I.

A. Quantum Image Processing Representation

- FRQI is the most used image representation method, it is represented the quantum image as is the normalized state [2]. Use unitary transform to express its state by three operators, first for color information, second for the color position, and third for both color and position. The drawback of this approach it is disabled to retrieve the original classical image because of the probability amplitude probability of the quantum state. Recently, an enhanced method based on FRQI suggested by Norhan and co-authors [11], enhances the time complexity of the FQRI Avoid combining SI and CGS units, such as current in amperes and magnetic field in oersteds. This often leads to confusion because equations do not balance dimensionally. If you must use mixed units, clearly state the units for each quantity that you use in an equation.

- Novel Enhanced Quantum Representation (NEQR). NEQR suggested 2013 [9], that it is based on the basic state to encode pixels' intensity value inside the image. NEQR solves the FRQI, by recovering the exact original image by using a single measurement only. Only one problem with this type it is used for square images only. Recently an enhanced ENQR (ENQR) was introduced by Norhan and co-authors [11], which enhances time complexity and has less quantum cost.

- Multi-channel representation for quantum images (MCQI). MCQI works based on FRQI and uses R, G, and B channels to encode color square quantum images, it encoded color information by using angle parameters [12]. In this approach three qubits are used to encode the color information, making the design of the color image easier and has less complexity. In the same direction flexible representation of color images suggested by [13] uses only a single bit to represent the color images.

- Caraiman's quantum image representation model (CQIR): In the CQIR approach [14], 2m possible color can be expressed in a superposition state. The retrieval of the image can be applied using a deterministic way instead of a probabilistic such as FRQI. This approach provided fast and efficient color image operation because it isn't using simple quantum gates.

- Quantum normalized amplitude-based image processing (QNAIMP): QNAIMP approach is suggested by [15], an image is represented by a two-dimensional matrix of m-qubit row and n-qubit column vectors. The tensor product of the row location and column-location vector results in a 2-D quantum state of a pixel in the Liouvillian space. Hence, m + n qubits without additional qubits will be required to represent quantum images.
- Quantum entangled image processing (QEIP): In the QEIP method [10] an entangled state is used to store a binary image in a quantum system. An image is stored as a two-dimensional array with two parameters x and y, which contain a grid point. This method has a special property over others that can represent rectangular images.

Recently different methods are suggested to represent and store the images by applying quantum algorithms such as Optimized quantum representation for color digital images (OCQR) [16]. A new quantum representation model of color digital images (QRCI) [17] which is based on entangled qubit sequence to represent the image. Double quantum color images encryption scheme DQRCI [18], etc.

TABLE. I: COMPARISON OF DIFFERENT QIP METHODS

QIP representation	Method used	Algorithm	Processing type	Image type/shape	Storage memory / no. of qubits needed	Time complexity
FRQI [2]	Normalize state	Quantum image compression (QIC	Image storage, retrieval	grayscale images/ square images only	A single bit is used to represent color information	$O(2^{4n})$
EFRQI [11]	Normalize state	Same as FRQI	Image storage, retrieval	Color images/square images only		$O(2^{4n})$
NEQR [9]	Basic state	Same as FRQI	Image storage, retrieval	Grayscale images only/square images only	2n + 8 qubits	$O(2qn2^{2n})$
ENEQR [11]	Basic state	Same as FRQI	Image storage, retrieval	Grayscale images	2n+1 qubits	$O(2n2^{2n})$
MCQI [12]	Normalize state		Image storage, retrieval	for all image types	3-qubits to store $2^n \times 2^n$	
CQRI [14]	Finite deterministic		Image storage, retrieval segmentation	2 m possible colors (m+2n)- qubit register	2 m possible colors (m+2n)- qubit register	
QNAIMP [15]	Normalize state		Storage and retrieval	For all image types	(m+n) qubits	
QEIP [10]	Entangled quantum sequence	Grover's quantum search algorithm	Image storage, retrieval, histogram, segmentation	Binary images only	N-qubits	O(n)

B. *Security base technologies of the QIP*

- Watermarking and authentication of quantum images WaQI Watermarking is a process by which the copyrights of an image was protected and authenticated which is represented while the fixed parameters are used for the other schemes' embedding process. Moreover, dynamic watermarking can be classified into wavelet transform watermark and Hadamard transform-based watermarking. Most of the quantum watermarking schemes are applied for the multi-channel FRQI representation, the adoption of MCQI representation for the carrier and watermark images facilitates the protection of colored quantum images and improves the capability of watermarked images to withstand malicious attacks.
- Quantum image encryption algorithms: Information sharing, and other communication types are needed to be encrypted to stop eavesdroppers and keep the information secure, especially in military communication, politics, and medical applications. Most algorithms of quantum images focus on two parameters position information and color information. The position-based algorithms are the Hilbert transform, Arnold transforms, and Fibonacci transform.
- Quantum image steganography: Steganography is the technique that focuses on hiding secret information. A Moire pattern-based NEQR image steganography strategy [19], designed as an algorithm work with a logo that may be visible or invisible. Reference [20] suggests the first quantum image security protocol, which is based

on quantum cosine transform to build an invisible watermarking. Generally, there are two types of watermarking techniques first based on fixed parameters, and the other based on a dynamic vector, dynamic vector is used to control the embedding strength quantum circuit to hide a binary image into a grayscale image. Then an enhanced version based on two blind LSB algorithms [21] based on NEQR representation, two types of this algorithm plain standard (used message bits to substitute for the pixels' LSB directly) and block LSB (embeds a message bit into several pixels that belong to one image block).

C. *Quantum Image recognition*

Quantum image recognition: image recognition is the ability of the machine to recognize people, objects, writing, etc in the image. The importance of such a field of research leads to an investigation of very wide algorithms to make the process more precise and better work. In 1997, [7], suggest using quantum mechanics to enhance image recognition. One of the important images that deal with is the medical one, [22] suggests a new algorithm based on quantum BP neural network (QBP) based on quantum particle swarm optimization (QPSO), that recognizes the pneumonia image

IV. CONCLUSION

In our paper, we introduced selected quantum algorithms that can be run on quantum computers soon to support the data handling process for images arriving from Earth Observation satellites. Quantum mechanics can be applied to image processing to attain high-performance image representation, storage, segmentation, etc. In this article, we reviewed some important algorithms used by the quantum system to represent images. Some security approaches including image watermarking and steganography techniques are presented based on using of quantum computing.

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