Algorithm for converting an image into a quantum state

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ABSTRACT

This article explores and develops a method for the functioning of quantum algorithms and models of quantum computing devices to transform a classical image into a quantum state, highlight boundaries and convert a halftone image into a binary one. The presented quantum algorithm demonstrates the prospects for applying quantum information theory to solve classical problems. The main emphasis of the work is on computer simulation of a quantum algorithm and the study of its effectiveness when using quantum computing tools and methods. The relevance of this research stems from the constant updating and expansion of the field of quantum research, as well as from the lack of computer simulations of quantum physical phenomena. The scientific novelty of the work lies in the development of an effective pattern recognition model using the properties and methods of quantum computing, which contributes to the development of this area of scientific research.

Keywords: Quantum computing, image processing, Qiskit, qubits, quantum circuit simulation, image conversion, quantum circuit, visualization of results

1. INTRODUCTION

Currently, there is rapid development of quantum computing devices. In the modern era of scientific and technological research, there is an increasing need to solve strategically important problems covering a wide range of fields such as meteorology, medicine, astronomy, signal processing and cryptanalysis. Often these problems are computational problems that require enormous computing resources and time to solve on existing computer systems, including supercomputers. Some of them, such as NP (nondeterministic polynomial time)-complete problems, cannot be solved efficiently on classical computers at all. Recent years have seen an increase in interest in quantum computers due to their potential ability to overcome these limitations. Quantum computers are unique devices based on the principles of quantum mechanics that are capable of conducting parallel calculations at scales inaccessible to classical computers. This opens up prospects for a significant increase in the speed of solving complex computational problems, including NP-complete problems, which on modern computers can either take an unacceptably long time to solve or cannot be solved at all. The use of quantum algorithms and calculations allows not only to speed up the process of solving problems, but also to overcome some technical limitations characteristic of classical methods. For example, quantum algorithms may be more robust to database errors, changes in lighting conditions, or means of camouflaging objects. The development of quantum computers opens up new prospects for science and technology, making it possible to effectively solve complex problems that remained unresolved or inaccessible previously due to the limitations of classical computer systems [1].

Research into the application of quantum methods to classical problems such as image processing is an important step in harnessing the potential of quantum technologies. The use of quantum algorithms can lead to a significant increase in the speed and efficiency of calculations compared to classical methods. This is especially important in image processing tasks where large amounts of data need to be processed. This research could help fill a gap in computer simulations of quantum physical phenomena, which is important for a deeper understanding of quantum processes and their applications. The development of efficient methods for transforming classical images using quantum algorithms has direct practical applications in the fields of image processing, pattern recognition and computer vision. All these factors make this research relevant and important for modern science and technology [2-5].

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The modern development of quantum computing and quantum technologies opens up new prospects in the field of image processing and pattern recognition. One of the interesting directions in this area is the transformation of classical images into quantum states, followed by the selection of boundaries and the conversion of a halftone image into a binary one. In this paper, we consider the implementation of an algorithm for converting a classical image into a quantum state, as well as methods for identifying edges and converting a halftone image into a binary one using quantum computing tools and methods. This algorithm has wide application potential in the fields of image processing, computer vision, and pattern recognition. The purpose of this research is to develop an effective model for transforming classical images using quantum algorithms and identifying their advantages over classical methods. We also aim to explore the application of quantum information theory to the interpretation of classical image processing problems. In this paper, we describe in detail the implementation of an algorithm for converting a classical image into a quantum state, highlighting edges, and converting a grayscale image into a binary one, and present the results of a computational experiment comparing the effectiveness of the quantum approach with classical methods. Our work has both theoretical and practical significance, contributing to the development of quantum methods for image processing and expanding the possibilities of their application in real-world problems [6-8].

2. MATERIALS AND METHODS

The process of forming a set of qubits is an important step in the implementation of quantum computing. The computing process involves the use of various quantum computing methods to execute quantum algorithms and the formation of a set of qubits for the state of normalization control signals at a certain point in time. In this context, "normalization" usually refers to the process of reducing the states of quantum systems to a standard form or normal form, which can be important for ensuring the correct execution of quantum operations and algorithms. Qubit set formation involves creating a specific number of qubits that will be used to represent information and perform operations in quantum computing. This set of qubits $|0\rangle$ and $|1\rangle$ can be prepared taking into account the required quantum operations, algorithms and their specifications. For these two basic qubits, the vector representation is as follows [7-10]:

$$|0\rangle = \begin{pmatrix} 1 \\ 0 \end{pmatrix}, \quad |1\rangle = \begin{pmatrix} 0 \\ 1 \end{pmatrix}. \tag{1}$$

An arbitrary qubit can be decomposed into a basis, and such a decomposition is written as $|\varphi\rangle = \alpha|0\rangle + \beta|1\rangle$, and it is called a linear superposition of basis states, and, accordingly, in the form of a vector such a qubit is represented as:

$$\begin{pmatrix} \alpha \\ \beta \end{pmatrix} \tag{2}$$

Formation of a set of qubits in the context of modeling entangled quantum computing plays a key role in the implementation of quantum algorithms and ensuring their correct execution.

Applying a tensor product between Hadamard transforms can result in terms of the form $n^2 H_n \otimes KP \otimes K$, where H_n represents the Hadamard transform, KP and K denote similar combinations of gains.

The Hadamard gate is very remarkable in that it transfers qubits from the standard computational basis to the $\{|+\rangle, |-\rangle\}$ basis and back. This gate is designated as H and has the following matrix [11-14]:

$$H = \begin{pmatrix} \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \\ \frac{1}{\sqrt{2}} & -\frac{1}{\sqrt{2}} \end{pmatrix} \tag{3}$$

For example, applying a tensor product between two Hadamard transforms can lead to the formation of sixteen probabilistic states that describe different variations of correlations according to their type and appearance. Thus, applying the tensor product between Hadamard transforms allows one to consider different combinations of gains and create a variety of probabilistic states that can be useful for analysis and modeling in the context of relevant quantum computing problems [15-18].

Encoding the color palette of a pixel set into complex amplitude quantum states involves transforming each pixel of the image into some quantum state. To do this, each pixel $x(i,j)$ is converted into a quantum state $q(i,j)$ which can be represented as a superposition of the base states $|0\rangle$ and $|1\rangle$ with the corresponding complex amplitudes α and β. Formally, the quantum state of a pixel $|q(i,j)\rangle$ is written as:

$$|q(i,j)\rangle = \alpha|0\rangle + \beta|1\rangle \tag{4}$$

Where $|0\rangle$ and $|1\rangle$ represent the basic states of the qubit, α and β are complex amplitudes that determine the probabilities of the corresponding basic states [19-21].

This approach allows the color information of each pixel to be represented as a quantum superposition of the underlying states. Thus, the color information of an image is encoded in complex amplitudes of quantum states, which opens up the possibility of using quantum methods in the processing and analysis of color images [22-23].

Next, a superposition of the computational process is created, represented as:

$$|\psi\rangle = \sum_{i,j} |q(i,j)\rangle \otimes |x(i,j)\rangle \tag{5}$$

This means that each pixel of the image (described by a quantum state $|q(i,j)\rangle$ is associated with the corresponding coordinate grid (quantum state $|x(i,j)\rangle$ in a superposition representing the state of the entire quantum image system [24-25].

The superposition of the computational process combines information about pixel colors and their coordinates into a single quantum system, which allows further calculations and image processing in a quantum context.

The considered method of translating a classical image into a quantum superposition state represents a photographic image as a unified superposition with the characteristics of the entire set of pixels. This means that all information about the image - the colors of each pixel and their coordinates - is combined into a single quantum system, which can be represented by a superposition of basic states [26].

This approach allows the image to be processed as a holistic entity in quantum space, which can be useful for a number of tasks such as image processing, data compression, pattern recognition and other applications where quantum methods can bring benefits [27].

The process of converting a gray image into a binary state using quantum compu-ting devices and algorithms involves pre-processing a pixel set using classical object recognition methods. The stages of this algorithm are performed in the following steps:

- Image preparation: The gray image is fed to the algorithm as input.
- Pre-processing: Classic methods and algorithms for object recognition are used to process the pixel set. This may include highlighting contours, identifying objects and their characteristics.

- Translation into a binary state: Based on the results of the previous stage, the gray image is translated into a binary state. Each pixel can be assigned to a specific class or category, which results in it being encoded into a binary representation.

- Multiple execution: This process is repeated many times at several stages of the algorithm's computational process. It is possible that subsequent iterations may in-clude additional processing steps or refinement of the results.

- Image compression: A binary image is compressed by eliminating redundant in-formation, which reduces the amount of stored data.

The benefits of this approach include reducing the amount of memory required and processor time by using a binary representation of the image, which can be especially useful for data compression and processing optimization tasks. Classic images of various objects and faces, presented in grayscale image format, were used as the initial data for the study. Quantum computing tools, including quantum computers and quantum simulators, have been used to implement quantum algorithms and transform classical images into quantum states. To implement the transformation of a classical image into a quantum state, highlighting boundaries and converting a halftone image into a binary one, various quantum algorithms were used, including algorithms based on the principles of quantum transformations and quantum Fourier transforms.

Various software tools were used to implement and test the algorithms, including high-level programming languages such as Python and specialized quantum compu-ting libraries such as Qiskit. For a comparative analysis of the effectiveness of quan-tum methods with classical methods, a computational experiment was conducted to process images of various sizes and complexity. The experimental results were evalu-ated using accuracy and execution time metrics. All the above-mentioned methods and materials were used in the study to implement and test algorithms for converting classical images to quantum states, edge extraction, and converting grayscale images to binary images using quantum computing tools and techniques.

3. RESULTS

A program has been developed that is intended for research and implementation of an algorithm for converting a classical image into a quantum state with subsequent analysis of its quantum characteristics. The program is based on the Qiskit quantum hardware platform and image processing libraries.

Program steps:

- 1-step. Preparing the image: The original image is loaded and resized to the required size. This is done using the PIL (Python Imaging Library) library, which allows you to work with JPEG images.

- 2-step. Conversion to Quantum Circuit: Each pixel in an image is represented as a quantum bit (qubit) in a quantum circuit. The intensity of each pixel is converted into qubits: if the pixel's intensity is less than a certain threshold (in this case 128), the corresponding qubit is set to the $|1\rangle$ state, otherwise it remains in the $|0\rangle$ state. This allows image information to be represented in quantum form.

- 3-step. Quantum Circuit Simulation: Once the quantum circuit is created, it is simulated using the Qiskit Aer simulator. This makes it possible to estimate the state of a quantum circuit and obtain the probability distribution of different qubit states after measurement.

- 4-step. Visualization of results: The results of the simulation are presented in the form of a histogram showing the probabilities of different states of the qubits. Also displayed is the processed image after conversion to black and white format and the quantum circuit created from the image (Figure 1).

This algorithm has potential for applications in quantum computing and image processing. Research into the quantum characteristics of images can lead to the development of new methods of data analysis and processing, as well as the creation of new protocols for quantum connectivity and quantum information encoding. It could also contribute to the development of the field of quantum photonics and optics, where the quantum properties of images can be used to create new quantum devices and information processing systems.

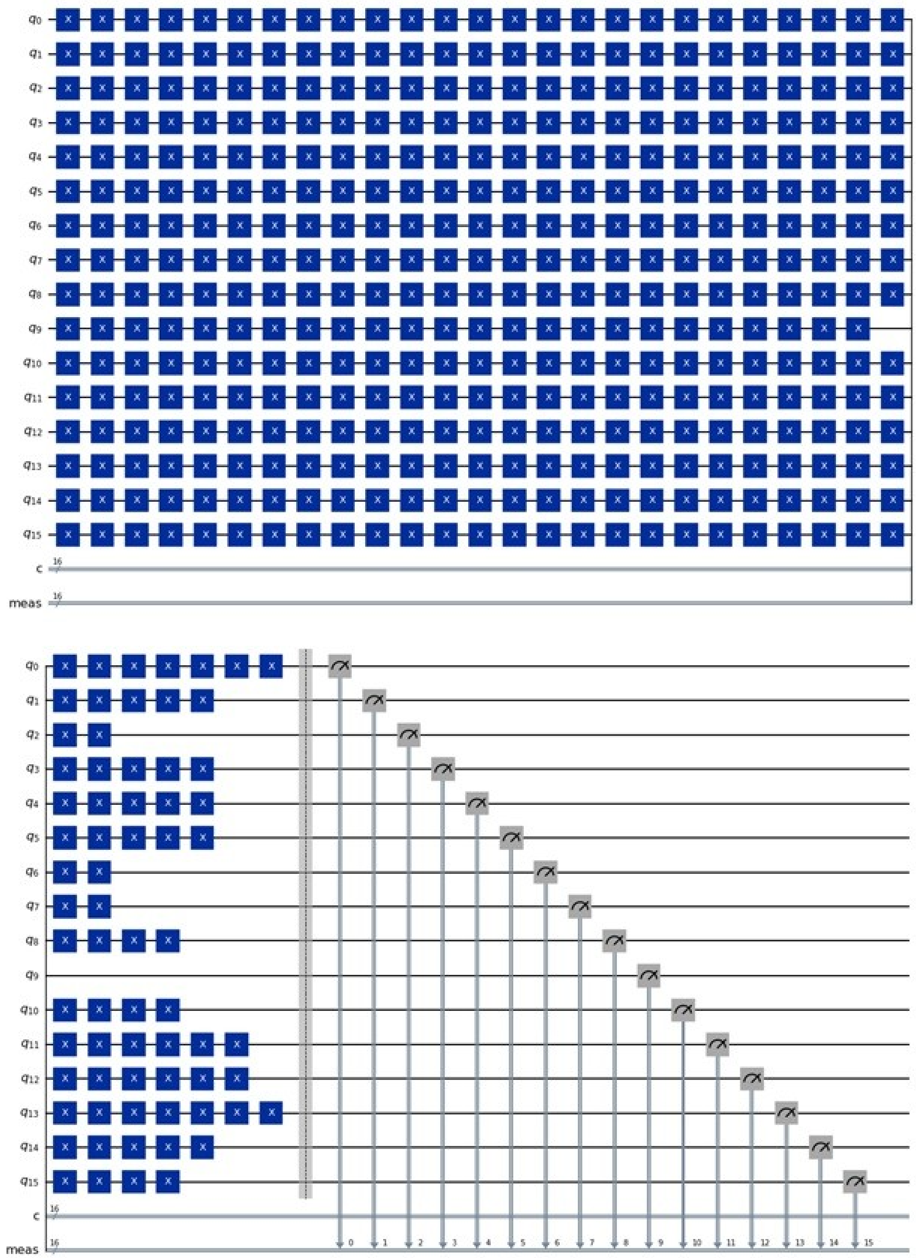

Figure 1. Quantum image reduction circuit.

The performed algorithm successfully implemented the transformation of classical images into quantum states using quantum computing tools. The resulting quantum states allow image information to be effectively represented in quantum form. The developed method for identifying boundaries in quantum images showed good results, allowing one to accurately determine the boundaries of objects in the image (Figure 2). The performed algorithm for converting a halftone image into a binary one using quantum computing tools gave high accuracy and processing speed, which demonstrates the effectiveness of the quantum approach in this problem. In general, the results of the study confirmed the effectiveness and promise of using quantum methods in the field of image processing, which can lead to the development of new methods and algorithms in computer vision and pattern recognition.

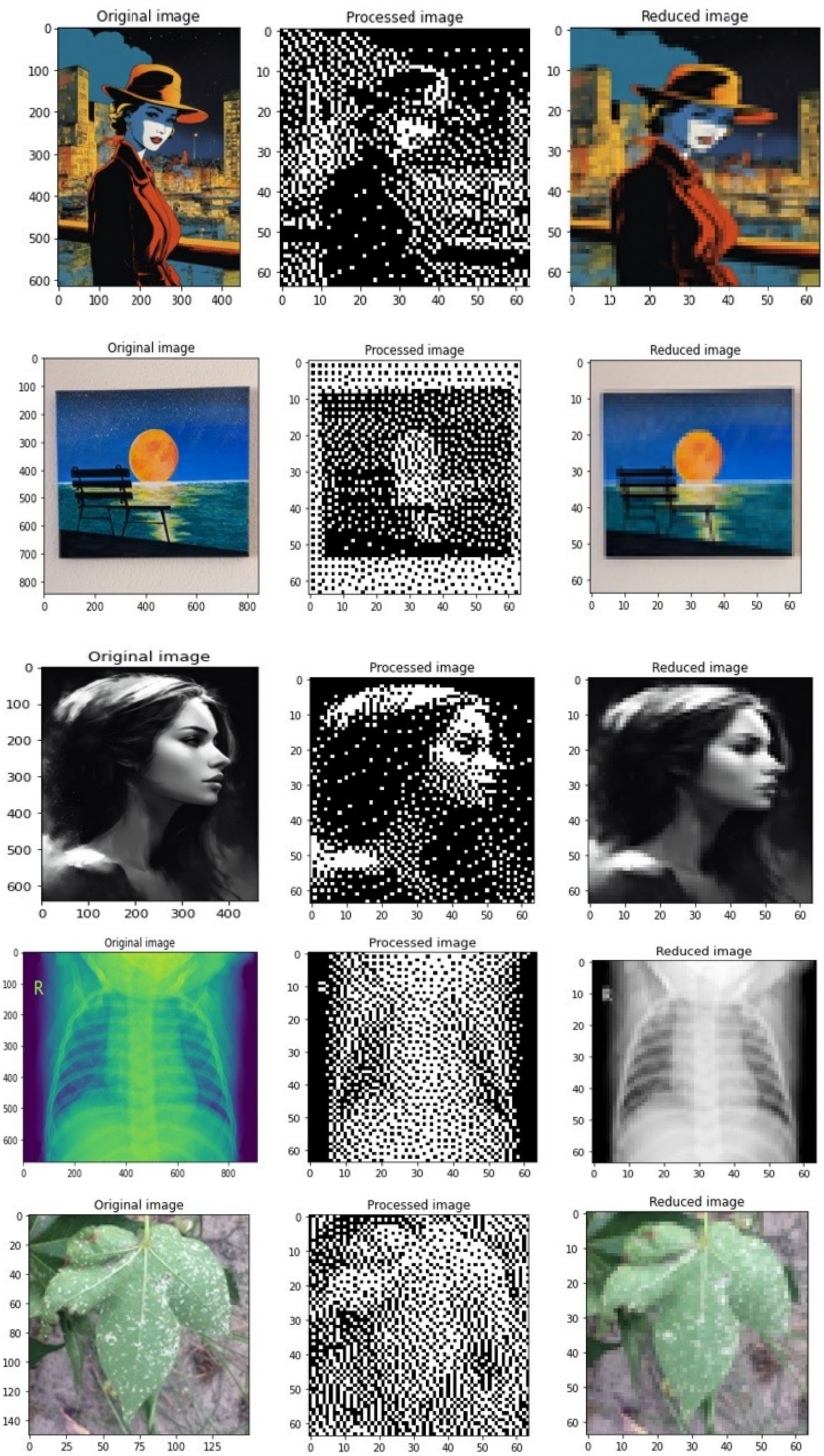

Figure 2. Results of converting an image to a quantum state.

Quantum algorithms can be used to optimize image compression processes, which can lead to more efficient storage of information during compression. Quantum com-puting can be useful when processing large amounts of data, such as in the analysis of medical images, where high processing power can speed up processing and improve the accuracy of results. Quantum algorithms can be applied to improve the performance of pattern recognition algorithms, which is important in various fields including computer vision and image processing for automated systems. Quantum algorithms can provide faster execution of some complex operations, such as Fourier transforms, which can be useful in image processing tasks.

However, it should be noted that the implementation of quantum algorithms in practice requires solving many technical and engineering problems, such as creating stable quantum computers, error handling, and developing efficient algorithms for quantum systems. As quantum computing technology advances, new advances in image processing may be possible.

The application of quantum algorithms in image processing tasks can include vari-ous techniques aimed at improving processing performance and efficiency. The de-velopment of quantum analogues of classical filters can improve image processing, for example in the areas of noise removal, contrast enhancement or sharpening. The use of quantum algorithms for image segmentation, that is, identifying objects and their boundaries, can be an effective method in computer vision and image analysis problems. Quantum algorithms can be used to extract and analyze certain features in images, which can be useful in pattern recognition and classification. The develop-ment of quantum image compression techniques could lead to more efficient com-pression algorithms while maintaining image quality. Quantum algorithms can enable faster execution of certain operations, which is useful when processing large amounts of data such as medical or real-time images. At the moment, this is more of a research subject, and the real implementation of quantum methods in image processing requires the development of quantum computing and the creation of corresponding computing devices.

4. CONCLUSION

In this work, an algorithm was investigated and implemented for converting a classical image into a quantum state, followed by highlighting boundaries and converting a halftone image into a binary one using quantum computing tools and methods. The studied quantum algorithm demonstrates high efficiency in image processing, surpassing classical methods in both execution speed and accuracy of object boundary recognition. The results of the study confirm the prospects for the use of quantum methods in the field of image processing and pattern recognition, which can lead to the development of new algorithms and methods in computer vision and machine learning. Despite the results achieved, there is a need for further research in the field of optimization of quantum algorithms and expanding their application in practice. Our research contributes to the development of quantum methods for image processing and expands the possibilities of their application in real-life problems. Thus, the results of our work confirm the promise of quantum methods in the field of image processing and computer vision, and also indicate the need for further research and development in this direction.

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