Communications in Computer and Information Science 2112

Arthur Gibadullin (Ed.)

Communications in Computer and Information Science 2112

Information Technologies and Intelligent Decision Making Systems

Third International Scientific and Practical Conference, ITIDMS 2023
Moscow, Russia, December, 12–14, 2023
Revised Selected Papers

Springer

Arthur Gibadullin
Editor

Information Technologies and Intelligent Decision Making Systems

Third International Scientific and Practical Conference, ITIDMS 2023
Moscow, Russia, December, 12–14, 2023
Revised Selected Papers

Springer

Preface

The Third International Conference "Information Technologies and Intelligent Decision Making Systems" (ITIDMS 2023) was held as a virtual event, December 12–14, 2023, on the Microsoft Teams platform due to COVID-19.

The conference was held with the aim of developing and exchanging international experience in the field of information, digital and intellectual technologies, within the framework of which proposals were formulated for digital, intellectual and information transformation, the development of computer models and the improvement of automated and computing processes. A distinctive feature of the conference was that it presented reports of authors from China, Vietnam, Uzbekistan, Russia, Korea, Finland and Israel. Researchers from different countries presented the process of transition of the information and digital path of development, and presented the main directions and developments that can improve efficiency and development.

The conference sessions were moderated by Arthur Gibadullin of the National Research University "MPEI", Moscow, Russia.

Thus, the conference still facilitated scientific recommendations on the use of information, computer, digital and intellectual technologies in industry and fields of activity that can be useful to state and regional authorities, international and supranational organizations, and the scientific and professional community.

Each presented paper was reviewed by at least three members of the Program Committee in a double-blind manner. As a result of the work of the reviewers, 17 papers were accepted for publication out of the 54 received submissions. The reviews were based on the assessment of the topic of the submitted materials, the relevance of the study, the scientific significance and novelty, the quality of the materials, and the originality of the work. Authors could revise their paper and submit it again for review. Reviewers, Program Committee members, and Organizing Committee members did not enter into discussions with the authors of the articles.

The Organizing Committee of the conference expresses its gratitude to the staff at Springer who supported the publication of these proceedings. In addition, the Organizing Committee would like to thank the conference participants, the reviewers and everyone who helped organize this conference and shape the present volume for publication in the Springer CCIS series.

Arthur Gibadullin

Editor
Arthur Gibadullin
National Research University "MPEI"
Moscow, Russia

ISSN 1865-0929 ISSN 1865-0937 (electronic)
Communications in Computer and Information Science
ISBN 978-3-031-60317-4 ISBN 978-3-031-60318-1 (eBook)
https://doi.org/10.1007/978-3-031-60318-1

This Springer imprint is published by the registered company Springer Nature Switzerland AG
The registered company address is: Gewerbestrasse 11, 6330 Cham, Switzerland

Paper in this product is recyclable.

Dmitry Morkovkin	Financial University under the Government of the Russian Federation, Russia
Dmitry Rastyagaev	Russian New University, Russia

Organizing Committee

Arthur Gibadullin	National Research University “Moscow Power Engineering Institute”, Russia
Elena Bovtrikova	Russian New University, Russia
Olga Matyunina	Russian New University, Russia
Dmitry Morkovkin	Financial University under the Government of the Russian Federation, Russia
Dmitry Rastyagaev	Russian New University, Russia

Organizer

Russian New University, Russia

Organization

Program Committee Chairs

Yuri Gulyaev	Institute of Radio-Engineering and Electronics, RAS, Russia
Alexander Bugaev	Institute of Radio-Engineering and Electronics RAS, Russia
Sergey Nikitov	Institute of Radio-Engineering and Electronics RAS, Russia
Vladimir Zernov	Russian New University, Russia
Andrey Kryukovskiy	Russian New University, Russia
Evgeny Palkin	Russian New University, Russia
Gulom Uzakov	Karshi Engineering-Economics Institute, Uzbekistan
Manuchehr Sadriddinov	International University of Tourism and Entrepreneurship of Tajikistan, Tajikistan
Arthur Gibadullin	National Research University “Moscow Power Engineering Institute”, Russia

Program Committee

Oleg Zolotarev	Russian New University, Russia
Leonid Labunets	Russian New University, Russia
Maurizio Palesi	University of Catania, Italy
Yixuan Wang	Northwestern University, USA
Afroz Shah	Columbia University, USA
Ghali Naami	Sidi Mohamed Ben Abdellah University, Morocco
Jencia J.	Karunya Institute of Science and Technology, India
Pratap Sekhar Puhan	Sreenidhi Institute of Science and Technology, India
Priscilla Joy	Noorul Islam University, India
Meng Wei	Lanzhou Jiaotong University, China
S. G. Hymlin Rose	RMD College of Engineering, India
Ke Wang	University of North Carolina at Charlotte, USA
Rajanarayan Prusty	Alliance University, India
Kamal Saluja	Chitkara University Institute of Engineering and Technology, India

Contents

The Structure and Principle of the Intelligent Micro-arc Oxidation System Operation

Ekaterina Pecherskaya(✉), Pavel Golubkov, Vladimir Alexandrov, Kirill Nikishin, and Ilya Kiryutkin

Penza State University, 40, Krasnaya Street, Penza 440026, Russia
pea1@list.ru

Abstract. The purpose of the work is to create an intelligent technology for obtaining oxide coatings with specified properties through an automated system being developed. The developed intelligent system implements the method of micro-arc oxidation to obtain protective oxide coatings on products made of aluminum, titanium or their alloys. The intelligent system consists of hardware, software, and information content. The software is developed in the LabVIEW graphical programming environment. The intelligent application contains three subroutines: identification of the electrophysical model parameters and optimization of process parameters to obtain the required properties of oxide coatings; visualization of the coating parameters dependences in real time on influencing factors. The algorithm of the developed automated system functioning is presented. The presence of an intelligent application allows feedback for software, in which the process current source can change the oxidation mode depending on the coating state at a given time, taking into account the required target coating parameters (thickness, porosity, hardness, etc.). The advantage of the proposed intelligent system is the possibility of implementing a regime of controlled synthesis of oxide coatings with the required properties. In turn, it makes it possible to increase the reproducibility of the MAO coatings parameters, reduce the time for testing the technological process.

Keywords: Intelligent Automated System · Process Current Source · Information Content · Oxide Coating · Algorithm

1 Introduction

With the development of programmable logic controllers since the late 1960s, a new stage of the creation of methods and algorithms for controlling complex technical systems began. In the last decade, real-time object monitoring systems have become widespread in various fields, they are becoming intelligent tools capable of solving a wide range of management tasks. Such devices necessarily contain a microprocessor system for collecting and processing information. For example, [1] an intelligent integrated air pollution monitoring system with Internet of Things support, built on the basis of the Arduino hardware platform is presented.

A. Gibadullin (Ed.): ITIDMS 2023, CCIS 2112, pp. 1–11, 2024.
https://doi.org/10.1007/978-3-031-60318-1_1

The article [2] contains the basic principles of building a multichannel system for collecting and preprocessing information about the control object state based on the precision analog microcontroller ADuC7060/61 Analog Devices in real time. The authors of the study [3] present the result of the development of a hardware sorting mechanism for peripheral computing devices with limited area and power consumption. It is important to use intelligent transport systems as part of a "smart city", which advisably can be presented in the form of a five-level hierarchical architecture, at the lower level of which there are sensors and actuators [4]. In control systems, feedback between sensors and actuators is organized thanks to programmable logic controllers. It opens up wide opportunities for the introduction of intelligent systems for automation of technological processes, control of technological parameters in real time. In [5–8], the possibility of automating the micro-arc oxidation (MAO) process for obtaining oxide coatings on products made of metals and alloys of the light group is described.

The recognized world leader in the field of micro-arc oxidation is Keronite, which offers its own range of automated process equipment. For example, an industrial installation with a capacity of 100 kW allows the application of MAO coatings in a pulsed bipolar mode with an adjustable voltage and current amplitude, pulse frequency and duty cycle [9, 10]. IBC Coatings Technologies (USA) has developed an MAO installation that allows performing various types of electrolyte-plasma treatment using a controlled source of rectangular high-voltage pulses of technological current [11, 12]. MILMAN THIN FILM SYSTEMS PVT. LTD. (India) has developed an automated Plasma electrolytic power supply installation, which is equipped with a remote touch control panel for the convenience of the operator [13]. The company "Mao Environmental Protection Technology Dg Co., Ltd" (China) produces MAO installations of three main types: fully inverter (4th generation); with the possibility of parallel connection (5th generation); based on a process current source with short pulses and low energy consumption (6th generation) [14].

The identified promising scientific and technical solutions were used in the development of an intelligent automated system structure for obtaining protective coatings of light alloys by the method of micro-arc oxidation, presented by the authors in this article.

2 The Structure of an Intelligent Micro-arc Oxidation System

The main functional parts of the proposed intelligent system for obtaining micro-arc coatings are hardware and software, as well as an information content subsystem (Fig. 1).

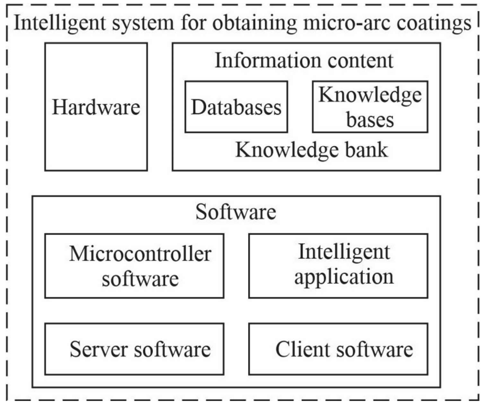

Fig. 1. The structure of an intelligent system for obtaining micro-arc coatings.

2.1 Hardware Part of an Intelligent System for Obtaining Micro-arc Coatings

The elements included in the hardware of the intelligent system (Fig. 2) are a galvanic cell, a process current source and a standby power source, measuring unit and control unit.

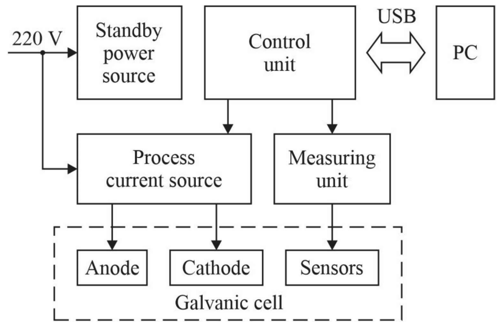

Fig. 2. Hardware part of the intelligent system.

The generation of a pulsed current for the formation of a micro-arc oxide layer on the sample is provided by a process current source. The process current source allows you to adjust a large number of electrical parameters of the output signal: amplitude, frequency, duration, polarity and pulse repetition mode, which makes it possible to effectively control the energy supply to the sample surface.

The standby power source is designed to power low-voltage circuits of measurement and control units, as well as other components of an automated system (for example, protection circuits). The standby power source is always on; it is used to control the switching on the process current source.

In the structure of the measuring unit, measuring channels, which are designed to measure both the control parameters of the technological process and the parameters of the oxide layers can be distinguished:

- Current strength, electrical voltage of the galvanic cell;
- The electrolyte parameters, which include its resistance, temperature and turbidity;
- Optical and acoustic parameters of micro-arc discharges;
- Coating impedance;
- Coating thickness (indirect determination by impedance).

The signals from the measuring channels are sent to the microprocessor control unit, which transmits them via the USB interface to the computer. Then, using the program, the measurement results are processed and used to construct the characteristic curves of the MAO process: the forming curve, dynamic current-voltage characteristics, etc. The output signals of the measuring channels also serve as an element of software feedback, through which the coating formation process is controlled.

The signals for controlling the nodes of the intelligent system are generated by the control unit, which provides a computer connection with the process current source and the measuring unit. The control unit includes a microcontroller, which, in turn, contains the following components: an analog-to-digital converter (ADC) for digitizing the analog output signals of the measurement module, a digital-to-analog converter (DAC) for controlling the process current source, a UART module (for communication with a computer), I/O ports for connecting external peripheral devices.

A galvanic cell is a bath with an electrolyte in which the anode (sample) and cathode are immersed. The bath is equipped with sensors of various physical quantities measured during the MAO treatment, as well as a protective fence. The galvanic cell is equipped with a cooling system on the Peltier element and a mixing system that circulates the electrolyte to maintain a constant temperature of the electrolyte and a continuous influx of ions to the sample surface.

2.2 Information Content Subsystem of the Intelligent System

The information content (Fig. 3) is a knowledge bank containing knowledge bases and databases. Conditionally, the knowledge bank contents can be divided into four subsystems. The MAO coatings subsystem contains information about the MAO coatings properties, as well as about the influencing factors of the MAO process. The subsystem of theoretical research concentrates knowledge about the physico-chemical laws applicable in the study and modeling of the MAO process, as well as about the currently existing mathematical expressions describing the relationship between the technological parameters of the MAO process, properties and quality parameters of coatings. The experimental studies subsystem includes information on methods and means of measuring the technological parameters of the MAO process and coating properties, their metrological characteristics, as well as on the technological modes used. The reference subsystem contains reference data on the MAO process mechanism and the MAO coatings application. All knowledge bases and databases available in the knowledge bank

7. Li, T., Yang, Q., Rong, S., Chen, L., He, B.: Distorted underwater image reconstruction for an autonomous underwater vehicle based on a self-attention generative adversarial network. Appl. Opt. **59**(32), 10049–10060 (2020)
8. Li, N., Thapa, S., Whyte, C., Reed, A. W., Jayasuriya, S., Ye, J.: Unsupervised non-rigid image distortion removal via grid deformation. In: Proceedings of the IEEE/CVF International Conference on Computer Vision (ICCV), pp. 2522–2532 (2021)
9. Sun, H., Du, H., Li, M., Sun, H., Zhang, X.: Underwater image matching with efficient refractive-geometry estimation for measurement in glass-flume experiments. Measurement **152**, 107391 (2020)
10. Dutta, A., Mondal, A., Dey, N., et al.: Vision tracking: a survey of the state-of-the-art. SN Comput. Sci. **1**(1), 57 (2020)
11. Yedjour, H.: Optical flow based on Lucas-Kanade method for motion estimation. Artif. Intell. Renew. Towards Energy Transit. **4**, 937–945 (2020)
12. Zhong, L., Meng, L., Hou, W., Huang, L.: An improved visual odometer based on Lucas-Kanade optical flow and ORB feature. IEEE Access **11**, 47179–47186 (2023)
13. Du, K., Bobkov, A.: An overview of object detection and tracking algorithms. Eng. Proc. **33**(1), 22 (2023)
14. Luo, W., Xing, J., Milan, A., Zhang, X., Liu, W., Kim, T.-K.: Multiple object tracking: a literature review. Artif. Intell. **293**, 103448 (2021)
15. Eelbode, T., et al.: Optimization for medical image segmentation: theory and practice when evaluating with dice score or jaccard index. IEEE Trans. Med. Imaging **39**(11), 3679–3690 (2020)
16. Nilsson, J., Akenine-Möller, T.: Understanding SSIM. arXiv preprint arXiv 2006.13846 (2020)
17. Starovoytov, V., Eldarova, E., Iskakov, K.: Comparative analysis of the SSIM index and the pearson coefficient as a criterion for image similarity. Eurasian J. Math. Comput. Appl. **8**(1), 76–90 (2020)

have the possibility of additions, which allows you to add new and refine existing mathematical models and technological modes of the MAO process, adjust measurement methods, thus improving the entire system operation.

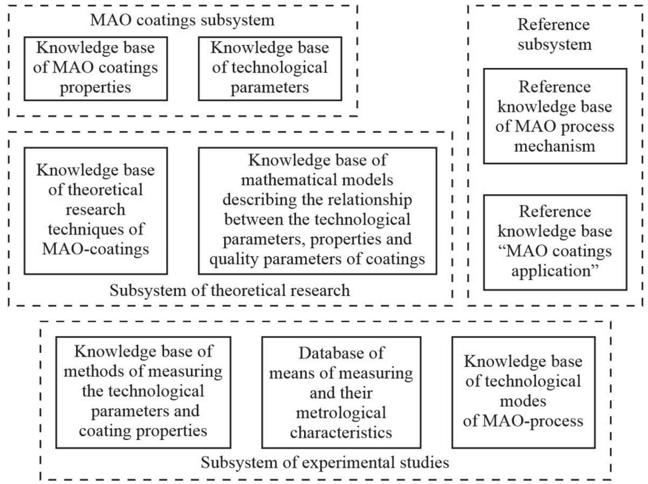

Fig. 3. Structure of the knowledge bank.

2.3 Software of the Intelligent Automated Micro-arc Oxidation System

The software includes microcontroller software and server software, an intelligent application that implements the methods of controlled synthesis of MAO coatings developed by the authors, and client software designed for user interaction. The microcontroller software is designed to control the process current source, process signals from measuring transducers and transfer the received information to a PC, as well as perform service functions (error messages, indication, etc.). The microcontroller software has been developed, which provides procedures for controlling the process current source; transmits signals for connecting measuring transducers and transmitting information from the output of measuring channels to a computer; performs service functions (for example, error reporting, indication, etc.). The server software is responsible for configuring the system and controlling the microcontroller. The intelligent application processes data from the output measuring transducers based on the proposed intelligent algorithms. In order to ensure the controlled synthesis of oxide coatings form control commands coming to the process current source, which varies the amplitude, duty cycle, frequency of current pulses intelligent algorithms and techniques are applied to the workpiece with a modifiable surface. The intelligent application structure is shown in Fig. 4.

Quantum Fourier Transform in Image Processing

D. T. Mukhamedieva[1](✉), R. A. Sobirov[1], N. M. Turgunova[1], and B. N. Samijonov[2]

[1] Tashkent Institute of Irrigation and Agricultural Mechanization Engineers National Research University, 39, Kari Niyaziy Street, Tashkent, Uzbekistan 100000
dilnoz134@rambler.ru

[2] Sejong University, 209, Neungdong-ro, Gwangjin-gu, Seoul, South Korea

Abstract. This paper presents an approach to apply quantum Fourier transform (QFT) to image processing using quantum computing. The use of quantum computing for image analysis and processing is becoming increasingly relevant in modern science and technology. A quantum QFT circuit is presented, implemented using the Qiskit framework, which is a tool for programming quantum computers. The paper presents the basic steps of QFT and their application to a state vector representing the pixel intensities of an image. The influence of quantum transformation on the image structure is studied and the results are presented in the form of graphs and visualizations. In addition, we have introduced QFT quantum circuit inference capabilities for a more visual representation of the algorithm. The results highlight the potential of quantum computing in the field of image processing and open new prospects for the use of quantum technologies in the field of computer vision.

Keywords: Quantum Computing · Image Processing · Qiskit · Qubits · Quantum Circuit Simulation · Image Conversion · Quantum Circuit · Visualization of Results · Fourier Transform

1 Introduction

With the development of quantum technologies, new opportunities appear for solving computational problems, including in the field of image processing. Traditional image processing methods often face limitations in speed and efficiency, especially when dealing with large volumes of data. In this context, the application of quantum computing for image processing represents a promising research direction. Quantum algorithms, such as the Quantum Fourier Transform (QFT), can provide more efficient data processing by using the principles of quantum mechanics. In this paper, we propose research on the application of QFT to images using quantum computing, which may lead to more efficient and faster image processing methods. This approach is relevant in light of the constant development of quantum technologies and their potential impact on the field of computer vision and image analysis [1].

A. Gibadullin (Ed.): ITIDMS 2023, CCIS 2112, pp. 143–151, 2024.
https://doi.org/10.1007/978-3-031-60318-1_12

With the development of quantum computing and the expansion of its scope, new opportunities in the field of data processing arise. One exciting area of research is the application of quantum methods to image processing. Traditional methods, although effective, often face limitations, especially when working with large amounts of information. Quantum computing represents a promising tool for creating new, more efficient methods of image processing. In particular, QFT has attracted the attention of researchers for its ability to efficiently process data in a quantum environment [2].

The purpose of this work is to review and analyze the application of QFT to images using quantum computing. We explore the key steps of quantum transformation in the context of image processing and consider the impact of this method on the structure of images. We also present a new aspect in the form of the output of QFT circuit for a clear demonstration of the algorithm [3].

This work aims to expand understanding of the capabilities of quantum computing in the field of image processing and contribute to the development of new data analysis methods using quantum technologies. The benefits of quantum computing, such as parallelism and superposition, promise to speed up the solution of certain problems, such as factoring large numbers or simulating complex molecular systems. This could have huge implications for fields ranging from cryptography to the development of new materials and drugs. However, for now, quantum computing is still in its infancy, and there are a number of technical and algorithmic hurdles that need to be overcome before it can become widely available. Despite this, the potential of quantum computing to revolutionize our ability to predict physical phenomena is exciting [4, 5].

2 Materials and Methods

The basic idea of quantum computing is to use quantum bits, or qubits, instead of classical bits. Unlike classical bits, which can be in either a 0 or 1 state, qubits can be in a superposition state, which means they can be both 0 and 1 at the same time. This property of superposition allows qubits to process information in parallel, which makes quantum calculations in some cases are much more efficient than classical ones. Additionally, qubits can be linked to each other in a phenomenon known as quantum entanglement, allowing them to jointly encode and process information. The use of qubits and their unique properties opens the door to the creation of new algorithms that can solve problems more efficiently than classical algorithms [6].

One of the main mysteries of quantum computing is its fragility and complexity. While quantum computers promise significant benefits in solving certain problems, they also face several technical and physical challenges. One such problem is decoherence, or the loss of quantum superposition due to environmental influences. This may occur due to unpredictable fluctuations in the surrounding electromagnetic field or thermal fluctuations. Controlling these effects is a complex task that requires the development of high-precision methods for isolating and stabilizing quantum systems. Another problem is errors in quantum computing due to non-ideal quantum elements and operations. For example, noise can occur in quantum gates, and interaction errors between qubits can occur in quantum circuits. Work is underway to improve error correction algorithms and develop more accurate quantum devices, but this still remains a challenge [7].

Thus, although quantum computing holds much promise, its successful implementation requires overcoming many technical and physical obstacles associated with its fragility and complexity. Converting quantum information into a format compatible with classical computers represents a significant obstacle to the practical use of quantum computing. This process, called dequantization, requires the development of specialized methods and algorithms to read and interpret the results of quantum calculations by classical devices. Despite the significant difficulties associated with dequantization, it is important to note that classical computers are also improving towards simulating quantum processes. New algorithmic strategies and optimizations allow classical computers to more efficiently simulate some aspects of quantum systems, which in certain cases can compete with the advantages provided by quantum computing [8].

This fact emphasizes the importance of further research and development of both quantum and classical computing methods. Both fields can complement each other, because some problems can be effectively solved using both quantum and classical approaches. Integrating classical and quantum methodologies represents a potentially powerful approach for improving computation and solving complex problems. This approach, known as hybrid computing, leverages the strengths of both classical and quantum computing to solve problems more efficiently than is possible with either method alone. For example, classical computers can be used to process and pre-train data, and then quantum computers can be used to perform complex quantum algorithms, analysis or optimization. The results can then be processed and interpreted using classical methods. This approach not only benefits from the benefits of both types of computation, but can also mitigate some of the limitations faced by both classical and quantum systems. As a result of integration, we can achieve higher efficiency and accuracy in solving complex problems, from cryptography to artificial intelligence optimization [9].

To conduct the study, a digital image of interest for analysis was selected. The image can be either monochrome or color to view the effect of quantum transformation on different types of data. The image is converted into a format suitable for processing, such as black and white. The image size can also be reduced to the nearest lesser power of two to facilitate the application of QFT [10, 11].

Each pixel in the image is converted to intensity and a state vector is generated. This vector is prepared for use in a quantum circuit. A quantum circuit is implemented to apply QFT to the image state vector. The Qiskit library for the Python programming language is used for this. Each element of the state vector represents the probability amplitude on the corresponding qubit [12].

The impact of QFT on image structure is studied. State vectors before and after transformation, as well as the resulting images, are analyzed. Visualization of results is used for a clearer understanding of the process. To visually represent the QFT algorithm in a quantum circuit, the Qiskit library is used. A quantum circuit is derived taking into account the application of QFT to the input data [13].

The experiment is carried out with various variants of images and QFT parameters to identify the features and influence of quantum transformation on the structure of the input data. To implement a quantum circuit, the program uses the Qiskit library, which

provides the ability to work with quantum circuits in the Python programming language. The quantum circuit includes the following steps [14]:

Quantum bits are created that will be used to represent the input image state vector. The number of qubits is equal to the nearest lesser power of two to the image size (for example, if the image size is 64 × 64, then 6 qubits are used) [15, 16].

The quantum circuit describing the QFT is represented by the following mathematical formula [17]:

For n quantum bits (qubits), the state of the input vector $|x\rangle$ is given as [18].

$$|x\rangle = \frac{1}{\sqrt{2^n}} \sum_{k=0}^{2^n-1} e^{\frac{2\pi i \cdot kx}{2^n}} |k\rangle \tag{1}$$

where $|k\rangle$ is the binary representation of the number k.

The QFT is applied to this state and its transformation matrix QFT_n is defined as follows [19]:

$$QFT_n = \frac{1}{\sqrt{2^n}} 1 \begin{bmatrix} 1 & 1 & 1 & \cdots & 1 \\ 1 & e^{\frac{2\pi i}{2^n}} & e^{\frac{2\pi i \cdot 2}{2^n}} & \cdots & e^{\frac{2\pi i \cdot (2^n-1)}{2^n}} \\ 1 & e^{\frac{2\pi i \cdot 2}{2^n}} & e^{\frac{2\pi i \cdot 4}{2^n}} & \cdots & e^{\frac{2\pi i \cdot 2(2^n-1)}{2^n}} \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ 1 & e^{\frac{2\pi i \cdot (2^n-1)}{2^n}} & e^{\frac{2\pi i \cdot 2(2^n-1)}{2^n}} & \cdots & e^{\frac{2\pi i \cdot (2^n-1)^2}{2^n}} \end{bmatrix} \tag{2}$$

where each element of the matrix $QFT_n\big[j, k\big]$ is calculated by the formula:

$$QFT_n[j, k] = \frac{1}{\sqrt{2^n}} e^{\frac{2\pi i \cdot jk}{2^n}} \tag{3}$$

where j and k take values from 0 to $2^n - 1$.

3 Results

Fourier transform of images is widely used in digital image and video processing due to its efficiency and power in signal analysis and processing. The Fourier transform of an image transforms an image from the spatial domain to the frequency domain. This means that it converts the image from a pixel representation to a frequency representation. Specifically, the Fourier transform of an image allows the image to be decomposed into a set of sine (or cosine) functions of different frequencies. These frequencies represent different details and structures in an image.

Fig. 1. Quantum Fourier transform circuit

The circuit uses quantum gates such as Hadamard gates (H), controlled phase gates R_ϕ, and controlled phase gates (C).

The initial state of the quantum system is initialized with an image, and then a quantum transformation is performed. The qubits are then measured to obtain classical information. The results of quantum transformation are visualized using graphs, allowing you to see how the state vector and image change after the transformation. Such a quantum circuit can be used to study quantum transformations in images and in the context of quantum data processing algorithms.

This program performs a quantum Fourier transform (QFT) on an image represented as a vector of pixel intensities. Let's look at the results of each stage of the program:

The original grayscale image is displayed.

The pre-QFT state vector shows the pixel intensity values represented as the state vector before the quantum transformation is applied.

State Vector after QFT Displays the state vector after applying the quantum transformation. This vector shows how the state amplitudes changed after applying QFT.

The transformed image after QFT is a rendering of the transformed image after quantum transformation. The image is formed based on the amplitudes of the states of the quantum bit.

Constructing an amplitude histogram for visual analysis of the distribution of amplitudes of states after quantum transformation.

It is important to note that the results of the program may depend on the choice of the number of quantum bits and the image itself. Also, the Fourier transform can highlight certain patterns in an image.

After the Fourier transform is performed, the image is represented in a two-dimensional frequency space, with low frequencies at the center and high frequencies at the periphery. Thus, a frequency domain image allows you to analyze the frequency components it contains, which can be useful for tasks such as noise filtering, sharpening, edge detection, etc. Visualizing the Fourier transform of an image allows you to see the contribution of different frequencies to the image, which can help in understanding its structure and characteristics.

This code creates a quantum circuit that applies a quantum Fourier transform to an image. All the pixels in the image are represented as quantum bits and the Fourier transform is then applied.

The program begins by loading a grayscale image from a file. We use the OpenCV (cv2) library for this purpose.

The original image is plotted in the first plot using Matplotlib. This allows us to visualize what the image looks like before applying the Fourier transform.

Determining the number of bits that are needed to represent each pixel in an image in binary form. This is necessary to determine the size of the quantum circuit.

Creating a quantum circuit for Fourier transform using the Qiskit library. In this circuit, we apply QFT. To do this, control rotations (cr) and Hadamar rotations (H) are used.

Drawing a quantum circuit using the circuit_drawer function from the Qiskit library. We use the *output = 'mpl'* parameter to get color graphical output.

Simulation of a quantum circuit. We use the Qiskit simulator to execute the quantum circuit. In this case, we use the state vector simulator, which builds the exact state of the quantum system.

Visualization of the results: We obtain the simulation results in the form of the number of dimensions for each possible state of the quantum bits. We then use the plot histogram function from the Qiskit library to plot a histogram of these results.

Thus, the program loads an image, applies a quantum Fourier transform to it using a quantum circuit, simulates the results and visualizes both the circuit itself and the results, and also displays the image before and after the Fourier transform (Fig. 1 and 2).

The QFT program has been developed for an image represented as a vector of pixel intensities. The quantum circuit presented in this program performs the Fourier transform on quantum qubits. The Fourier transform is a mathematical transformation that has applications in various fields, including classical and quantum information science. A quantum circuit uses quantum bits, which are the quantum analogues of classical bits. Qubits can be in a linear combination of states $|0\rangle|0\rangle$ and $|1\rangle|1\rangle$ due to the phenomenon of quantum interference [19, 20].

The Fourier transform in this context is performed on quantum bits. This transform is the quantum analogue of the classical Fourier transform, which is applied to a sequence of values.

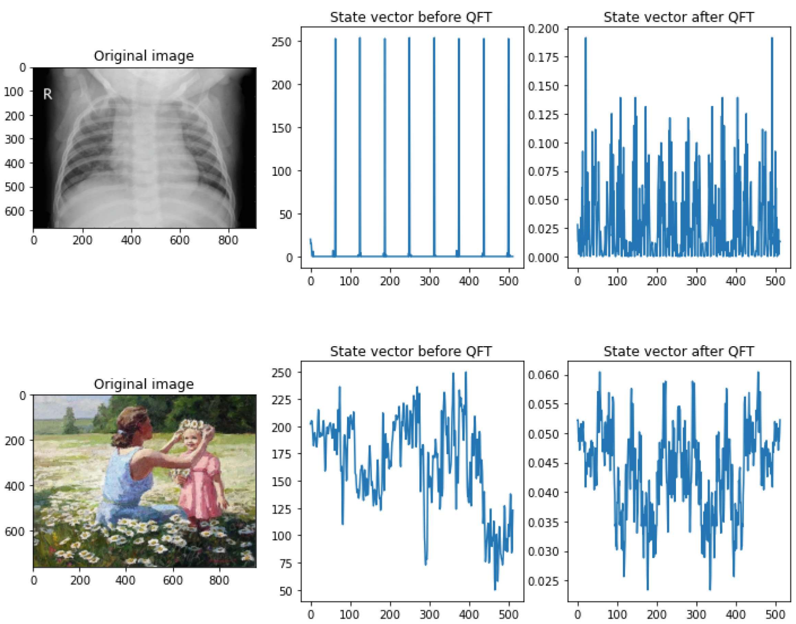

Fig. 2. (*continued*)

4 Conclusion

In this work, the application of QFT in the context of image processing was analyzed. Experimental results show that quantum transformation can affect the structure of images, leading to changes in pixel amplitudes. The efficiency of quantum conversion was assessed using images using different numbers of quantum bits. Increasing the number of bits resulted in higher transformation granularity, but required more computational resources. The amplitude histogram after QFT can serve as an indicator of important image characteristics. However, it must be taken into account that the results can greatly depend on the image itself and the parameters of the quantum circuit. It also highlighted areas of application where quantum image processing techniques could be most useful, such as highlighting singular points and patterns. However, it should be noted that quantum image processing methods have their limitations, and the performance of such approaches can be improved with further research and optimization.

These results highlight the promise of using quantum approaches in image processing, providing new opportunities for analyzing and modifying visual data. Further research in this area will help optimize the parameters of quantum circuits and expand the scope of their application in practical image processing problems.

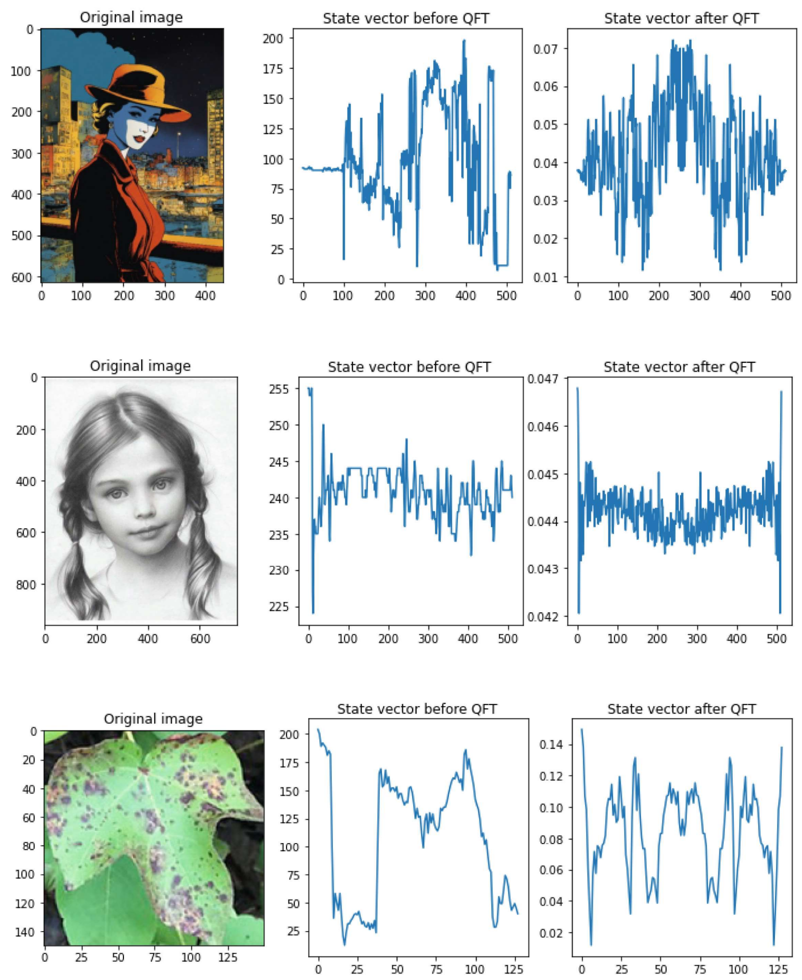

Fig. 2. Quantum Fourier transform.

References

1. Yao, X., et al.: Quantum image processing and its application to edge detection: theory and experiment. Phys. Rev. X **7**, 031041 (2017). https://doi.org/10.1103/physrevx.7.031041
2. Sysoev, S.: Introduction to Quantum Computing. In: Quantum Algorithms: Textbook. Allowance, St. Petersburg, pp. 140–144 (2019)
3. Park, J.E., Quanz, B., Wood, S., Higgins, H., Harishankar, R.: Practical application improvement to Quantum SVM: theory to practice. Cornell University (2020)
4. Rieffel, E., Polak, W.: Quantum computing: a gentle introduction. Choice Rev. Online **49**, 49–0911 (2011). https://doi.org/10.5860/choice.49-0911
5. Kopczyk, D.: Quantum machine learning for data scientists. Cornell University (2018)
6. Weber, J.R., et al.: Quantum computing with defects. Proc. Natl. Acad. Sci. U.S.A. **107**, 8513–8518 (2010). https://doi.org/10.1073/pnas.1003052107
7. Cong, I., Choi, S., Lukin, M.D.: Quantum convolutional neural networks. Nat. Phys. **15**, 1273–1278 (2019). https://doi.org/10.1038/s41567-019-0648-8
8. Kaye, P., Laflamme, R., Mosca, M.: An introduction to quantum computing (2006). https://doi.org/10.1093/oso/9780198570004.001.0001
9. Oh, S., Choi, J.W., Kim, J.: A tutorial on quantum convolutional neural networks (QCNN). In 2020 International Conference on Information and Communication Technology Convergence (ICTC), pp. 236–239 (2020). https://doi.org/10.1109/ictc49870.2020.9289439
10. Fitzsimons, J.F.: Private quantum computation: an introduction to blind quantum computing and related protocols. Npj Quant. Inf. **3**, 23 (2017). https://doi.org/10.1038/s41534-017-0025-3
11. Deng, L.: The MNIST database of handwritten digit images for machine learning research [best of the web]. IEEE Signal Process. Mag. **29**, 141–142 (2012). https://doi.org/10.1109/msp.2012.2211477
12. Harper, R., Flammia, S.T.: Fault-Tolerant logical gates in the IBM quantum experience. Phys. Rev. Lett. **122**, 080504 (2019). https://doi.org/10.1103/physrevlett.122.080504
13. Steffen, M., DiVincenzo, D.P., Chow, J.M., Theis, T., Ketchen, M.B.: Quantum computing: an IBM perspective. IBM J. Res. Dev. **55**, 13:1-13:11 (2011). https://doi.org/10.1147/jrd.2011.2165678
14. Han, X., Rasul, K., Vollgraf, R.: Fashion-MNIST: a novel image dataset for benchmarking machine learning algorithms. Cornell University (2017)
15. Muhamediyeva, D.: Fuzzy logical model for assessing soil salinity. IOP Conf. Ser. Earth Environ. Sci. **1206**, 012019 (2023). https://doi.org/10.1088/1755-1315/1206/1/012019
16. Recht, B., Roelofs, R., Schmidt, L., Shankar, V.: Do CIFAR-10 classifiers generalize to CIFAR-10? Cornell University (2018)
17. Muhamediyeva, D.: Application of artificial intelligence technologies to assess water salinity. IOP Conf. Ser. Earth Environ. Sci. **1206**, 012020 (2023). https://doi.org/10.1088/1755-1315/1206/1/012020
18. He, K., Zhang, X., Ren, S., Sun, J.: Deep residual learning for image recognition. 2016 IEEE Conference on Computer Vision and Pattern Recognition (CVPR), pp. 770–778 (2016). https://doi.org/10.1109/cvpr.2016.90
19. Muhamediyeva, D.T., Niyozmatova, N.A.: Monitoring of biodiversity of water communities. In: E3S Web of Conferences, vol. 411, p. 02042 (2023)
20. Howard, J., Gugger, S.: FastAi: a layered API for deep learning. Information **11**, 108 (2020). https://doi.org/10.3390/info11020108