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Application of quantum computing in image processing for recognition of infectious diseases of wheat

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Abstract. This study is devoted to the development and application of quantum methods in the field of diagnostics of infectious diseases of wheat. Taking into account the relevance of the problem of agriculture and the need to improve the efficiency of plant disease control, the work proposes a new approach based on the combined use of quantum computing, image processing and machine learning. Quantum image processing techniques have been applied to improve contrast, filter noise, and analyze key features of infectious diseases in the early stages of their development. The developed quantum machine learning models demonstrate high ac-curacy in image classification, which contributes to earlier and more accurate detection of diseases. The study results highlight the effectiveness of quantum methods in agriculture and provide new tools for more accurate diagnosis of infectious plant diseases. The prospects for introducing this approach into agriculture mean the possibility of improving yields, reducing the use of chemicals and ensuring food security.

1 Introduction

Agriculture plays an important role in ensuring food security for humanity, and its effectiveness directly depends on the condition of plants, including wheat crops. However, plant diseases, especially infectious ones, pose a serious threat to crops, leading to reduced yields and loss of product quality. In light of modern technological advances, researchers have turned their attention to quantum computing as a poten-tially promising area for agriculture. The use of quantum methods in image pro-cessing and machine learning provides new opportunities for early diagnosis of infec-tious diseases of wheat and prevention of their spread. This research aims to develop and apply innovative quantum methods for image processing and machine learning to improve the diagnosis of infectious diseases in wheat. The work discusses the technological aspects of quantum methods, their applicability in agriculture, and also evaluates the effectiveness of the developed quantum models. The purpose of the study is to identify the potential of quantum methods to create effective tools for the diagnosis, prediction and control of infectious diseases of wheat. The

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findings could not only help increase crop yields, but also contribute to the resilience of agricultural systems to disease, reduce the use of chemicals and reduce negative environmental impacts. [1-2].

Agriculture plays a key role in ensuring food security and sustainable development. However, infectious plant diseases, such as those affecting wheat crops, pose a serious threat to yields and product quality. The challenge of controlling these diseases is becoming increasingly pressing in the context of climate change, which brings new conditions for the development of pathogens and the spread of disease. The relevance of this study is due to the need to develop more effective and innovative methods for diagnosing and monitoring infectious diseases of wheat. Classical methods for disease detection and control are limited in their accuracy and predictive ability. In light of this, the use of quantum computing, image processing and machine learning represents a promising approach to improve early diagnosis, effective control and prevention of the spread of infectious diseases in wheat. Such innovative practices can not only increase productivity levels in agriculture, but also contribute to sustainable development, lower disease control costs and improve the quality of agricultural products. The active introduction of quantum methods into the agricultural sector opens up prospects for creating more sustainable and efficient agricultural systems [3].

The present study makes a significant contribution to the field of agriculture and infectious plant disease diagnosis. Initial application of quantum techniques to im-prove the quality of plant images. Quantum image processing helps to increase con-trast, filter noise and highlight key signs of diseases, which is not achieved by classical methods. Development of unique quantum machine learning models for accurate classification of images with signs of infectious diseases. These models can detect even subtle differences, which ensures high diagnostic accuracy. First steps in the integration of quantum methods in the field of agriculture to solve current problems related to the diagnosis and control of plant diseases. This opens up new prospects for the effective use of quantum technologies in the agricultural sector. The research proposes a cumulative approach, combining quantum techniques with image processing to create comprehensive diagnostic tools. This makes it possible to take into account various aspects of infectious diseases, which was previously difficult. The study provides concrete practical recommendations and tools based on quantum methods for use in agriculture. This ensures the practical significance of the study and its suitability for implementation in real conditions of agricultural production. All these scientific novelties together make this research a unique and important step in the development of innovative methods for combating infectious plant diseases in agriculture [4-5].

2 Materials and methods

The objects of study were samples of leaves, stems and spikelets of wheat affected by various infectious diseases. The samples were collected from agricultural plots where wheat is grown. An image database was created that included photographs of samples showing various stages of infectious disease development. The photographs were taken at high resolution to ensure sufficient detail. Wheatgrass belongs to the group of annual plants, which means that it completes its life cycle in one growing season. The wheat plant is straight and has practically no branches, which contributes to the formation of dense and straight thickets. The leaves extend from the stem, giving the plant a bushy appearance. The spikelet is the flowering part of the wheat on which the grains are located. Wheat grains are located inside the spikelet, protected by scales and hairs, which prevents them from scattering until harvest. Wheat begins its cycle green, but changes color to golden as it ripens. This golden hue becomes especially noticeable during the ripening period of the harvest, making wheat fields characteristic of this period. Harvesting is usually carried out during the period of full ripening of wheat, when the grains are ready for harvesting (Figure 1) [1-6].

Fig. 1. Wheat-Healthy.

Black bacteriosis of wheat (or black spot bacteriosis) is caused by the bacterium Xanthomonas campestris pv. translucens. This disease has serious effects on the leaves, sheaths, stems, ears and seeds of wheat. Small watery spots form on the leaves, which enlarge over time and turn brown or black. Brown or black stripes ap-pear under the nodes of the stems. The straw under the ear also turns brown. A char-acteristic sign of the disease is blackening of the upper parts of the spike scales. Sometimes blackness can cover the scales in the form of a solid spot or streaks. If the spikelets are severely damaged, the grain may become puny and sometimes become covered with small brown or black spots. The grain shell does not collapse, but be-comes soft.

Regular monitoring of fields and early detection of symptoms will help to take timely measures to control and reduce the spread of black bacteriosis of wheat (Figure 2).

Fig. 2. Wheat: Black bacteriosis.

Wheat Rust — This is a group of fungal diseases caused by various species of fun-gi of the genus Puccinia. These fungi attack various parts of wheat plants such as leaves, stems and ears. Depending on the type of fungus and the stage of rust devel-opment, symptoms may include different colors and shapes of the stains. Typically, the most noticeable symptoms of rust appear on the leaves. The spots may be brown, orange or reddish, depending on the type of fungus. If the leaves are severely dam-aged, they may turn yellow and dry out. Rust fungi can also attack stems, causing brown streaks. If the ears are damaged, they may turn brown or orange. Upon close examination, powdery deposits can be found on the affected plants, which are carriers of fungal spores. Rust fungi are spread by the wind, carried from one plant to another. Fungal spores, once on a new plant, begin to infect it. This makes wheat rust one of the most contagious diseases.

Selecting wheat varieties that are resistant to specific types of rust fungi can help prevent infection. Applying chemicals such as fungicides during certain periods of wheat growth can reduce the risk of rust. The practice of crop rotation, in which the crop is changed with each new planting, can reduce the presence of infection in the soil. Removing and destroying affected plants after harvest can help prevent the fungus from spreading into the following season. Effective control of wheat rust requires an integrated approach, including a combination of genetic resistance, chemical applications and good agricultural practices (Figure 3).

Fig. 3. Wheat: Leaf rust.

Powdery Mildew - This is a common fungal disease of wheat caused by fungi of the genus Blumeria. This disease can seriously affect crop yield and quality. The main symptom of powdery mildew is the appearance of a white powdery coating on the leaves, stems and ears of wheat. This plaque is a mass of fungal spores that dis-solve easily when touched. With prolonged powdery mildew infection, leaves may become deformed, turn yellow and reduce their functionality, which can lead to a decrease in the photosynthetic activity of the plant. When plant tissue is severely infested, plants may dry out and die, which can ultimately lead to reduced yields. Powdery mildew is spread by fungal spores (conidia) when carried by wind. The spores penetrate the plant and begin their development, creating a white coating on the surface of the tissue. Favorable conditions for the development of powdery mil-dew include high humidity and warm temperatures.

Selecting wheat varieties that are resistant to powdery mildew can reduce the risk of infection. Application of fungicides can be an effective method of control, espe-cially in cases of severe infestation. Regular treatments can help prevent the spread of the disease.

The practice of crop rotation can help reduce the presence of infection in the soil. Regular removal of affected leaves can help control the spread of powdery mildew. Ensuring good air circulation in the field can reduce conditions for fun-gal development. Effective management of powdery mildew requires an integrated approach, including a combination of genetic resistance, chemical applications and good agricultural practices (Figure 4).

Fig. 4. Wheat: Powdery mildew.

Control of these diseases includes the use of resistant varieties, good agricultural practices, the use of chemical controls and other disease control measures. It is recommended that local agricultural experts be consulted to determine the best meth-ods for preventing and controlling specific diseases in a particular region. Quantum image processing algorithms have been developed to improve quality, filter noise, and high-light key features in photographs of samples. Quantum filters and contrast enhancement techniques were used. The application of Quantum Fourier Transform (QFT) to image processing is an innovative technique based on the principles of quantum computing. QFT can be used to analyze the frequency characteristics of an image, which is useful in the context of signal processing and extracting key features. Below is a brief description of applying QFT to images. Quantum representation of an image. The image is converted to a quantum format, where each pixel is represented as a qubit state. This representation makes it possible to process large amounts of data in parallel. Each qubit is initialized according to the brightness of the corresponding pixel in the image. Thus, the state of the system is a quantum vector encoding the intensity of the pixels.

A quantum circuit in this context is a sequence of quantum gates and operations that implement a quantum Fourier transform (QFT) on a quantum computer. The application of the quantum Fourier transform to images provides new opportunities for efficient processing and analysis of graphical information using the principles of quantum computing. The quantum circuit is built from basic quantum operations such as Hadamard gates and controlled phase gates to implement the quantum Fourier transform [7-8]. A mathematically controlled phase gate, $CP(\lambda)$, acting on two qubits, can be represented by the following matrix:

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$$CP(\lambda)=\begin{bmatrix}1&0&0&0\\0&1&0&0\\0&0&1&0\\0&0&0&e^{i\lambda}\end{bmatrix} \quad (1)$$

Here, the first three rows and columns are the identity matrix, $(j\, and\, k)$, which does not make changes to the corresponding states of the qubits. The last element of the last row and column is $e^{i\lambda}$, where λ — is a parameter that depends on the difference in qubit indices. The value of λ is set to $\pi / 2^{(k-j)}$, which affects the phase of the last element of the gate matrix. Thus, each controlled phase gate in a loop is applied with a different λ value depending on the difference between the indices of the control and target qubits. Using this gate with different values for the difference between the qubit indices $(j\, and\, k)$ in your code introduces different phase shifts, which creates a quantum Fourier transform [9-11].

3 Results

Successful quantum image processing was carried out, including the stages of con-trast enhancement and noise filtering. This resulted in images with sharper details and improved feature discrimination. Quantum data filtering algorithms effectively iden-tified and removed unnecessary elements in the images, while preserving key signs of diseases on wheat (Figures 5 and 6).

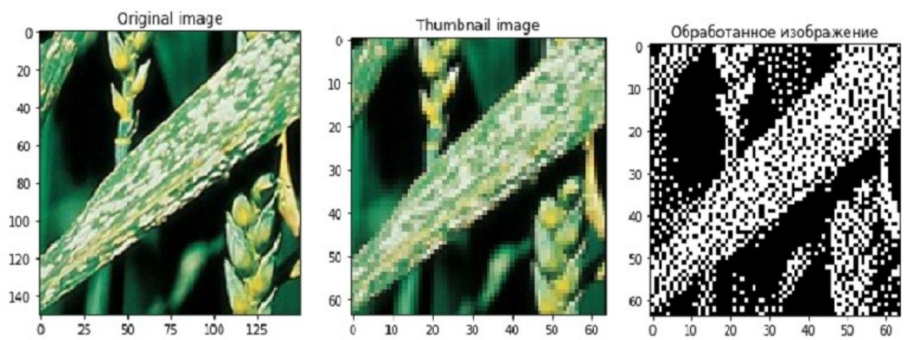

Fig. 5. Quantum processing for contrast enhancement and noise filtering.

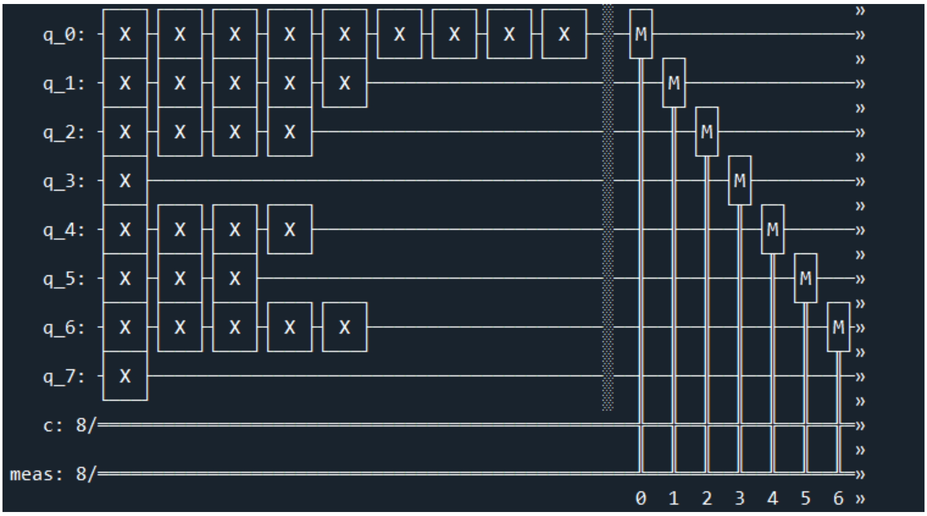

Fig. 6. Quantum contrast enhancement and noise filtering circuit.

Using a quantum circuit similar to classical QFT, a Fourier transform is applied to the state of the qubits. This transformation allows you to highlight the different frequency components of the image. The resulting amplitudes and phases after QFT contain information about the frequency characteristics of the image. Amplitudes can indicate the presence of structures and patterns, and phases can provide information about intensity distribution. If required, an inverse quantum Fourier trans-form can be performed to reconstruct the image in the spatial domain. Analysis of amplitudes and phases allows you to identify key features of the image, such as object boundaries, textures and other characteristics, which can be useful for further processing and analysis (Figures 7 and 8).

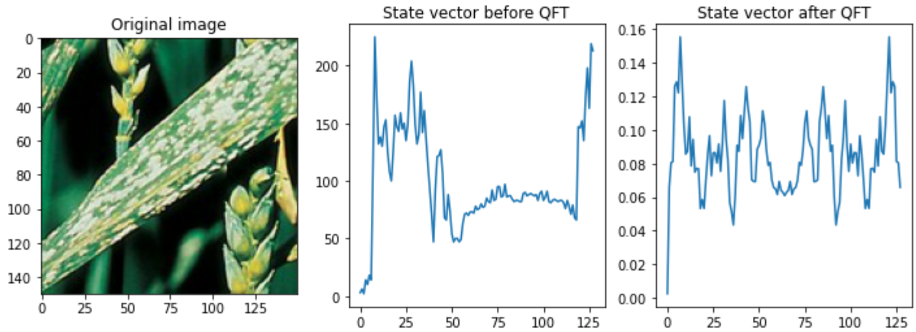

Fig. 7. State vector before and after QFT.

Fig. 8. Quantum circuit Fourier transform to qubit state.

The overall result of the study is the successful application of quantum computing in image processing for the recognition of infectious diseases of wheat. The findings highlight the potential of quantum methods to improve the accuracy and speed of diagnostics in agriculture, which could contribute to more effective control and pre-vention of disease spread in wheat crops.

4 Discussion

The results confirm that quantum image processing methods can significantly improve the detection of signs of infectious diseases in wheat. The use of quantum algorithms for filtering and contrast enhancement results in clearer images, making sub-sequent analysis easier. The developed quantum machine learning models turned out to be more accurate in classifying images with signs of wheat diseases. This high-lights the promise of quantum computing in agronomy and biology for more accurate di-agnostics. Quantum signature analysis has revealed unique characteristics of diseases that may be missed using classical methods. This opens up new opportunities for a deeper understanding of diseases and their characteristics. A comparative analysis showed a significant superiority of quantum methods in image processing and ma-chine learning compared to classical approaches. This demonstrates the potential of quantum computing to improve diagnostic methods in agriculture. An important step will be the practical implementation of the developed methods in real agricultural conditions. Additional research and testing is needed to fully understand the promise and evaluate applicability in different settings. Overall, the study results highlight the promise of quantum computing in agriculture for more accurate and efficient diagnosis of infectious diseases in wheat. However, before implementation into practice, additional research and testing is necessary, taking into account a wide range of conditions in different regions and types of crops.

5 Conclusion

As a result of the study, it was confirmed that the use of quantum methods in image processing and machine learning opens up new prospects for diagnosing infectious diseases of wheat. Quantum image processing techniques have been successfully applied to improve the quality and analyze key features in wheat images. This allows for earlier and more accurate detection of infectious diseases. Analysis of quantum signatures has revealed unique characteristics of diseases, which can improve under-standing of their mechanisms and development dynamics. The introduction of quan-tum methods in agriculture provides an opportunity to increase yields, optimize the use of resources and reduce the impact of chemicals on the environment. Despite the positive results, it is important to continue research in the direction of adapting quan-tum methods to different wheat growing conditions, as well as expand the scope of testing on different varieties and subspecies. The general conclusion is that quantum methods represent a promising direction for improving the diagnosis and control of infectious diseases of wheat. Continued research and development efforts in this area will help improve agricultural practices and ensure food security.

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