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Article

Development of an Electronic Program for Digital Analysis of Plant Diseases and Pests and Its Practical Application

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Abstract: This article addresses the creation of an electronic software product that makes it possible to detect and analyze diseases and pests occurring in agricultural crops on the basis of modern digital technologies and to determine measures for controlling them. The possibilities of using digital images, artificial intelligence, and computer vision algorithms to identify pathological symptoms manifested on the leaves, stems, fruits, and other organs of plants are analyzed. The functional structure of the proposed software system, the formation of its database, the classification of diseases and pests, the storage of diagnostic results, and the mechanisms for providing practical recommendations to the user have been substantiated for development. The practical application of this technology serves to increase the effectiveness of rapid diagnostics, monitoring, and decision-making in the plant protection system.

Keywords: digital technology, artificial intelligence, plant diseases, pests, electronic program, computer vision, digital diagnostics, image processing, phytopathology, integrated protection.

Introduction

At present, one of the main factors adversely affecting crop yield and product quality in agricultural production is the diseases and pests occurring in plants [1], [2]. Various phytopathogenic microorganisms, fungi, bacteria, viruses, and harmful insects directly affect the development, physiological state, and yield formation of crops during the growing season.

Under traditional conditions, the detection of diseases and pests is carried out mainly through visual observations by specialists, laboratory analyses, and field monitoring. However, conducting regular observation over large areas requires a great deal of time and labor [3]. In some cases, delays in detecting the initial symptoms of diseases cause protective measures not to be carried out in a timely manner.

The development of digital agriculture, artificial intelligence, and computer vision technologies is creating new opportunities for the automated assessment of plant condition [4]. In particular, by

processing digital images of plant organs, it is possible to detect disease symptoms, delineate affected areas, and classify them into the appropriate categories [5], [6].

In the systematic review by Pacal I. and co-authors , the capabilities of deep learning algorithms in classifying and detecting plant diseases and in segmenting affected areas were analyzed [7]. Such approaches serve as a scientific basis for developing digital diagnostic systems in the field of plant protection.

From this perspective, creating an electronic program for the digital analysis of plant diseases and pests and applying it in agricultural practice is a topical scientific and practical task.

The aim of the research – to develop the scientific and methodological foundations of an electronic software system that makes it possible to detect, analyze, and classify diseases and pests occurring in agricultural crops on the basis of digital images and to develop recommendations for controlling them.

The main objectives of the research:

- to form a digital database of plant diseases and pests;
- to collect and classify images of diseased and healthy plant organs;
- to select algorithms for image processing and analysis;
- to develop a model for detecting diseases and pests based on artificial intelligence;
- to form the interface and functional modules of the electronic program;
- to provide practical protection recommendations based on diagnostic results;
- to test the software product under field conditions and evaluate its effectiveness.

Materials and Methods

Diseases and pests occurring in agricultural crops and their external symptoms manifested on plant organs are selected as the object of the research.

The subject of the research consists of algorithms for detecting, classifying, and analyzing plant diseases and pests on the basis of digital images, as well as the functional capabilities of the electronic software.

The following methods are envisaged for use in the research process:

1. **Visual observation method.** Identification of disease and pest symptoms observed on the leaves, stems, roots, flowers, and fruits of plants under field conditions.
2. **Digital imaging method.** Capturing images of infected and healthy plant organs using a mobile phone or a digital camera.
3. **Image processing method.** Bringing the obtained images to a uniform format and size and normalizing light, contrast, and color indicators.
4. **Machine learning method.** Building a model for the automatic classification of diseases and pests on the basis of the collected data.
5. **Deep learning method.** Identifying important features in images using convolutional neural networks (CNN) and other computer vision algorithms.
6. **Statistical analysis method.** Evaluating the accuracy, sensitivity, completeness, and overall effectiveness of the software model.

In developing the software model, it is recommended to divide the data into training, validation, and independent testing groups.

Results and Discussion

Conceptual model of a system for the digital detection of plant diseases and pests

The proposed electronic program is intended to detect plant diseases and pests from images, store diagnostic results in a database, and provide appropriate recommendations to the user [8].

The operation of the software product is organized in the following sequence:

Stage 1. Data collection. Photographs of healthy and affected plant organs are taken from crop fields. The crop type, plant organ, name of the disease or pest, observation date, and location data are attached to each image.

Stage 2. Digital image processing. The obtained photographs are uploaded to the software. Image quality is checked, the size is standardized, and the images are prepared for analysis.

Stage 3. Analysis using artificial intelligence. The prepared images are fed into a pre-trained neural network model. By analyzing the visual features in the image, the model identifies the probable type of disease or pest.

Stage 4. Classification of results. The program assigns the detected object to the appropriate category: healthy plant, plant affected by a disease, or plant affected by a pest.

Stage 5. Formation of recommendations. Information on preventive and protective measures is provided to the user according to the identified condition.

Stage 6. Storing results. Diagnostic data are stored in an electronic database and used for subsequent monitoring and analysis.

Table 1. Main functional modules of the electronic software product

№	Software module	Main function
1	User module	Registration and logging in to the system
2	Crop database	Storing crop species and their biological characteristics
3	Image upload	Entering plant photographs into the system
4	Digital diagnostics	Detecting diseases and pests
5	Analysis module	Assessing symptoms and degree of damage
6	Recommendations module	Providing protection and prevention measures
7	Monitoring module	Storing observation results by time and region
8	Reporting module	Producing diagnostic results in the form of an electronic report

These modules are to be integrated into a single electronic system, and a convenient and understandable interface is envisaged for the user.

Algorithm for detecting diseases and pests based on digital images

Image processing and deep learning algorithms are of great importance in the automatic detection of plant diseases. In this process, spots on the leaf surface, color change, necrosis, wilting, deformation, perforation, and other morphological changes are taken into account as disease symptoms [9].

The following algorithmic sequence is proposed for creating the software model:

- receiving the image;
- checking image quality;
- preliminary image processing;
- extracting important visual features;
- classification using a neural network;
- calculating the confidence level of the result;
- forming the diagnostic conclusion.

The CNN architecture can be used for disease classification models of the YOLO family for object detection and segmentation algorithms for delineating affected areas [10].

The study by Murphy and co-authors demonstrated the capabilities and limitations of deep learning technologies in image-based assessment of plant phenotype [11].

Table 2. Main symptoms that can be detected in a digital diagnostic system

Plant organ	Observed symptom	Probable problem
Leaf	Yellow spots	Chlorosis or a symptom of disease
Leaf	Brown and black spots	Fungal or bacterial disease
Leaf	Whitish, floury coating	Possibility of powdery mildew disease
Leaf	Perforation and gnawing	Insect damage
Stem	Darkening and rotting	Stem diseases
Fruit	Rotten and softened parts	Fruit rot diseases
Leaf and stem	Deformation	Viral disease or effect of pests

It should be noted that the symptoms presented in the table serve for preliminary visual diagnostics. The same external symptom may also arise as a result of different diseases, nutrient deficiency, or abiotic stresses [12]. Therefore, the output of the program should be regarded not as a final laboratory diagnosis but as a preliminary conclusion supporting specialist examination.

Evaluation of the diagnostic effectiveness of the software product

In evaluating the effectiveness of the electronic program to be created, it is recommended to determine the accuracy and reliability of classification results on the basis of mathematical-statistical indicators [13].

Overall accuracy is calculated by the following formula:

$$\text{Accuracy} = (TP + TN) / (TP + TN + FP + FN) \times 100$$

Where:

TP – correctly identified positive cases;

TN – correctly identified negative cases;

FP – false positive results;

FN – false negative results.

Model precision (Precision):

$$\text{Precision} = TP / (TP + FP)$$

Model sensitivity (Recall):

$$\text{Recall} = TP / (TP + FN)$$

Generalized F1 indicator:

$$F1 = 2 \times (\text{Precision} \times \text{Recall}) / (\text{Precision} + \text{Recall})$$

With the help of these indicators, it is possible to assess how reliably the program performs in detecting diseases and pests. In this regard, it is important to analyze the results separately for all disease classes and, especially, to determine the sensitivity of the model with respect to rarely occurring diseases and pests.

Possibilities for practical application of the electronic program

The introduction of the proposed software product into agricultural production can be carried out in several directions.

First, an opportunity is created in farms to upload photographs of plants to the program via a mobile phone and to obtain preliminary diagnostic results.

Second, a system for monitoring the spread of diseases and pests is formed for agronomists and plant protection specialists.

Third, an electronic database is created on the occurrence of diseases and pests by region. This, in turn, makes it possible to observe changes in the phytosanitary situation in a particular region.

Fourth, on the basis of diagnostic results, recommendations are developed for organizing an integrated protection system and for selecting biological, agrotechnical, and, where necessary, chemical control measures.

In this regard, recommendations on the use of chemical agents should be given under specialist supervision, taking into account the crop type, the identified type of pest or disease, the economic threshold, whether the preparation is currently included in the state register, the application rate, and safety requirements.

Stages of development and implementation of the software product

It is advisable to organize the development of the electronic software product in the following stages:

Stage 1. Formation of a scientific database. Images are collected on the main diseases and pests occurring in cotton, grain, vegetable, melon, and fruit crops.

Stage 2. Image labeling. Each image is checked by a specialist and assigned to the corresponding disease or pest class.

Stage 3. Training the artificial intelligence model. Using the collected data, the selected neural network model is trained and optimized [14].

Stage 4. Creating the electronic program. A mobile or web platform is developed, integrating the functions of image upload, diagnostics, data storage, and output of results.

Stage 5. Experimental testing. The program is tested in different crop fields and under different light and weather conditions.

Stage 6. Practical implementation. Opportunities for use are created in farms, agroclusters, plant protection organizations, and higher education institutions.

In evaluating the effectiveness of the program, images obtained under laboratory and field conditions should be examined separately. This is because a model that has shown good results under laboratory conditions is not guaranteed to perform equally well against a complex field background and under different light and image quality conditions. This issue has also been noted as an important problem in modern scientific reviews [15].

Conclusion

Creating an electronic program for the digital analysis of plant diseases and pests is one of the promising directions for the broad introduction of digital technologies in agriculture. The following scientific and practical conclusions were formulated within the research: There are opportunities to use artificial intelligence, computer vision, and deep learning algorithms in detecting plant diseases and pests on the basis of digital images. The proposed electronic software system should include modules for receiving and processing images, classifying diseases and pests, storing diagnostic results, and providing recommendations to the user. For the reliability of the software product, it is necessary to create a high-quality, specialist-verified database consisting of images of healthy and affected organs of crops grown under local conditions. In evaluating the effectiveness of the program, it is advisable to use statistical indicators such as Accuracy, Precision, Recall, and F1. Applying the software product in the practice of farms and agroclusters can help in the early detection of diseases and pests, the improvement of monitoring, and the timely organization of protective measures. In the future, the functional capabilities of this system can be expanded by integrating it with a mobile application, a geographic information system (GIS), meteorological data, and agrotechnological monitoring tools.

Thus, the development of an electronic program for the digital analysis of plant diseases and pests serves to improve phytosanitary monitoring in agriculture, to use modern information technologies, and to form a scientifically based plant protection system.

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