The system of automatic greenhouse care and its informational model

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Abstract
The article deals with an automatic greenhouse care system that ensures monitoring and regulation of the microclimate to enhance plant growth efficiency. An informational model of the system is proposed, reflecting the structured representation of data about the greenhouse condition and its control elements. The informational model includes sensor modules for collecting data on temperature, humidity, light levels, CO content, and other parameters, as well as algorithms for information processing to automatically manage ventilation, irrigation, and lighting. The system architecture, its operating principles, and integration possibilities with intelligent platforms for analysis and forecasting are described. The informational model facilitates the visualization and modeling of processes within the greenhouse, enabling prompt responses to changes in conditions and improving resource use efficiency. The research confirms the effectiveness of automation in optimizing resources and increasing crop yields.

Keywords
Automation, greenhouse, microclimate, monitoring, sensors, informational model, neural networks.

1. Introduction

Global climate changes and population growth contribute to the rapid development of greenhouse farming worldwide. According to NASA research, over the past forty years, the area of greenhouses worldwide has increased from 300 km² to more than 13,000 km² as of May 2024 [1]. Over 60% of these greenhouses are located in China. The total production of tomatoes and cucumbers in China increased sixfold between 1990 and 2020. Although, according to Mordor Intelligence, Europe remains the largest market by value, with projected annual growth rates of 7% until 2030, European greenhouse farming faces a number of challenges [2]. In many European countries, there is a shortage of skilled workers in agriculture. Particularly due to urbanization and aging population, fewer people want to work in the agricultural sector. Moreover, the salaries and social guarantees in the EU contribute to high labor costs. Additionally, water and electricity are becoming more expensive and the excessive use of water in traditional greenhouses leads to significant losses.

The growing demand for food products forces agricultural companies to find ways to increase crop yields without expanding land area, while the instability of climatic conditions requires enhanced control over temperature, humidity and CO_2 levels (especially in light of the strict environmental regulations in EU regarding the use of chemicals and greenhouse gas emissions). The spread of diseases in a closed environment occurs more rapidly, which can lead to the loss of a significant portion of the harvest and manual monitoring of plant conditions is not always effective due to human factors and the difficulty of detecting problems at early stages. All of this, along with competition in international markets, defines the need for automation in the greenhouses of European agricultural companies.

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2. The Role of Automation in Greenhouse Optimization

The definition of the informational image of a greenhouse is the process of creating a digital model that reflects all the key aspects of the operation of the greenhouse workshop. The informational representation includes data on the spatial arrangement of equipment, microclimate parameters (temperature, humidity, lighting), plant condition and data on technological processes (irrigation [3], ventilation, fertilization). This model integrates information from various sources in real-time, ensuring comprehensive control and management of the greenhouse environment.[4]. The goal of creating such a model is to ensure comprehensive control and management of greenhouse production. This is achieved by collecting data from Internet of Things (IoT) sensors, integrating them into a unified management and analysis system using artificial intelligence algorithms. The informational representation allows real-time monitoring of the greenhouse condition, detecting deviations from optimal parameters and making quick adjustments to increase yield and resource efficiency [5]. Additionally, it facilitates decision-making regarding the optimization of production processes and provides the capability for remote monitoring and management. The informational model is an essential element of the digitalization of the agribusiness complex and enables the use of advanced technologies such as predictive analytics, machine learning and automation to improve greenhouse efficiency. To collect information in the greenhouse, a specific set of sensors is used, including temperature, humidity, light intensity, carbon dioxide, pressure sensors, computer vision systems and others. Temperature sensors are used to measure air and soil temperature, which helps maintain optimal conditions for photosynthesis and plant growth and prevents overheating or overcooling of the plants. Soil temperature measurement can be carried out to optimize irrigation and mineral nutrition. Humidity sensors monitor the level of humidity in the air and soil, which influences water evaporation and photosynthesis. They are used to adjust the irrigation system depending on soil moisture and to control air humidity to prevent the development of fungal diseases. Light intensity sensors measure the intensity of light, which affects photosynthesis and plant growth. This information allows for automatic regulation of artificial lighting intensity and optimization of lighting regimes for photoperiodic plants. Carbon dioxide (CO_2) sensors monitor the CO_2 level in the air, which affects the intensity of photosynthesis and is necessary for determining the need for additional greenhouse ventilation to prevent the accumulation of excessive CO_2. Air quality sensors measure the concentration of harmful gases (ethylene, ammonia) that may affect plant growth. These can include gas analyzers that measure the concentration of specific gases, such as ethylene (C_2H_4), which influences fruit ripening, as well as sensors for volatile organic compounds (VOC), used to determine the overall concentration of harmful gases. Pressure and flow sensors are used to monitor irrigation and ventilation systems. In particular, pressure gauges measure pressure in irrigation systems, while flow sensors control the volume of water or air supplied to irrigation and ventilation systems. The use of various sensors in greenhouses allows for automated monitoring of all key parameters affecting plant growth. This enables the optimization of the microclimate, increased yield and reduced resource costs [6]. The integration of sensors with IoT systems and artificial intelligence opens up new opportunities for the development of modern agriculture.

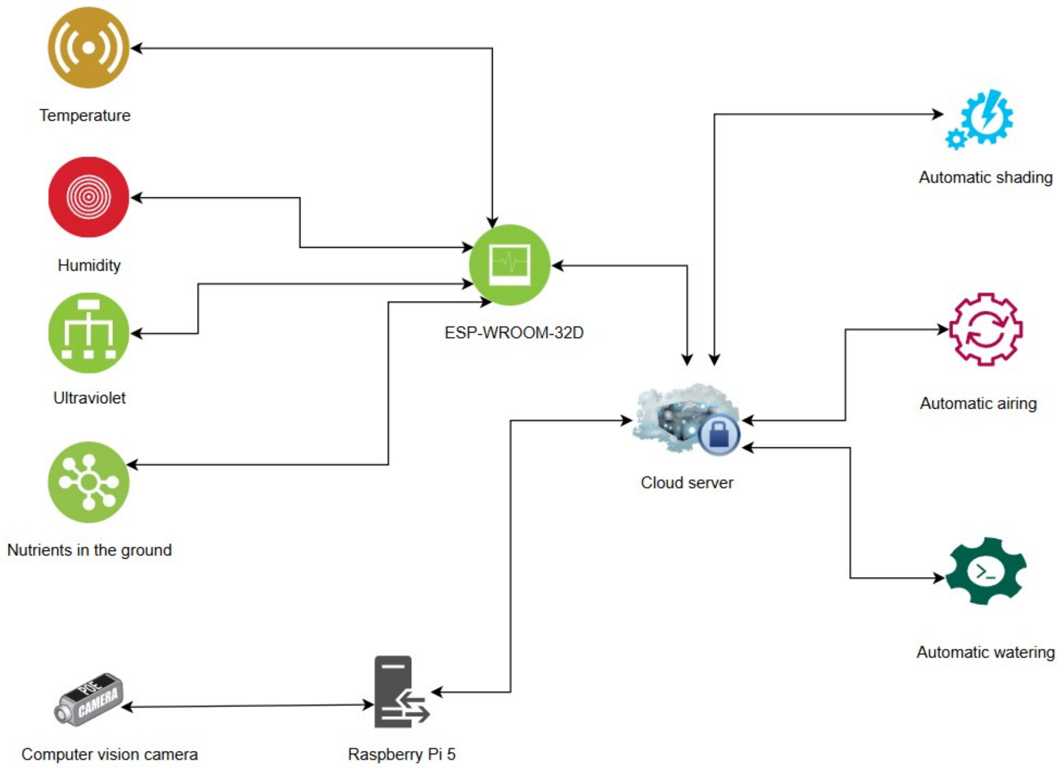

Figure 1: Proposed system of data collection and analysis in a greenhouse.

A system is proposed (see Figure 1), which represents a composition of a set of traditional sensors for monitoring the internal environment of the greenhouse (temperature, humidity, lighting, and soil condition sensors), an integrated Computer Vision system based on Raspberry Pi 5 for detecting diseases and problematic plant conditions, automated mechanisms for controlling lighting, ventilation and irrigation levels, as well as a cloud service responsible for automated control of management mechanisms. To limit the maximum level of solar radiation, a shading control system is used. It is proposed to implement both data collection from sensors at specific time intervals and the ability to respond to signals from sensors or the Computer Vision system in case of sharp changes in tracked parameters in real-time.

The integration of the module with computer vision demonstrates the potential to extend traditional methods of collecting system status information with modern developments, which can be either semi-autonomous elements, as in this case, or embedded within the core of the control system. In this case, images can be processed directly in the cloud environment, which would allow for a more complete use of Computer Vision capabilities for diagnosing plant conditions. However, this would make the system less universal for integration into various control systems.

3. Computer Vision for Plant Condition Monitoring

The use of computer vision for detecting pests and diseases in plants has become a crucial component of modern agriculture, especially in automated greenhouses. This technology uses cameras and image processing algorithms to monitor plant conditions in real-time [7]. It allows for the timely detection of signs of pest infestations or disease development, significantly increasing the effectiveness of agronomic interventions [8]. The core of the computer vision system consists of high-quality cameras installed in the greenhouse to continuously capture images of the plants. These images are processed using machine learning (ML) or deep learning (DL) algorithms, which help identify anomalies on leaves, stems or fruits. Computer vision analyzes the color, texture, shape and size of affected areas, comparing them to reference samples of healthy plants. The main components of the system include:

- **High-resolution cameras:** designed to provide detailed images of the plants.
- **Image processing:** used for object segmentation and highlighting affected areas.
- **ML and DL algorithms:** classify diseases and pests based on visual characteristics.
- **Cloud data processing:** used for storing and analyzing large volumes of data.

Let us consider the information flow in the computer vision system for monitoring plant conditions (Figure 2).

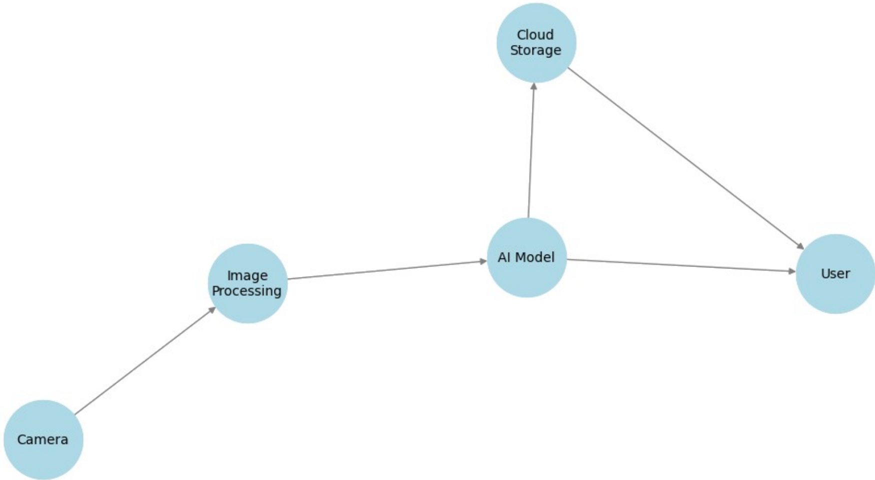

Figure 2: Information Flow in a Computer Vision System for Plant Monitoring**.**

The following methods for detecting pests and diseases on plants can be highlighted:

1. Spectral Analysis – the use of multispectral or hyperspectral cameras to analyze light waves reflected from the surface of plants. Changes in spectral characteristics may indicate plant stress or disease infection.
2. Image Segmentation – dividing the image into individual areas to highlight diseased leaves or affected fruits. Deep learning methods, such as U-Net or Mask R-CNN are used for this.
3. Classification – after segmentation, classification algorithms determine the type of disease or pest. Neural networks, such as Convolutional Neural Networks (CNN) or Vision Transformers (ViT) are used for this purpose.
4. Texture and Shape Analysis – detecting anomalies by changes in the texture or shape of leaves, which may indicate the presence of pests.

Greenhouse farms in Europe actively apply computer vision to detect spider mites and whiteflies. For example, PATS Indoor Drone Solutions uses drones equipped with cameras for monitoring pests in greenhouses [9]. An Indian startup, Plantix, developed a mobile app that uses computer vision to identify over 30 types of plant diseases based on photos taken with a smartphone [10]. In particular, the PEAT (Progressive Environmental & Agricultural Technologies) project uses this app for identifying insect pests, diseases, and nutrient deficiencies [11].
However, it should be noted that this solution may not be suitable for all companies due to a number of limitations, such as the need for large data volumes to train models, high computational resource requirements, and the difficulty of detecting diseases at early stages or in cases of complex infections.

4. Information Flows in the Informational Model of a Greenhouse

The informational model of a greenhouse is based on data flows coming from various sensors and control systems [12]. Let's model this system using the following mathematical formulas. Data collection from sensors:

$$I_s(t)=\sum_{i=1}^{N} S_i(t) \quad (1)$$

where:

I_s (t) - The flow of information from all sensors at a given moment in time;
S_i (t) - The value obtained from the i-th sensor;
N - The total number of sensors.

Data processing and analysis are performed using machine learning algorithms and analytics [13].

For example, for predicting the microclimate:

$$P(t+1)=f\left(I_s(t),H(t)\right), \quad (2)$$

P(t+1) – The predicted state of the microclimate at the next moment in time;
H(t) –Historical data for previous periods;
f – predictive analytics function, which can be implemented using machine learning models.

Process control in the greenhouse:

$$C(t)=g(P(t+1),R), \quad (3)$$

·*C(t)* – Control signals sent to the actuators (irrigation systems, ventilation, etc.);
·*R* – A set of control rules that define the optimal microclimate parameters;
g – A decision-making algorithm.

$$E(t)=P(t)-A(t), \quad (4)$$

where:

E(t) – the error between the predicted *(P(t))* and actual *(A(t))* values of microclimate parameters. This error is used to adjust the forecasting model and control rules, ensuring the system self-learning.

Explanation of information flows:

1. Input flow [14]: Data is received from sensors measuring temperature, humidity, light intensity, CO_2 levels, etc.
2. Processing and analysis: Data is stored in a database, processed to detect trends and deviations and used for predicting changes in parameters.
3. Output flow: Based on the analysis, control signals are generated and sent to actuators (e.g. opening ventilation openings or turning on the irrigation system).
4. Feedback: Continuous monitoring of control results allows the system to optimize its decisions and adjust forecasting algorithms.

Figure 3 shows a diagram of the information flow in the greenhouse, considering remote monitoring and Computer Vision for detecting pests and diseases. It illustrates the information flows between sensors, the computer vision system, data processing center, analytics, decision-making, and executive mechanisms.

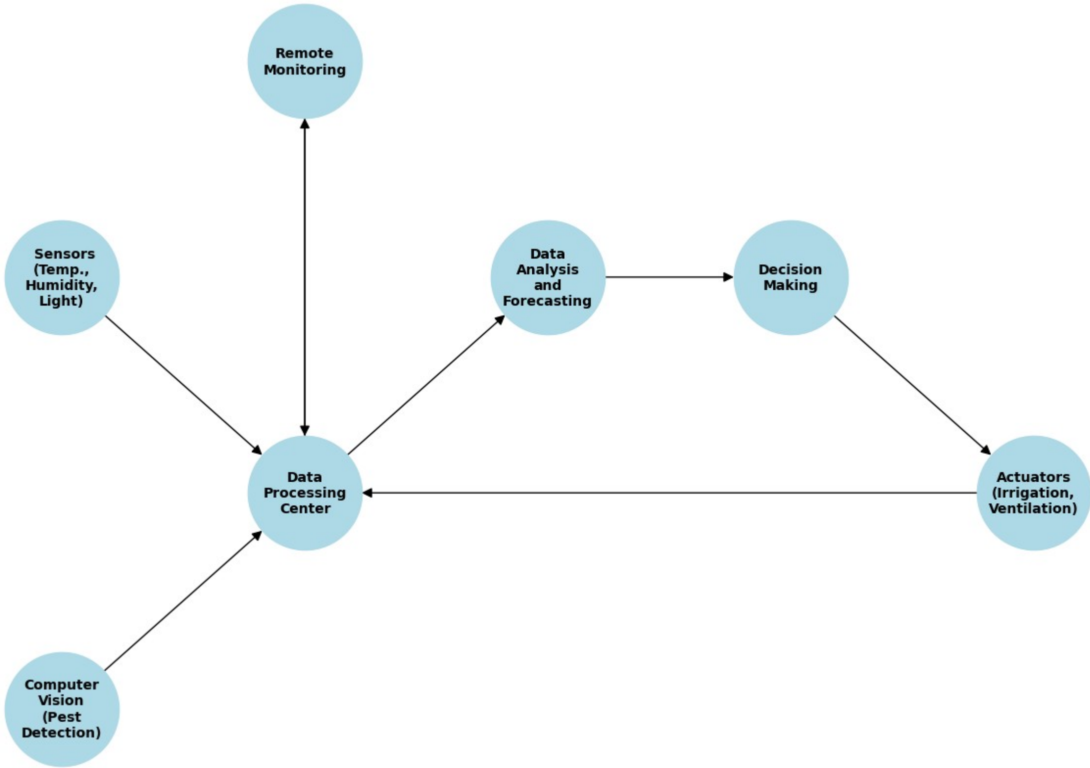

Figure 3: Information Flow in a Greenhouse.

The digital information model of the greenhouse [15] allows:

1. To increase the efficiency of resource use (water, energy, fertilizers);
2. To ensure the stability of the microclimate for optimal plant growth;
3. To reduce costs through process automation;
4. To improve productivity and crop quality.

Thus, the information model of the greenhouse is the foundation for building intelligent management systems for agro-industrial complexes, enabling the implementation of the concept of smart greenhouses.

5. Application of Neural Networks

Create a neural network to predict optimal microclimate parameters in the greenhouse. It will analyze incoming signals from temperature, humidity, CO_2 level and light sensors, and make decisions regarding the optimal control mode (ventilation, heating, lighting, and irrigation). Use an artificial neural network (ANN) to forecast the system's state and train it to find optimal control parameters. Let's assume that the desired state of the greenhouse is described by the following parameters:
T_MAX – maximum allowable temperature;
T_MIN – minimum allowable temperature;
CO_MAX – maximum CO_2 level;
LIGHT_MIN – minimum allowable light level;
H_MIN – minimum allowable humidity level.
Based on sensor data contained in a CSV file, we will create an array of correct commands for each set of input data according to the algorithm in Figure 4. Each command consists of an array of values, either 1 or 0, corresponding to whether to turn on or off the relevant control system.

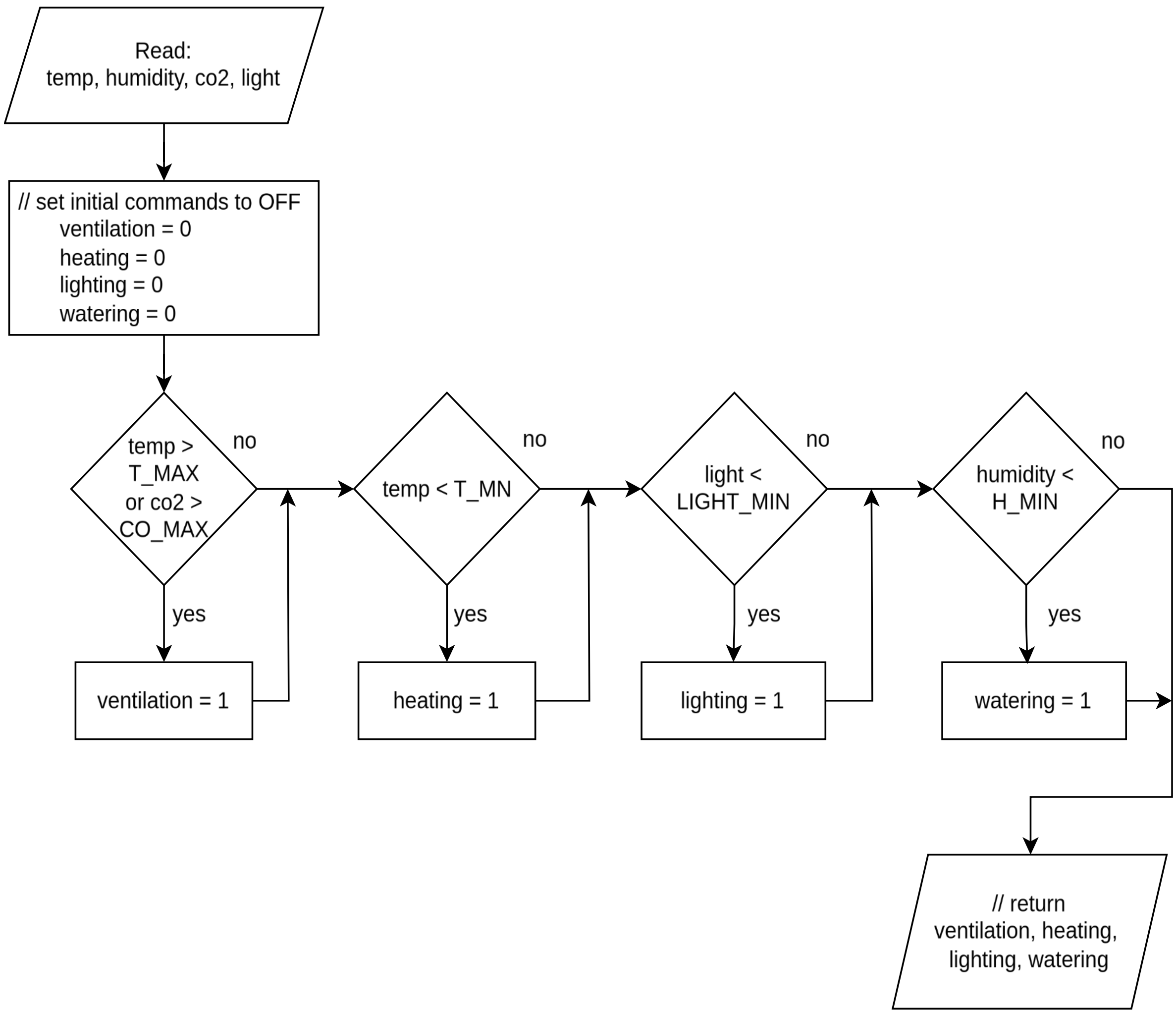

Figure 4: Algorithm for Determining Behavior Rules for Neural Network Training.

The proposed algorithm can be easily adapted to the required set of rules and the available range of equipment. The values from the sensors temp, humidity, CO_2 and light serve are the input data for the algorithm, while the output is a command consisting of four signals for the corresponding systems: ventilation, heating, lighting, and watering.

Since the output actions are not mutually exclusive (it is possible to turn on ventilation, lighting and irrigation simultaneously), a multilabel classification approach was applied using the activation='sigmoid' parameter [16]. Additionally, the binary_crossentropy loss function [17] was used, which allows for training each action independently. In order to accelerate the training process of the neural network, input data normalization was performed using the scaler.fit_transform function [18]. The model was successfully trained in 41 epochs, achieving an accuracy of 71.95% (see Figure 5).

Figure 5: Algorithm for determining behavior rules for neural network training.

The confusion matrix in Figure 6 shows the minor errors of the model and characterizes it as a model that can be used for decision-making in control processes for the automation of greenhouse management.

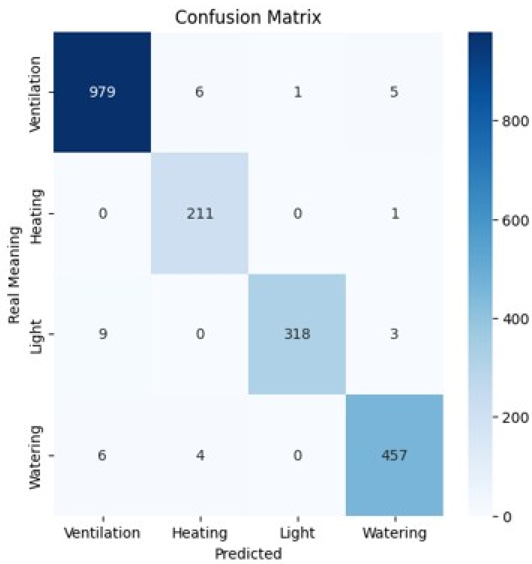

Figure 5: Confusion matrix.

Conclusions

The need for automation in greenhouses of agricultural companies in Europe is determined by factors such as labor shortages, high resource costs, strict environmental regulations, plant disease risks, climate changes, and market competition. Automated systems not only help improve efficiency and yield but also reduce costs, meet environmental standards and ensure production stability. In the future, greenhouses controlled by artificial intelligence, robotic harvest collection systems and intelligent climate management will become the standard for the agricultural business, allowing companies to remain competitive and efficient.

The modern market offers a wide range of sensors and devices for automation, which can be used in greenhouse management. This article examined the construction of the information model for the system and analyzed the interconnections between the main component groups and the information flows between them. Additionally, management processes for greenhouse operations were modeled using a neural network, which uses sensor data as input parameters to generate control signals for system mechanisms. The modeled system requires adaptation to specific plant types and available equipment in the operating environment and can easily be scaled or expanded with additional tools using the algorithms discussed. This experience can be used for the overall coordination of flexible, innovative systems for automated greenhouse management, their modernization and adaptation to new conditions. At this stage, the model's accuracy is sufficient; however, improvements are possible:

- Use class balancing.
- Optimize the model's hyperparameters to reduce confusion between similar classes.
- Use more data or better features to distinguish complex cases.

This is planned for future research.

Declaration on Generative AI

During the preparation of this work, the authors utilised ChatGPT and LanguageTool to identify and rectify grammatical, typographical, and spelling errors. Following the use of these tools, the authors conducted a thorough review and made necessary revisions, and accept full responsibility for the final content of this publication.

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