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SMART GREENHOUSE CONTROL MODEL BASED ON INTERNET OF THINGS TECHNOLOGY

Today, with the continuous growth of the world's population, every country faces the challenge of timely supplying its people with high-quality fruits and vegetables. One of the key ways to achieve this goal is the development of greenhouse farming, which enables the cultivation of crops regardless of climate conditions. A crucial factor for the efficiency of greenhouses is precise microclimate control. Traditional control methods require constant human involvement and lead to significant resource consumption.

The purpose of this article is to develop a smart greenhouse control model based on Internet of Things (IoT) technology using an Arduino microcontroller, sensors, the ESP8266 Wi-Fi module, and the ThingSpeak cloud platform, which enables monitoring and remote control of microclimate parameters via mobile and web applications.

The article presents an analysis of modern approaches to greenhouse automation and substantiates the feasibility of applying IoT-based architecture for their modernization. A structural scheme of the system is proposed, which includes sensors for measuring temperature, humidity, light intensity, and CO_2 concentration, as well as actuators for irrigation, ventilation, heating, and lighting. The principles of integrating the system with the ThingSpeak cloud service are described, providing data visualization and analytics. Control algorithms based on threshold values and proportional–integral regulation are also discussed.

The proposed system is designed for the automation of existing greenhouses with the possibility of scaling, integration into a network, and the use of predictive algorithms. Future research is planned to implement machine learning methods for optimizing cultivation regimes and to explore the use of alternative energy sources to improve energy efficiency.

Keywords: smart greenhouse; Internet of Things; automated control system; Arduino; ThingSpeak; sensors; cloud technologies.

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Introduction

Contemporary developments in the agricultural sector necessitate the adoption of innovative technologies to enhance crop productivity, reduce production costs, and optimize resource utilization. Greenhouse farming occupies a pivotal role in ensuring year-round availability of vegetables and leafy greens; however, its operational efficiency largely depends on the ability to maintain a stable and controlled microclimate. Conventional greenhouse management approaches demand substantial human and energy resources, thereby limiting their economic feasibility [1 - 2].

The Internet of Things provides new avenues for automating greenhouse operations. The integration of microcontrollers, sensors, and cloud-based platforms enables the development of systems capable of autonomously regulating environmental parameters, facilitating remote access, and supporting real-time monitoring. This approach not only minimizes operational expenditures but also enhances the quality of the cultivated produce [1].

This paper presents a model of a smart greenhouse based on an Arduino controller, utilizing a Wi-Fi module for transmitting data to the ThingSpeak cloud platform, with seamless integration into mobile and web applications for remote monitoring and control.

Problem Statement

The growing global population and the increasing demand for food products necessitate innovative solutions in agriculture. Greenhouse farming enables year-round cultivation of vegetables and fruits; however, its operational efficiency directly depends on the precision of microclimate control. Conventional methods require constant human intervention and are characterized by low efficiency. The adoption of IoT technologies provides the opportunity for automated greenhouse management with remote monitoring and control, thereby enhancing productivity and reducing energy and water consumption [1 - 3].

Analysis of Recent Research and Publications

The automation of greenhouses using microcontrollers has been the subject of numerous studies. Scientific works [3 - 4] explore mathematical models for microclimate control, the application of fuzzy logic, and PLC-based systems. However, most developments [4 - 5] focus on closed solutions without the possibility of integration with cloud services. Contemporary IoT trends, by contrast, emphasize centralized data storage, mobile access, and scalability [5]. The use of the Arduino platform in combination with cloud services (e.g., ThingSpeak) has been considered in isolated studies, with the main advantages being low cost and ease of implementation [5 - 6].

The purpose of the article is to build a model of a smart greenhouse control system based on an Arduino microcontroller with connected sensors and a Wi-Fi module, which provides data transmission to the ThingSpeak cloud platform for further monitoring and remote control using a mobile application and web interface.

Presentation of the main research material

The development of a smart greenhouse model based on IoT technologies involves creating an integrated hardware-software system capable of collecting real-time data from sensors, analyzing it, storing it in cloud services, and providing the user with remote monitoring and control capabilities. The core of the system is an Arduino microcontroller, which facilitates the connection of hardware components and interaction with the ThingSpeak cloud platform via the ESP8266 Wi-Fi module [4 - 5]. Within this architecture, several functional layers can be distinguished: the data acquisition layer, the information transmission layer, the data processing and cloud storage layer, and the user layer, which is implemented through a web application and a mobile app [5, 7].

At the data acquisition level, various sensors are employed to monitor environmental parameters inside the greenhouse. The most basic sensors include air temperature and humidity sensors, such as the DHT22, which provides sufficiently accurate measurements within a range suitable for horticultural activities. For soil temperature control, the digital DS18B20 sensor is recommended, featuring a waterproof casing suitable for operation in moist environments. Soil moisture is measured using the FC-28 sensor, which detects the electrical conductivity of the medium and allows the determination of root-zone hydration levels. Light intensity is monitored using photoresistors or specialized light flux sensors. Additionally, a carbon dioxide sensor (e.g., MH-Z19) can be integrated, which is essential for supporting photosynthesis. All these sensors are connected to the Arduino, which periodically reads their values, digitizes the data, and prepares it for transmission to the cloud [5 - 8].

The next stage involves connecting actuators that actively regulate microclimate parameters. These include water pumps for irrigation, fans for air circulation and cooling, heating elements to maintain temperature during cold periods, and LED or fluorescent lamps to provide supplemental lighting when natural light is insufficient. All actuators can be connected via relay modules, enabling the Arduino to send low-voltage control signals while switching on and off devices powered by the main electrical network. This setup establishes a complete operational cycle: sensors capture environmental measurements, the controller analyzes the data, and the actuators adjust the cultivation conditions accordingly.

A key component of the system is the ESP8266 communication module, which provides connectivity to a local Wi-Fi network and access to the Internet. The Arduino transmits data to the ThingSpeak cloud service through this module. Data transfer occurs via HTTP requests, with each parameter (such as temoerature, humidity, and light intensity) sentto the corresponding field of a channel. ThingSpeak offers the user an interface for visualizing the collected data in the form of graphs, tables, or widgets. Additionally, the system stores historical data, enabling analysis of parameter dynamics over time. A unique feature of ThingSpeak is the integration of MATLAB analytics, which allows data processing, calculations, and forecasting directly in the cloud. This capability opens the way for the development of intelligent algorithms that can predict changes in temperature or humidity and perform proactive regulation [7]. The conceptual diagram of the smart greenhouse control model based on Arduino and the ThingSpeak service is shown in fig. 1.

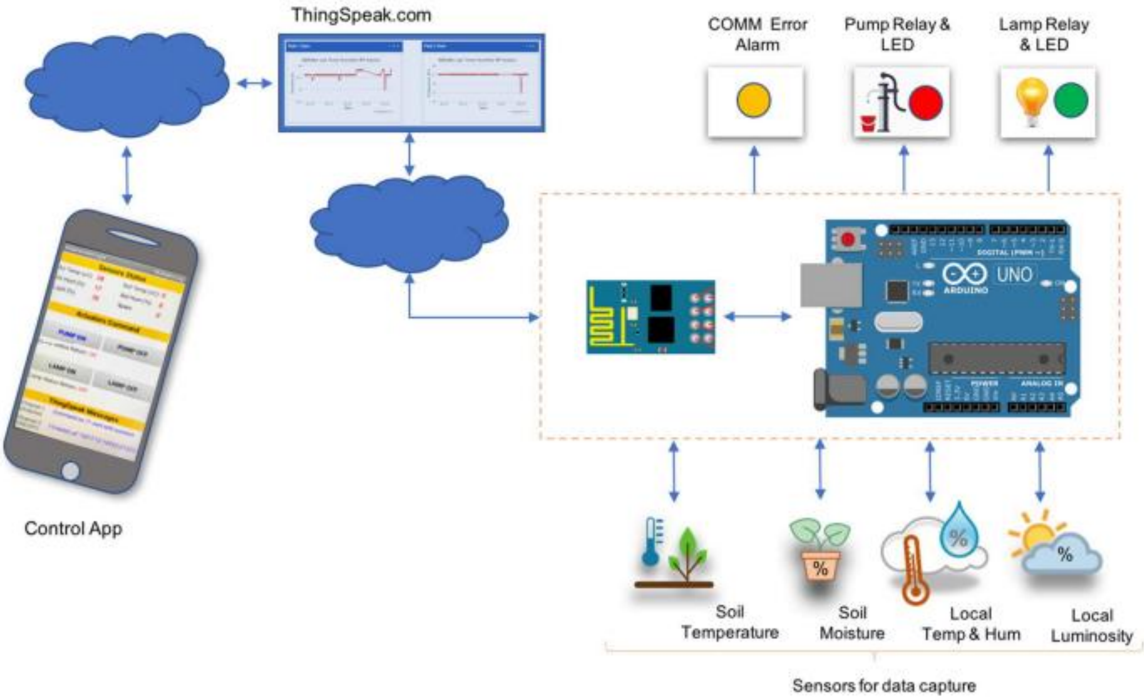

Fig. 1. Conceptual diagram of the smart greenhouse control model based on Arduino and the ThingSpeak service

The system operates on a cyclic polling algorithm of the sensors, making decisions based on pre-defined threshold values. For instance, if the soil moisture falls below a certain threshold, the controller activates the irrigation pump until the moisture reaches the desired level. Similarly, when air temperature exceeds a set limit, the system activates fans or opens ventilation vents, and in the case of a temperature drop, it switches on heating elements. The operational logic can be implemented using conditional statements or more advanced control regulators. The simplest approach is a two-position control principle:

$$u(t) = \begin{cases} 1, & \text{if } x(t) < x_{min} \\ 0, & \text{if } x(t) \geq x_{min} \end{cases}$$

where $u(t)$ – represents the control signal to the actuator; $x(t)$ is the measured parameter; x_{min} is the threshold value [8].

However, a more effective approach is the proportional-integral control method. In this case, the system not only responds to threshold exceedances but also considers the magnitude of deviation from the setpoint. For temperature regulation, this can be described by the following formula:

$$u(t) = K_p \cdot (T_{set} - T_{actual}) + K_i \int (T_{set} - T_{actual}) dt,$$

where K_p, K_i are the controller coefficients; T_{set} is the desired temperature; T_{actual} is the current temperature. Thus, if the deviation is large, the system responds quickly and with high power; if the deviation is small, the control signal decreases, preventing oscillations [2].

Storing data in the ThingSpeak cloud not only enables real-time monitoring but also facilitates the development of analytical models. For example, soil moisture trends can be forecasted based on historical measurements, allowing determination of an optimal irrigation schedule. Furthermore, integration with a mobile application provides the user with a convenient interface to view graphs, receive push notifications about critical deviations, and remotely control equipment. This ensures that even when physically distant from the greenhouse, the owner can monitor its condition and intervene if necessary.

The mobile application is designed with simplicity and clarity in mind. Its primary functions include visualization of sensor data, archiving of parameters, control of actuators, and receipt of alerts. A web application offers similar functionality but is intended for use on a personal computer, allowing for more advanced data analysis. Through cloud integration, all devices receive the same information, providing a unified access point to the system.

A practical use case involves automatic irrigation control. If the FC-28 sensor indicates that soil moisture falls below 30%, the Arduino sends a command to activate the pump. Simultaneously, the data are transmitted to ThingSpeak, where they are stored and displayed in graphical form. The user receives a notification about the irrigation activation via the mobile app and can manually adjust parameters if desired. This setup allows both automatic and manual operation modes.

Another scenario concerns temperature regulation. During winter, the greenhouse temperature can drop rapidly. If the DHT22 sensor records a value below 18 °C, the system activates the heating element. When the temperature rises above 25 °C, a fan is switched on or ventilation vents are opened. The user can monitor current temperature values, heater and ventilation status, and set threshold values via the application [3].

Particular attention is given to the system's energy efficiency. By employing sensors and automation, water and electricity consumption are reduced. For instance, drip irrigation is activated only when soil moisture drops below the required level, preventing unnecessary waste. Automated lighting control ensures that lamps operate only under insufficient natural illumination, thereby reducing electricity usage.

The system is easily scalable. To control multiple greenhouses, each can be equipped with its own Arduino and sensor set, sending data to a shared cloud channel or to separate channels that are consolidated in a single user interface. This enables the creation of a network of greenhouses operating under a unified monitoring system.

In summary, the proposed smart greenhouse model represents a comprehensive solution that integrates hardware components, cloud technologies, and a user-friendly interface. It automates core processes, reduces resource consumption, improves product quality, and provides a foundation for the future implementation of intelligent predictive algorithms.

Conclusions

This article presents a model of a smart greenhouse based on an Arduino microcontroller, integrated with the ThingSpeak cloud platform. The proposed system enables automated microclimate control, optimizes the use of water and energy resources, and provides remote management through mobile and web applications.

Future research will focus on implementing predictive algorithms based on machine learning, integrating alternative energy sources, and expanding the functionality of the mobile application for agricultural analytics.

References

1. Miskevych O., Shulhach I. Methods and tools for developing a web interface to control hardware modules of Arduino within an Internet of Things system / O. Miskevych, I. Shulhach // Computer-Integrated Technologies: Education, Science, Production. – 2025. – № 59. – P. 247–252. – DOI: https://doi.org/10.36910/6775-2524-0560-2025-59-31

2. Development of software for an IoT system on the Arduino hardware platform / N. O. Sokolova, A. S. Bielov // Applied Issues of Mathematical Modelling. – 2020. – Vol. 3, No. 2.1. – P. 251–259. – DOI: https://doi.org/10.32782/KNTU2618-0340/2020.3.2-1.23

3. Kovalenko A. M., Kovalchuk D. M. Development and research of an automated hydroponic system / A. M. Kovalenko, D. M. Kovalchuk // Current Issues and Prospects of Ukraine's Development in Management and Administration: Youth Initiatives : Proceedings of the V International Scientific and Practical Conference of Higher Education Students and Young Scientists, October 20, 2023. – Kharkiv : State Biotechnological University, 2023. – P. 507.

4. Storchak K. P., Tushych A. M., Tkalenko O. M., Chorna V. M., Zhyla T. M. Analysis of requirements for designing a cloud platform for the Internet of Things / K. P. Storchak, A. M. Tushych, *O. M. Tkalenko, V. M. Chorna, T. M. Zhyla // Connectivity. – 2019. – No. 6. – P. 8–11. – DOI: https://doi.org/10.31673/2412-9070.2019.060811*

5. Oleshko D. M., Kovalchuk D. M. Development of software-hardware modules for automated greenhouse microclimate control / D. M. Oleshko, D. M. Kovalchuk // Current Issues and Prospects of Ukraine's Development in Management and Administration: Youth Initiatives : Proceedings of the V International Scientific and Practical Conference of Higher Education Students and Young Scientists, October 20, 2023. – Kharkiv : State Biotechnological University, 2023. – P. 507.

6. Zavatskyi V. O., Danilchenko V. M. Optimization of parameters in the Internet of Things network / V. O. Zavatskyi, V. M. Danilchenko // Connectivity. – 2024. – No. 5. – P. 18– 23. – DOI: https://doi.org/10.31673/2412-9070.2024.051139

7. Porokhnya Yu. R., Kovalchuk D. M. Development of software-hardware modules for greenhouse microclimate control / Yu. R. Porokhnya, D. M. Kovalchuk // Information Technologies in the Modern World : Proceedings of the International Scientific and Practical Conference of Higher Education Students and Young Scientists, April 22, 2024. – Kharkiv : State Biotechnological University, 2024. – P. 341.

8. Tsyrulnyk S. Mobile applications and online Wi-Fi monitoring platforms of weather stations / S. Tsyrulnyk // Open Educational E-Environment of Modern University: Electronic Scientific Professional Journal. – 2020. – No. 9. – P. 181–192. – DOI: https://doi.org/10.28925/2414-0325.2020.9.15

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МОДЕЛЬ КЕРУВАННЯ СМАРТ-ТЕПЛИЦЕЮ НА ОСНОВІ ЗАСТОСУВАННЯ ТЕХНОЛОГІЇ ІНТЕРНЕТУ РЕЧЕЙ

На сьогодні, коли населення світу постійно зростає, будь-якій країні потрібно вирішувати проблему своєчасного забезпечення населення овочами та фруктами високої якості. Одним із ключових шляхів досягнення цієї мети є розвиток тепличного господарства, яке дозволяє вирощувати сільськогосподарські культури незалежно від кліматичних умов. Одним із головних факторів ефективності теплиць є точне керування мікрокліматом. Традиційні методи контролю потребують постійної участі людини та супроводжуються значними витратами ресурсів.

Метою статті є розроблення моделі керування смарт-теплицею на основі технології Інтернету речей із використанням мікроконтролера Arduino, сенсорів, Wi-Fi модуля ESP8266 та хмарної платформи ThingSpeak, яка дозволяє здійснювати моніторинг і дистанційне керування параметрами мікроклімату за допомогою мобільного та веб-застосунків.

У статті наведено аналіз сучасних підходів до автоматизації теплиць та обґрунтовано доцільність використання архітектури IoT для їх модернізації. Запропоновано структурну схему системи, яка включає сенсори для вимірювання температури, вологості, освітленості та рівня CO_2, а також виконавчі пристрої для поливу, вентиляції, нагрівання та освітлення. Показано принципи інтеграції системи з хмарним сервісом ThingSpeak, що забезпечує візуалізацію та аналітику даних. Розглянуто алгоритми автоматичного регулювання мікроклімату на основі порогових значень і пропорційно-інтегрального регулювання.

Запропонована система призначена для автоматизації існуючих теплиць з можливістю масштабування, інтеграції в мережу та застосування алгоритмів прогнозування. У подальших дослідженнях планується впровадження методів машинного навчання для оптимізації режимів вирощування та використання альтернативних джерел енергії для підвищення енергоефективності.

Ключові слова: автоматизована система керування; Інтернет речей; Arduino; ThingSpeak; сенсори; хмарні обчислення; розумна теплиця.

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