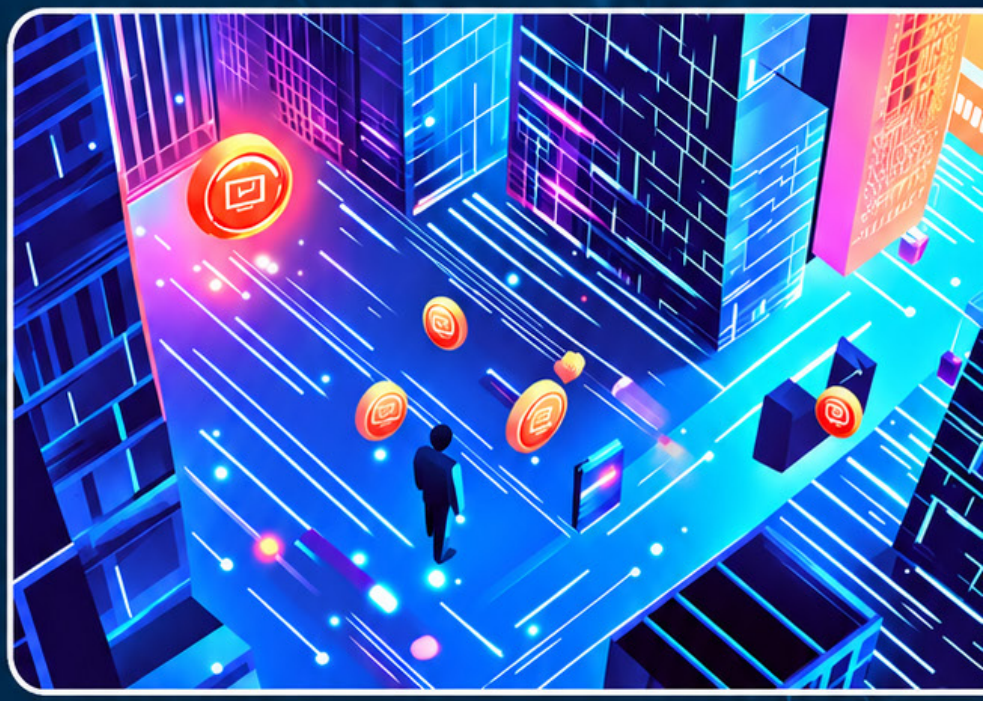
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05.01.00 – Axborot texnologiyalari, boshqaruv va kompyuter grafikasi
05.01.01 – Muhandislik geometriyasi va kompyuter grafikasi. Audio va video texnologiyalari
05.01.02 – Tizimli tahlil, boshqaruv va axborotni qayta ishlash
05.01.03 – Informatikaning nazariy asoslari
05.01.04 – Hisoblash mashinalari, majmualari va kompyuter tarmoqlarining matematik va dasturiy ta'minoti
05.01.05 – Axborotlarni himoyalash usullari va tizimlari. Axborot xavfsizligi
05.01.06 – Hisoblash texnikasi va boshqaruv tizimlarining elementlari va qurilmalari
05.01.07 – Matematik modellashtirish
05.01.11 – Raqamli texnologiyalar va sun'iy intellekt
05.02.00 – Mashinasozlik va mashinashunoslik
05.02.08 – Yer usti majmualari va uchish apparatlari
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05.04.01 – Telekommunikasiya va kompyuter tizimlari, telekommunikasiya tarmoqlari va qurilmalari. Axborotlarni taqsimlash
05.05.03 – Yorug'lik texnikasi. Maxsus yoritish texnologiyasi
05.05.05 – Issiqlik texnikasining nazariy asoslari
05.05.06 – Qayta tiklanadigan energiya turlari asosidagi energiya qurilmalari
05.06.01 – To'qimachilik va yengil sanoat ishlab chiqarishlari materialshunosligi
05.08.03 – Temir yo'l transportini ishlatish
05.08.06 – "G'ildirakli va gusenisali mashinalar va ularni ishlatish" (texnika fanlari)
05.09.01 – Qurilish konstruksiyalari, bino va inshootlar
05.09.04 – Suv ta'minoti. Kanalizatsiya. Suv havzalarini muhofazalovchi qurilish tizimlari
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10.00.04 – Yevropa, Amerika va Avstraliya xalqlari tili va adabiyoti
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08.00.02 – Makroiqtisodiyot
08.00.03 – Sanoat iqtisodiyoti
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08.00.05 – Xizmat ko'rsatish tarmoqlari iqtisodiyoti
08.00.06 – Ekonometrika va statistika
08.00.07 – Moliya, pul muomalasi va kredit
08.00.08 – Buxgalteriya hisobi, iqtisodiy tahlil va audit
08.00.09 – Jahon iqtisodiyoti
08.00.10 – Demografiya. Mehnat iqtisodiyoti
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08.00.15 – Tadbirkorlik va kichik biznes iqtisodiyoti
08.00.16 – Raqamli iqtisodiyot va xalqaro raqamli integratsiya
08.00.17 – Turizm va mehmonxona faoliyati

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DEVELOPMENT OF AN IOT-BASED REMOTE MONITORING AND AUTOMATED CONTROL SYSTEM FOR GREENHOUSE CROP GROWTH

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Annotatsiya. Maqolada issiqxonada yetiştiriş şaroitlarini masofadan monitoring qiliş va avtomatlaştirilgan boşqariş uçun Internet of Things (IoT) texnologiyasiga asoslangan tizimni işlab çiqiş masalasi körib çiqilgan. Taklif etilayotgan yondaşuv atrof-muhit sensorlari, NodeMCU ESP8266 mikrokontrolleri, Raspberry Pi asosidagi server muhiti, simsiz aloqa, ma’lumotlar bazasi va veb-interfeysni yagona tizimga birlaştiradi. Tizim havo harorati, namligi, tuproq namligi va yoruğlik darajasi haqidagi ma’lumotlarni yiğiş, ularni masofadan kuzatiş uçun uzatiş hamda oldindan belgilangan iş şaroitlari asosida şamollatiş, suğoriş, isitiş va yoritiş jarayonlarini boşqarişga möljallangan. Qurilmalarning dasturiy arxitektura bilan özaro boğliqligiga, jumladan, MQTT protokoli asosida ma’lumotlar almaşinuvi, sensor körsatkiçlarini saqlaş va vizual taqdim etiş jarayonlariga alohida e’tibor qaratilgan. Maqolada tizimning loyihaviy yeçimi, virtual işlab çiqiş va sinovdan ötkaziş jarayoni tahlil qilingan. Tadqiqotda hosildorlik, suv sarfi yoki energiya iste’moli böyiça dala şaroitida ölçangan yaxşilanişlar da’vo qilinmaydi. Aksinça, taklif etilgan arxitekturaning amaliy salohiyati hamda keyingi issiqxona sinovlarida örganilişi lozim bölgan masalalar aniqlab berilgan.

Kalit sözlar: Internet of Things, aqlli issiqxona, masofaviy monitoring, NodeMCU ESP8266, Raspberry Pi, MQTT, atrof-muhit sensorlari, avtomatlaştirilgan boşqaruv, himoyalangan qişloq xöjaligi.

Аннотация. В статье рассматривается разработка системы на основе технологии Интернета вещей (IoT) для дистанционного мониторинга и автоматизированного управления условиями выращивания растений в теплице. Предлагаемый подход объединяет датчики окружающей среды, микроконтроллер NodeMCU ESP8266, серверную среду на базе Raspberry Pi, беспроводную связь, базу данных и веб-интерфейс. Система предназначена для сбора информации о температуре и влажности воздуха, влажности почвы и уровне освещённости, передачи показаний для дистанционного наблюдения, а также управления вентиляцией, поливом, отоплением и освещением на основе предварительно заданных условий функционирования. Особое внимание уделяется взаимосвязи аппаратных компонентов и программной архитектуры, включая обмен данными на основе протокола MQTT, хранение и визуализацию показаний датчиков. В статье анализируются проектное решение системы, а также процессы её виртуальной разработки и тестирования. Полученные результаты не предполагают утверждений об улучшении урожайности, снижении потребления воды или энергоресурсов на основе полевых измерений. Вместо этого определяются практический потенциал предложенной архитектуры и вопросы, требующие дальнейшего изучения в ходе последующих испытаний в тепличных условиях.

Ключевые слова: Интернет вещей, умная теплица, дистанционный мониторинг, NodeMCU ESP8266, Raspberry Pi, MQTT, датчики окружающей среды, автоматизированное управление, защищённое сельское хозяйство.

Abstract. The article explores the development of an Internet of Things (IoT)-based system for remote monitoring and automated control of greenhouse cultivation conditions. The proposed architecture integrates environmental sensors, a

NodeMCU ESP8266 microcontroller, a Raspberry Pi-based server environment, wireless communication, a database, and a web interface. The system is designed to collect data on air temperature, air humidity, soil moisture, and light intensity, transmit sensor readings for remote monitoring, and facilitate the control of ventilation, irrigation, heating, and lighting according to predefined operating conditions. Particular emphasis is placed on the integration of hardware components with the software architecture, including MQTT-based data communication, sensor data storage, and visualization. The article analyses the system architecture, its design implementation, and the virtual development and testing workflow. The study does not claim experimentally verified improvements in crop yield, water consumption, or energy efficiency. Instead, it highlights the practical potential of the proposed architecture and identifies key aspects requiring further investigation through subsequent greenhouse-based experimental trials.

Keywords: Internet of Things, smart greenhouse, remote monitoring, NodeMCU ESP8266, Raspberry Pi, MQTT, environmental sensors, automated control, protected agriculture.

INTRODUCTION

Greenhouse production offers growers a degree of control over the environment in which crops develop. Temperature, air humidity, soil moisture and light can be managed more deliberately than in open-field cultivation. This control, however, requires regular observation and timely intervention. Where measurements are taken manually, the quality of management depends heavily on how often a greenhouse is inspected and how quickly a worker can respond to a change. A monitoring system that gathers measurements continuously and makes them available remotely can therefore support more consistent day-to-day decisions.

The need for such tools is relevant to Uzbekistan, where protected cultivation is an important part of the effort to extend the production season and diversify fruit and vegetable growing. The monograph underlying this study places greenhouse automation within the broader development of digital agriculture and discusses the use of information and communication technologies in agricultural production [1]. Earlier work on precision farming and intelligent technical equipment likewise points to the value of combining measurement, data processing and control rather than treating these functions as separate activities [2, 3].

The purpose of this article is to examine an IoT-based architecture for remote monitoring and automated control of greenhouse conditions. The focus is not on presenting an unverified performance claim. Instead, the article explains how the selected hardware, communication protocol, database and web application fit together, and considers what the design can and cannot establish before field testing.

LITERATURE REVIEW

Digital agriculture covers a range of technologies, from precision measurement and automated machinery to connected sensors and data-driven decision support. In protected cultivation, the value of these technologies is especially clear: the greenhouse is a bounded environment in which changes in temperature, humidity and illumination can be observed and addressed through technical equipment. Research and practical publications on precision farming describe the broader movement towards the use of intelligent devices and information systems in agricultural processes [2].

The literature cited in the source monograph also includes studies concerned with automated information systems and the management of technological processes in crop production [3, 4]. These works provide a general engineering context for systems in which data are collected, processed and used to support operational decisions. Publications by Abasxanova address remote monitoring in agriculture and the development of hardware-software solutions for monitoring tasks [5–8]. Taken together, these sources establish the relevance of applying information technologies to greenhouse monitoring, although they do not remove the need to evaluate each implementation under its own operating conditions.

A practical greenhouse monitoring system has to solve several connected problems. Sensors must provide readings that are meaningful for the crop and the growing environment; the controller must be able to receive and process those readings; communication must remain sufficiently reliable; and the user needs a clear way to inspect the information and adjust operating parameters. If these parts are designed independently, the result may be technically functional but difficult to maintain. The architecture considered here therefore treats sensing, communication, storage, visualisation and actuation as parts of one system.

RESEARCH METHODOLOGY

The study follows a system-design approach based on the technical configuration described in the monograph. The proposed architecture combines a sensor layer, a local control layer, a communication layer

and a remote information layer. The sensor layer collects environmental measurements. The control layer processes the readings and operates connected devices. The communication layer transfers data between the greenhouse controller and the server. The information layer stores the measurements and presents them through a web interface.

The NodeMCU ESP8266 board is used as the main microcontroller platform for sensor communication and local control. Its integrated Wi-Fi capability makes it suitable for sending readings to a local network or the Internet without requiring a separate wireless module. The monograph describes the board's GPIO, UART, ADC, SPI and software-implemented I²C capabilities, which allow different types of sensors and peripheral devices to be connected [1]. The final selection of a sensor and its interface must, of course, be checked against the electrical and measurement requirements of the particular greenhouse installation.

The monitored parameters include air temperature, air humidity, soil moisture and light intensity. The source material discusses temperature and humidity sensors, light sensors and soil-moisture measurement as part of the greenhouse monitoring arrangement. It also describes the use of the DS18B20 temperature sensor and 1-Wire communication, alongside serial data exchange options such as RS-485 in the wider system context. These interfaces are relevant because greenhouse installations may involve sensors positioned at different points and may require different wiring and communication arrangements.

A Raspberry Pi single-board computer is used as the server-side platform in the described implementation. The monograph outlines a software environment in which sensor data are received through MQTT, processed by a Python-based web application and stored in a MariaDB database. Flask is used to organise the web application and its routes, while the database stores readings together with identifying and time-related fields. The described configuration also uses Apache-related components for deploying the web application and SSH for remote administration [1].

MQTT is used as a lightweight messaging protocol for communication between the greenhouse controller and the server. In the described arrangement, the controller publishes sensor information to designated topics, while the server-side client subscribes to those topics and processes incoming messages. This publish–subscribe model separates the production of sensor readings from the application that receives them. It also provides a flexible basis for adding further sensors or monitoring points, provided that topic names, message formats and data validation rules are kept consistent.

The control logic is based on user-defined thresholds and operating modes. In automatic mode, the controller compares current readings with preset values and activates the corresponding equipment when a condition is met. In manual mode, the user issues commands through the web interface. The design described in the monograph includes relays for switching lighting, irrigation and heating, as well as a mechanism for opening and closing ventilation openings. The system also allows the user to view the measurements remotely through a browser on a computer or mobile device.

The development process described in the source includes circuit preparation in Fritzing and system development and emulation in Proteus 8.5. These tools support the design and preliminary checking of circuit connections and control logic. Such virtual work is useful for identifying configuration problems before physical assembly, but it should not be confused with validation in a working greenhouse. Real operating conditions introduce issues such as sensor placement, calibration, electrical noise, network interruptions, actuator response and environmental variation.

ANALYSIS AND RESULTS

System architecture and hardware configuration. The proposed system is organised around a simple operational sequence: sensors measure the greenhouse environment; the NodeMCU receives the measurements; the controller applies the programmed logic; and the data are forwarded to the server for storage and remote viewing. Where the control algorithm requires an intervention, the controller switches the relevant relay or actuator. This arrangement keeps time-sensitive local actions close to the greenhouse while allowing the user to examine the system remotely.

The choice of NodeMCU ESP8266 is consistent with the project's emphasis on a compact and relatively accessible platform. The board integrates Wi-Fi and provides general-purpose input/output pins for connecting peripheral devices. It can therefore serve as a practical interface between sensors, relays and the remote monitoring environment. The Raspberry Pi has a different role: it provides a more capable platform for database management, message handling and web-based presentation. Using these two devices in complementary roles avoids placing every task on a single microcontroller.

The sensor arrangement is central to the usefulness of the system. A temperature value taken at one point cannot necessarily represent conditions throughout a large greenhouse, and a soil-moisture reading is

meaningful only in relation to the sensor's position, soil properties and the crop's root zone. For this reason, the number and placement of sensors should be selected according to the dimensions of the greenhouse and the characteristics of the crop. The monograph discusses the use of different measuring instruments and the need to consider the suitability of the data they provide [1].

Data exchange, storage and remote monitoring. MQTT provides the communication link between the microcontroller and the server-side application. Once a message reaches the broker, the subscribed client can process the incoming data and pass it to the web application and database. The database structure described in the monograph records the monitoring board, the date and time of receipt, and the measured value. Separate tables are used for different sensor data, allowing measurements to arrive at different intervals and leaving room for later extension [1].

The web interface gives the user access to current and previously recorded measurements. It is not merely a display layer: the source describes the possibility of using the interface to change selected parameters and to control the greenhouse in manual mode. This distinction matters in practice. Monitoring helps a grower understand what is happening, while control provides a means of responding. Combining both functions in one interface can make the system easier to use, although access rights and safeguards are needed to prevent unintended operation.

Automated control of greenhouse conditions. The control strategy described in the monograph uses upper and lower thresholds for temperature and light. When the temperature rises above the specified upper limit, the system can open ventilation openings and activate cooling-related equipment. When the temperature falls below the lower limit, the heating relay can be activated. Humidity management is linked to a user-defined threshold: when the measured level falls below the set value, the irrigation system is switched on and remains active until the required condition is restored. Lighting is controlled through preset limits, allowing artificial light to be switched on or off according to the measured illumination [1, 8].

This threshold-based approach is understandable and relatively straightforward to implement. It also makes the control rules visible to the user. At the same time, fixed thresholds are not a complete substitute for agronomic decision-making. Different crops and growth stages may require different conditions, and a single sensor reading may not capture the distribution of temperature or moisture across the greenhouse. The control parameters should therefore be selected for the crop being cultivated and reviewed by a qualified specialist. Where the system is expanded, hysteresis, minimum operating times and fault-handling rules may help reduce frequent switching and unintended actuator activity.

Development, testing and practical limitations. The source describes the preparation of circuit diagrams in Fritzing and the use of Proteus 8.5 for system development and virtual testing. It also reports the preparation of software for processing digital and analogue signals and signals received through the I²C bus [1]. These steps demonstrate that the project considered both hardware connections and software behaviour. However, the available description does not provide a controlled field-trial dataset, a comparison with a conventional greenhouse, or measured percentage changes in yield, water consumption, labour or energy use. Such numerical claims should not be added to the article without further experimental evidence.

Several practical issues deserve attention before deployment. First, sensors need calibration and periodic inspection; readings can drift or be affected by their installation position. Second, wireless communication and server availability should not become single points of failure for essential local control. The greenhouse controller should retain a safe local operating mode if the Internet connection is interrupted. Third, relay-controlled equipment must be selected and installed with appropriate electrical protection. Finally, the system's dependence on a stable power supply should be considered. The monograph itself identifies energy dependence as an important limitation and notes that backup power does not necessarily cover high-consumption equipment such as lamps or fans [1].

Despite these limitations, the architecture offers a useful foundation for small and medium-sized greenhouse monitoring. It brings together relatively accessible hardware and open software components, while leaving room for additional sensors, monitoring points and control rules. Its practical value will depend on careful installation, crop-specific configuration and testing under real operating conditions. A next stage of work should therefore include sensor calibration, a pilot installation, logging over a full growing period and a comparison of system records with independent measurements.

CONCLUSIONS AND RECOMMENDATIONS

An IoT-based greenhouse monitoring and control system can connect environmental measurement, local automation and remote observation within a single technical arrangement. The architecture examined in this article uses NodeMCU ESP8266 for sensor acquisition and local control, Raspberry Pi for server-side

processing, MQTT for message exchange, MariaDB for data storage and a Flask-based web interface for monitoring and user interaction.

The described control logic supports the management of ventilation, irrigation, heating and lighting according to preset environmental thresholds, while manual mode allows the user to intervene through the web interface. The use of Fritzing and Proteus 8.5 forms part of the design and preliminary virtual testing process. These steps provide a basis for further development, but they do not by themselves establish the system's effectiveness in commercial greenhouse conditions.

The main conclusion is that the proposed arrangement is a technically coherent starting point for remote greenhouse monitoring. Its performance should next be assessed through field trials that examine sensor accuracy, communication reliability, actuator behaviour, power continuity and crop-specific control settings. Only after such testing would it be appropriate to quantify any effects on productivity, water use, energy consumption or labour requirements.

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