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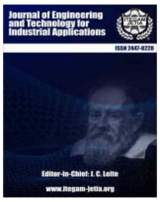

RESEARCH ARTICLE OPEN ACCESS

IOT-BASED REAL TIME GREENHOUSE MONITORING AND CONTROLLING SYSTEM

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ABSTRACT

With the ongoing rise of social and economic levels, as well as people's living standards, the demand for out-of-season vegetables and fruits has increased in recent years. Nowadays, advanced scientific technologies are increasingly applied to traditional agricultural production. With the aid of Internet of Things (IoT) applications, intelligent greenhouses have helped cultivate growth. Intelligent greenhouses can produce a proper growing environment for crops, improve crop yields and quality, and achieve efficient production output. Temperature, humidity, and other elements are the key factors impacting crop development in greenhouses; how to effectively measure and control these environmental parameters is critical for farmers. In this study, an IoT-based, low-cost, intelligent agricultural production environment monitoring system is designed and developed. This system could monitor interior ambient temperature and humidity in real-time through the DHT22 sensor. Besides, monitored sensor data is uploaded and stored on the ThingSpeak cloud platform. In addition, a fan and a heating panel are utilized to control the inside environment. The results showed that the environment would be constantly adjusted and maintained at an ideal level for crop growth.

I. INTRODUCTION

By 2030, the global population is expected to reach 8.6 billion, posing a significant challenge to adequate meat production and provision [1]. Due to world population expansion, industrialization, urbanization, climate change, and environmental pollution, agricultural land is continuously contaminated and decreasing. This results in new challenges to food supply and food security in the future [2]. The greenhouse is an emerging farming method that allows the environment to be controlled at a suitable level for crops to grow rapidly, in contrast with traditional planting methods [3]. The greenhouse is also called a controlled environment plant production system or controlled environment agriculture. With the development of agricultural facilities, greenhouses are becoming more critical to agricultural production. The use of greenhouses effectively reduces the harsh environment brought about by the external environment on the growth of agriculture and is one of the most effective ways to reduce the growth cycle and improve the yields of agriculture production. A greenhouse also reduces the amount of water and pesticides needed for crop production, as well as minimizing labor costs. Additionally, greenhouses can be used to grow crops year-round, allowing for a more consistent supply of fresh produce. In traditional farming, vegetables and fruits are prone to diseases, pesticides are sprayed, and pesticide residues harm human health. By contrast, in the smart greenhouse, pesticides could be reduced or even avoided [4].

Traditionally, greenhouse planting management has been based primarily on experience. There is a low degree of intelligence, one cannot effectively measure and control the growth environment, there is a high labor input, a low level of labor efficiency, and a serious waste of resources, among other issues. With the utilization of intelligent computing technology in the agriculture field, the intelligent agriculture revolution came about. More and more countries are eager to construct modern, intelligent agriculture systems empowered by technology. Industry managers and scholars have drawn attention to intelligent agriculture systems as intelligent computing technologies have been rapidly developed and applied widely in recent years. Well-managed and controlled agriculture is more efficient, reliable, and cost-effective [5].

The use of intelligent monitoring and control systems could reduce the amount of time and manpower consumed by production. Providing farmers with more accurate and intelligent information allows them to make more informed decisions [6]. As the global economy and modern technology are developing rapidly, modern agriculture has also begun to gradually develop in the direction of intelligence. A variety of agricultural facilities are used to create a favorable environment for the growth of crops, among which smart greenhouses have become an important part of agricultural farming. At present, the degree of automation in traditional crop greenhouses is low, and the technology used to gather environmental data is relatively backward. The application of greenhouse has accelerated since modern technological developments like the big data, IoT, and machine learning [7-10].

Farmers could monitor the greenhouse in real-time remotely in the Industry Revolution (IR) 4.0 era. This allowed for greater efficiency in crop production as well as better use of resources. Automation in greenhouses has also been made smarter by artificial intelligence (AI), helping farmers save time and reduce costs [11]. As science and technology have advanced gradually, the imperative need for innovative solutions and emerging technologies to increase agricultural production efficiency has led to the implementation of IoT applications [12]. IoT technology plays a crucial role in precision agriculture management. IoT makes agriculture management more efficient, and all related data could be visualized and controlled as well. By 2030, the development and deployment of IoT technology in agriculture would create about a $500 billion increase in GDP.

Farmers are able to take proactive steps to maximize their yields and minimize their losses [13]. As IoT technology becomes more popular in the modern world, it is utilized in a variety of fields of human life, including industry, healthcare, transportation, and agriculture. The greenhouse sector is facing new opportunities for productivity and efficiency improvement as a result of new technologies [14]. There are some other benefits of using IoT technology in the greenhouse field, such as reducing costs, increasing efficiency, improving product quality, easy resource management, aiding in disease and pest control, and enabling sustainable production [15].

Various communication methods are used to transmit data from sensors to user interfaces (UI) and controllers, such as wired communication, Controller Area Network (CAN), Bluetooth, General Packet Radio System (GPRS), System for Mobile Communications (GSM), and wireless networks [16]. The data collection, analysis, transmission, and control of greenhouse environmental parameters are of substantial significance in guiding agribusiness production and improving agricultural modernization. At present, most greenhouse control methods are achieved through short-distance communication, the sensor signal acquisition to the control host, the control host, and the host computer for communication, and through the host computer to realize the control information feedback regulation [17]. Temperature is one of the most significant factors that affects the growth and productivity of indoor agriculture [18].

Agriculture production requires environmental variables such as humidity, soil moisture, temperature, and carbon dioxide concentration to be at a suitable level. Monitoring these parameters is essential for optimal crop growth. Automated systems can be used to monitor these environmental parameters and adjust them accordingly. This can help to ensure optimal crop growth and reduce the risk of crop loss [19]. The gases emitted from the greenhouse affect the inside environment and further influence the growth of internal plants, animals, and even human health. Therefore, it is necessary to maintain the greenhouse environment at an optimal level continuously and dynamically so that it facilitates healthy growth [20].

Technological advancements are critical in agricultural engineering, especially in greenhouses. These structures change the environment, allowing plants to be better managed and produce better outcomes. whereas there is still limited use of sophisticated IoT infrastructure in the agriculture industry, resulting in low production yields and profits [21].

II. THEORETICAL REFERENCE

IoT technologies are applied in the greenhouse field to revolutionize and facilitate management solutions. It has been proven that the deployment of IoT in the greenhouse could improve production efficiency and profits. In this section, the latest work has been explained based on the communication methods between sensor data and user interfaces and controllers.

II.1 Wireless communication

According to [22] proposed a low-cost, high-efficiency climatic behavior detection system based on the ESP8266 Node MCU microcontroller. This system could monitor the inside temperature, light intensity, content of soil water, and humidity in the greenhouse. Furthermore, water pumps, motors, lighting systems, and exhaust systems were utilized in order to automate the process. Farmers could access acquired data on their smartphones through wireless internet connections. For [23] developed an IoT-based intelligent hydroponic greenhouse system. In this system, Arduino Mega was used as the microcontroller, and DHT11, DS18B20, LDR module, and Ph4502C were incorporated to acquire humidity, temperature, light intensity, and water PH correspondingly. The collected data would be transmitted to the ThingSpeak cloud via ESP8266 wireless communication. And the data could be visualized on a smartphone APP through the Internet. Apart from that, relays and pumps were used to automatically control it to maintain the predefined environmental condition. The results showed that the system could ease farmers' workload and improve overall production. According to [24] proposed an intelligent IoT-based greenhouse system. Node MCU was used as the microcontroller, and DHT11 and LDR sensors were utilized to collect temperature, humidity, and brightness concentrations. The monitored data could be accessed through a Blynk application (APP) on mobile phones or via the Internet. Based on the collected data, a DC fan, DC motor, and bulb were used to adjust the environment.

This system could be deployed in real greenhouses to improve yield and save power as well. According to [25] demonstrated an illumination monitoring and automatic control system for the greenhouse. A Raspberry Pi 3 was used as the main microcontroller, allowing uniform lighting and satisfying plants' needs. With the help of Python and MySQL, the microcontroller extracted the values of nine light-sensitive TSL2561 sensors and stored them in a local database. A web application was created for accessing the data and remotely controlling the light intensity. Brightness management was autonomous or manual, using sensor data or user-chosen manual control. This IoT-based system optimizes lighting energy in greenhouses, reducing energy costs and improving tomato productivity and quality. The solar source could be used to supply power to the intelligent greenhouse system. In this way, it can reduce costs by reducing its reliance on power demand. Nouadjep et al. proposed a smart greenhouse monitoring and control system for year-round crop production using an

Arduino Mega controller. The system consisted of different sensors to gather room environment parameters like temperature, humidity, light intensity, soil humidity, and PH value. It also had a solar system to provide power for the whole system. Furthermore, an Android application allows displaying and analyzing parameters through the Internet. The system could reduce the exploitation of farm land and improving agricultural yields [26].

II.2 Wired Network

An intelligent sensor network prototype for an automated urban greenhouse (AUG) was proposed based on an Arduino Pro microcontroller, which enabled automatic monitoring and control of heating, illumination, ventilation, and watering. Adafruit AM2302, Adafruit TSL2591, and Decagon Devices 10HS sensors were utilized for environmental humidity, temperature, soil water concentration, and light intensity parameter collection. The gathered data could be viewed from a web-based application via an Ethernet network [27].

II.3 Bluetooth

Intelligent agriculture could solve global and regional agricultural issues. This research examined smart greenhouse agriculture using IoT technologies. A climate-programmed smart greenhouse prototype was built using an Arduino microcontroller. Environmental humidity and temperature, soil moisture, and illumination intensity were monitored and controlled. The smartphone-based application could be used to visualize and remotely control the greenhouse via an HC-06 Bluetooth connection. A test was conducted to compare the efficacy of traditional plant methods and smart plant methods in the same greenhouse. The results show that the smart greenhouse was proven to improve cucumber, tomato, pepper, and begonia growth. The smart greenhouse system saved 16.5% more water than the pot, and its manual and autonomous operation made greenhouse management easier [28].

II.3 GSM

Aafreen, R. *et al.* [29] implemented a novel industrial greenhouse monitoring and control system based on IoT technology, utilizing the Blynk IoT platform. An Arduino Mega 2560 board was used as the main microcontroller. EVANA SM12, BH1750, and MQ135 sensors were employed to monitor soil water content, ambient light intensity, and CO_2 content, respectively. The system provided wireless data transmission in real-time, data visualization, and analysis on the central server of the ThingSpeak cloud. The fast and lightweight Blynk IoT platform was used for message transmission on the mobile app and control through GSM communication, enabling real-time irrigation needs. The experimental results demonstrated the system's effectiveness in energy-efficient smart farming in greenhouses. According to [30] presented an IoT-based intelligent greenhouse real-time monitoring and automatic control data logger system. Built-in sensors to monitor soil moisture, indoor temperature, humidity, carbon dioxide concentration (Co_2), air pressure, soil pH value, illumination, and water level. A microcontroller to collect sensor data and send action commands. As part of the system, the GSM module and the GPRS communication protocol enabled wireless Internet access and data transmission. Implementing this smart agriculture service on the property enabled autonomous greenhouse control and increased production and efficiency.

The remaining of this writing is broken into the following parts: Section II is a literature review that summarizes the latest smart greenhouse-associated studies. Section III describes the required devices and experiment steps. Section IV discusses the results of this study. Section V summarizes the conclusion and future scope.

III. MATERIALS AND METHODS

Applications based on the Internet of Things tend to make everything convenient and intelligent. In this undertaking, a smart, low-cost greenhouse real-time monitoring and control system is conceived and developed for agricultural planting. This section describes the system architecture and experimental prototype buildup for this research project.

III.1 System Architecture

An intelligent agriculture environment monitoring system was developed to monitor the environmental temperature and humidity of the greenhouse. It adjusts the environment to an optimal level so that plants' health and growth can be maintained. In this system, there are six main workflow stages, including data gathering, data processing, data storage, data analysis, data response, and data visualization. Firstly, data collection involves collecting temperature and humidity values through a DHT22 sensor attached to a microcontroller. Then, data pre-processing is used to remove incomplete and invalid data gathered from the sensor. After that, the collected data is analyzed to check whether they are in a normal range or not at the data analysis stage. Following that, the data is uploaded and stored in the ThingSpeak cloud through the Internet. Next, stored data could be retrieved and visualized remotely by users through a smartphone or a webpage with an Internet connection. In the last, based on the results of data analysis, the corresponding electrical devices may be triggered to adjust and maintain the plant's growth environment. If the humidity or temperature is high, the ventilation fan will turn on automatically until it drops to a normal level. If the temperature is low, the heater will be turned on until it reaches normal. Besides, if environmental parameters are abnormal, an alarm would be triggered to alert farmers. The system can provide insight into the environment and suggest optimized strategies for improving crop growth. The proposed system architecture of this research project is illustrated in Figure 1.

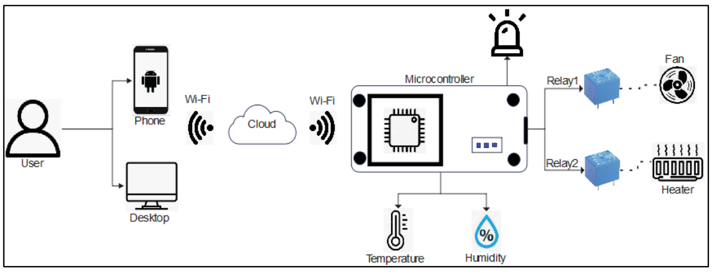


Figure 1: Proposed System Architecture.
Source: Authors, (2024).

III.2 Experimental Setup

In this project, the NodeMCU ESP8266 is utilized as the primary microcontroller to control sensors and electrical devices via relays. It is a low-cost and cheap tool for developing IoT applications. In the programming part, the Arduino IDE is used to write the code. The ESP8266 environment is chosen for firmware development. The NodeMCU ESP8266 is programmed to communicate with the sensors, actuators, and central server. It also monitors the system to ensure it works as expected. The gathered data is transmitted to the server for further analysis. The diagram of NodeMCU is shown in Figure 2.

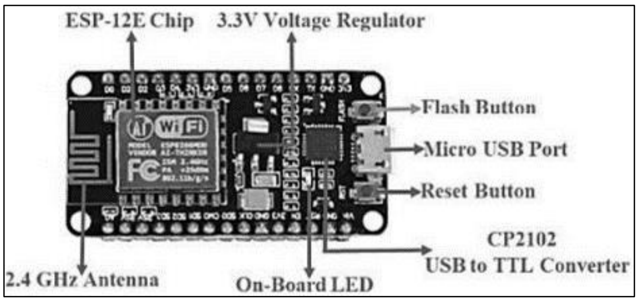


Figure 2: ESP8266 microcontroller.
Source: Sunidhi Goel, (2022).

As the module for detecting humidity and temperature, the DHT22 sensor is utilized. There are four pins: DATA, VCC, GND, and NC. The standard voltage range for VCC is between 3 volts and 5 volts. The DHT22 sensor measures humidity and temperature values through an integrated capacitive humidity sensor and thermistor. Through the DATA port, data is transmitted to the microcontroller. The maximum operational current is 2.5 mA. Figure 3 illustrates the DHT22 picture.

Figure 3: DHT22 sensor.
Source: Malika, N. Z., (2021).

A dual-channel relay is utilized to connect a fan and a heater so that they can be triggered later to maintain the ambient environment at a suitable level dynamically and constantly. This allows for efficient energy savings while providing optimal temperature and airflow. The dual-channel relay can be programmed to respond to changes in humidity and temperature, ensuring the environment is always kept at the desired level. It is utilized as a bridge to connect the controller to the heater panel and fan. The dual-channel relay diagram is shown in Figure 4.

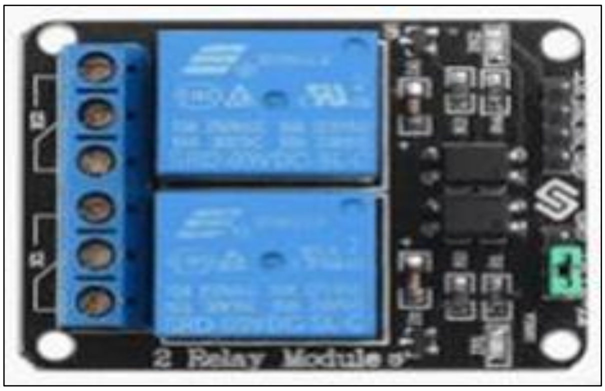


Figure 4: Dual-channel relay.
Source: Y. Liu, (2022).

The 16x2 LCD display is utilized to indicate the current monitoring parameter values. In addition, a buzzer is directly connected to the microcontroller. The connection diagram of different modules is described in Figure 5.

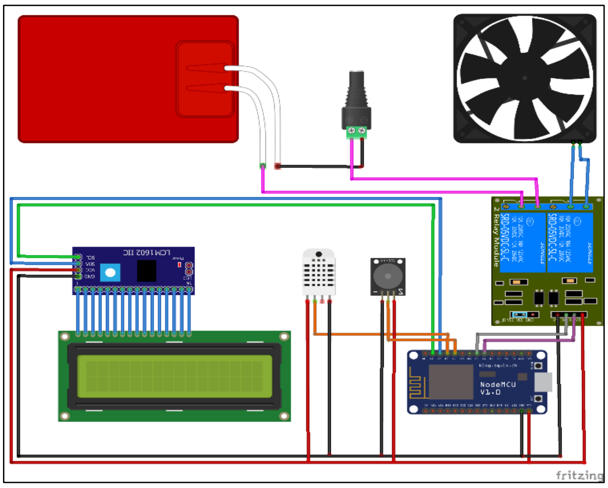


Figure 5: System scheme.
Source: Authors, (2024).

The control flowchart of the proposed system is depicted in Figure 6. The procedure begins with system initialization, and then the microcontroller collects temperature and humidity data from the greenhouse. The data obtained by the DHT22 sensor will be processed further by the ESP8266 microcontroller and displayed on the LCD panel. The parameters will be checked by the microcontroller based on two situations. First, determine whether the temperature is less than 20 degrees Celsius; if so, a signal will be sent to relay 1 to activate the heating panel. Otherwise, no action will be taken. Second, determine whether the temperature is above 40 degrees Celsius or the humidity is above 80%. If this is the case, the activation signal will be delivered to relay 2 to activate the fan and speed up the ventilation process until the parameters return to normal. As a result, the greenhouse atmosphere can be dynamically modified within a preset range.

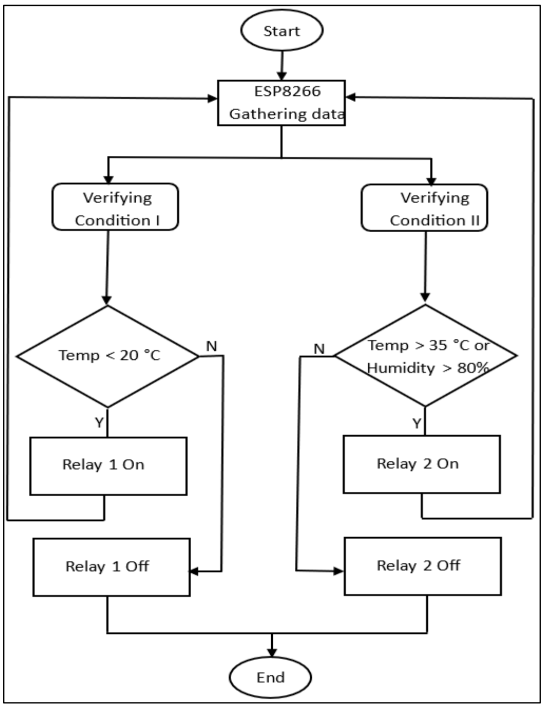


Figure 6: Flowchart of control.
Source: Authors, (2024).

The proposed system prototype is designed and built, as demonstrated in Figure 7.

Figure 7: Prototype of proposed system.
Source: Authors, (2024).

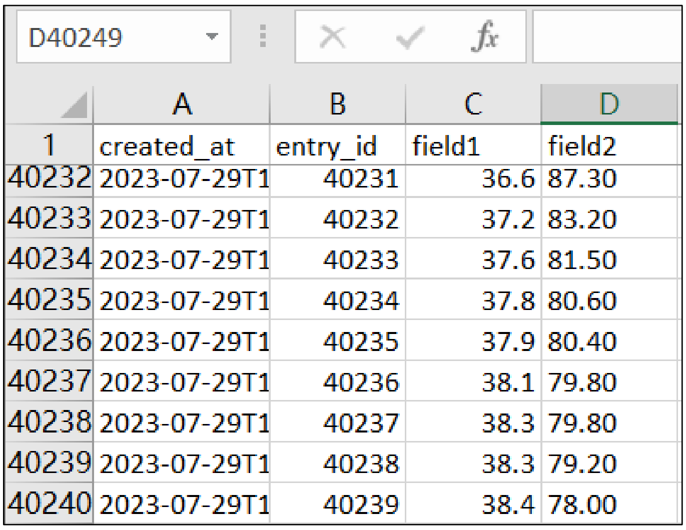
Overall, the system was developed to provide real-time ambient monitoring and automatic maintenance of the environment, which can facilitate plant growth and reduce farmer workload. The system is equipped with a temperature and humidity sensor to measure environmental conditions. The data collected from the sensor is then sent to the ThingSpeak cloud for storage and further analysis. The ESP8266 microcontroller acts as the brain of the proposed system, processing sensor data and controlling the other components. The ThingSpeak APP provides a user-friendly interface for interacting with the system, and the ESP8266 connects the system to the internet. An I2C interface connects the LCD display to the microcontroller. Two 18650 batteries are used as a power supply to deliver power to the system. Furthermore, a small greenhouse is constructed to test and verify the proposed system. The planting box measures 60 inches in height, 25 inches in width, and 30 inches in length. The planting box is placed on a shelf made of aluminum. In addition, four wheels are installed to facilitate movement. The indoor ambient temperature and humidity are monitored to ensure an optimal environment for the plants. Figure 8 shows the constructed greenhouse.

Figure 8: Constructed greenhouse.
Source: Authors, (2024).

Additionally, a light lane is used to provide adequate light for the plants to perform photosynthesis. The temperature and humidity in the greenhouse are closely monitored and controlled to simulate the environment of the actual growing space. With this setup, the performance of the prototype is evaluated to ensure it meets the desired requirements.

IV. RESULTS AND DISCUSSIONS

The collected data is uploaded and stored in the ThingSpeak cloud via a wireless network using a specific channel identification number. The stored data is not only directly retrieved using an HTTP request but can also be exported to a CSV format file, as shown in Figure 9.



D40249

	A	B	C	D
1	created_at	entry_id	field1	field2
40232	2023-07-29T1	40231	36.6	87.30
40233	2023-07-29T1	40232	37.2	83.20
40234	2023-07-29T1	40233	37.6	81.50
40235	2023-07-29T1	40234	37.8	80.60
40236	2023-07-29T1	40235	37.9	80.40
40237	2023-07-29T1	40236	38.1	79.80
40238	2023-07-29T1	40237	38.3	79.80
40239	2023-07-29T1	40238	38.3	79.20
40240	2023-07-29T1	40239	38.4	78.00

Figure 9: Data storage in CSV format.
Source: Authors, (2024).

The monitoring data could be accessed not only through the smartphone APP but also on the ThingSpeak webpage with an Internet connection. Figure 10 shows the real-time monitoring results of the greenhouse on the webpage.

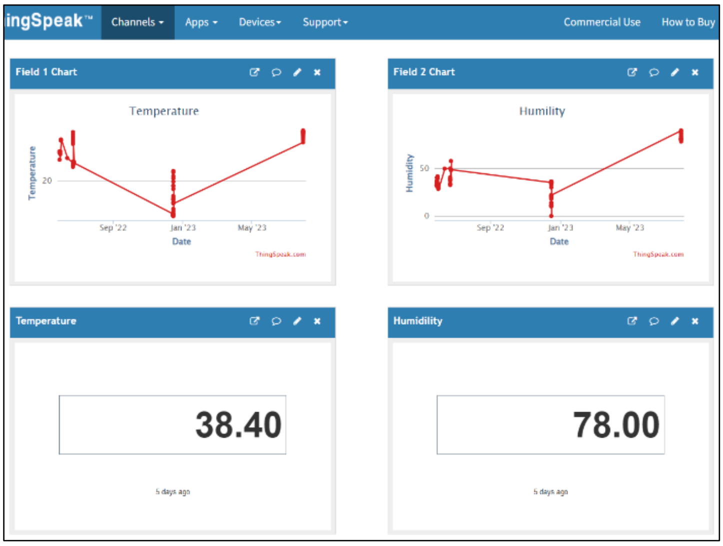
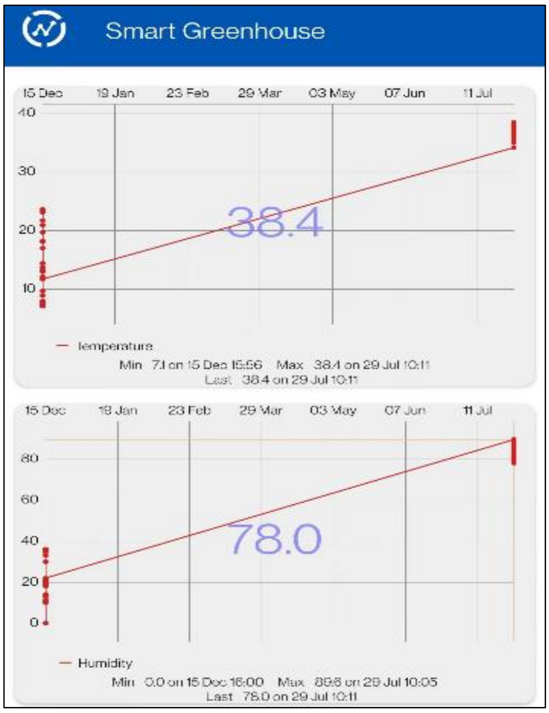


Figure 10: Webpage interface.
Source: Authors, (2024).

On this page, temperature and humidity parameter values are displayed in a line diagram. The current values are also displayed below the diagram. Besides, the smartphone application provides the ability to access real time monitoring results by using a particular channel ID via the network, as seen in Figure 11.



Min 7.1 on 15 Dec 15:56 Max 38.4 on 29 Jul 10:11
Last 38.4 on 29 Jul 10:11

Min 0.0 on 15 Dec 16:00 Max 89.8 on 29 Jul 10:05
Last 78.0 on 29 Jul 10:11

Figure 11: Phone interface.
Source: Authors, (2024).

The cloud data is reloaded every fifteen seconds. The inside environment of the greenhouse is controlled and maintained at an appropriate level that has been predetermined.

V. CONCLUSIONS

With the rapid development and deployment of modern science and technology in agriculture, as well as the increasing level of automation, intelligent greenhouse is becoming more and more popular in agricultural cultivation. Most traditional agricultural greenhouses rely on manual control, and their production efficiency is low. In this research, an IoT-based, low-cost intelligent greenhouse management system is designed and implemented to regulate the internal environment of the greenhouse and create an optimal growing environment for crops. In future work, more environmental monitoring parameters like light intensity, soil moisture, and carbon dioxide concentration may be further considered. Solar panels could be used as a source of power to save energy. Apart from that, machine learning technology could be applied to data analysis and predictions. Predictive analytics could forecast future weather and climatic changes. An alert system could be implemented to alert farmers of any potential weather changes. Finally, the data collected can be used to inform agricultural policy decisions and better manage natural resources.

VI. AUTHOR'S CONTRIBUTION

Conceptualization: Liu Yajie.
Methodology: Md Gapar Md Johar and Asif Iqbal Hajamydeen.
Investigation: Liu Yajie and Md Gapar Md Johar.
Discussion of results: Liu Yajie, Md Gapar Md Johar and Asif Iqbal Hajamydeen.
Writing – Original Draft: Liu Yajie.
Writing – Review and Editing: Liu Yajie, Md Gapar Md Johar and Asif Iqbal Hajamydeen.
Resources: Md Gapar Md Johar.
Supervision: Md Gapar Md Johar and Asif Iqbal Hajamydeen.
Approval of the final text: Liu Yajie, Md Gapar Md Johar and Asif Iqbal Hajamydeen.

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VIII. REFERENCES

[1] F. Oecd, "OECD-FAO agricultural outlook 2022-2031," 2022, doi: https://doi.org/10.1787/f1b0b29c-en.

[2] B. Ahmad *et al.*, "Evaluation of smart greenhouse monitoring system using raspberry-Pi microcontroller for the production of tomato crop," *Journal of Applied Research in Plant Sciences*, vol. 4, no. 01, pp. 452-458, 2023, doi: https://dx.doi.org/10.5935/2447-0228.20200001.

[3] P. Srihari and M. Vibha, "A STUDY ON USE OF IOT TECHNOLOGY IN GREENHOUSE FARMING."

[4] R. Geethamani and S. Jaganathan, "IoT Based smart greenhouse for future using node MCU," in *2021 7th International Conference on Advanced Computing and Communication Systems (ICACCS)*, 2021, vol. 1: IEEE, pp. 1615-1620, doi: https://doi.org/10.1109/ICACCS51430.2021.9441708.

[5] H. Zhang and L. Zhang, "A Reliable Data-Driven Control Method for Planting Temperature in Smart Agricultural Systems," *IEEE Access*, vol. 11, pp. 38182-38193, 2023, doi: https://doi.org/10.1109/ACCESS.2023.3267803.

[6] Y. Ji, "Design and Implementation of Monitoring and Controlling System for Greenhouse Plantation."

[7] F. J. Adha, M. G. M. Johar, M. H. Alkawaz, A. I. Hajamydeen, and L. Raya, "IoT based Conceptual Framework for Monitoring Poultry Farms," in *2022 IEEE 12th Symposium on Computer Applications & Industrial Electronics (ISCAIE)*, 2022: IEEE, pp. 277-282, doi: https://doi.org/10.1109/ISCAIE54458.2022.9794471.

[8] F. J. Adha, R. Ramli, M. H. Alkawaz, M. G. M. Johar, and A. I. Hajamydeen, "Assessment of Conceptual Framework for Monitoring Poultry Farm's Temperature and Humidity," in *2021 IEEE 11th International Conference on System Engineering and Technology (ICSET)*, 2021: IEEE, pp. 40-45, doi: https://doi.org/10.1109/ICSET53708.2021.9612437.

[9] N. Z. Malika, M. G. M. Johar, M. H. Alkawaz, A. I. Hajamydeen, and L. Raya, "Temperature & humidity monitoring for poultry farms using IOT," in *2022 IEEE 12th Symposium on Computer Applications & Industrial Electronics (ISCAIE)*, 2022: IEEE, pp. 76-81, doi: https://doi.org/10.1109/ISCAIE54458.2022.9794520.

[10] N. Z. Malika, R. Ramli, M. H. Alkawaz, M. G. M. Johar, and A. I. Hajamydeen, "IoT based Poultry Farm Temperature and Humidity Monitoring Systems: A Case Study," in *2021 IEEE 9th Conference on Systems, Process and Control (ICSPC 2021)*, 2021: IEEE, pp. 64-69, doi: https://doi.org/10.1109/ICSPC53359.2021.9689101.

[11] K. Fatima, S. Hussain, S. A. Khan, M. A. Khan, S. R. Saleem, and S. Kanwal, "Digital Twin Greenhouse Technologies for Commercial Farmers," *Environmental*

Sciences Proceedings, vol. 23, no. 1, p. 33, 2023, doi: https://doi.org/10.3390/environsciproc2022023033.

[12] V. K. Quy *et al.*, "IoT-enabled smart agriculture: architecture, applications, and challenges," *Applied Sciences*, vol. 12, no. 7, p. 3396, 2022, doi: https://doi.org/10.3390/app12073396.

[13] C. Maraveas, D. Piromalis, K. Arvanitis, T. Bartzanas, and D. Loukatos, "Applications of IoT for optimized greenhouse environment and resources management," *Computers and Electronics in Agriculture*, vol. 198, p. 106993, 2022, doi: https://doi.org/10.1016/j.compag.2022.106993.

[14] A. Kudratov, "INTERNET OF THINGS AS A TOOL FOR OPTIMIZING PROCESSES IN AGRICULTURE," *Modern Science and Research*, vol. 2, no. 6, pp. 813-818, 2023, doi: https://doi.org/10.5281/zenodo.8041353.

[15] P. Cihan, "IoT Technology in Smart Agriculture," in *International Conference on Recent Academic Studies*, 2023, vol. 1, pp. 185-192, doi: http://dx.doi.org/10.59287/icras.693.

[16] V. Lavanya, B. SriLatha, B. B. Sesank, S. Harshavardhan, and M. S. Shahsavara, "GREENHOUSE MONITORING AND CONTROLING USIN IOT," *IJETMS*, vol. 6, no. 4, pp. 79-81, July, 2022, doi: http://dx.doi.org/10.46647/ijetms.2022.v06si01.015.

[17] J. Zhao, S. Liu, and Z. Qiao, "Research and Implementation of Android-based Intelligent Greenhouse Environment Measurement and Control System," *Jiangsu Agricultural Science*, vol. 3, no. 44, pp. 394-397, 2016.

[18] Z. Guo, Y. Shen, S. Wan, W.-L. Shang, and K. Yu, "Hybrid intelligence-driven medical image recognition for remote patient diagnosis in internet of medical things," *IEEE journal of biomedical and health informatics*, vol. 26, no. 12, pp. 5817-5828, 2021, doi: https://doi.org/10.1109/JBHI.2021.3139541.

[19] J. Lv, W. Kong, Y. Shi, and H. Bao, "Design of Intelligent Greenhouse Management and Control System," *International Core Journal of Engineering*, vol. 7, no. 1, pp. 230-232, 2021, doi: https://doi.org/10.6919/ICJE.202101_7(1).0030.

[20] F. A. Akomaye, E. I. Etim, and E. J. Ekanem, "Importance of Smart Farming Practices for Sustainable Agriculture," *International Contemporary Journal of Science Education and Technology*, vol. 2, no. 2, 2023.

[21] G. Gebresenbet and S. A. Finecomess, "Assessment of the Smart Mechatronics Application in Agricultural: A Review," *Appl. Sci.*, no. 13, 2023, doi: https://doi.org/10.20944/preprints202305.0169.v1.

[22] J. Sujin, R. Murugan, M. Nagarjun, and A. K. Praveen, "IOT based greenhouse monitoring and controlling system," in *Journal of Physics: Conference Series*, 2021, vol. 1916, no. 1: IOP Publishing, p. 012062, doi: 10.1088/1742-6596/1916/1/012062.

[23] A. C. H. Austria, J. S. Fabros, K. R. G. Sumilang, J. Bernardino, and A. C. Doctor, "Development of IoT Smart Greenhouse System for Hydroponic Gardens," *arXiv preprint arXiv:2305.01189*, 2023, doi: https://doi.org/10.48550/arXiv.2305.01189.

[24] S. Goel, N. Tyagi, A. Yadav, S. Goel, and G. Gupta, "Greenhouse Monitoring & Control System using Node MCU ESP 8266," in *IPEC*, 2022, vol. 1, p. 02.

[25] A. Belkadi, D. Mezghani, and A. Mami, "IoT and lighting control for smart greenhouse," *Zenodo.*, vol. 3813434, 2019, doi: http://doi.org/10.5281/zenodo.

[26] S. N. Nouadjep and H. F. Djouodjinang, "IoT and Arduino Based Design of a Solar, Automated and Smart Greenhouse for Vegetable," in *E3S Web of Conferences*, 2022, vol. 354: EDP Sciences, p. 01002, doi: https://doi.org/10.1051/e3sconf/202235401002.

[27] K. Meah, J. Forsyth, and J. Moscola, "A smart sensor network for an automated urban greenhouse," in *2019 international conference on robotics, electrical and signal processing techniques (ICREST)*, 2019: IEEE, pp. 23-27, doi: https://doi.org/10.1109/ICREST.2019.8644079.

[28] P. Kirci, E. Ozturk, and Y. Celik, "A novel approach for monitoring of smart greenhouse and flowerpot parameters and detection of plant growth with sensors," *Agriculture*, vol. 12, no. 10, p. 1705, 2022, doi: https://doi.org/10.3390/agriculture12101705.

[29] R. Aafreen, S. Y. Neyaz, R. Shamim, and M. S. Beg, "An IoT based system for telemetry and control of Greenhouse environment," in *2019 International Conference on Electrical, Electronics and Computer Engineering (UPCON)*, 2019: IEEE, pp. 1-6, doi: https://doi.org/10.1109/UPCON47278.2019.8980258.

[30] M. Djordjevic, V. Punovic, D. Dankovic, and B. Jovicic, "Smart autonomous agricultural system for improving yields in greenhouse based on sensor and IoT technology," *Journal of Applied Engineering Science*, vol. 18, no. 4, pp. 606-613, 2020, doi: https://doi.org/10.5937/jaes0-26722.