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Data-driven farming: implementing internet of things for agricultural efficiency

Mohamed Ismail Lafta, Wisam Dawood Abdullah
Department Computer Science, Computer Science and Mathematics College, Tikrit University, Tikrit, Iraq

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ABSTRACT

Integrating internet of things (IoT) technology into agriculture has become essential to address challenges such as low crop productivity, which is often due to insufficient soil nutrients and suboptimal environmental conditions. This paper discusses the design and implementation of an IoT-based system for agriculture that aims to automate key parameters, facilitate real-time monitoring, and promote sustainable practices. Equipped with a graphical user interface (GUI), the system focuses on improving irrigation, regulating temperatures, and correcting soil nutrient deficiencies to improve crop productivity. Our research includes the use of humidity sensors to monitor soil moisture and temperature sensors. Soil nutrient levels, especially nitrogen, phosphorus, and potassium (NPK), were also assessed. We conducted experiments on three radish varieties using this IoT system and compared the results with traditional farming methods. The germination rate was impressive, reaching 98% within the first four days, while in a traditional greenhouse, it did not exceed 50%. As for plant height and leaf area, the smart greenhouse was better. These results were promising and demonstrated the potential of IoT in enhancing agricultural productivity. These results highlight the significant impact of IoT technology in enhancing agricultural productivity and its potential for broader application in this sector.

Corresponding Author:

Wisam Dawood Abdullah
Department Computer Science, Computer Science and Mathematics College, Tikrit University
Tikrit, Iraq
Email: wisamdawood@tu.edu.iq

1. INTRODUCTION

Modern agriculture systems available to land and water are putting growing pressure on food production [1]. It increasingly depends on information and communication technology, especially robotics, cloud computing, sensing technologies, and artificial intelligence internet of things (IoT) [2]. IoT technology has the potential to revolutionize the agriculture filed [3]. The IoT is a global network of connected things [4], [5] that can be uniquely interacted with using popular communication protocols [6], [7]. It's a modern search technology that connects physical items with the digital world, providing a path to the Internet of the future [8]. Sensors and heterogeneous actuators are the key components of the IoT [9]. Recently, the IoT has become one of the top trending technologies, expanding innovation and achieving standardization. It is certainly the opportunity of digital connectivity that has transformed the original human objects into smarter electronic devices [10]. The IoT is a holistic idea that integrates everything [11]. This reality has aided in the creation of smart farming, which monitors crops as they grow with the use of irrigation systems and sensors [12]. Accurate data regarding the crop, soil, and environment could be obtained via sensor-based computer applications. Farmers are still using traditional techniques of agricultural supervision resulting in wastage of inputs and production close to the ground due to inaccurate types and quantities of water used in agriculture [13].

Agriculture can only become self-sufficient through the use of advanced, environmentally solutions and contemporary agricultural techniques necessary to increase productivity and reduce production costs. The unique thing about greenhouse agriculture is that it is effective in natural crop separation and protecting plants from the direct effects of external weather conditions [14]. Microcontrollers facilitate simple and effective job organization and monitoring for the user throughout the smart greenhouse [15]. This centralized system's main characteristic is its ability to monitor and regulate many agricultural system parameters, including humidity of soil, temperature, and nutrient levels in the soil. Recently, many companies have produced hardware devices needed by IoT, like sensors with a communication module and control equipment with self-network ability, this means IoT's main problem is the overall system design and implementation [16], [17].

Many previous studies were reviewed that used IoT technologies in agriculture, including proposed and implemented IoT in smart agriculture or greenhouse use some of this study. Bandara *et al*. [18] proposed a system that collected information from IoT sensors, such as soil moisture, temperature, and water volume sensors. Vandôme *et al.* [19] proposed developing a wireless soil moisture sensor that is open source, low power, and affordable. This inexpensive sensor can be used to track irrigation in real time [19]. Cheruvu *et al.* [20] proposed the implementation of a smart farm using the IoT. The farmer will be able to track plant and soil vitals in real time [20]. Bappa *et al.* [21] proposed to develop and implement an "IoT-based greenhouse monitoring and monitoring system" to track and regulate environmental variables to maintain the ideal climate for small plants inside the greenhouse. Benyezza *et al.* [22] proposed a smart platform based on the IoT for climate and irrigation monitoring and control. Temperature, humidity, and soil moisture were collected and sent to a Raspberry Pi-to process it [22]. Mohabuth *et al.* [23] proposed a completely automation model for greenhouses with all the features it need, including fans, pumps, sensors, and microcontrollers, to provide real-time data for accurate plant growth monitoring. Ali *et al.* [24] proposed to design a smart greenhouse that relies on Arduino to control sensors and IoT components to grow strawberries.

In this paper presents an innovative approach and proposes a new system that can help in the design and implementation of agricultural IoT systems. Electronic circuits and sensors are designed to connect the central control unit (ESP32) to control and provide the ideal atmosphere. In addition, a website has been designed to monitor the operation of the system running on smartphone and computers by using Blynk platforms. A traditional greenhouse and a smart greenhouse were created that can regulate heating and cooling systems and make irrigation automatic, in addition to inquiring about the amount of nutrients present in the soil (nitrogen, phosphorus, and potassium (NPK)). And control the water level in the smart greenhouse tank. The following results will be compared, such as the level of germination, the size of the leaf area, and the plant height rate. The smart homes project is considered one of the most important field agricultural projects in the field of agriculture. It can be used to reduce labor and rationalize water consumption, in addition to knowing soil fertility. This paper has been designed and implemented using ESP32 and sensors. and designed and implemented the software App by using the Blynk platform. The proposed smart greenhouse experiment was conducted in growing radishes, and the results were excellent compared to traditional greenhouses.

2. HARDWARE IMPLEMENTATION

The suggested system's architecture consists of a peer-to-peer connection between separate sensors connected by a shared router [25]. The user will specify the number of sensors present, as this is only limited by the number of sensors present in the "smart greenhouse" [26], [27]. Automated irrigation system: constant observation and soil condition assessment are necessary to sustain crops in good health. As a result, the system records data using several sensors and sends it to the central control system for processing. Depending upon a few variables, like the surrounding temperature, the soil's moisture content, and the proportion of nutrients in the soil [28]–[30]. Figure 1 shows how to connect the electrical circuit of the proposed system in terms of connections to the inputs and outputs. The sensors will be connected to the analog ports and the outputs will be connected to the digital ports of the ESP32 as follows: the first stage is the 5V power supply stage of the ESP32, through which all the IoT components are controlled. When it works, the sensors connected to it are supplied with power, each according to the required power. The data is then read from the sensors and the readings are compared with the ideal values stored in the ESP32, after which a decision is made. To turn the engine on or off, then send the data over the Internet to the Blynk server to provide the app with the data for real-time monitoring and then store a copy of the data for each sensor in a Google Sheet, which is maintained by a pre-set timer. The smart greenhouse is monitored continuously, while storage in Google Sheets depends on the exact storage time. The sensors will be connected to the analog and digital pins of the ESP32 as follows:

First: Soil moisture sensor. The soil moisture sensor is supplied with a voltage of 3.3 volts, and the data received from the sensor is read through the SVP port in the ESP32, and then the reading is compared with the ideal value stored in the ESP32 after which the decision is made whether to turn ON, or OFF. The irrigation actuator from port 13 to the relay that connects to the irrigation system. Second:

temperature sensor. The DHT22 temperature sensor is supplied with a voltage of 3.3 volts, and the data received from the sensor is read through port 25 on the ESP32, and then the reading is compared with the ideal value stored in the ESP32 so that a decision is made if the value is higher or equal to the ideal value in ESP32. A signal is sent to the relay via pin 32 of the ESP32 to turn on the cooling fans of the smart greenhouse. However, if the value is low, a signal will be sent to the relay via port 33 to turn on the heaters in the smart greenhouse so that the temperature remains closer to ideal. Third: Water level sensor. The water level sensor is supplied with a voltage of 3.3 volts, and the data received from the sensor is read through port 35 on the ESP 32, and then the reading is compared with the ideal value stored in the ESP32 so that a decision is made and a command to turn on or off the alarm is sent through the port. 26 to the relay that connects to the alarm in the system. Fourth: NPK sensor. The NPK sensor is supplied with 12 volts from an external source because the ESP32 is the highest power port with 5 volts. Next, the MAX485 is connected between the NPK sensor and the ESP32, where the NPK sensor is connected. The MAX-485 is connected to a 5V power supply through the ESP32, the yellow cable is connected to the NPK sensor to port A on the Max 485, and the blue cable is connected to port B on the Max 485. Next, the Max 485 is connected to the ESP32 through the following ports: DE port 14, RE to port 12, DI to TX port, and RO to RX port. Then a 4*20 LCD display is connected to the ESP32 device via ports 21 and 22 to display the results to the user. After that, a copy of the data for each sensor is sent to Google sheets. every five minutes. Figure 2 shows the final design of the proposed system after connecting all the sensors to the ESP32 and the design was done using simulation programs before starting the real design. And explain the operation connection for each sensor with the ESP32 as explained in Figure 1.

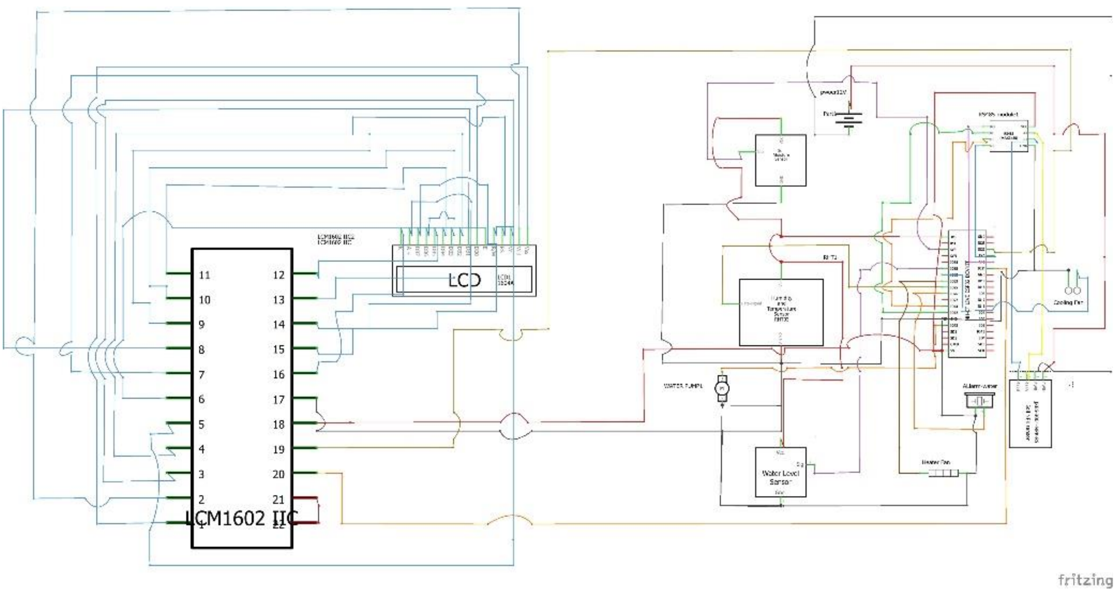


Figure 1. The electrical circuit method of the proposed system

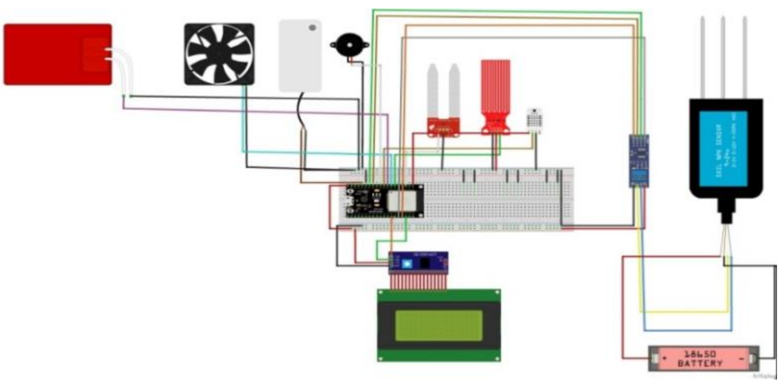


Figure 2. Design of the proposed system

3. SOFTWARE IMPLEMENTATION

Compared to other applications, IoT infrastructure for the agricultural sector is more complicated because of the need for real-time monitoring in the agricultural environment. Additionally, agricultural developers should have access to source tools to build sustainable and affordable applications [31]–[33]. Figure 3 shows the architecture of the Blynk platform where the proposed system will be analyzed to see how it communicates between the ESP32 and the server, which will use the Blynk platform to monitor the system's work. Websites need engineering and planning regarding how the website is built or set up so that users have a positive experience while achieving business goals. In this project, the platform is represented by model-view-controller (MVC) architecture. The greenhouse architectural model creates user interfaces specific to the Blynk platform based on the smart greenhouse's sensors' functionality. The system will be monitored by the user using a smartphone or computer through the website, where the programming work is divided into two parts: the front-end section, which is shown to the end user, and the back-end, which is responsible for the database and how to communicate between the server and the proposed system, where it was designed. The system was powered and monitored the greenhouse by the Blynk platform. Blynk can be defined as a comprehensive software suite that enables prototyping, deployment, and remote management of connected electronic devices at all IoT.

Backend: Figure 3 shows the architecture of the Blynk platform, which refers to the server-side components of the Blynk platform responsible for processing requests from the front-end components (Blynk console or Blynk apps). Backend components include databases to store device, user, and enterprise data. It also includes security mechanisms such as authentication and authorization to ensure secure access to data and devices on the platform.

Front-end: refers to the user interface (UI) components of Blynk console web app or Blynk mobile applications allow interaction between users and the platform. Front-end components include user interface elements, such as buttons, sliders, charts, and gauges, which visualize data from connected devices and enable users to control them remotely. Including screens for device configuration, user management, and organization management. Figure 4 shows how the Blynk platform works, requesting from the Blynk platform, and data is retrieved from the platform's database. After sending the required data from the database and configuring the required interface, it is sent from the Blynk platform to the user's smartphone or computer.

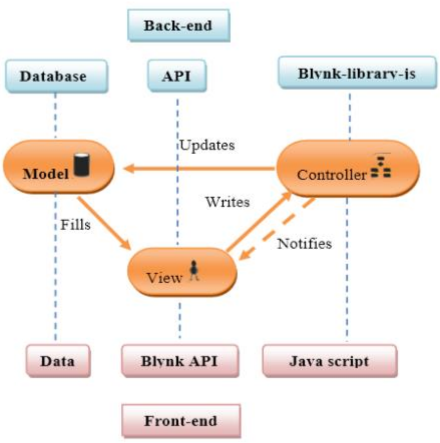


Figure 3. The architecture of Blynk platform

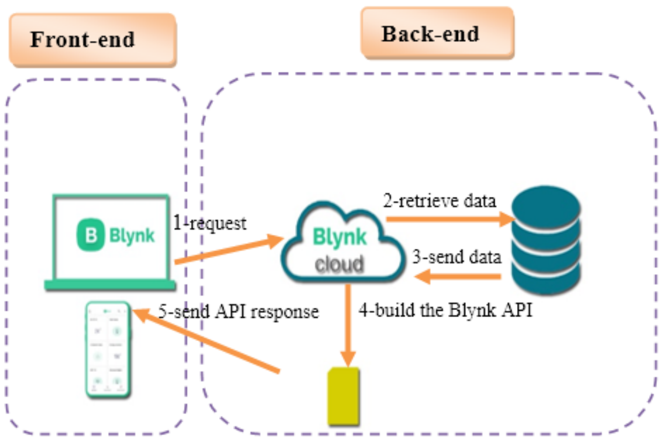


Figure 4. Mechanism of the Blynk platform

4. METHOD

This study presents the design and implementation of a smart greenhouse model through IoT-based smart agriculture. Sensors are used and connected to the ESP32 which controls soil moisture, air temperature, and water level in the tank. A sensor was also used to determine the amount of nutrients present in the soil. Smart decision-making is based on real-time data from the greenhouse. We hope to help farmers monitor greenhouses. IoT-based smart farm technology aims to help manage non-uniform elements such as moisture, temperature, and soil nutrients [34], [35]. Farmers can expect good health and consistent crop yields by automating irrigation systems and analyzing data to find ideal levels of moisture, temperature, and soil nutrients. They can also easily share this information with other farmers 36. Figure 5 shows a flowchart of the sensor control mechanism using ESP32. It represents the sensor control mechanism in terms of reading data and sending it to the ESP32 to compare the data reading of each sensor with the stored ideal threshold value and make the appropriate decision regarding turning on or off the actuator.

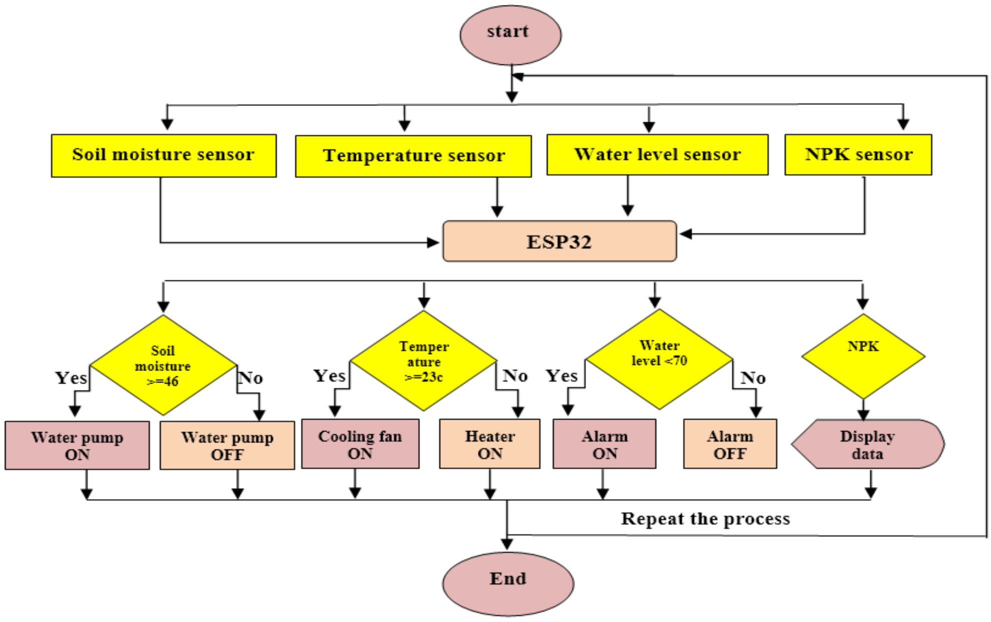


Figure 5. Flowchart of sensors to control mechanism by ESP32

The work will be divided into two parts. The first part will be the admin, the ESP32, as it analyzes data received from sensors and makes the appropriate decision after comparing the data with the ideal values stored in it. Figure 6 shows the flowchart of a proposed system work. The soil is monitored using a soil moisture sensor, which measures the soil's moisture level. It reads the humidity level in the soil and compares it with the ideal value stored in ESP32. If the humidity of the soil is less than or equal to 45%, the ESP32 will turn on a 12V pump to push water to the area to be irrigated. However, if the humidity of the soil is greater than the required level, the water pump will stop. Heating and cooling operations can also be controlled by relying on the DHT22 sensor linked to the ESP32. If the value received from the sensor is less than or equal to 22 °C, the ESP32 will turn on the heater inside the smart greenhouse. However, if the temperature exceeds or equals 23 °C, the ESP32 will turn on the cooling fans to bring the temperature down to the desired rate. It is also possible to inquire about the values of nutrients in the soil by relying on the NPK sensor. The ESP32 reads data received from the sensor and prints it on the screen so that the farmer knows whether the soil needs NPK. It also controls the water level in the smart greenhouse tank. If the level is lower than 70%, the ESP32 turns on the alarm, but when the level of the water in the tank is equal to or greater than the required level; then the alarm is off. The ESP32 then sends a copy of each sensor's values to Google Sheets to save them in a preset database. It was decided to take a copy of the reading and save it every 5 minutes in the normal condition. In the event of a malfunction in any sensor, an inquiry will be sent to the farmer to alert him. The second part is that the farmer will have the authority to turn off or turn on the system in the greenhouse. The system can also be monitored through the Blynk application that was previously prepared for the system, as the system will help the farmer monitor the environmental conditions in the smart greenhouse.

4.1. Proposed system

This section explains the design and implementation of the proposed system. Figure 7(a) shows the internal components of the system, where the ESP32 device is connected to the sensors and placed in a plastic plate to protect it from external damage. The board consists of an ESP32 connected to a 24-hour power supply where the outputs are connected to a 6-pin relay used to turn on or off the cooling and heating systems, irrigation system, and alert when there is a fault of low water level in the tank. Displays NPK values in the soil which appear on the screen. As for the inputs, they are connected to the sensors. Figure 7(b) shows the external appearance of the proposed system. All devices and relays were wrapped to protect them from external damage.

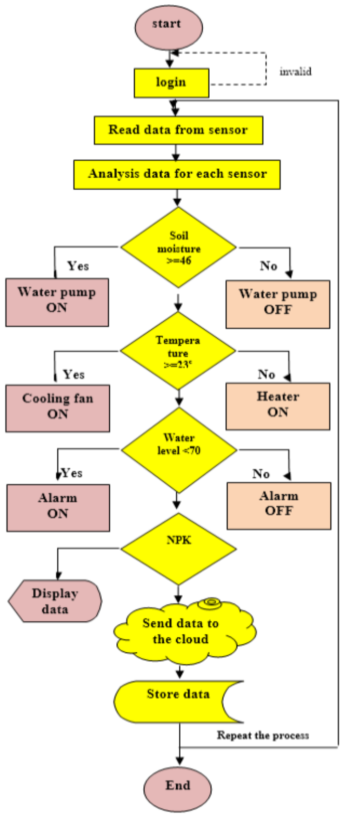
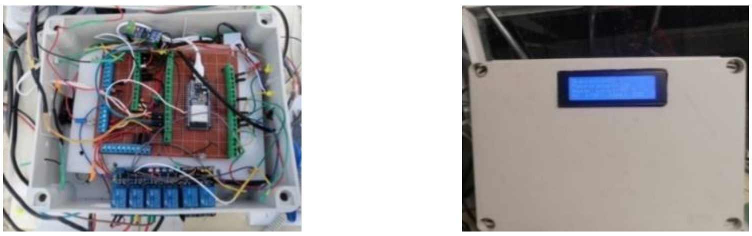


Figure 6. The Flowchart of a proposed system work



(a) (b)

Figure 7. Final design of the proposed system: (a) internal connection of devices, and (b) system experience

Table 1 shows the needs of each sensor and the amount of voltage it requires, as the ESP32 equips each sensor with the power required to work in the proposed system. Figure 8(a) shows the placement of the NPK sensor in the soil. Figure 8(b) shows the placement of the soil moisture sensor in the anvil. Figure 8(c) shows the implementation of the proposed system in the smart greenhouse and links the sensors to the proposed system to work in it.

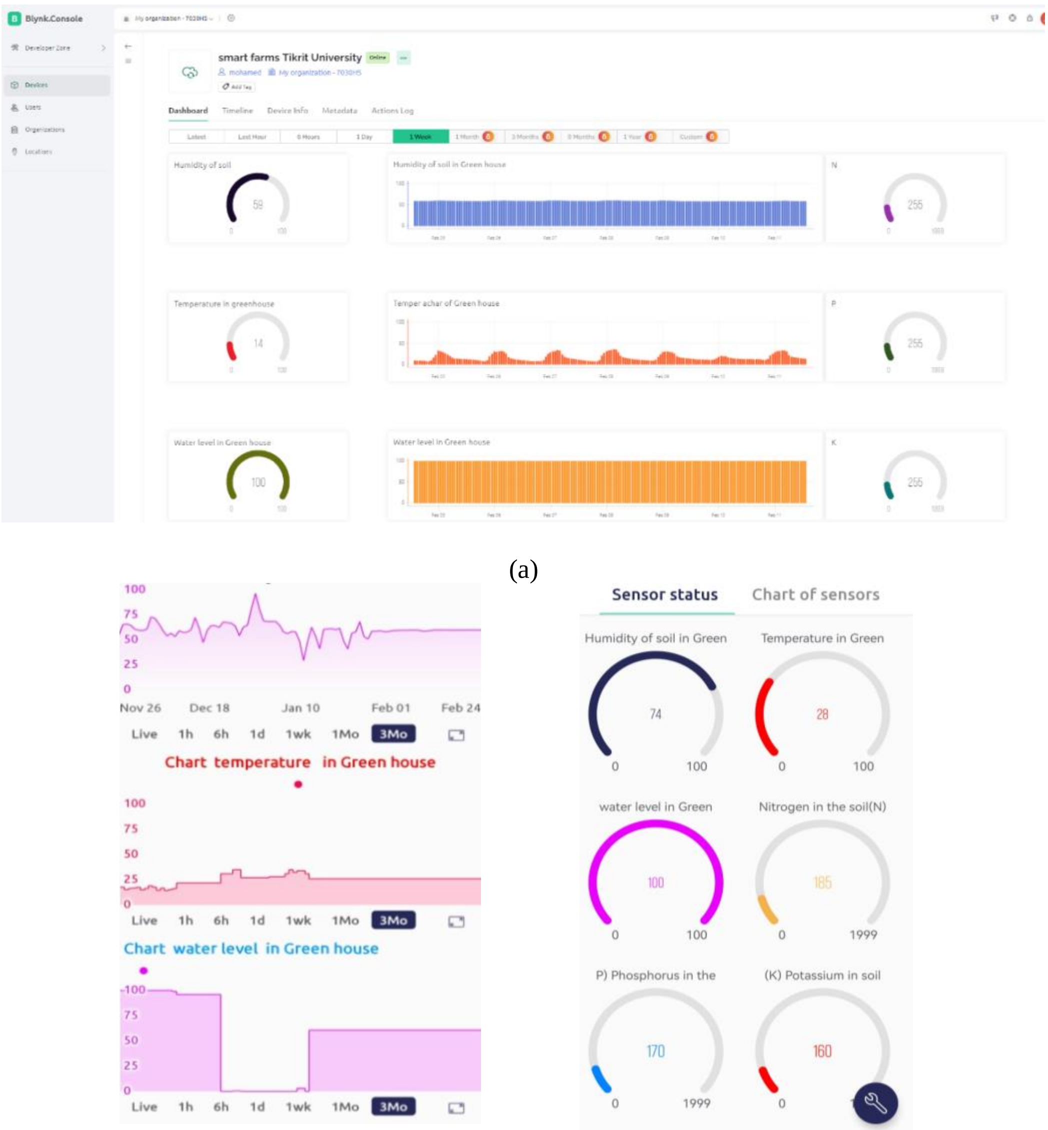
Figure 9(a) shows the computer application. Figures 9(b) and 9(c) show the application for mobile devices. The application works to monitor the work of sensors in the greenhouse and follow the work in real-time, provided by the Blynk platforms. Table 2 shows the values sent from the Esp32 to the Google Sheets. The values received from the sensors are automatically saved to the Google Sheets, where they are connected to the farmer's Google account.

Table 1. The voltage of power sensors

Sensor	Power (V)
NPK	12
Temperature	3.3
Soil moisture	3.3
Water level	3.3

(a) (b) (c)

Figure 8. Implementation of the proposed system in the smart greenhouse: (a) NPK sensor in anvil, (b) soil moisture sensor in the anvil, and (c) smart distillation in the greenhouse



(a)

(b) (c)

Figure 9. Implementing a smart greenhouse monitoring system using the Blynk platform: (a) monitoring the system by computer, (b) monitoring the chart of the sensors by phone, and (c) monitoring sensors status by phone

Table 2. Data sent from Esp32 to google sheets

K	P	N	Watering plant Pump	Water level	Water pump actuator	Humidity of soil	Fan actuator	Temperature	Date
160	190	185	OFF	100	OFF	59	ON	24C	2023/12/01
160	190	185	OFF	100	OFF	60	ON	24C	2023/12/01
160	190	185	OFF	100	OFF	60	ON	25C	2023/12/01
160	190	185	OFF	100	OFF	60	ON	25C	2023/12/01
160	190	185	OFF	100	OFF	60	ON	25C	2023/12/01
160	190	185	OFF	100	OFF	60	ON	26C	2023/12/01
160	190	185	OFF	100	OFF	60	ON	25C	2023/12/01
160	190	185	OFF	100	OFF	60	ON	26C	2023/12/01
160	190	185	OFF	100	OFF	60	ON	28C	2023/12/01
160	190	185	OFF	100	OFF	60	ON	28C	2023/12/01
160	190	185	OFF	100	OFF	62	ON	29C	2023/12/01
160	190	185	OFF	100	OFF	61	ON	31C	2023/12/01
160	190	185	OFF	100	OFF	61	ON	32C	2023/12/01
160	190	185	OFF	100	OFF	61	ON	31C	2023/12/01

5. RESULT AND DISCUSSION

Were made two greenhouses measuring 170×200×150 cm, and the first (smart) greenhouse was equipped with a special system equipped with sensors that detect air temperature, soil humidity, the amount of water in the tank, measure the percentage of minerals in the soil (NPK) and is connected to the internet via IoT technology while allowing the monitoring of temperature, humidity, and the percentage of minerals in the soil using an electronic application that was designed and linked to the Blynk platform. Three varieties of radishes: Dutch, Syrian, and Italian; were grown in smart and traditional greenhouses on Tuesday, 28/11/2023, at three in the afternoon, and on Friday, 1/12/2023, at ten in the evening. Whereas the germination level in the (smart) greenhouse on Monday, 4/12/2023, at nine in the morning, the germination rate reached 98%, while in the traditional (unattended) greenhouse, the first germination level appeared on Sunday, 4/12/2023, at three in the afternoon, and on Monday at three o'clock in the afternoon, it did not exceed 50%, and it was noted that there was a big difference between the two greenhouses.

The radish plants were harvested in the two greenhouses and the data for the plants was analyzed. The symbol (S) was designated as the smart greenhouse, and the symbol (T) was designated as the traditional greenhouse, and the results of the samples were as follows.

- Plant height rate: Table 3 shows the effect of the greenhouse and the varieties and the similarity between the characteristics of the plant height rate. It is clear from it that the S greenhouse showed the highest average plant height rate ratio of 63.536 mm, significantly superior to the T greenhouse, which gave the lowest value of the plant height rate ratio of 54.553 mm.

Table 3. Plant height rate

	A	B	C	Average
S	55.743	75.640	59.223	63.536
T	53.557	68.177	41.927	54.553
Average	54.650	71.908	50.575	

- Average leaf area of the plant: Table 4 shows the effect of the greenhouse, the varieties, and the similarity between the average characteristics of the average leaf area of the plant. It is clear from this that the S greenhouse showed the highest average plant leaf area ratio, 1243.03 mm, significantly superior to the T greenhouse, which gave the lowest value for the average leaf area of the plant, 885.03 mm.

Table 4. Average percentage of leaf area per plant

	A	B	C	Average
S	1091.6	1480.2	1157.2	1243.03
T	757.8	1047.1	850.3	885.03
Average	924.70	1263.63	1003.76	

Figure 10(a) shows the growth stage of the radish plant and germination level of the smart greenhouse. On the fourth day of planting, the germination rate of radish plants reached 98%. Figure 10(b) shows the height of the plant. Figure 10(c) shows the size of the leaf area of a plant in the smart greenhouse.

(a) (b) (c)

Figure 10. Plant growth in smart greenhouse: (a) growth stage of plant, (b) the height of plant, and (c) leaf area of a plant

Figure 11(a) shows the growth stage of the radish plant and the level of germination in the greenhouse in it did not exceed 50%. Figure 11(b) shows the height of the plant. Figure 11(c) shows the size of the leaf area of a plant in the traditional greenhouse.

(a) (b) (c)

Figure 11. Plant growth in the traditional greenhouse: (a) growth stage of plant, and (b) the height of plant, and (c) leaf area of a plant

6. CONCLUSION

The use of the IoT in the agricultural system is necessary because there are basic requirements for plant life that farmers do not know because they are not clear, such as the difficulty of monitoring soil moisture, the amount of nutrients in the soil, temperature, and the amount of water in tanks. The study dealt with the design and implementation of the smart system. The work was done in two parts, where the first part was the design and implementation of the software part, which was the design and implementation of a website for the proposed system and how to monitor the greenhouse in real time and then send a copy of the reading of each sensor to Google Sheets. The second part is the design and implementation of the smart greenhouse, as the proposed system can measure soil moisture, the amount of nutrients in the soil (NPK), the temperature of the smart greenhouse, and the water level in its tank. In this research, the assistance of the agricultural expert specializing in plants, Professor Dr. Harith Burhan Al-Din, was sought in terms of following the stages of plant growth and knowing the plant's differences. After implementing the system in the city of Samarra, it was found that the use of the IoT in the agricultural system showed a promising and excellent result in terms of plant growth in the first four days, and the germination rate reached 98%. In the smart greenhouse. While in traditional greenhouses, it did not exceed 50%. As for plant height, there was a clear significant difference in the average plant height. There was also a significant difference evident in average leaf area. So a smart greenhouse is better than a traditional greenhouse. Our findings provide The proposed model can be realistically applied in smart greenhouses, and for this reason, it can help reduce resource, reduce labor usage, and increase productivity.

FUTURE WORKS

We faced some challenges in this research, such as plant-specific diseases, energy sources, and soil salinity and acidity. In the future, we hope to add a camera to the proposed system to monitor plant diseases and determine the type of disease using artificial intelligence algorithms. Adding a sensor to determine soil acidity and basicity (PH). Adding alternative energy (solar energy) to reduce consumption power. To help farmers reduce hand labor, and increase and improve resources and yield.

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BIOGRAPHIES OF AUTHORS

Mohamed Ismail Lafta received a bachelor's degree. He holds a computer science degree from the Computer Science and Mathematics, Department of Computer Science, and a master's student in the College of Computer Science and Mathematics, Department of Computer Science, Tikrit University. He can be contacted at email: mohammedi.lafta@st.tu.edu.iq.

Wisam Dawood Abdullah received his B.Sc. degree in Computer Science from Tikrit University, and his M.S. degree in Information Technology (with concentration in Telecommunications and Networks) from the University Utara Malaysia (UUM). He received an expert certification from Cisco Networking Academy CCNP, CCNA, CCNA Security, IoT, Entrepreneurship, Grid, Voice, Wireless Cloud, Linux, CCNA Cyber Security and IT, also he is a NetAcad administrator in Cisco Networking Academy, currently he is lecturer in the Tikrit University, Cisco Networking Academy, member in IEEE. Research interest: protocol engineering, network analysis, internet architecture and technologies, wireless performances, network traffic engineering, data mining, future internet, internet of things, AI, and ML. He can be contacted at email: wisamdawood@tu.edu.iq.