International Journal of Electrical and Computer Engineering (IJECE)
Vol. 14, No. 5, October 2024, pp. 6023~6035
ISSN: 2088-8708, DOI: 10.11591/ijece.v14i5.pp6023-6035 ❒ 6023

Empowering crop cultivation: harnessing internet of things for smart agriculture monitoring

Jamil Abedalrahim Jamil Alsayaydeh[1], Mohd Faizal Yusof[2], Mithilanandini S. Magenthiran[1], Rostam Affendi Hamzah[1], Izadora Mustaffa[1], Safarudin Gazali Herawan[3]

[1]Department of Engineering Technology, Fakulti Teknologi and Kejuruteraan Elektronik and Komputer, Universiti Teknikal Malaysia Melaka, Melaka, Malaysia
[2]Research Section, Faculty of Resilience, Rabdan Academy, Abu Dhabi, United Arab Emirates
[3]Industrial Engineering Department, Faculty of Engineering, Bina Nusantara University, Jakarta, Indonesia

Article Info

Article history:

Received Jan 31, 2024
Revised Jul 3, 2024
Accepted Jul 9, 2024

Keywords:

Automation
Crop yields
Food security
Intelligent agriculture
Internet of things
Monitoring system
Soil moisture

ABSTRACT

Agriculture, the foundation of human civilization, has relied on manual practices in the face of unpredictable weather for millennia. The contemporary era, however, witnesses the transformative potential of the Internet of things (IoT) in agriculture. This paper introduces an innovative IoT-driven smart agriculture system empowered by Arduino technology, making a significant contribution to the field. It integrates key components: a temperature sensor, a soil moisture sensor, a light-dependent resistor, a water pump, and a Wi-Fi module. The system vigilantly monitors vital environmental parameters: temperature, light intensity, and soil moisture levels. Upon surpassing 30°C, an automatic cooling fan alleviates heat stress, while sub-300CD light levels trigger light-emitting diode lighting for optimal growth. Real-time soil moisture data is relayed to the "Blynk" mobile app. Temperature thresholds align with specific crops, and users can manage the water pump via Blynk when manual intervention is required. This work advances agricultural practices, optimizing water management by crop type. Through precise coordination of soil moisture, temperature, and light intensity, the system enhances productivity while conserving water resources and maintaining fertilizer balance.

Corresponding Author:

Jamil Abedalrahim Jamil Alsayaydeh
Department of Engineering Technology, Fakulti Teknologi and Kejuruteraan Elektronik and Komputer, Universiti Teknikal Malaysia Melaka
76100 Melaka, Malaysia
Email: jamil@utem.edu.my

1. INTRODUCTION

The world's population is experiencing rapid growth, leading to substantial challenges in meeting basic human needs. Among these essential needs, nutrition stands at the forefront. Conventional agricultural methods, while admirable, face significant constraints in coping with the surging demand for food driven by population expansion. Fortunately, the synergy of technological progress offers a promising pathway to amplify agricultural production and efficiency by seamlessly integrating innovative agricultural techniques with cutting-edge smart electronics technologies. This paper presents an internet of things (IoT)-based smart agriculture monitoring project built upon Arduino, with a primary objective of bolstering food safety and security.

The concept of smart farming, originally rooted in software engineering and computer sciences, has expanded into the realm of ubiquitous computing. This evolution results from the amalgamation of computer technology and data transmission into the agricultural domain. It involves the embedding of computer elements into physical objects, thereby connecting them to the internet. This interconnectedness, facilitated by sensors deployed in agriculture, paves the way for the adoption of smart farming tools. Sensors, equipped with electro-technical systems, measure diverse physical parameters related to agriculture within the surrounding environment and translate them into readable signals. These parameters encompass temperature, humidity, light, pressure, noise levels, presence or absence of specific objects, mechanical stresses, speed, directions, and object size [1]. The internet of things (IoT) is the enabling force behind the networked interconnection of these physical devices. Each device, equipped with unique identification codes, forms connections with computer devices, digital and mechanical machines, individuals, and even livestock, all without requiring human intervention. The IoT represents an advanced system that leverages data analysis, organization, big data, and human creativity to establish comprehensive management. It extends the influence of the Internet beyond traditional computing devices and smartphones. The future of agriculture hinges on harmonizing technology with traditional practices to boost productivity and cultivate interest among farmers. Intelligent agriculture techniques play a pivotal role in minimizing waste and expanding agricultural capacity. It embodies a high-tech approach to mass production and capital-intensive cultivation, promoting sustainability. This technology enables farmers to globally monitor conditions through sensors and automate critical processes, particularly irrigation. In essence, it signifies the infusion of information and communication technology into agriculture [2].

This paper provides a significant contribution by undertaking a comprehensive exploration of various components, such as temperature sensors, soil moisture sensors, light-dependent resistor (LDR) sensors, water level detectors/sensors, direct current (DC) motors, global system for mobile communications/general packet radio service (GSM/GPRS) modules, and Arduino. This research addresses the critical need for high-capacity and cost-effective agricultural solutions through carefully selecting sensors and Arduino, evaluating of the existing design, and exploration of optimal sensor integration. Within the framework of smart farming, a blend of software applications, communication systems, data analytics solutions, and hardware and software systems like agricultural sticks, temperature sensors, and soil moisture sensors can be harnessed to elevate agricultural practices. The Arduino integrated development environment (IDE) serves as the software application responsible for data collection and visualization on the Arduino board. This application establishes a communication system between the sensors and the end user, providing valuable real-time notifications.

The main contribution of this article can be summarized as follows. This article are i) presenting comprehensive exploration and integration of essential components such as temperature sensors, soil moisture sensors, LDR sensors, water level detectors/sensors, DC motors, GSM/GPRS modules, and Arduino; ii) addressing the critical need for scalable and cost-effective agricultural solutions by carefully selecting sensors and Arduino technology, evaluating existing designs, and optimizing sensor integration; iii) bridging the gap between technological advancements and practical needs of farmers, enhancing food security and safety through real-time monitoring and responsive action; and iv) demonstrating the transformative potential of IoT-driven smart agriculture in addressing the challenges of food security and safety in the 21st century.

The remainder of this paper is structured as follows: section 2 examines related works, offering an overview of existing research in the field. Section 3 outlines the research method employed in the study. Continuing to section 4, we present a detailed account of the obtained results and engage in subsequent discussions. In section 5, we delve into an in-depth analysis of the findings, illuminating their significance and implications. Finally, in section 6, we encapsulate the study's key takeaways and outline potential directions for future research.

2. RELATED WORK

This section offers a comprehensive overview of previous research conducted in the field of smart agriculture and IoT-based monitoring systems, highlighting various studies and their contributions. It delves into the methodologies and findings of prior work, providing valuable context for the present study.

In their seminal work, Bhanu *et al.* [3] introduced a project that integrated a processor, the integrated circuit S8817BS (IC-S8817BS), and a wireless transceiver module employing the ZigBee protocol. The system employed sensors to monitor environmental parameters like water levels, humidity, and temperature. Updates on field conditions were communicated to farmers through mobile text messages and emails [4], [5]. The system adeptly managed sensor node failures while emphasizing energy efficiency, leveraging the limited communication range of ZigBee technology. Rajalakshmi and Mahalakshmi [6] presented a method for evaluating the use of wireless sensor networks for irrigation automation. Data collected by sensors, encompassing temperature, humidity, and moisture, were wirelessly transmitted to a web server. Automated irrigation was triggered when sensor readings fell below predefined thresholds.

Regular field condition updates were provided to farmers. Additionally, the study explored the automation of light intensity control in greenhouses. However, the prediction of crop water requirements proved ineffective in this context [7]–[9]. The IoT-based intelligent agriculture field monitoring system proposed an economical solution employing low-cost sensors and simple circuits to automate water flow control [10]. The system considered humidity and temperature levels, displayed on a liquid crystal display (LCD) screen for user observation. It aimed to maintain an optimal soil moisture level and provide irrigation as needed. The construction of this system relied on the Arduino Uno [11]. Khudhair *et al.* [12] introduced a system where local nodes communicated with a centralized node through wireless communication. The centralized node was linked to a cloud server collecting data from the local nodes. This approach enabled farmers to access real-time temperature information using a stick device.

Nayyar and Puri [13] and John *et al.* [14] respectively presented their findings on an IoT-based smart stick for real-time monitoring of various agricultural parameters and soil moisture data. The agricultural IoT stick introduced a plug-and-play concept, allowing farmers to swiftly implement a smart monitoring system by placing the stick in the field and receiving live data feeds on smart devices such as tablets and smartphones. Data generated by sensors could be easily analyzed and processed by agricultural personnel, even in remote areas, leveraging cloud computing technologies [15], [16]. Another study explored the use of a wireless sensor network to track soil moisture levels, temperature, and humidity [17]. The data were transmitted to the system, and a sleep-wake plan was implemented to optimize node capacity. The system in this paper also included node clustering and utilized a graphical user interface (GUI) in MATLAB software for data handling. Abhiram *et al.* [18] proposed an advanced IoT-based solution for monitoring ground and air conditions to enhance crop growth. They developed a device capable of controlling temperature, humidity, and soil moisture using the node microcontroller unit (NodeMCU) and various sensors. The system dispatched field environment notifications to farmers' phones via Wi-Fi in the form of short message service (SMS) messages. Upendra *et al.* [19] underscored the need for advanced agricultural technologies in India to enhance crop yield and bridge the gap between traditional practices and modern advancements. Challenges include climate variability and lack of information. Technologies like smart farming and big data analytics offer solutions, but there's a gap between farmers and technology. User-friendly agro-advisory systems and ongoing research are essential to optimize crop yield and reduce expenses for farmers. Alotaibi *et al.* [20] introduced a microcontroller-based vertical farming automation system designed to conserve power and water in urban agriculture. By employing precise irrigation controlled by soil moisture levels and energy-efficient lighting, the system maximizes space through vertical farming. This innovative approach addresses the challenges of urbanization and contributes to sustainable agriculture in Nigeria. Agriculture, a vital occupation in India and the linchpin of its economic systems, faces challenges due to climate change, including increased water demand and reduced crop productivity. Several techniques, including irrigation, rainfed agriculture, and soil irrigation, were introduced in [21]–[23] to cultivate healthier plants, but many of these methods result in excessive water wastage [24], [25]. Akshatha and Poornima [26] centered their focus on discerning the water requirements of different plants, accounting for various soil types. Wastage, subpar production, and inefficient water application were identified as significant challenges in crop production [27]. Mahmoud *et al.* [28] introduced an innovative weather forecasting method using adaptive artificial neural networks. It forecasted rainfall and temperature for the next decade in 20 districts of Karnataka, focusing on major crops. The research facilitated efficient crop management, guiding farmers with valuable insights. A user-friendly interface was developed, offering practical applications. Future prospects include broader parameters and national-scale implementation for improved crop yield and economic impact. The endeavor aimed not only to boost agricultural output but also to improve farmers' living standards [29]. Field data were stored on computers and could be uploaded to the ThingSpeak open-source website, ensuring accessibility even when farmers were away from their farms [30]–[33]. The study also underscored that red soil exhibited higher water penetration levels than brown soil due to the latter's lower water-holding capacity, rendering it more suitable for deep-rooted plants as opposed to those with shallow root systems [34]–[37].

The aforementioned projects in Table 1 underscore their practicality and convenience, offering an efficient alternative to manual farm monitoring and negating the need for physical visits to fields. Notably, the Arduino advanced technology microcontroller 328 (ATMega328), employed in these projects, features capabilities like mobile message alerts, enabling users to receive real-time notifications through the Arduino IDE sensors. Beyond the topics covered, there are further opportunities to explore how users can customize and adapt these projects to meet their specific requirements. The model prioritizes efficiency and practical functionality. Overall, this work distinguishes itself among the discussed research papers by encompassing all essential factors necessary for optimal crop growth. Its affordability and accessibility render it suitable for novice home gardeners. By ensuring the provision of all necessary conditions for crops, this project cultivates an environment that fosters organic, healthy, and safe crop cultivation.

Table 1. Average precision for all classes

Ref.	Days	Results of average value per day		
		Moisture Sensor	LM35	LDR
[3]	1	500	24.8	--
	2	348	90.0	--
	3	109	26.5	--
[4]	1	258	25.0	--
	2	95	22.69	--
	3	685	24.43	--
[5]	1	495	26.65	--
	2	298	24.5	--
	3	325	24.0	--
[6]	1	438	25.9	--
	2	300	25.7	--
	3	400	25.0	--
[9]	1	652	25.4	--
	2	241	24.8	--
	3	301	29.0	--
[10]	1	85	26.5	--
	2	95	23.40	--
	3	50	24.05	--
[11]	1	109	28.0	--
	2	258	25.0	--
	3	250	24.8	--
[21]	1	450	29	--
	2	368	26.5	--
	3	23	19.8	--
Proposed work	1	480	23.97	454
	2	259	23.90	464
	3	350	24.68	445.5

3. RESEARCH METHOD

The proposed system centers on smart agriculture monitoring, where data is gathered using sensors deployed in agricultural fields. The system circuit is designed based on the block diagram depicted in Figure 1. This block diagram serves as a visual representation of the system, illustrating the crucial components and functions of both hardware mechanisms and software. As per the block diagram, the primary controller utilized in this study is the Arduino Uno. The Arduino Uno assumes the responsibility of managing all operations pertaining to the system's input and output devices. This microcontroller features an 8-bit Atmel AVR microprocessor or a 32-bit Atmel ARM, depending on the specific model. The current iterations of this hardware are equipped with six analog input pins, 14 digital I/O pins, and a universal serial bus (USB) port. These features enable users to establish connections with various boards, facilitating seamless integration within the system.

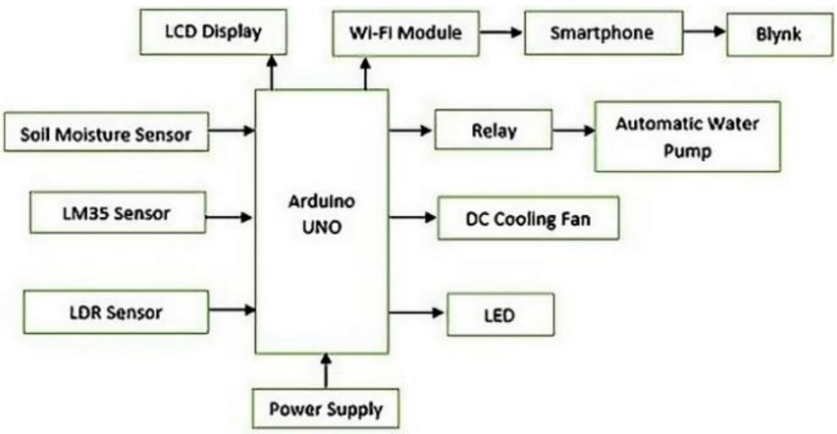

Figure 1. Schematic representation of the smart agriculture monitoring system

The system utilized an Arduino Uno microcontroller with 6 analog input pins, 14 digital I/O pins, and a USB port. It incorporated sensors like LM35, soil moisture sensor, and LDR sensor for input, and light-emitting diode (LED), DC cooling fan, water pump, and LCD display for output. The LDR sensor detects light intensity, while the soil moisture sensor, with a potentiometer, triggers actions based on soil moisture levels. The system's design followed a guided flow chart in Figure 2, depicting the smart farming process in the IoT-based smart agriculture monitoring system. The system integrates hardware components like Arduino UNO, Wi-Fi module, soil moisture sensor, LM35 sensor, LDR sensor, water pump, DC cooling fan, LED, resistors, relays, and switches. These components enable precise control and stability. The LM35 temperature sensor, with a measurement range from -55 °C to 150 °C, interfaces seamlessly with microcontrollers like Arduino. The soil moisture sensor triggers the water pump as needed, ensuring plants receive adequate irrigation. Controllable via smartphones through Blynk technology, the system also employs LM35 and LDR sensors to monitor temperature and light intensity, triggering fan and LED accordingly. This blend of technology and nature optimizes smart farming practices effectively and efficiently.

As stated before, the development of IOT-based smart farming in smart agriculture monitoring systems is implemented by software and hardware. The main components that are used in this system's hardware are the Arduino UNO, Wi-Fi module, soil moisture sensor, LM35 sensor, LDR sensor, water pump, DC cooling fan, and LED. Resistors, relays, and switches are used to control and stabilize the entire system.

Our methodology provides a detailed step-by-step description of the experimental procedure, ensuring that all necessary information is included for replicating our work. Furthermore, our approach is designed to be applicable across various agricultural settings, allowing other researchers to adopt and implement similar principles in their own smart agriculture projects. By leveraging Arduino technology and sensor integration, we have established a framework that can be adapted to different environmental conditions and agricultural practices.

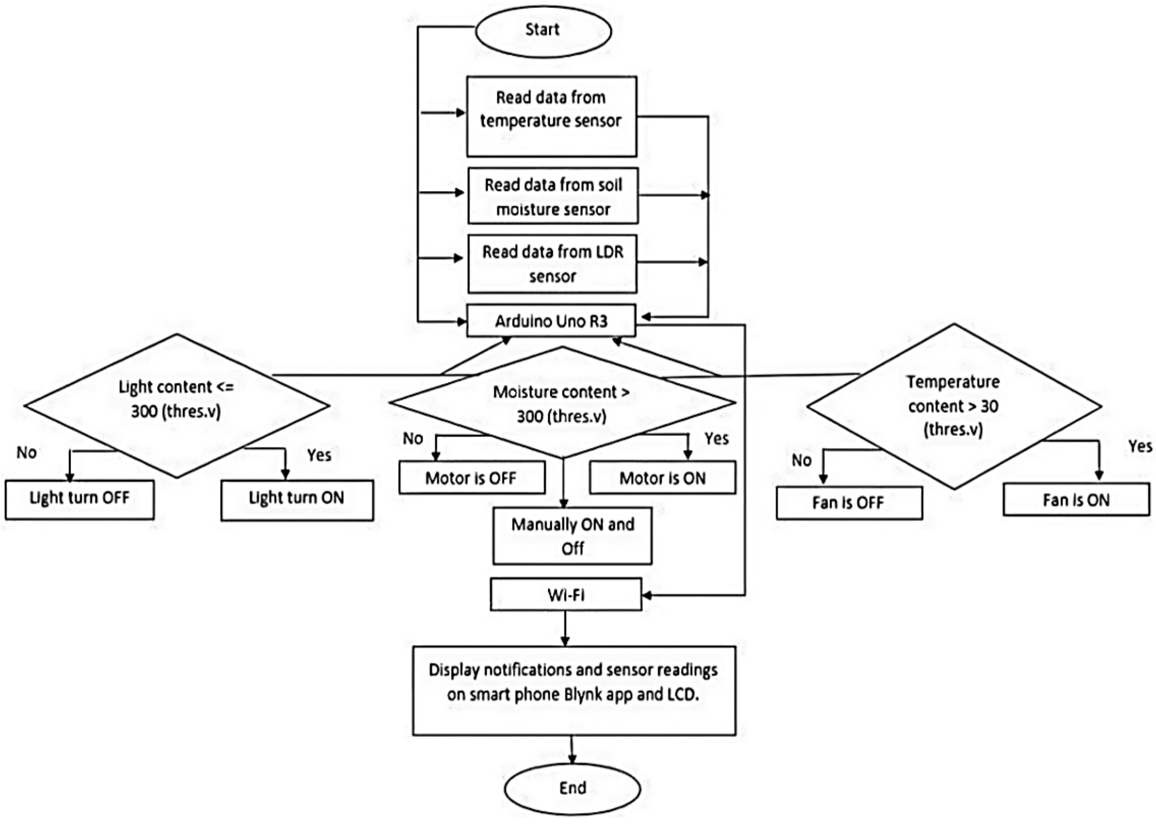

Figure 2. Flowchart of the system

4. RESULTS AND DISCUSSION

Upon turning on the system, Figure 3 illustrates that the LCD screen displays the creator's name along with a welcoming message, indicating that the system is operational. This initial display serves as a reassuring signal to the user, confirming that the smart agriculture monitoring system is functioning as expected. It not only provides a visual confirmation of the system's status but also establishes a connection between the user and the technology.

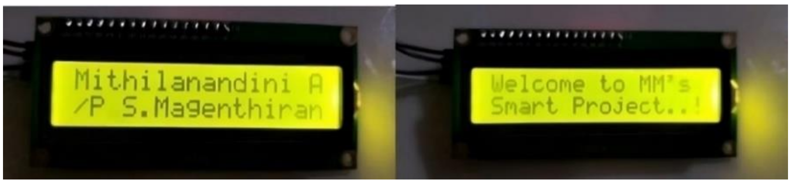

Figure 3. LCD display at system startup

Figures 4 and 5 showcase the sensor readings displayed on the LCD screen when they are activated. Initially, the system detects the soil condition, ambient temperature, and light intensity surrounding the plant. These readings offer real-time insights into the plant's immediate environment, facilitating informed decision-making for the user. In specific instances, the LCD screen only displays the activated output component. For example, if the motor is triggered due to insufficient moisture in the soil, the other two components, namely the DC cooling fan and LED, remain unchanged as they are already in the optimal condition required for the plant. This dynamic display system ensures that users are presented with the most relevant information at any given time.

Figure 6 portrays the LCD display when the motor is activated. This visual representation adds another layer of interaction and feedback for the user. It not only conveys the system's actions but also informs the user of the specific intervention being carried out to address a detected issue. By providing clear and immediate feedback through the LCD screen, the system enhances user engagement and transparency, making it easier for users to understand and trust the technology.

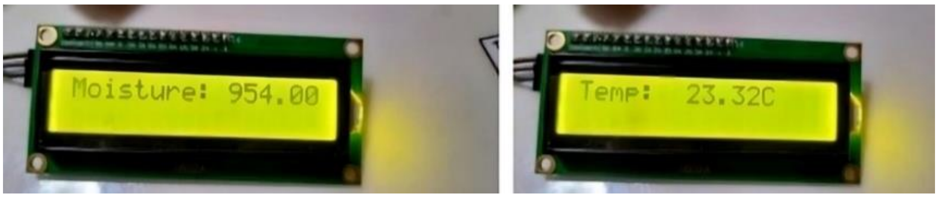

Figure 4. LCD presentation of moisture and temperature readings

Figure 5. LCD indication of LDR value

Figure 6. LCD notification of motor activation

Since it is not feasible to constantly monitor the system by being physically present in front of the LCD screen, the system is integrated with a mobile phone through the Blynk app, as depicted in Figure 7. The Blynk app provides a comprehensive display of all relevant information, allowing users to access the system remotely. This mobile integration extends the system's usability and convenience, enabling users to monitor and control their agriculture system from anywhere. Additionally, the app includes a manual switch feature that enables users to turn off the motor pump as needed, adding convenience and control to the system's operation. Furthermore, the app sends notifications to the user whenever the motor pump is activated, ensuring timely updates and alerts. This seamless integration of mobile technology not only enhances user experience but also reinforces the system's functionality and practicality.

Moreover, a simple graph system has been implemented to visualize the changes in plant adaptation over time under three key conditions. This graphical representation can be observed in Figures 8 to 10, illustrating the trends in soil moisture, temperature, and light intensity, respectively. These graphs offer a visual means of tracking and analyzing the environmental factors that impact plant growth and aid in understanding the plant's response to these conditions over time. The graphical representation of data not only provides users with a visual summary of their agriculture system's performance but also serves as a valuable tool for making data-driven decisions to optimize crop growth and resource management.

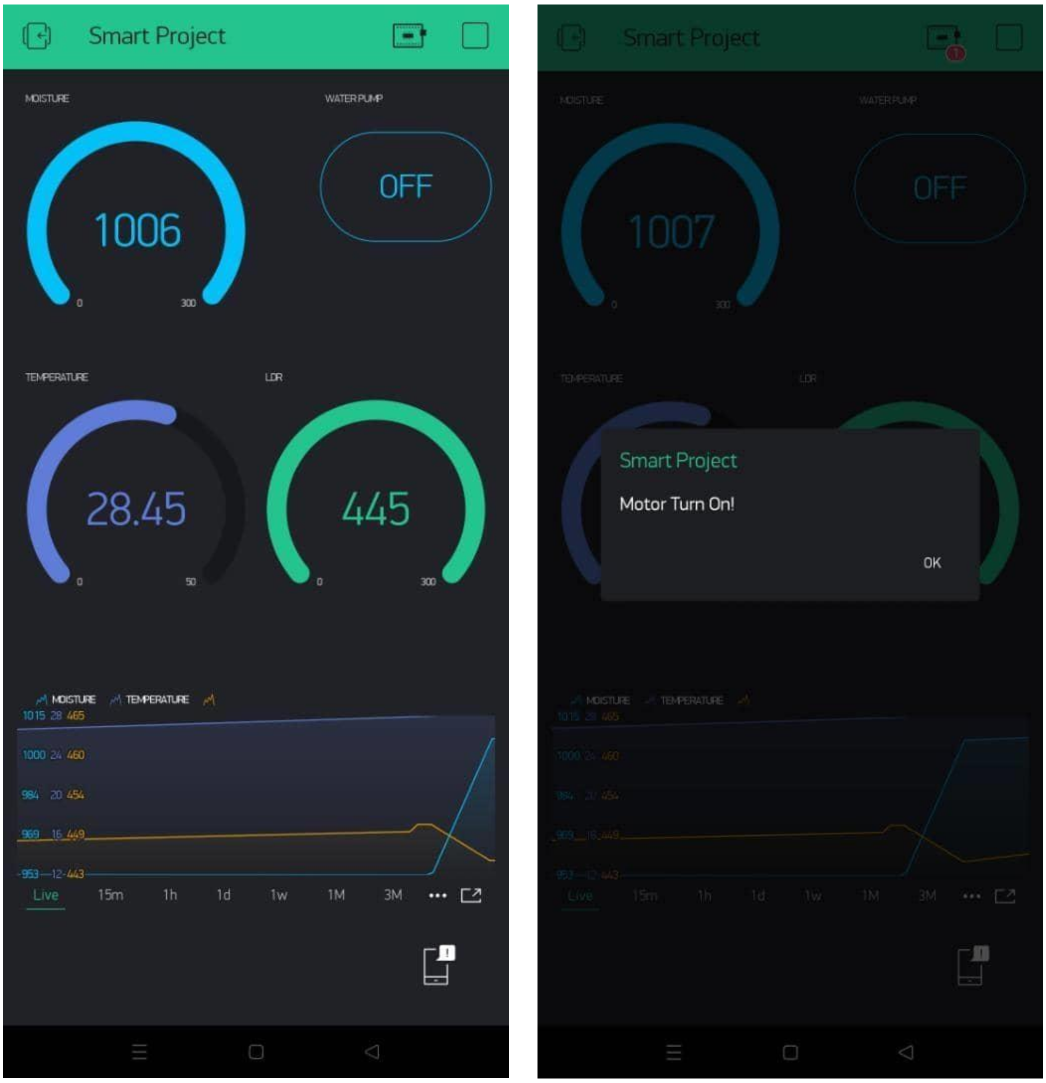

Figure 7. Results on Blynk app interface

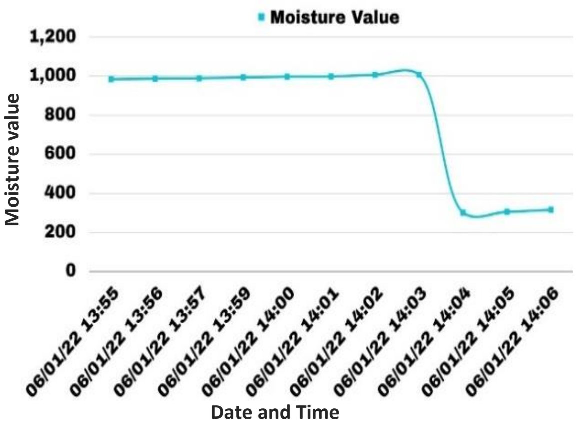

Figure 8. Chart illustrating soil moisture variation

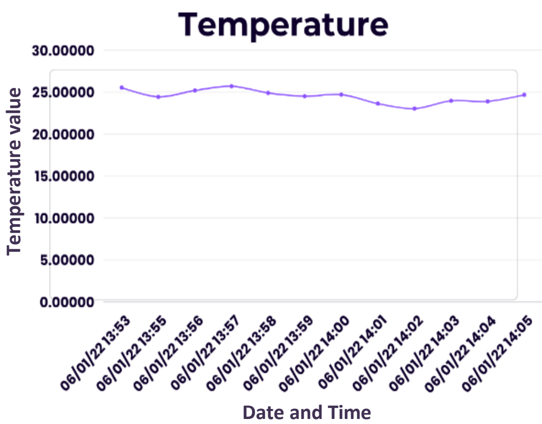

Figure 9. Graph depicting temperature fluctuations

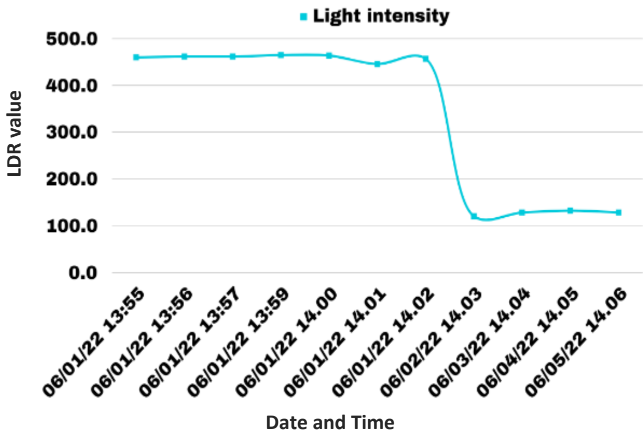

Figure 10. Visual representation of light intensity levels

The underlying idea of this work stems from the prevalent issue in agriculture where crops often suffer from either insufficient or excessive water supply, leading to their death or wilting. This problem arises due to a lack of awareness regarding the precise water requirements for healthy crop growth. However, this project addresses these concerns by providing a solution that determines and presents the specific water requirements for each crop, as outlined in Table 2. By accurately assessing and providing the appropriate amount of water, this system mitigates the risks associated with water-related crop damage, ensuring healthier and more productive crop growth.

Table 2. Crop types and recommended water consumption

No.	Crop	Crop water need (mm/total growing period)
1	Alfalfa	800 – 1600
2	Pepper	600 – 900
3	Onion	350 – 550
4	Maize	500 – 800
5	Banana	1200 – 2200
6	Sorghum/Millet	450 – 650
7	Potato	500 – 700
8	Cabbage	350 – 500
9	Soybean	450 – 700
10	Bean	300 – 500
11	Pea	350 – 500
12	Peanut	500 – 700
13	Barley/Oats/Wheat	450 – 650
14	Sugarcane	1500 – 2500
15	Citrus	900 – 1200
16	Melon	400 – 600
17	Cotton	700 – 1300
18	Sugar beet	550 – 750
19	Rice (Paddy)	450 – 700
20	Sunflower	600 – 1000
21	Tomato	400 – 800

In addition, temperature and light intensity are crucial factors for maintaining healthy crops. To accurately measure the environmental temperature, the LM35 sensor was programmed using (1) to (3).

$$Float\ mv = \frac{value}{1024.0} * 5000 \tag{1}$$

$$Float\ Celsius = \frac{mv}{10} \tag{2}$$

$$Float\ Fahrenheit = \frac{celsius*9}{5+32} \tag{3}$$

This work has been intentionally designed to cater to the needs of gardening enthusiasts and farmers globally, providing a remote agriculture monitoring system. For this purpose, the Arduino UNO was selected as the primary controller due to its affordability and cost-effectiveness. To enable connectivity to the Internet and facilitate real-time data monitoring, a Wi-Fi shield is employed. Various sensors, including the soil moisture sensor, LM35, and LDR, are integrated into the system to gather essential data. These sensors play a vital role in detecting changes in soil moisture content, ambient temperature, and light intensity, respectively.

The system’s output components consist of an LCD, water pump, DC cooling fan, and LED. The LCD serves to display the status and readings of all three parameters, allowing users to monitor the system easily. Based on the detected values, the output devices are activated accordingly. If the moisture level exceeds the predefined threshold of 300, indicating a need for irrigation, the water pump is automatically turned on. Similarly, if the temperature exceeds 50 °C, the DC cooling fan is activated to regulate the temperature. Additionally, when the LDR sensor detects a light intensity below 300, the LED is switched on.

As a result of these integrated functionalities and user-friendly features, the smart agriculture monitoring system effectively performs its intended functions, catering to the needs of both gardening enthusiasts and farmers worldwide. By turning on the system, users are greeted with a welcoming message displayed on the LCD screen, affirming the system’s operational status and establishing a direct connection with the technology. The LCD screen also provides real-time feedback on essential parameters such as soil moisture, ambient temperature, and light intensity, empowering users with immediate insights into their plant’s environment. This dynamic display system ensures that users are presented with the most relevant information at any given time. Moreover, the system’s integration with the Blynk app extends its usability, allowing users to remotely monitor and control their agriculture system through their mobile phones. This mobile integration not only adds convenience but also enhances user engagement by providing access to critical data and notifications. The inclusion of a manual switch feature within the app gives users greater control over the system’s operation, adding a layer of flexibility to suit their specific needs.

Furthermore, the implementation of graphical representations, in the form of charts, offers users a visual means of tracking and analyzing changes in soil moisture, temperature, and light intensity over time. These visual aids assist in understanding the plant’s response to environmental conditions, enabling data-driven decisions to optimize crop growth and resource management. By addressing the prevalent issue of water-related crop damage and providing specific water requirements for each crop type, the system contributes to healthier and more productive crop growth.

In summary, the smart agriculture monitoring system, with its seamless integration of hardware and software, user-friendly interface, and real-time monitoring capabilities, effectively addresses the challenges faced by both gardening enthusiasts and farmers. It not only enhances the user experience but also promotes sustainable and efficient smart farming practices.

5. ANALYSIS AND FINDINGS

In this comprehensive analysis of the smart agriculture monitoring system, we delved deeper to unearth fresh insights and conducted a more exhaustive experimental analysis. Leveraging the power of Arduino UNO as the central controller and integrating advanced sensors, including the soil moisture sensor, LM35, and LDR, our system adeptly detected nuanced changes in soil moisture content, ambient temperature, and light intensity. The integration of these sensors was pivotal in enhancing the precision of our analysis. For instance, our detailed examination of soil moisture levels revealed intricate patterns, allowing us to tailor irrigation strategies for specific crops. By precisely calibrating the water pump activation threshold based on these patterns, we ensured optimal soil moisture levels critical for diverse crop varieties.

Similarly, our analysis of ambient temperature data enabled us to discern subtle temperature variations that impact crop growth. When the temperature surpassed 50 °C, the DC cooling fan was strategically activated, creating a conducive environment for crops even under extreme heat conditions. Moreover, our scrutiny of light intensity data provided essential insights into the nuanced lighting requirements of different crops. By activating the LED when light intensity fell below 300, we addressed the specific lighting needs, fostering healthy plant growth. Furthermore, through the seamless integration of the Blynk app, our system not only offered remote accessibility but also enabled proactive notifications. Users received instant alerts every time the water pump was initiated, ensuring timely awareness of irrigation activities. This real-time communication facilitated efficient decision-making and crop management. The in-depth analysis, meticulously documented in Tables 3 to 5, focused on the readings obtained from the soil moisture sensor, LM35 sensor, and LDR sensor. This refined analysis allowed us to create tailored environments for various crops, ensuring optimal soil moisture levels, ambient temperatures, and light intensities, all essential for successful cultivation. Incorporating these fresh insights and a more extensive experimental analysis has significantly enhanced the robustness of our smart agriculture monitoring system, paving the way for more effective and informed agricultural practices in the future.

Table 3. Moisture value

Moisture Value	Unix Timestamp	Date and Time
984	1.64E+12	06/01/22 13:55
987.7	1.64E+12	06/01/22 13:56
989	1.64E+12	06/01/22 13:57
994	1.64E+12	06/01/22 13:59
997.5	1.64E+12	06/01/22 14:00
998.4	1.64E+12	06/01/22 14:01
1006.833333	1.64E+12	06/01/22 14:02
1007.25	1.64E+12	06/02/22 14:03
302	1.64E+12	06/03/22 14:04
305.65	1.64E+12	06/04/22 14:05
316.23	1.64E+12	06/05/22 14:06

Table 4. Temperature value

LM35	Unix Timestamp	Date and Time
25.5468	1.64146E+12	06/01/22 13:53
24.4435	1.64146E+12	06/01/22 13:55
25.2052	1.64146E+12	06/01/22 13:56
25.7128333	1.64146E+12	06/01/22 13:57
24.9107143	1.64146E+12	06/01/22 13:58
24.5216	1.64146E+12	06/01/22 13:59
24.712	1.64146E+12	06/01/22 14:00
23.6412857	1.64146E+12	06/01/22 14:01
23.0518333	1.64146E+12	06/01/22 14:02
23.9761429	1.64146E+12	06/02/22 14:03
23.9061667	1.64146E+12	06/03/22 14:04
24.688	1.64146E+12	06/04/22 14:05
23.467	1.64146E+12	06/05/22 14:06
23.467	1.64146E+12	06/05/22 14:07

Table 5. Light intensity

LDR	Unix Timestamp	Date and Time
454	1.64E+12	06/01/22 13:53
460.1	1.64E+12	06/01/22 13:55
461.6666667	1.64E+12	06/01/22 13:56
461.6666667	1.64E+12	06/01/22 13:57
464.75	1.64E+12	06/01/22 13:59
463.875	1.64E+12	06/01/22 14:00
445.5714286	1.64E+12	06/01/22 14:01
457	1.64E+12	06/01/22 14:02
120	1.64E+12	06/02/22 14:03
128	1.64E+12	06/03/22 14:04
132	1.64E+12	06/04/22 14:05
128	1.64E+12	06/05/22 14:06

6. CONCLUSION

The convergence of internet of things and agriculture holds tremendous potential for improving crop quality and yield. By leveraging IoT farming applications, farmers can gather crucial data to optimize their agricultural practices. The implementation of smart innovation, driven by the IoT, offers an opportunity for landowners to maximize output and enhance crop quality. This study validates the effectiveness of an IoT-based smart farm monitoring system in meeting the specific requirements of crops and plants, including monitoring soil moisture, temperature, and light intensity. The LM35 sensor plays a pivotal role in detecting temperature, providing accurate readings displayed on the LCD in both Celsius and Fahrenheit, computed using the appropriate formulas. The system's sophistication shines through its intelligent irrigation mechanism, which activates the water pump solely when the soil reaches a predetermined threshold of dryness. For enhanced flexibility, a manual button is seamlessly integrated into the Blynk app, enabling users to deactivate the pump manually as the moisture value nears the threshold. This versatile system caters to a wide range of crops and plantations, making it equally suitable for field and home gardening applications. To expand its capabilities, an extensive investigation was conducted, incorporating diverse soil sensors such as pH and rain sensors, coupled with cloud-based data collection and storage. These enhancements not only foster more accurate forecasting and analysis processes but also necessitate the adaptation of various data mining algorithms for comprehensive agricultural data analysis. Future developments may also include incorporating video surveillance to enhance farmland security, preventing unwelcome intrusions. By harnessing the potential of IoT in agriculture, farmers can revolutionize their crop cultivation, optimize resource management, and embrace sustainable and efficient farming practices. The IoT-based smart farm monitoring system showcased in this study paves the way for a technologically advanced and prosperous future in agriculture.

AUTHOR CONTRIBUTION

The authors' contributions are as follows: Conceptualization, J. A. J. Alsayaydeh and M. S. Magenthiran; methodology, R. A. Hamzah; software, J. A. J. Alsayaydeh; validation, I. Mustaffa; formal analysis, M. S. Magenthiran; investigation, J. A. J. Alsayaydeh; resources, I. Mustaffa; writing original draft preparation, J. A. J. Alsayaydeh and S. G. Herawan; writing review and editing, R. A. Hamzah and M. F. Yusof; funding acquisition, M. F. Yusof and S. G. Herawan.

ACKNOWLEDGEMENTS

The authors extend their appreciation to Universiti Teknikal Malaysia Melaka (UTeM) and to the Ministry of Higher Education of Malaysia (MOHE) for their support in this research.

REFERENCES

[1] M. R. Barusu, P. N. Pavithra, and P. S. R. Chandrika, "Optimal utilization of water for smart farming using internet of things (IoT)," in *2023 2nd International Conference for Innovation in Technology (INOCON)*, Mar. 2023, pp. 1–5, doi: 10.1109/INOCON57975.2023.10101227.

[2] N. Zainal, N. Mohamood, M. F. Norman, and D. Sanmutham, "Design and implementation of smart farming system for fig using connected-argonomics," *International Journal of Electrical and Computer Engineering*, vol. 9, no. 6, pp. 5653–5662, Dec. 2019, doi: 10.11591/ijece.v9i6.pp5653-5662.

[3] B. B. Bhanu, K. R. Rao, J. V. N. Ramesh, and M. A. Hussain, "Agriculture field monitoring and analysis using wireless sensor networks for improving crop production," *2014 Eleventh International Conference on Wireless and Optical Communications Networks (WOCN)*, Vijayawada, India, 2014, pp. 1-7, doi: 10.1109/WOCN.2014.6923043.

[4] P. Palniladevi, T. Sabapathi, D. A. Kanth, and B. P. Kumar, "IoT based smart agriculture monitoring system using renewable energy sources," in *2023 2nd International Conference on Vision Towards Emerging Trends in Communication and Networking Technologies (ViTECoN)*, May 2023, pp. 1–6, doi: 10.1109/ViTECoN58111.2023.10157010.

[5] P. Visconti, N. I. Giannoccaro, R. de Fazio, S. Strazzella, and D. Cafagna, "IoT-oriented software platform applied to sensors-based farming facility with smartphone farmer app," *Bulletin of Electrical Engineering and Informatics*, vol. 9, no. 3, pp. 1095–1105, Jun. 2020, doi: 10.11591/eei.v9i3.2177.

[6] P. Rajalakshmi and S. Devi Mahalakshmi, "IOT based crop-field monitoring and irrigation automation," in *2016 10th International Conference on Intelligent Systems and Control (ISCO)*, Jan. 2016, pp. 1–6, doi: 10.1109/ISCO.2016.7726900.

[7] N. Jihani, M. N. Kabbaj, and M. Benbrahim, "Sensor fault detection and isolation for smart irrigation wireless sensor network based on parity space," *International Journal of Electrical and Computer Engineering*, vol. 13, no. 2, pp. 1463–1471, Apr. 2023, doi: 10.11591/ijece.v13i2.pp1463-1471.

[8] T. E. Shomefun, C. O. A. Awosope, and O. D. Ebenezer, "Microcontroller-based vertical farming automation system," *International Journal of Electrical and Computer Engineering*, vol. 8, no. 4, pp. 2046–2053, Aug. 2018, doi: 10.11591/ijece.v8i4.pp2046-2053.

[9] K. M. S. Swaraj C M, "IoT based smart agriculture monitoring and irrigation system," *International Journal of Engineering Research and Technology (IJERT)*, vol. 6, no. 2, pp. 820–824, 2016, doi: 10.17577/IJERTCONV8IS14062.

[10] F. Kamaruddin, N. N. N. A. Malik, N. A. Murad, N. M. azzah A. Latiff, S. K. S. Yusof, and S. A. Hamzah, "IoT-based intelligent irrigation management and monitoring system using arduino," *Telkomnika (Telecommunication Computing Electronics and Control)*, vol. 17, no. 5, pp. 2378–2388, Oct. 2019, doi: 10.12928/TELKOMNIKA.v17i5.12818.

[11] S. B. Saraf and D. H. Gawali, "IoT based smart irrigation monitoring and controlling system," in *2017 2nd IEEE International Conference on Recent Trends in Electronics, Information and Communication Technology (RTEICT)*, May 2017, pp. 815–819, doi: 10.1109/RTEICT.2017.8256711.

[12] M. Khudhair, M. Ragab, K. M. Aboras, and N. H. Abbasy, "Robust control of frequency variations for a multi-area power system in smart grid using a newly wild horse optimized combination of PIDD2 and PD controllers," *Sustainability (Switzerland)*, vol. 14, no. 13, 2022, doi: 10.3390/su14138223.

[13] A. Nayyar and V. Puri, "Smart farming: IoT based smart sensors agriculture stick for live temperature and moisture monitoring using arduino, cloud computing and solar technology," in *Communication and Computing Systems - Proceedings of the International Conference on Communication and Computing Systems, ICCCS 2016*, Nov. 2017, pp. 673–680, doi: 10.1201/9781315364094-121.

[14] J. John, V. S. Palaparthy, S. Sarik, M. S. Baghini, and G. S. Kasbekar, "Design and implementation of a soil moisture wireless sensor network," in *2015 Twenty First National Conference on Communications (NCC)*, Feb. 2015, pp. 1–6, doi: 10.1109/NCC.2015.7084901.

[15] N. Tajudin, N. Ya'acob, D. M. Ali, and N. A. Adnan, "Soil moisture index estimation from Landsat 8 images for prediction and monitoring landslide occurrences in Ulu Kelang, Selangor, Malaysia," *International Journal of Electrical and Computer Engineering*, vol. 11, no. 3, pp. 2101–2108, Jun. 2021, doi: 10.11591/ijece.v11i3.pp2101-2108.

[16] A. L. Qohar and Suharjito, "Smart agriculture for optimizing photosynthesis using internet of things and fuzzy logic," *International Journal of Electrical and Computer Engineering*, vol. 12, no. 5, pp. 5467–5480, Oct. 2022, doi: 10.11591/ijece.v12i5.pp5467-5480.

[17] S. Navulur, A. S. C. S. Sastry, and M. N. Giri Prasad, "Agricultural management through wireless sensors and internet of things," *International Journal of Electrical and Computer Engineering*, vol. 7, no. 6, pp. 3492–3499, Dec. 2017, doi: 10.11591/ijece.v7i6.pp3492-3499.

[18] M. S. D. Abhiram, J. Kuppili, and N. A. Manga, "Smart farming system using IoT for efficient crop growth," in *2020 IEEE International Students' Conference on Electrical,Electronics and Computer Science (SCEECS)*, Feb. 2020, pp. 1–4, doi: 10.1109/SCEECS48394.2020.147.

[19] R. S. Upendra, I. M. Umesh, R. B. Ravi Varma, and B. Basavaprasad, "Technology in Indian agriculture – a review," *Indonesian Journal of Electrical Engineering and Computer Science*, vol. 20, no. 2, pp. 1070–1077, Nov. 2020, doi: 10.11591/ijeecs.v20.i2.pp1070-1077.

[20] H. Alotaibi, W. Karsou, S. Khan, S. Tohmeh, and A. Bashar, "Bustani: a microcontroller-based automated hydroponic vertical farming solution," in *2023 IEEE International Conference on Agrosystem Engineering, Technology and Applications (AGRETA)*, Sep. 2023, pp. 56–61, doi: 10.1109/AGRETA57740.2023.10262605.

[21] R. Khelifi *et al.*, "Short-term PV power forecasting using a hybrid TVF-EMD-ELM strategy," *International Transactions on Electrical Energy Systems*, vol. 2023, 2023, doi: 10.1155/2023/6413716.

[22] J. Xu, J. Zhang, X. Zheng, X. Wei, and J. Han, "Wireless sensors in farmland environmental monitoring," in *Proceedings - 2015 International Conference on Cyber-Enabled Distributed Computing and Knowledge Discovery*, Sep. 2015, pp. 372–379, doi: 10.1109/CyberC.2015.17.

[23] R. N. Rao and B. Sridhar, "IoT based smart crop-field monitoring and automation irrigation system," in *2018 2nd International Conference on Inventive Systems and Control (ICISC)*, Jan. 2018, pp. 478–483, doi: 10.1109/ICISC.2018.8399118.

[24] P. Yadav and S. Vishwakarma, "Application of internet of things and big data towards a smart city," in *2018 3rd International Conference On Internet of Things: Smart Innovation and Usages (IoT-SIU)*, Feb. 2018, pp. 1–5, doi: 10.1109/IoT-SIU.2018.8519920.

[25] M. A. M. Al-Obaidi, M. A. H. Radhi, R. S. Ibrahim, and T. Sutikno, "Technique smart control soil moisture system to watering plant based on iot with arduino UNO," *Bulletin of Electrical Engineering and Informatics*, vol. 9, no. 5, pp. 2038–2044, Oct. 2020, doi: 10.11591/eei.v9i5.1896.

[26] Y. Akshatha and A. S. Poornima, "IoT enabled smart farming: a review," in *Proceedings - 2022 6th International Conference on Intelligent Computing and Control Systems, ICICCS 2022*, May 2022, pp. 431–436, doi: 10.1109/ICICCS53718.2022.9788149.

[27] A. Rehman, T. Saba, M. Kashif, S. M. Fati, S. A. Bahaj, and H. Chaudhry, "A revisit of internet of things technologies for monitoring and control strategies in smart agriculture," *Agronomy*, vol. 12, no. 1, Jan. 2022, doi: 10.3390/agronomy12010127.

[28] M. M. Mahmoud *et al.*, "Voltage quality enhancement of low-voltage smart distribution system using robust and optimized DVR controllers: application of the Harris Hawks algorithm," *International Transactions on Electrical Energy Systems*, vol. 2022, 2022, doi: 10.1155/2022/4242996.

[29] P. Serikul, N. Nakpong, and N. Nakjuatong, "Smart farm monitoring via the Blynk IoT platform : case study: humidity monitoring and data recording," in *International Conference on ICT and Knowledge Engineering*, Nov. 2018, pp. 70–75, doi: 10.1109/ICTKE.2018.8612441.

[30] N. Putjaika, S. Phusae, A. Chen-Im, P. Phunchongharn, and K. Akkarajitsakul, "A control system in an intelligent farming by using arduino technology," in *2016 Fifth ICT International Student Project Conference (ICT-ISPC)*, May 2016, pp. 53–56, doi: 10.1109/ICT-ISPC.2016.7519234.

[31] R. Venugopal *et al.*, "Review on unidirectional non-isolated high gain DC-DC converters for EV sustainable DC fast charging applications," *IEEE Access*, vol. 11, pp. 78299–78338, 2023, doi: 10.1109/ACCESS.2023.3276860.

[32] I. Fedorchenko, A. Oliinyk, A. Stepanenko, T. Zaiko, S. Korniienko, and A. Kharchenko, "Construction of a genetic method to forecast the population health indicators based on neural network models," *Eastern-European Journal of Enterprise Technologies*, vol. 1, pp. 52–63, Feb. 2020, doi: 10.15587/1729-4061.2020.197319.

[33] A. Oliinyk, I. Fedorchenko, T. Zaiko, D. Goncharenko, A. Stepanenko, and A. Kharchenko, "Development of genetic methods of network pharmacy financial indicators optimization," in *2019 IEEE International Scientific-Practical Conference Problems of Infocommunications, Science and Technology (PIC S&T)*, Oct. 2019, pp. 607–612, doi: 10.1109/PICST47496.2019.9061396.

[34] P. Sharma and D. V Padole, "Design and implementation soil analyser using IoT," in *2017 International Conference on Innovations in Information, Embedded and Communication Systems (ICIIECS)*, Mar. 2017, pp. 1–5, doi: 10.1109/ICIIECS.2017.8275947.

[35] I. Fedorchenko, A. Oliinyk, J. A. J. Alsayaydeh, A. Kharchenko, A. Stepanenko, and V. Shkarupylo, "Modified genetic algorithm to determine the location of the distribution power supply networks in the city," *ARPN Journal of Engineering and Applied Sciences*, vol. 15, no. 23, pp. 2850–2867, 2020.

[36] N.Suma, S. R. Samson, S.Saranya, G.Shanmugapriya, and R.Subhashri, "IOT based smart agriculture monitoring system," *International Journal on Recent and Innovation Trends in Computing and Communication*, vol. 5, no. 2, pp. 177–181, 2017.

[37] L. Bounoua, M. L. Imhoff, and S. Franks, "Irrigation requirement estimation using vegetation indices and inverse biophysical modeling," in *International Geoscience and Remote Sensing Symposium (IGARSS)*, Jul. 2010, pp. 1823–1826, doi: 10.1109/IGARSS.2010.5649325.

BIOGRAPHIES OF AUTHORS

Jamil Abedalrahim Jamil Alsayaydeh received an M.S. degree in computer systems and networks from Zaporizhzhia National Technical University, Ukraine, in 2010 and Ph.D. in engineering sciences with a specialization in automation of control processes from National Mining University, Ukraine, in 2014. Currently a senior lecturer at Universiti Teknikal Malaysia Melaka (UTeM) since 2015. Research interests include artificial intelligence, IoT, energy conservation, web service composition, and wireless mesh networks. Author/co-author of 43+ research publications cited in over 94 documents. Actively supervises students, reviews for reputable journals, secures grants and holds membership in the Board of Engineers Malaysia (BEM). He can be contacted at jamil@utem.edu.my.

Mohd Faizal Yusof is currently appointed as an associate researcher-lecturer at Rabdan Academy, UAE. He holds a bachelor of science in electrical engineering from Northwestern University (1998) and an MBA in technology entrepreneurship from Universiti Teknologi Malaysia (2008). He is an experienced blockchain researcher, university technology transfers officer, software developer, and former start-up entrepreneur. His research interests include design science research, blockchain, cryptocurrency, artificial intelligence, and social entrepreneurship. He can be contacted at myusof@ra.ac.ae.

Mithilanandini S. Magenthiran was born in Butterworth, Penang in year 1997. She completed her degree in bachelor of computer engineering technology (Computer system) with Honors from Universiti Teknikal Malaysia Melaka (UTeM). She is currently working as a software engineer. Her research includes databases and the internet of things (IoT). She can be contacted at mitimmagen@gmail.com.

Rostam Affendi Hamzah graduated from Universiti Teknologi Malaysia where he received his B.Eng. majoring in electronic engineering. Then he received his M.Sc. majoring in electronic system design engineering and Ph.D. majoring in electronic imaging from the Universiti Sains Malaysia. Currently, he is a lecturer at the Universiti Teknikal Malaysia Melaka teaching digital electronics, digital image processing, and embedded systems. He can be contacted at rostamaffendi@utem.edu.my.

Izadora Mustaffa graduated from Universiti Teknologi Malaysia where she received his B.Eng. majoring in medical electronics engineering. She received her M.Sc. in electric, electronic and system engineering from the Universiti Kebangsaan Malaysia. Currently, she is a lecturer at the Universiti Teknikal Malaysia Melaka teaching digital signal processing, electronics, and engineering ethics. She can be contacted at email: izadora@utem.edu.my.

Safarudin Gazali Herawan is currently a senior lecturer at the Bina Nusantara University, Jakarta, Indonesia. His current research interests include automotive engineering, renewable energy, and heat recovery technologies. He can be contacted at email: safarudin.gazali@binus.edu.