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PAPER

Reliable Multi-Path Communication for IoT Based Solar Automated Monitoring as Motivation Towards Multi-Farming Hydroponic

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ABSTRACT

The current reliance on single-path communication presents limitations for effectively monitoring and controlling critical parameters that are essential for hydroponic success. This hampers the achievement of optimal plant growth and overall system performance in multi-farming hydroponic setups. The issue lies in the inherent vulnerabilities of single-path communication, which can result in data loss and transmission errors. Therefore, reliable multi-path communication is essential for Internet of Things (IoT)-based automated monitoring systems. The research aims to enhance monitoring and control capabilities in multi-farming hydroponic environments by integrating advanced communication technologies. Utilizing the ESP microcontroller in conjunction with the Painless Mesh library enables seamless communication among nodes, facilitating real-time data exchange and control. Additionally, app-based dashboard monitoring offers a user-friendly interface for remote monitoring. The findings demonstrate that reliable multi-path communication, combined with app-based dashboard monitoring, promotes optimal plant growth, efficient resource allocation, and sustainable multi-farming practices. In summary, this research contributes to a deliberate efficiency increase of 30% in pH level, 25% in humidity level, and 35% in temperature level. This paves the way for adopting efficient multi-farming hydroponic solutions that are based on resource-efficient energy usage.

KEYWORDS

ESP, mesh, internet of things (IoT), solar, hydroponic

1 INTRODUCTION

The world's population is projected to reach 10 billion people by 2050, according to United Nations data from 2019. This population growth will result in a persistent increase in the need for agricultural products [1, 19]. However, the limited availability

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of farmland, the depletion of natural resources, and the advent of unanticipated environmental challenges such as flooding, salinization, and global warming have made food security a paramount concern worldwide [2]. Due to these trends, hydroponics, a soil-less cultivation method, has emerged as a viable solution, offering higher yields, water efficiency, and reduced environmental impact [3, 20]. Building upon the principles of hydroponics, multi-farming hydroponics represents a significant advancement that takes crop cultivation to new heights [4]. By integrating diverse crops within a single controlled environment, multi-farming hydroponics optimizes resource utilization, enhances productivity, and promotes sustainable farming practices [5].

Despite the availability of real-time control of farm equipment through automated actuation devices, such as feeders, seed drills, valve-controlled irrigation systems, etc., in the market, there has been limited progress in the development of wireless technologies for transferring sensor data wirelessly from crop fields to remote servers [6, 21]. Besides that, agriculture has become more complex, and farmers cannot rely solely on traditional farming methods to improve their yields and profits [7]. Farmers must collect, manage, and analyze data generated from various sources, such as drones, sensors, and weather stations. Without the proper skills to interpret and apply the data, the gathered information becomes meaningless [8]. Hence, mesh networks allow for communication between sensors, enabling real-time data analysis at the farm level. This leads to timely interventions and optimizations, which can address the identified research gap [9]. This data can help farmers optimize their crop yields while managing soil fertility efficiently.

Another topic that is gaining popularity over time is solar energy, as well as automation. Malaysia, being located close to the equator, experiences high levels of solar radiation throughout the year. Instead of wasting this renewable energy, it can be utilized to power modern agricultural systems, such as the hydroponic approach.

The constant development and implementation of new technologies and solutions are aimed at addressing the current global needs of humanity. This has led to the emergence of the Internet of Things (IoT), with a focus on smart agriculture systems. These systems have emerged as potential solutions for sustainable and efficient farming [10]. However, these systems require reliable communication channels to ensure seamless data transmission and control [11]. Multi-path communication has emerged as a promising solution to address the reliability issues associated with single-path communication, leads it in a very positive direction, and promotes irrigation to a higher level of efficiency [12].

The main aim of this project is to enable IoT-based automated monitoring systems with multi-path communication for multi-farming hydroponics to improve remote decision-making during irrigation processes. Multi-farming hydroponics, also known as multi-crop hydroponics, is an innovative farming method that involves growing multiple crops using hydroponic techniques in a single system. This can provide reliable and efficient real-time data on vital parameters such as moisture levels. The structure of the paper is as follows: In Section 2, the methods employed in the study are described. Section 3 presents the results obtained, while Section 4 provides the concluding remarks.

2 LITERATURE REVIEW

With developments in various fields of agricultural technology, the way crops are grown and monitored has been revolutionized. This has provided farmers with real-time data that can help them make informed decisions about their farming practices [13]. To the best of my knowledge, in related work, there is limited research or work available on multi-farming hydroponics based on mesh network technology, which is a relatively new and innovative farming method that involves growing multiple crops in a single hydroponic system. However, IoT has been used in other related areas such as smart irrigation, smart gardening, and smart greenhouses farming. These application solutions are briefly explored below.

2.1 Smart irrigation using IoT

In a recent study [14], a simulation model was developed to evaluate the performance of a smart irrigation system based on IoT. The simulation model was based on the integration of a crop growth model, a soil water balance model, and an IoT-based smart irrigation system. The crop growth model was used to simulate crop growth and water uptake, while the soil water balance model was used to simulate soil moisture dynamics. The IoT-based smart irrigation system was used to generate irrigation schedules based on crop water requirements and weather conditions. The simulation study evaluated the performance of the smart irrigation system under different scenarios of crop types, soil types, weather conditions, and irrigation strategies. The results showed that the system was able to maintain soil moisture levels within the desired range and improve crop yields. In contrast to the conventional irrigation system, this IoT-based technology automates irrigation, which can save time, water, and energy. However, the major drawback is that this system has not been used in real life; though; it is limited to simulation-based only. This could result in limitations in terms of the applicability of the findings to practical scenarios, where they could not accurately represent the complexities of real-world smart irrigation systems in their actual environment.

2.2 Fuzzy logic greenhouse farming prediction intelligent system

In this paper [15], the author proposes a fuzzy logic-based multiclass support vector machine (SVM) algorithm for predicting factors that affect the control of greenhouses in farming. The study aims to develop a model that can accurately predict the factors that influence the control of greenhouses and enable farmers to make better decisions for optimizing the growth of crops. The authors collected data from various sensors installed in a greenhouse, such as temperature, humidity, CO_2 concentration, and light intensity, and used these data to train the fuzzy-based multiclass SVM algorithm. The algorithm takes into account the uncertainties and imprecisions of the input data, which are common in real-world greenhouse environments. However, this respective system has a main drawback since it is not easy to customize or amplify due to its complexity of fuzzy logic and SVM fusion. The fusion of fuzzy logic and SVM techniques could lead to a more complex model that might be challenging to implement and interpret, especially for new users who are unfamiliar with these kinds of methods.

2.3 Smart gardening monitoring system

The paper proposes a smart gardening monitoring system that uses sensors to monitor environmental factors such as temperature, humidity, soil moisture, and light intensity [16, 18]. The system is designed to provide real-time data and notifications to gardeners, enabling them to make informed decisions about plant care. The authors reported that the system was able to effectively monitor the growth of plants and improve the efficiency of gardening practices. However, there are several limitations to this approach. One limitation is the need for a reliable Internet connection in this respective field of work. The smart gardening monitoring system heavily relies on the Internet's strength to transmit data and notifications to gardeners effectively. In this case, the drawback is that if the Internet connection is unstable or unavailable, the system may not function properly and efficiently.

The benchmarking for this project was done with the paper in [17] on the part method for mesh network-based multi-farming hydroponic farming. The benchmarking research aimed to develop an IoT-based vertical indoor farming system using microcontrollers for monitoring and control, but with the limitation of single path communication, such as connectivity issues and addressing maintenance challenges. The goal of this project is to present an alternative smart hydroponic method that can be easily modified to accommodate different crops while also managing the administrative and economic aspects of the farm without knowing too much about the technical details behind the system implementation.

3 METHODOLOGY

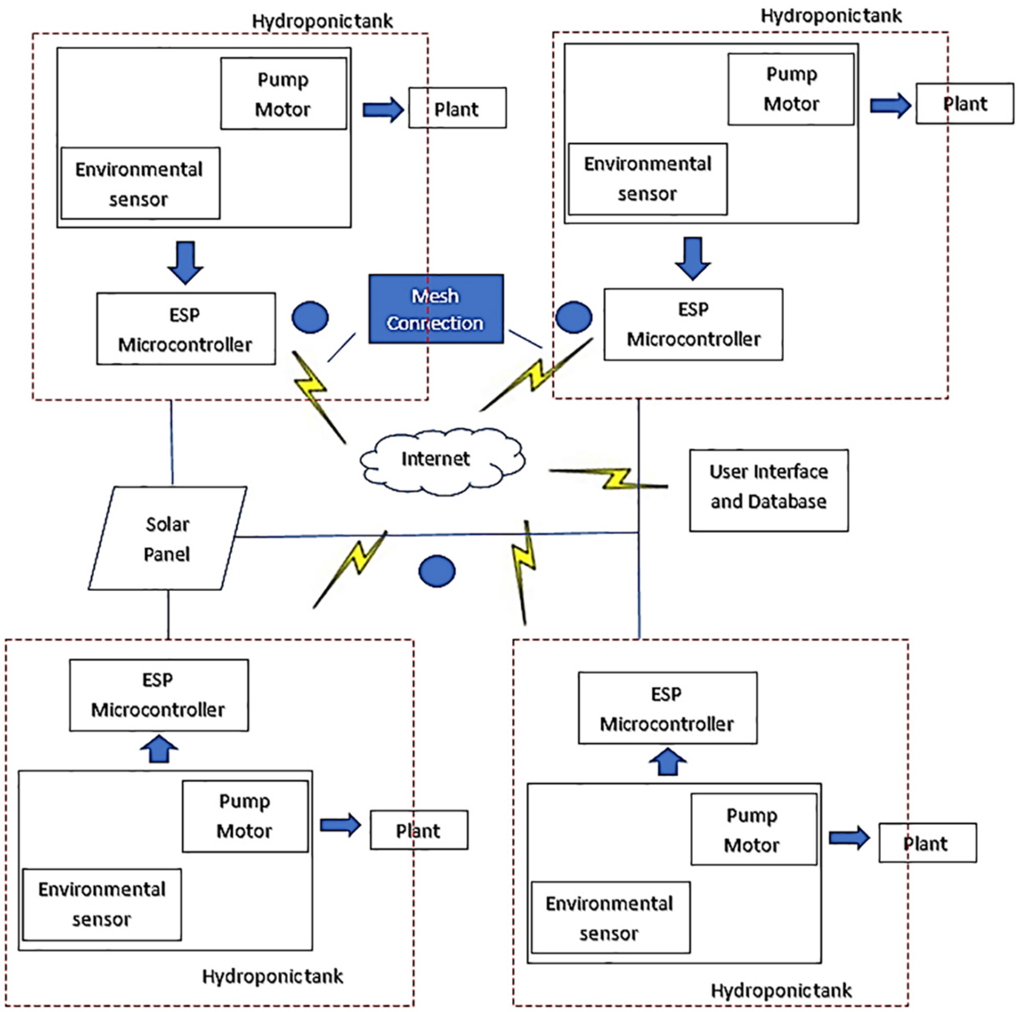

Fig. 1. Block diagram of the proposed system

Figure 1 depicts the smart hydroponics proposed system block diagram since it is considered to be a cutting-edge agricultural practice that combines the power of hydroponics with the connectivity and intelligence of the IoT mesh network. This innovative system utilizes sensors, actuators, and a network of interconnected devices to create an efficient and automated hydroponic environment. The IoT mesh network enables seamless communication between various components, such as nutrient dosing systems, water pumps, and temperature and humidity sensors. By connecting these devices through the IoT mesh network, real-time data on environmental conditions, nutrient levels, and plant health can be collected and analyzed. The data is then used to optimize and regulate the hydroponic system, ensuring precise control over factors such as irrigation, lighting schedules, and nutrient delivery. This is because the system is programmed using the Painless Mesh library. It is used to connect the nodes to one another. If one sensor breaks down, the system would be able to auto-configure and auto-setup, which would allow it to reconnect the system and proceed with its programmed functions. Consequently, the functionality of the sensor data will be transmitted to the Google Firebase cloud server and showcased within the MIT Android application, catering to user accessibility. Additionally, comprehensive logs of the sensor data will be archived on the Google Firebase cloud server, facilitating the option to export this data to Excel for offline analytical purposes by the users. Ultimately, the integration of smart hydroponics with the IoT mesh network revolutionizes the way farmers nowadays cultivate plants, enabling higher yields, reduced resource consumption, and improved sustainability in agriculture.

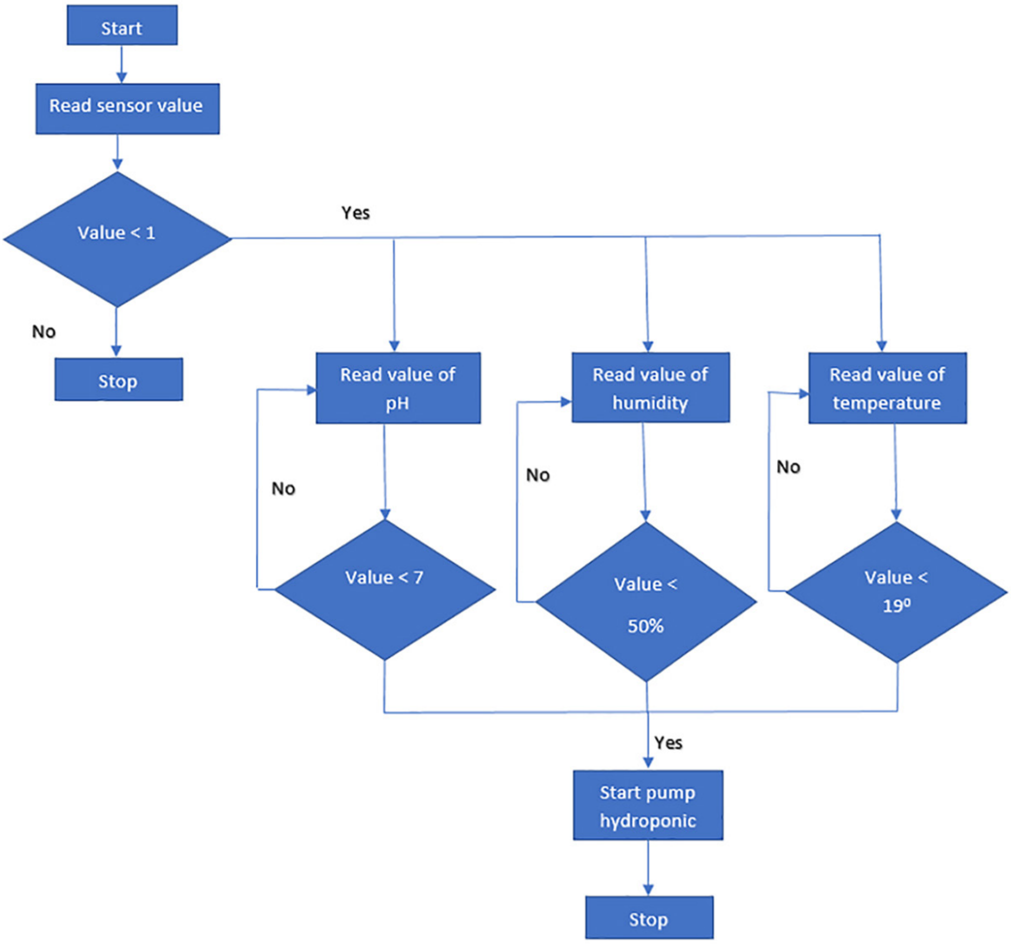

Fig. 2. Flowchart of the system

The provided flow chart in Figure 2 illustrates a fundamental framework for effectively monitoring three distinct parameters using sensors and implementing appropriate actions based on predefined thresholds. Specifically, this flow chart incorporates thresholds of 40% for soil moisture, 29 degrees for humidity, and 7 for pH level. If any of these parameters fall below their respective thresholds, the flow chart activates the water pump and fertilizer to rectify the situation. By employing sensors and automated systems, this monitoring structure ensures that the hydroponic environment remains within the desired range for soil moisture, humidity, and pH level. It enables timely interventions, guaranteeing optimal conditions for the growth and development of the hydroponic plants.

Apart from that, a centralized and intuitive platform based on web-based applications is developed to provide monitoring of the interconnected nodes, known as the ESP-Mesh Dashboard, shown in Figure 3. This function is to display the root node that the system is connected to. In this case, the illustrative representation presented here can be referred to as node visualization, which serves as a graphical depiction of the root node, thus underscoring the connection between the monitoring system and its central hub. This graphical aid not only enhances the platform's user-friendliness but also aids users in understanding the network's topography, fostering a more intuitive grasp of the IoT-based configuration. Only one node will be the root node at a time and listed as active. In the mesh network, all nodes can be root nodes, but only one at a time to provide the access point (Wi-Fi ID) so that other nodes can connect to it. When the original root node fails or disconnects, another node will become the root node and provide AP/Wi-Fi so that other nodes can be connected. Figure 3 also specifically illustrates that node 1 is active. It shows that node 1 is the root node that will send the information to the system. Besides that, a solar smart plant monitoring interface is also being developed, which will be discussed in the next section.

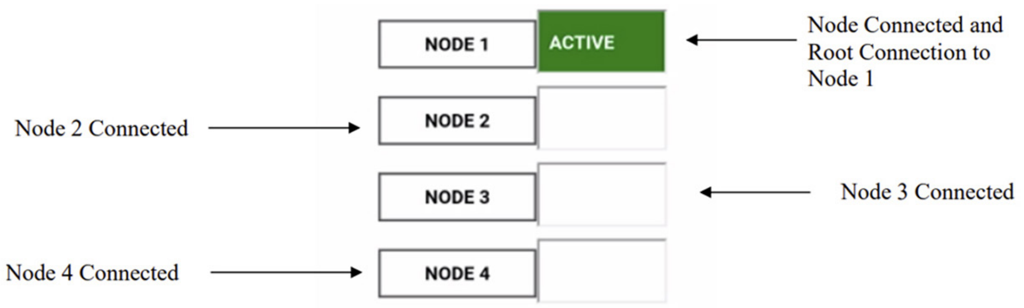

Fig. 3. Interface of root connection of mesh network

4 RESULTS AND DISCUSSION

Figure 4 depicts the innovative system of captivating visuals that showcases the intricate connection between four nodes, all orchestrated by an ESP node. This arrangement forms the backbone of a robust mesh network designed to seamlessly transmit data. At the heart of this network lies a water pump, a pivotal component that responds to signals from the nodes accordingly. What sets this system apart is its feature of being a sustainable energy source, in which solar energy fuels the entire operation, ensuring efficiency and environmental consciousness among the users. Furthermore, if one of the nodes goes down, the rest of the system will still function. In this case, to evaluate the performance results, two hydroponic systems were established: a conventional hydroponic system and a system equipped with multipath communication.

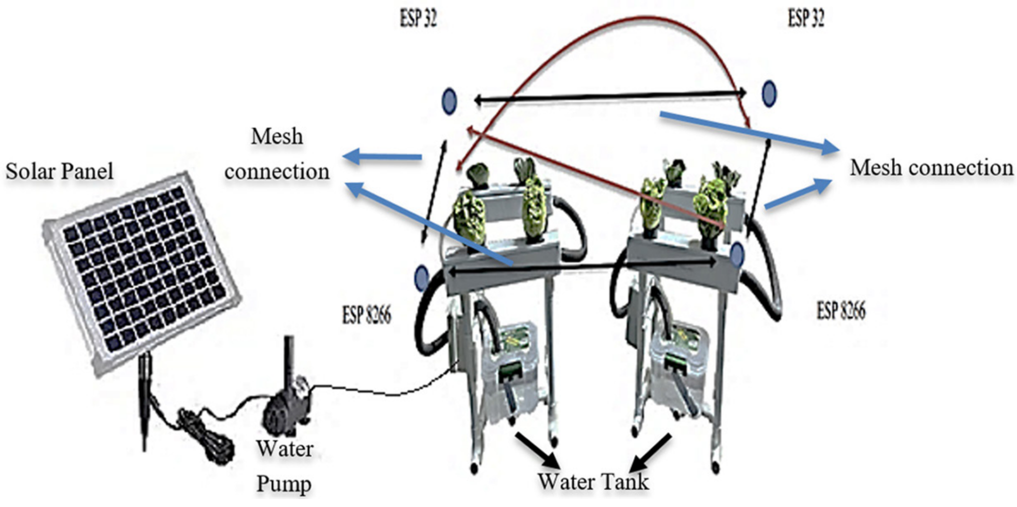

Fig. 4. Hydroponic prototype with ESP-mesh connection

4.1 pH level

The results of Figure 5 demonstrate that the pH levels in the conventional hydroponic system exhibited significant fluctuations around the target threshold of 7, which is prone to being inefficient and could negatively impact plant growth. In contrast, the hydroponic system with multipath communication consistently maintained pH levels close to the desired threshold. In the meantime, it can also be observed that a 30% increase in efficiency highlights the importance of precision pH management in multi-farming hydroponic systems. It means that there is potential for the multipath communication to improve pH control and stability in hydroponic systems. Apart from that, the conventional system relied on manual pH adjustments, while the multipath communication system utilized a network of sensors for real-time pH monitoring and feedback control. The real-time monitoring and automated control provided by the multipath communication system enabled quick and accurate adjustments with the purpose of minimizing deviations from the desired pH threshold, resulting in improved pH stability.

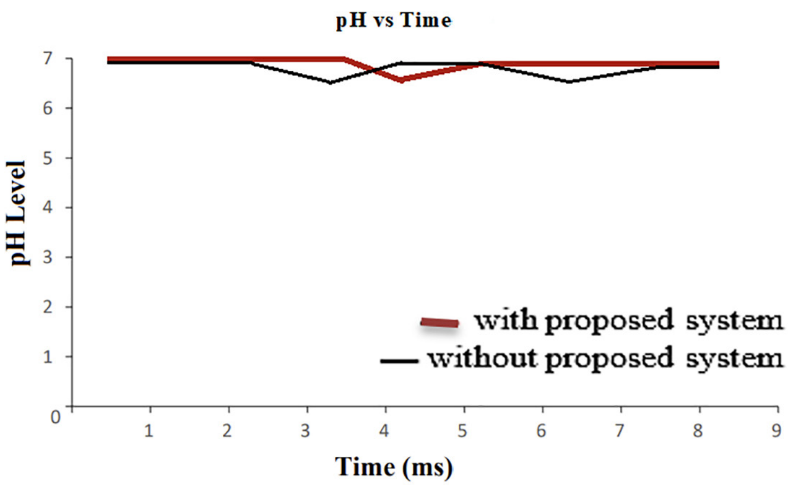

Fig. 5. pH variation comparison

4.2 Humidity level

When compared to a traditional hydroponic system without the proposed system, the results of Figure 6 show that the suggested system has superior humidity-regulating capabilities with only sporadic departures beyond the required threshold of 50%. Consequently, it can be observed that 25% of the improvement in productivity emphasizes the significance of precise humidity control in multi-farming hydroponic systems. The multipath communication protocol allows for the transmission of data and control signals through multiple paths or channels. This redundancy helps mitigate signal loss, interference, or degradation that can occur in a complex indoor environment where hydroponic system is installed. By using multiple paths, the system can overcome potential obstacles or signal blockages, ensuring that the humidity-related information reaches its destination reliably. It shows that the proposed system holds the promising potential to exchange data across multiple farming environments, which allows for centralized monitoring and control, thus improving system efficiency and reducing resource waste.

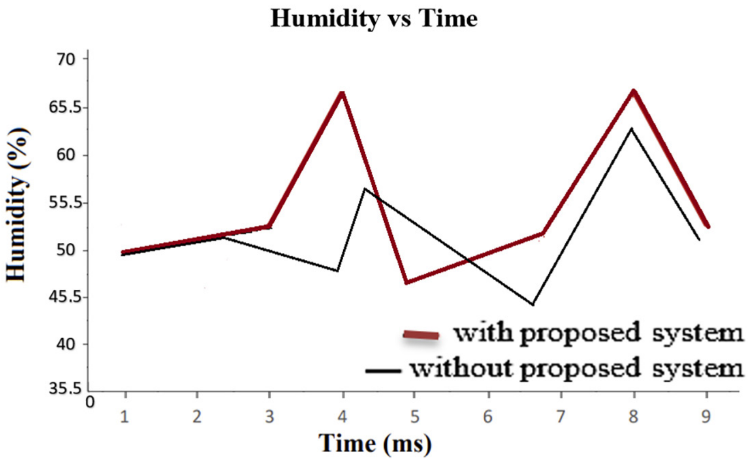

Fig. 6. Humidity variation comparison

4.3 Temperature level

From Figure 7, the proposed system demonstrated a significant temperature regulation compared to the conventional hydroponic system without the integration of the proposed system, based on the target threshold of 19˚C. This indicates that precision temperature management in multi-farming hydroponic systems is crucial, as evidenced by the 35% improvement in efficiency found. This is due to the multipath communication protocols, which can provide redundancy and fault tolerance in the event of communication failures or disruptions, which further allows for the integration of multiple temperature sensors across the hydroponic system. This ensures that temperature data continues to be transmitted reliably, even if there are temporary obstacles or interference in the communication path. Consistently maintaining temperatures within the optimal range created favorable conditions for plant physiological processes, including nutrient absorption and facilitated more effective temperature control. As a result, the plants in the proposed system exhibited healthier foliage, faster growth rates, and higher overall productivity compared to the conventional hydroponic system without the integration of the proposed system.

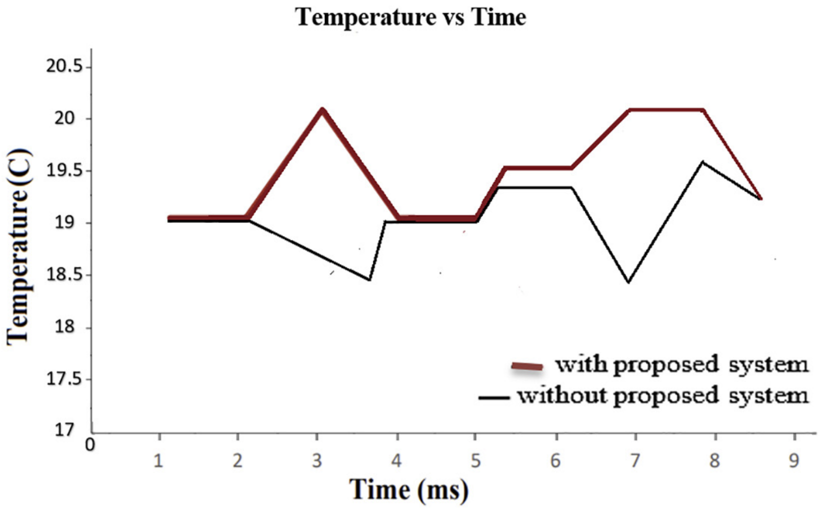

Fig. 7. Temperature variation comparison

On top of that, Figure 8 serves as a visual representation of the further improvement of this proposed system, named the Solar Smart Plant application interface for monitoring plant parameters. It was developed using block-based software. The depiction highlights how the system's interface appears on smartphones, providing users with a glimpse of the real-time data and controls available at their fingertips. The interface features dynamic data displays that showcase the current values of various parameters being monitored in real-time manner. By leveraging remote access capabilities, farmers can monitor and control their hydroponic systems from anywhere through an Internet connection, thus enhancing flexibility and convenience of use. This user-friendly and intuitive interface further enhances the overall user experience and encourages seamless interaction with the Solar Smart Plant system. Considerably, the Android application user interface for hydroponic monitoring is designed to empower users with real-time insights and informed decision-making in hydroponic farming.

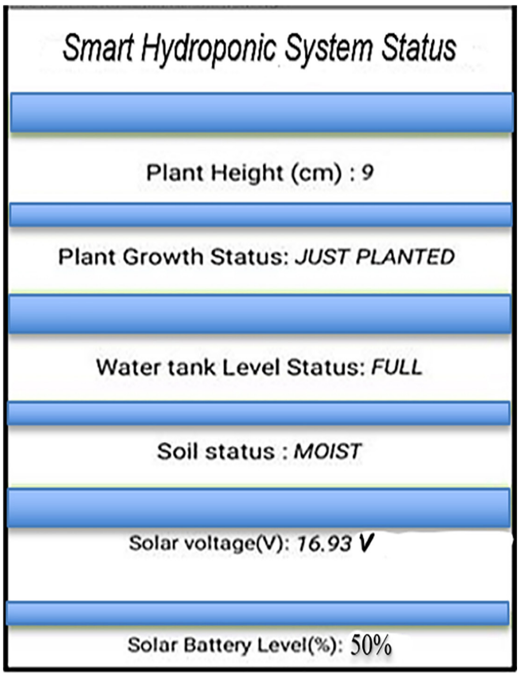

Fig. 8. Android application user interface for monitoring

The findings strategically manipulate the environmental conditions by deliberately adjusting the pH level by 30%, humidity level by 25%, and temperature level by 35%, thus offering practical insights into optimizing plant growth and productivity within this proposed method. These deliberate alterations resulted in a demonstrably conducive environment for enhanced plant growth. Implementing this technology results in deploying an array of solar-powered sensor nodes across the multi-farming hydroponic setup, facilitating continuous monitoring of these critical variables. Through the multi-path communication system, real-time data is seamlessly transmitted to a central hub and cloud platform accordingly. Farmers can then access this data via an intuitive application, enabling them to make timely adjustments to environmental parameters as well. By replicating the observed favorable conditions, farmers can effectively fine-tune their hydroponic environments, thus promoting optimized plant growth, increased yields, and overall agricultural efficiency.

Nevertheless, there are potential challenges to this kind of implementation. Different communication paths might have varying signal strengths based on factors like distance and obstacles. Ensuring reliable data transmission across all paths, especially in challenging environments, can be demanding as well.

5 CONCLUSION

In summary, the deliberate increase of 30% in pH level, 25% in humidity level, and 35% in temperature level have proven to be instrumental in creating an environment conducive to better plant growth and productivity. The development of reliable multi-path communication for IoT-based automated monitoring represents a significant stride toward the realization of multi-farming hydroponics.

The integration of IoT devices and automated monitoring systems enables real-time data collection, analysis, and decision-making, facilitating precise control over environmental conditions, nutrient delivery, and plant growth. This enhanced level of monitoring and control ensures optimal resource utilization, reduces waste, and maximizes crop yield. Moreover, the ability to remotely monitor and manage multiple hydroponic farms from a central location streamlines operations, reduces labor requirements, and opens up opportunities for scalability.

The implementation of multi-path communication is particularly crucial to ensuring the reliability and robustness of the system. By utilizing multiple communication paths, such as Wi-Fi, Bluetooth, cellular networks, and even satellite connections, the system becomes resilient to failures or disruptions in a single network. This redundancy enhances the system's ability to maintain seamless data transmission, ensuring uninterrupted operation and reducing the risk of crop loss due to communication breakdowns.

Furthermore, the integration of multi-farming techniques with hydroponics opens up possibilities for diversification and specialization in crop production. Different types of plants with varying environmental requirements can be grown simultaneously, allowing farmers to cater to a broader range of market demands and optimize their yield considerably.

In addition to its current contributions, the proposed research direction also presents several promising avenues for future exploration, such as the paper's concept of multi-path communication, which could be combined with machine learning algorithms to predict optimal communication paths based on real-time network conditions simultaneously. Such predictive capabilities could significantly enhance overall communication reliability, both positively and intuitively.

As a conclusion, reliable multi-path communication for IoT-based automated monitoring holds immense potential for transforming agriculture, particularly in the context of multi-farming hydroponics. By harnessing the capabilities of interconnected devices, advanced communication technologies, and precise control systems, farmers can achieve greater efficiency, sustainability, and scalability in their operations. Embracing these innovations can pave the way for a future where agriculture meets the growing demands for high-quality produce while minimizing environmental impact.

6 ACKNOWLEDGMENT

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