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Greening of Automated Hydroponic System Based on IoT and Enhanced Solar Energy with Electricity Saving Box

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ABSTRACT

In recent years, advancements in technology have reshaped the landscape of agricultural practices, aiming to address the challenges posed by conventional farming methods such as traditional hydroponic system. Traditional hydroponic systems often rely on conventional energy sources, leading to elevated energy consumption and carbon emissions. Addressing these challenges, the primary objective of this study is to design, implement, and evaluate an integrated hydroponic system that leverages IoT-based real-time monitoring and control, optimized solar energy utilization, and an electricity-saving box. IoT-enabled sensors and actuators monitor key parameters, facilitating automated adjustments to nutrient delivery, temperature, and humidity. Enhanced solar energy capture is achieved through advanced photovoltaic technologies, while the electricity-saving box ensures efficient power management. The findings demonstrate a substantial reduction in energy consumption compared to traditional hydroponic systems. The integrated approach contributes to minimized carbon emissions and resource utilization, aligning with eco-friendly cultivation practices. Real-time monitoring and control capabilities empower growers to optimize cultivation conditions for enhanced plant health and growth. In conclusion, this research underscores the potential of merging IoT technology, enhanced solar energy, and an electricity-saving box to transition hydroponic systems into sustainable and environmentally responsible platforms with the 35% of system efficiency enhancement achieved through the proposed method bring about transformative implications for automated hydroponic systems

Keywords:

Hydroponic; Electricity saving box; Solar; IoT

1. Introduction

The escalating global demand for sustainable and resource-efficient agricultural practices has propelled the exploration of innovative farming technologies as reflected in a study by Nawab *et al.,*

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[1]. Some more, many countries worldwide experience extreme temperatures, alongside issues such as drought, desertification, water scarcity, and chemical toxicity, all exacerbated by rapid population growth, which impacts agricultural cultivation as described in a study by Zhou *et al.,* [2]. In recent years, the increasing demand for food has heightened public awareness about the quality of their consumed food. Consequently, agriculture faces significant pressure to meet both the high demand and stringent quality standards. Hydroponics, a soilless cultivation method, has emerged as a promising solution that allows precise control of nutrient delivery and maximizes crop yields while conserving valuable resources as examined in a study by Roberto *et al.,* [3]. The Nutrient Film Technique (NFT) system is a widely adopted hydroponic method for plant cultivation. In an NFT system, a thin film of nutrient-rich water continuously flows over the plant roots, providing essential water, oxygen, and nutrients as reflected by both Hidayat *et al.,* [4] and Despommier *et al.,* [5]. As traditional soil-based farming faces challenges as mention above, hydroponic systems have gained popularity for their potential to revolutionize modern agriculture.

Advancements in hydroponic technology have further solidified its position as an advanced and popular farming technique. Approaches like the Nutrient Film Technique (NFT) and deep flow technique have been devised to utilize the advantages of soilless cultivation and enhance the growth of plants as reviewed in a study by Andre *et al.,* [6]. Additionally, the adoption of hydroponic systems in plant factories has been on the rise, primarily due to their exceptional advantage of automated monitoring and controlled fertilization, leading to significant labour savings as explored in a study by Lakhiar *et al.,* [7]. However, the implementation of hydroponic systems on a practical scale poses its own set of challenges, particularly in terms of resource management. To mitigate this challenge is by the integration of Internet of Things (IoT) technology with hydroponic systems through enabling precise monitoring and control of environmental conditions in order to optimize nutrient delivery, water usage, and climate control, thereby improving overall efficiency and productivity according to both S. Nižetić *et al.,* [8] and Nurfatin *et al.,* [9].

Furthermore, the proposed method suggests the incorporation of an electricity saving box which further enhances the system's energy efficiency that could minimizes electricity wastage during the system's operation, optimizing energy consumption and reducing the overall ecological footprint. Through this research, it is aimed to highlight the transformative potential of merging enhanced solar energy utilization in automated hydroponic systems. The results obtained from rigorous experimental trials will underscore the advantages of this integrated approach over conventional hydroponic setups, illustrating its potential as a sustainable and eco-conscious solution for modern agriculture as outlined in a study by Michal *et al.,* [10].

Despite the promising advantages of hydroponics, the energy-intensive nature of conventional setups presents a significant obstacle towards achieving true sustainability in accordance with the depiction in a study by Csambalik *et al.,* [11]. The reliance on non-renewable energy sources not only leads to increased operational costs but also impacts the ecological balance. This concern has prompted researchers to explore renewable energy alternatives to power hydroponic systems as summarized by both Yadav *et al.,* [12] and Li *et al.,* [13]. It is reported that among various renewable energy sources, solar power has emerged as a prime candidate for integrating with hydroponic setups while in recent years also, research efforts have been directed towards combining enhanced solar energy utilization with typical solutions such as integrated electronic or power management approaches.

A notable research gap lies in the limited exploration of the integration between automated hydroponic systems, IoT technology, solar energy enhancement, and electricity-saving mechanisms within a single framework. Existing studies often focus on individual aspects without fully exploring the potential synergies and holistic optimization of these components. Therefore, the contributions to this paper include the following: The two objectives for the proposed approach were as follows. The first objective is to build a prototype for an IoT-based automated smart home gardening system. This technology will use Nodemcu, which is inexpensive. The next goal is to incorporate solar panels with the automated hydroponic system coupled with an electricity saving box to make it an energy efficient system. The remaining portions of the paper are structured as follows: Following Section 3, which elaborates on the system design, Section 2 lists a few related publications as literature review. The project is concluded in Section 5 after Section 4 presents and examines the outcomes.

2. Literature Review

The increasing global demand for sustainable and resource-efficient agricultural practices has led to the exploration of innovative farming techniques, with hydroponics being at the forefront of this research. Hydroponic method, which enable soilless cultivation but based on waste-water, have started to gain attention for their potential corresponding to Mai *et al.,* [14] where wastewater hydroponics is classified into open systems, which do not recirculate the nutrient solution, and closed systems, which do. But using the waste water in hydroponic system has the high-risk health concern need to be resolve first.

Several studies also have investigated various hydroponic techniques to optimize plant growth and nutrient uptake. The Nutrient Film Technique (NFT) and deep flow technique are among the well-established methods that have demonstrated higher crop yields and reduced water consumption compared to conventional soil-based systems as depicted by Fussy *et al.,* [15]. For example, the NFT method involves directing the nutrient solution through a slanted growth tray. This solution travels to the tray's opposite end before being returned to the reservoir. Remarkably, this system operates without the need for both a growth medium and a timer. Additionally, an air pump is unnecessary due to the unique reliance on air as the growth medium. However, a drawback arises as the plants are susceptible to wilting when the nutrient flow halts, leading to relatively rapid root drying as reported by Baiyin *et al.,* [16].

The role of monitoring and control features in hydroponic systems have been studied extensively especially by both Dudwadkar *et al.,* [17] and Nguyen *et al.,* in [18] that involved remote monitoring systems, such as Internet of Things (IoT)-based automated monitoring, have been implemented to enable real-time data collection, analysis, and control of the hydroponic environment Both works can be summarized where an automated mobile control system utilizing sensors has been created for hydroponics, employing cost-effective technologies for managing and overseeing gardening activities. This application automates the monitoring of hydroponic conditions through a range of sensors, encompassing water temperature, humidity, temperature, and light intensity. Harvested data will inform future growth phases for hydroponic planning. The integration of automation in hydroponic setups to can enhances operational efficiency, increases productivity, and allows for remote monitoring and control which reduce human dependency, making it an attractive option for modern farming practices.

A broad similar point has also recently been made by Kamarulzaman *et al.,* [19] as the benchmarking paper on the method for the greening of automated hydroponic system. By the way, the method was not built for remote manner in the benchmarking paper. In contrast to this benchmarking paper solution, a system of remote monitoring based on software application is proposed in this paper to monitor the condition of the plants based on the water level. Additionally, there was a study by Laseinde *et al.,* [20] suggested that by using an automated water-cooling technique on solar panel based on an Arduino microcontroller, the system’s efficiency can be increased which is about 16.65%. Unlike the solutions in this previous work, the proposed work in this paper deals with the integration an electricity-saving box with hydroponic systems, in this case offers an innovative approach to optimize energy consumption and improve system efficiency. The proposed work here is supported by Sudianto *et al.,* [21] notes on incorporation of integrated capacitors through an electricity saving box can further optimize energy consumption and reduce environmental impact. By merging enhanced solar energy utilization, smart monitoring, and electricity saving box, the proposed "Automated Hydroponic System based on Enhanced Solar Energy with Electricity Saving Box" aims to contribute to the growing body of knowledge on sustainable agricultural technologies and pave the way for greener and more efficient farming practices.

3. Methodology

Figure 1 shows the overall system design of the block diagram for the proposed project. The main idea of this project is to develop a greener automated hydroponic system based on IoT coupled with the solar PV system with power-saving circuit. The solar PV system will be the main supply source that will power up the automated hydroponic system. The solar panel selected features a 12-V DC output, MC4 connections, and a maximum power of 50W. Besides that, a solar PWM charger controller is used to keep and step down the power source to power up the proposed system from the solar panel, which ranges from 12V to 18V that able to charge a rechargeable lead acid battery safely without any problem for process continuality. From here, it will be connected to a power-saving circuit. The respective automated hydroponic system here also has a relay board combined with input sensors such as the water level sensor and current level sensor, which control the water pump operation. A microcontroller called the Nodemcu of ESP 32 with Wi-Fi capability is used here for sensor data processing as well as to transmit the data to the cloud platform. Finally, all the sensor data will be displayed in the BLYNK Android application for the user interaction.

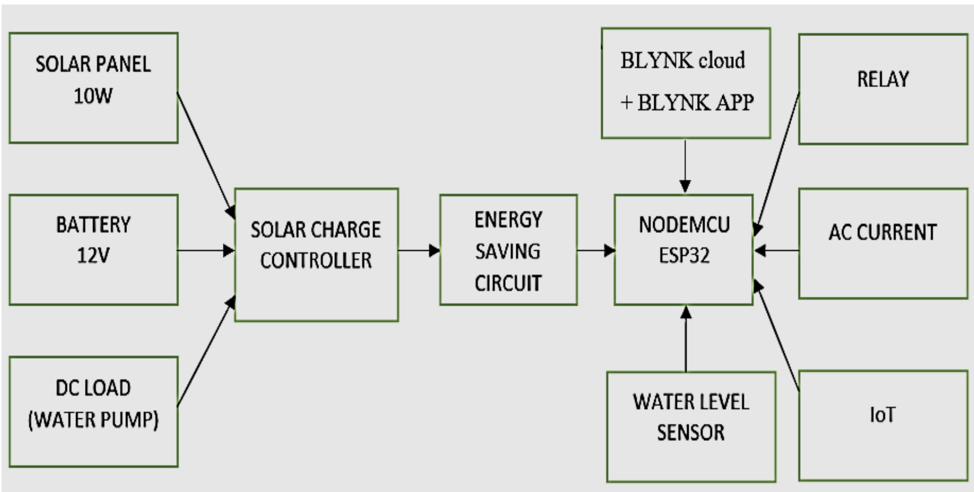

Fig. 1. System block diagram

By referring to Figure 2, the main highlight here is the electricity-saving circuit of an electronic component designed to reduce energy consumption and enhance overall efficiency in automated hydroponic systems. Its primary purpose is to optimize the utilization of electrical power, thereby minimizing energy wastage and contributing to sustainability. When plugged in, it becomes part of the wiring for the power points of the system and automatically stabilizes all incoming power voltage. Specifically, this electrical part of the respective system based on installation and integrated capacitors are connected in series into an electricity circuit can effectively address current losses with the help to offset reactive power demands, thus resulting in improved power quality, enhanced energy efficiency, and prolonged the respective system lifespan. The capacitors are designed to have high capacitance values and are connected in series create a voltage division effect, reducing the voltage across each capacitor. The voltage drop is determined by the ratio of the capacitance values of the capacitors. Capacitors with capacitance values in the microfarad (μF) or millifarad (mF) range are common choices. Capacitance values in the range of 5 to 25 microfarads (μF) per kVA of connected load are common. Simply to say, it can immediately attain the electricity-saved effect without the need for maintenance work.

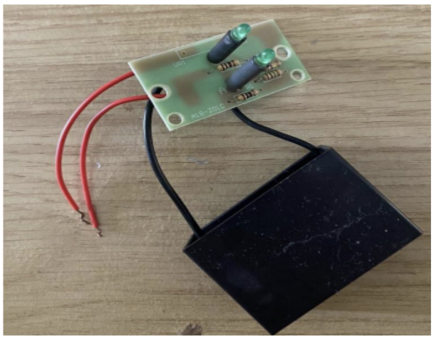

Fig. 2. Power saving circuit

The algorithm flowchart as illustrated in Figure 3 represents the embedding process. From the beginning, the information from the water level sensor is collected. A parameter of less than 50% has been set for the water level sensor. If the water level is below 50%, the plant will be deficient in the hydroponic system. The accurate water level for this system is around 60% to 70%. In addition, when the water pump reaches above 50%, it will trigger accordingly. When the water level falls below 50%, the water pump will be activated until the optimum water level is reached. When the water level reaches a critical level, it will send a notification alert via the Blynk app. Consequently, it also sends a corresponding email to the user.

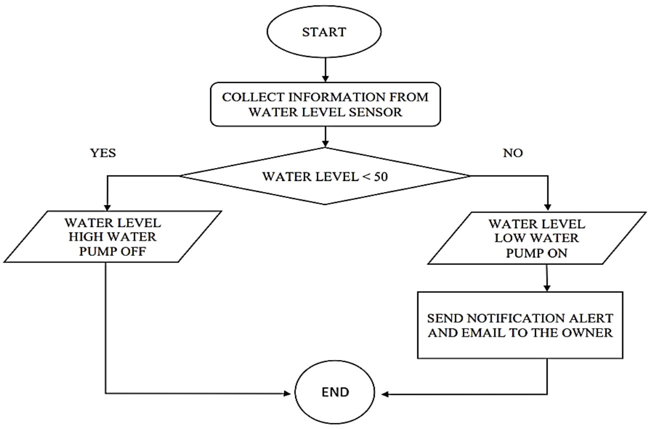

Fig. 3. Flowchart of the IoT monitoring system

4. Results

The Figure 4 illustrates a prototype development for a solar-powered nutrient film technique (NFT) hydroponic system. This system integrates several key components to function autonomously using renewable energy. At the top, a solar panel is mounted, which harnesses solar energy and converts it into electrical power. This power is then managed by a circuit box, which likely contains the necessary electronics and controls to regulate the system's operation. Below the solar panel, there is a water tank that stores the nutrient solution essential for plant growth. The solution is pumped from the water tank through the NFT hydroponic set, which is designed with hollow tubes that allow a thin film of nutrient-rich water to flow over the roots of plants housed in the circular openings. The closed-loop design ensures efficient use of water and nutrients while minimizing waste. This setup exemplifies a sustainable approach to agriculture, combining clean energy with efficient water and nutrient management to support plant cultivation in a controlled environment. Leveraging cutting-edge technologies, including IoT features and enhanced solar energy utilization with an electricity-saving box, the system's capabilities were elevated to new heights.

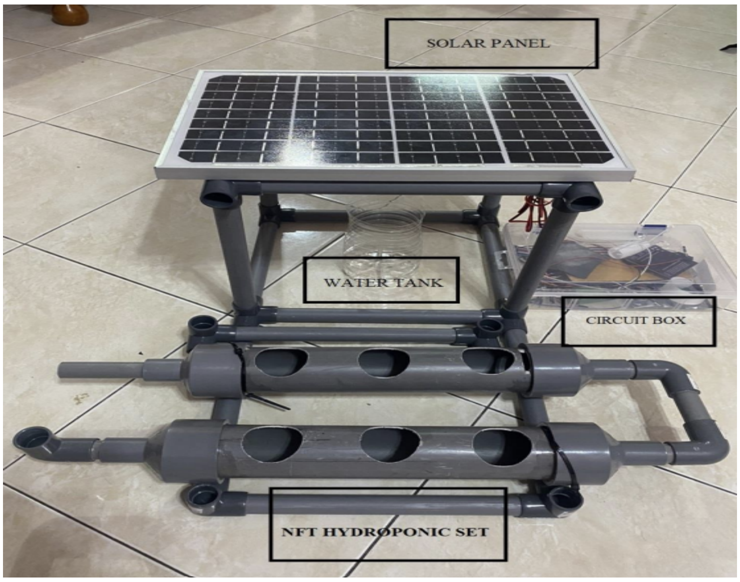

Fig. 4. Prototype development

In the Figure 5 shows the user interface of the Blynk application, specifically focusing on the notification alert feature related to water level monitoring. This interface is designed to provide real-time alerts to users, indicating the status of water levels within the system it is monitoring—likely a hydroponic setup, as suggested by its integration with a renewable energy-powered prototype. The alerts are listed chronologically, with timestamps for each notification, which allows the user to track the frequency and timing of these alerts. The notifications emphasize the need for "Attention," indicating that the water level requires monitoring or adjustment to maintain optimal conditions for the system's operation. The interface is streamlined with a simple design, featuring clear labels such as "Alerts," "Devices," and "Notifications" at the bottom, which suggests ease of navigation within the application. This functionality is critical for maintaining the automated system's efficiency by ensuring that the water level remains within the desired range, preventing potential issues like insufficient water supply that could disrupt plant growth or system performance. By extending monitoring capabilities to users' phones, this feature encapsulated the essence of convenience, control, and real-time responsiveness within the hydroponic environment. Together, these advancements paint a picture of a more sustainable and efficient hydroponic cultivation environment, thus redefining the landscape of modern agriculture.

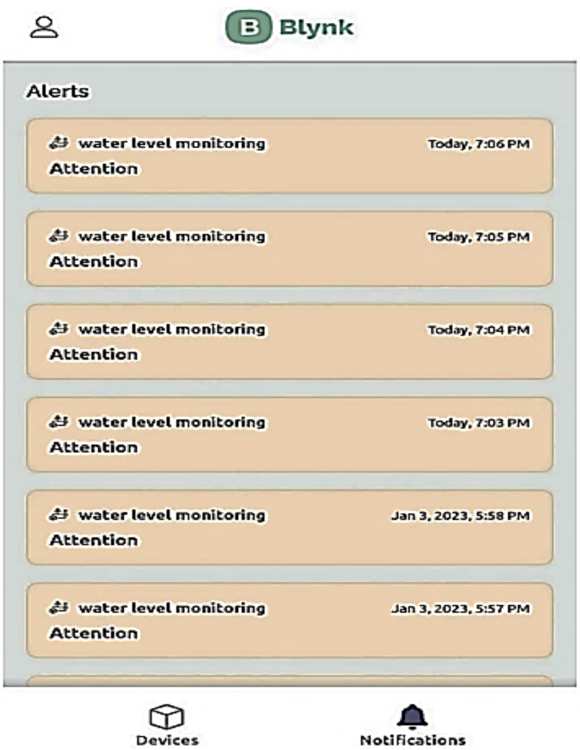

Fig. 5. BLYNK application user interface of notification alert for the proposed method

Furthermore, a comparison of energy consumption in the automated hydroponic system with and without the energy-saving circuit is shown in Figure 6, which can be observed in a pattern of substantial reduction. Overall, the data reveals a consistent pattern where the energy consumption with the proposed method is significantly lower than without it throughout the day. The investigation aimed to evaluate the impact of the proposed energy-efficient method on energy consumption reduction in comparison to the conventional approach. The results reveal significant energy-saving benefits that are achieved through the implementation of the proposed method, which boosts a 35% increase in system efficiency. The substantial energy consumption reduction and 35% system efficiency enhancement have profound implications in this project whereby the respective automated hydroponic systems can allocate energy more judiciously, resulting in improved crop yields, better growth rates, and enhanced crop quality.

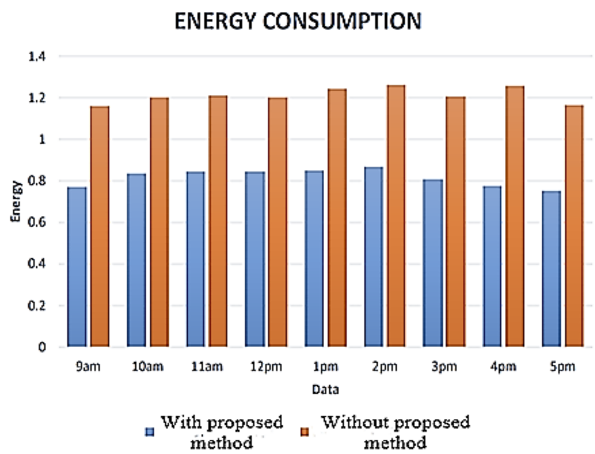

Fig. 6. Comparison graph of energy consumption with and without the proposed method

4. Conclusions

In conclusion, the integration of IoT features, enhanced solar energy, and an electricity-saving box has ushered in a new era of sustainability and efficiency in automated hydroponic systems. Specifically, the substantial energy consumption reduction and 35% of system efficiency enhancement achieved through the proposed method bring about transformative implications for automated hydroponic systems. Apart from that, the automated hydroponic system can provide optimal conditions for plant growth, resulting in healthier crops and enhanced yield harvests. Overall, the achieved results have unequivocally demonstrated that the amalgamation of IoT-driven monitoring, enhanced solar energy utilization, and the implementation of an electricity-saving box is a powerful strategy for optimizing crop resource utilization. This greening initiative not only reduces energy consumption but also minimizes wastage, aligning seamlessly with the principles of sustainable agriculture.

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