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Optimizing Electrical Performance in PV Hydroponic Systems Through Automated Pump Control and TDS-Based IoT Monitoring

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Abstract: This work aims to develop an IoT-based automated control system for a photovoltaic hydroponic system, integrating sensor-based nutrient delivery, energy-efficient pump control, and real-time monitoring. The objectives include designing an automated pump control system, implementing an IoT monitoring system for real-time data collection, and evaluating the optimization of electrical energy usage. Key findings indicate significant energy savings achieved by the automated pump control system, resulting in reduced energy consumption and a more sustainable approach to hydroponic cultivation.

Keywords: Hydroponic Systems, Automated Control System, Photovoltaic Integration, Nutrient Delivery, Energy Efficiency, Real-Time Monitoring, Iot

1. Introduction

Hydroponic systems have emerged as a modern approach to agriculture, particularly in urban areas where land availability is limited. These systems offer numerous advantages, such as higher yields and resource efficiency[1]. However, effectively managing nutrient levels in hydroponic systems remains a challenge due to the varying requirements of different crops. Conventional methods often rely on generic nutrient delivery, which can result in inadequate or excessive nutrition for plants [2]. Furthermore, energy consumption in hydroponic systems, specifically related to water pumps used for circulating the nutrient solution, is a concern. Traditional systems operate the pumps continuously, irrespective of the actual nutrient requirements, leading to unnecessary energy usage and higher costs [3].

To address these challenges, researchers have developed automated nutrient delivery systems that utilize sensors to monitor the nutrient concentration in real-time. This enables precise adjustments in nutrient delivery, optimizing plant growth and overall system efficiency [1]. Additionally, automated control systems have been explored to regulate pump operation based on sensor readings, resulting in

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energy savings without compromising nutrient delivery [4]. Furthermore, the integration of photovoltaic systems, harnessing solar energy, provides a sustainable and cost-effective solution for powering hydroponic systems, particularly in off-grid areas [5].

The objectives of this research can be divided into three clear subdivisions. Firstly, the aim is to design an automated pump control system for photovoltaic (PV) hydroponic systems. This system will optimize the pump's operation based on real-time data, ensuring efficient nutrient delivery to the plants. Secondly, the work aims to implement an IoT monitoring system for real-time total dissolved solids (TDS)-based data collection. This system will enable continuous monitoring of nutrient levels, allowing for timely adjustments and precise control. Lastly, the research intends to evaluate the optimization of electrical energy usage in PV hydroponic systems. By analyzing and comparing energy consumption data, the work seeks to identify ways to minimize energy usage while maintaining optimal system performance.

The combination of automated nutrient delivery, energy-efficient pump control, and photovoltaic integration holds great potential for revolutionizing agriculture. By optimizing nutrient delivery based on real-time data and reducing energy consumption through smart pump control and renewable energy sources, these systems can achieve high yields with minimal resource usage. This work aims to contribute to this advancement by designing an automated control system for a photovoltaic hydroponic system, enabling precise nutrient delivery and energy-efficient operation.

2. Materials and Methods

This work was structured into multiple stages to enhance organization and manageability, ensuring that the work progresses smoothly. In Figure 1, the flowchart depicts the hardware connection process, while in Figure 2, the flowchart illustrates the microcontroller logic development process. These flowcharts serve as helpful guides for facilitating the work's completion with efficiency and effectiveness. The system's inputs include a TDS sensor and a submersible temperature sensor, while its outputs include a relay and an I2C interface. In accordance with the system's design, when the TDS measurement declines below 800 ppm, the motor begins to operate and stops when the TDS measurement reaches 1000 ppm[6].

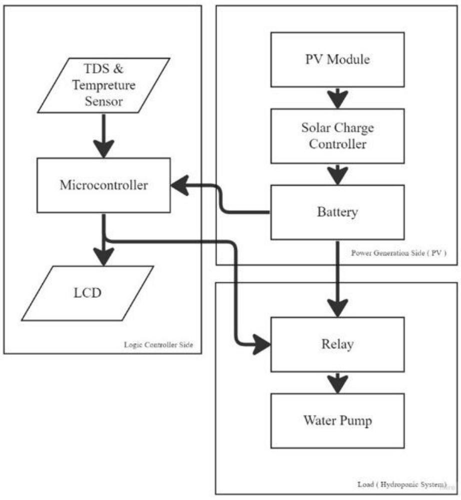

Figure 1: Hardware Connection Flowchart

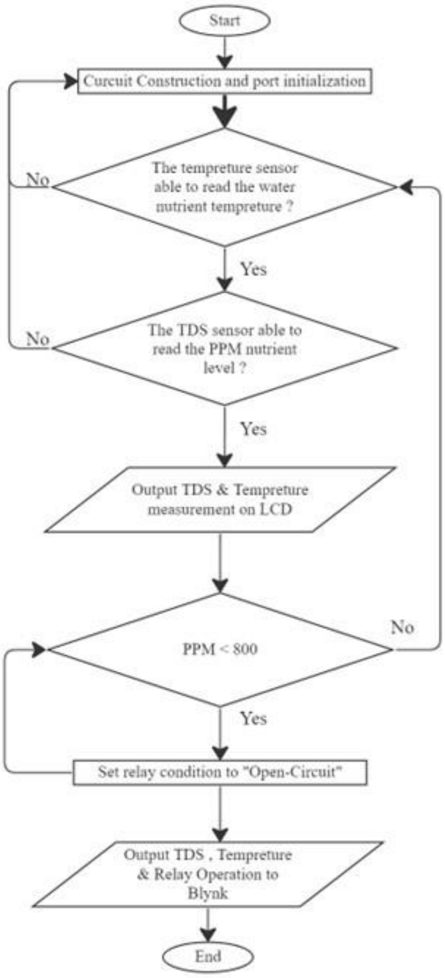

Figure 2: Microcontroller Logic development Flowchart

2.1 Component involved in PV hydroponic monitoring & control system.

As shown in Table 1, the hardware components utilized in this work comprised a TDS sensor, temperature sensor, relay, microcontroller (Durian UNO) equipped with a Wi-Fi module ESP8266, battery/power supply, LCD, photovoltaic cell, solar charge controller, pump with PWM for water nutrient flow control, and a hydroponic system. These components played crucial roles in facilitating the monitoring and control of the hydroponic system, ensuring precise data collection, system automation, and efficient energy utilization.

Figure 3 showcases the circuit configuration in the Fritzing Simulation, illustrating the interconnections and arrangements of the various hardware components. The figure visually represents how the TDS sensor, temperature sensor, relay, microcontroller with a Wi-Fi module ESP8266, and other components are integrated within the system. Figure 4 displays the proposed hydroponic system, providing an overview of the entire setup. The figure showcases the arrangement of the solar charge controller, battery/power supply, LCD, pump with PWM for water nutrient flow control, and the hydroponic system itself. It offers a visual representation of the hardware components and their placement within the hydroponic system.

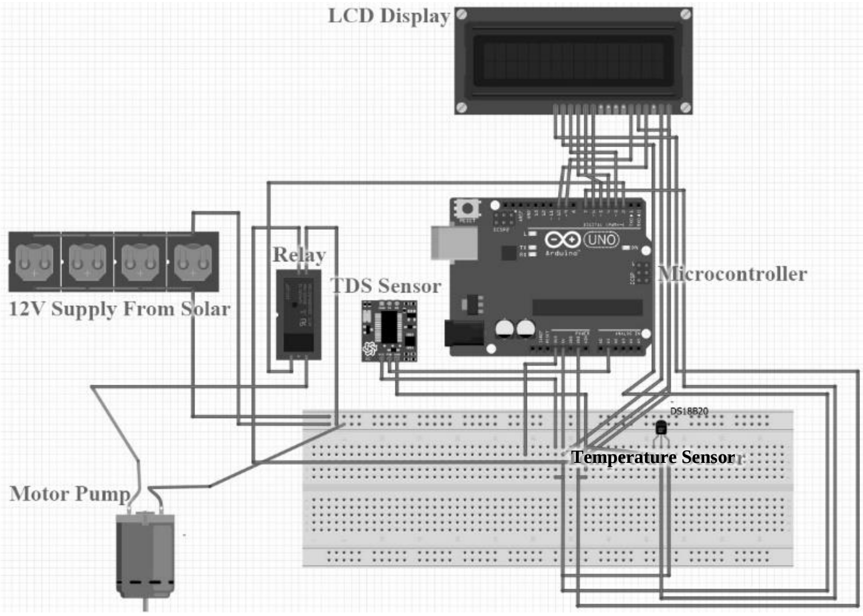

Figure 3: Circuit configuration in Fritzing Simulation

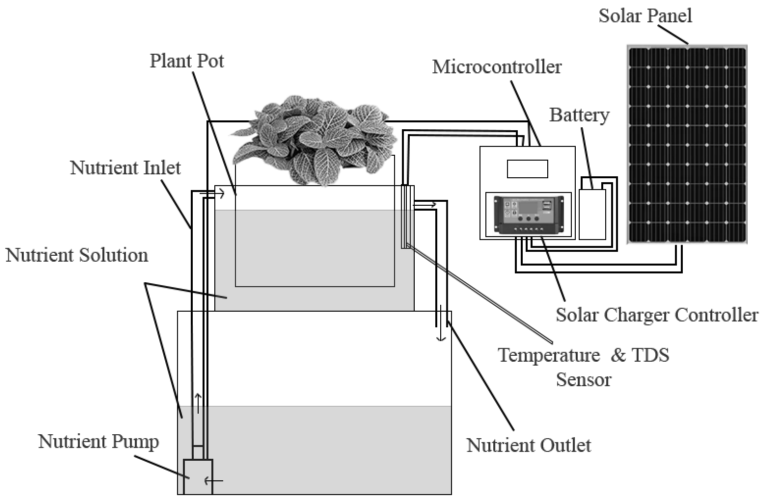

Figure 4: Proposed hydroponic system.

Table 1: List of hardware and software

Hardware	Software
Solar panel, MPPT, TSD sensor, temperature sensor, relay, microcontroller (Durian UNO), Battery, LCD with I2C module, deep water culture hydroponic system.	Fritzing, Arduino IDE, Blynk

3. Results and Discussion

3.1 TDS and temperature sensor performance evaluation

The dependability of the TDS and temperature sensors was evaluated by comparing their readings with an independent TDS meter (Table 2). The analysis revealed a slight difference between the sensor and the independent TDS meter readings, with an error of 18 ppm (3.64% error) for TDS measurements and 0.19 degrees Celsius (0.67% error) for temperature measurements. Despite these minor discrepancies, the results affirm that the sensors can be relied upon to provide accurate measurements.

Table 2: results comparison between independent TDS meter & sensor

Results	Independent TDS Meter	Sensor
TDS (PPM)	495	513
Temperature (Degree Celsius)	28.5	28.69
TDS Difference	18 (3.64% Error)	
Temperature Difference	0.19 (0.67% Error)	

3.2 Relay Performance in Controlling Water Pump based on TDS Measurements

As can be seen in the results presented in Table 3, tests were conducted to adjust the nutrient levels in the water within the range of 600 to 1000 ppm. The objective of these tests was to validate the capability of the relay to control the operation of the pump. The test results, as shown in the table, indicate that the desired TDS readings were effectively maintained by the relay.

Table 3: TDS level and relay condition

TDS Reading	Relay Condition
628	Closed Circuit
788	Closed Circuit
835	Open Circuit
955	Open Circuit
1153	Open Circuit

3.3 Motor Power Consumption and Water Flow Rate Measurements

After careful analysis as shown in Figure 5 and Table 4, it was determined that a motor voltage of 2.8 volts (V) and a current of 0.76 amperes (A) resulted in a water flow rate of approximately 5.8 l/min. This setting closely matches the desired flow rate for optimal plant growth in the hydroponic system, as specified in the optimal plants growth flow rate range of 4-6 l/min. [7].

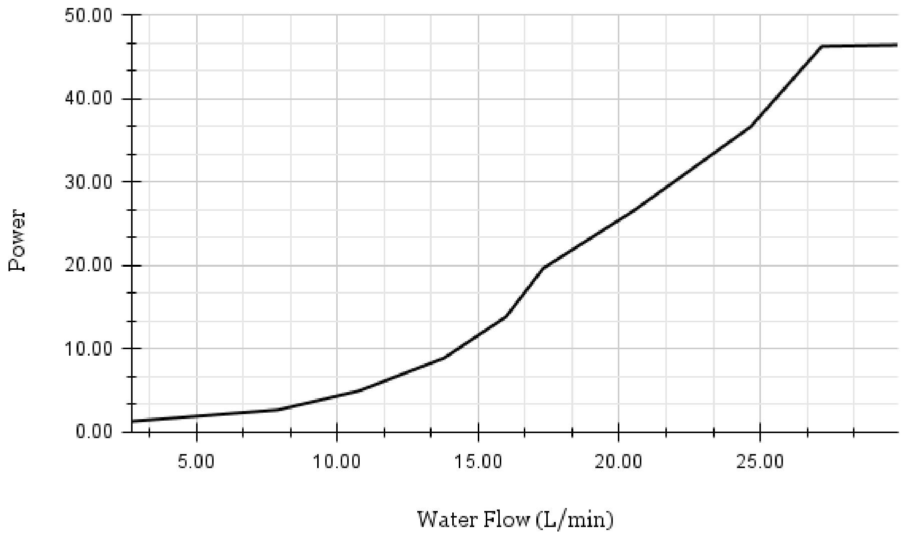

Figure 5: Relation between Power (Watt) & Waterflow (l/min)

Table 4: Pump power requirement and waterflow

Power (W)	Waterflow (l/min)
46.4	29.9
46.3	27.1
36.6	24.6
26.6	20.5
19.7	13.8
13.8	16.0
8.9	13.8
5.0	10.8
2.7	7.9
2.1	5.8
1.3	2.7

3.4 Energy usage comparison of traditional hydroponic with automated pump control and TDS-based IoT monitoring hydroponic

Figure 6 shows the test setup at Perwira Residential College, UTHM, the pump's activation frequency and duration were recorded over a 24-hour period. The total running time per day was obtained by multiplying the number of pump cycles by the average duration. Energy consumption was calculated by multiplying the data from Table 3.3, which represents energy usage for a flow rate of 5.8 liters per minute, with the total pump operating time. Through this analysis, the system's energy consumption was quantified and compared to traditional hydroponic systems, providing valuable insights into the potential energy savings achieved through automated pump control technology [8].

Figure 6: 24 hours Test Setup

3.4.1 Raw Data from blynk platform.

Raw data from the Blynk platform, documenting temperature and TDS readings over a 24-hour period, was collected. The data was transformed into a graph format for better comprehension. Figure 7 illustrates this graph, showcasing the fluctuations in temperature and TDS levels throughout the day. The shaded region within the graph highlights the activation period of the water nutrient, visually indicating its operation. This graphical representation facilitates the observation of temperature and TDS trends and changes, aiding in the analysis of the hydroponic system's performance.

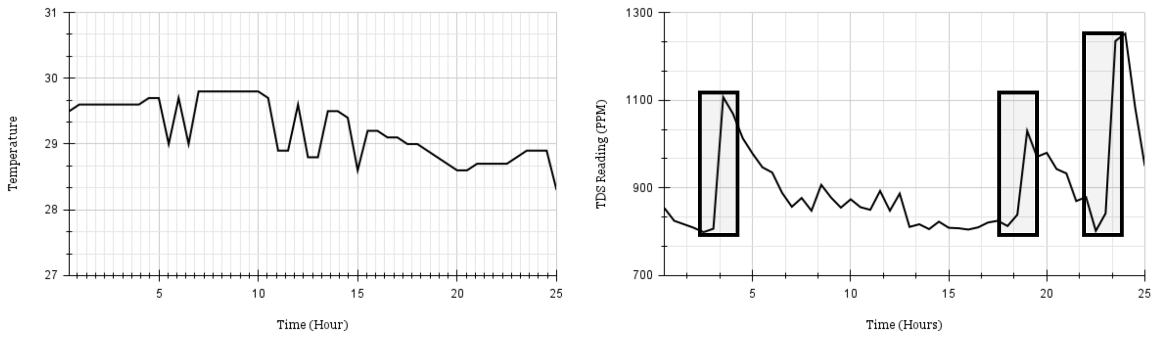

Figure 7: 24 Hour graph TDS & Temperature data from Blynk

3.4.2 System comparison

In the comparison of energy usage between traditional hydroponic systems and the automated pump control system with TDS-based IoT monitoring, notable differences are observed. It is observed that in Table 5, the same 24-hour period, a typical system with a 5-minute pump cycle every 15 minutes would have completed 96 cycles. However, in the work system, only 10 minutes of total operation time was accumulated across 3 cycles per day. The energy consumption of the system was significantly lower, with only 0.35 watt-hours consumed in the 24-hour period, in contrast to the substantial consumption of 17.04 watt-hours in traditional systems. As shown in Table 6, a substantial energy saving of approximately 16.69 watt-hours was achieved, demonstrating the significant efficiency gains enabled by the automated pump control technology.

Table 5: Duration of each pump operation cycle in 24 hours

Cycle	Time (minute)
1	4
2	3
3	3

Table 6: Comparison between proposed system and conventional system

Measurement	Proposed System	Conventional System
Pump time operation (minutes)	10	480
Energy Consumption (Watt)	0.35	17.04
Energy Saving (Watt)	16.69	

4. Conclusion

In conclusion, a reliable hydroponic monitoring and control system was successfully established by the work, demonstrating accurate functioning and efficient energy usage. The precise monitoring and control of nutrient concentration and system operations were enabled through the integration of TDS and temperature sensors, along with the Durian UNO microcontroller and Blynk platform. Only 0.638 watt-hours of energy were consumed by the system in a 24-hour period, which is significantly less than the 17.04 watt-hours consumed by traditional systems. A substantial energy saving of approximately 16.4 watt-hours was achieved. The implementation of the automated pump control technology not only offers cost savings but also contributes to sustainable and resource-efficient hydroponic practices.

Based on the findings and outcomes of the work, several recommendations can be made to further improve and implement hydroponic systems. Firstly, integrating advanced sensors like pH sensors and dissolved oxygen sensors can enhance monitoring capabilities and provide insights into water quality and nutrient levels. Secondly, expanding automation and remote monitoring features through smart devices and IoT technologies can enable real-time adjustments and reduce manual intervention. Thirdly, exploring energy optimization techniques, including the incorporation of renewable energy sources, can significantly reduce energy consumption and promote sustainability. Additionally, developing robust data analysis algorithms and decision support systems can leverage collected data for informed decision-making. Lastly, planning for scalability and modularity from the initial system design phase allows for future expansions and modifications. Implementing these recommendations will enhance the efficiency, productivity, and sustainability of hydroponic systems, paving the way for advanced agricultural practices.

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