



SOLAR POWERED HYDROPONIC CONTROL SYSTEM

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Abstract:

With accelerating population growth, urban expansion, reduction in cultivable land, water stress, and climatic uncertainties, there is an urgent need for sustainable agricultural practices. Hydroponics presents a viable alternative to conventional soil-based farming by cultivating crops in a nutrient-rich aqueous medium. This technique offers significant advantages including reduced water consumption, precise regulation of growth parameters, and the ability to produce crops in space-constrained or non-arable regions. Despite these benefits, the productivity of hydroponic systems heavily depends on maintaining optimal environmental conditions such as temperature, humidity, and water availability. Traditional manual monitoring is inefficient and prone to delays in corrective action. The convergence of embedded systems and renewable energy technologies provides a promising pathway for developing automated and self-sustaining hydroponic setups. This paper presents a review of a Solar Powered Hydroponic Control System implemented using the ESP32 microcontroller. The system architecture incorporates environmental sensors for temperature and humidity, water level detection, photovoltaic panels, rechargeable battery backup, cooling mechanisms, and an LCD interface for real-time monitoring. The ESP32 serves as the core processing unit, acquiring sensor data and regulating ventilation based on predefined thresholds. Solar energy serves as the primary power source, supplemented by battery storage to ensure uninterrupted operation during inadequate irradiance. The review further examines the significance of hydroponics, sensor-driven monitoring, IoT in agriculture, solar energy integration, and microcontroller-based automation. Existing challenges identified include limited capability for nutrient, pH, and EC monitoring, absence of remote accessibility, and scope for energy optimization and intelligent control strategies. The findings suggest that the fusion of hydroponics, solar power, and embedded automation can contribute toward developing energy-efficient, sustainable, and resource-conserving agricultural systems.



Keywords: IoT Automation, Sustainable Agriculture, Water Conservation, Smart Farming, Hydroponics, Renewable Energy.

1. INTRODUCTION

Agriculture is fundamental to food security and economic development. However, conventional farming is facing increasing challenges such as limited cultivable land, water scarcity, soil degradation, urbanization, and climate change. With rising global population, there is an urgent need for sustainable agricultural techniques that can ensure efficient food production with minimal resource consumption. Hydroponics has emerged as a viable alternative to soil-based agriculture.

Hydroponics is a soilless cultivation method where plants receive nutrients directly through a water-based solution. This technique offers significant advantages including reduced water usage, independence from soil fertility, and the ability to grow crops in urban and land-scarce areas. Hydroponic systems are widely used in greenhouses, vertical farms, and controlled environments. Successful crop production in such systems depends on maintaining optimal environmental conditions, especially temperature, humidity, and water availability.

Temperature and humidity directly affect plant growth, transpiration, and nutrient uptake, while proper water level ensures continuous nutrient supply to roots. Manual monitoring of these parameters is inefficient and prone to delays. Hence, automated sensor-based monitoring is essential for effective hydroponic management. Recent developments in microcontrollers and IoT have enabled smart agricultural systems. The ESP32 microcontroller is well suited for this purpose due to its low power consumption, sufficient processing capability, and built-in wireless communication. It can collect data from temperature, humidity, and water-level sensors, process the data, and control devices such as cooling fans based on set conditions. An LCD display provides real-time monitoring of system parameters.

A reliable power supply is also essential for continuous operation. Solar photovoltaic systems offer a renewable and cost-effective solution for powering automated systems, especially in remote areas. A solar panel combined with a rechargeable battery can provide uninterrupted energy to sensors, controllers, and actuators.

A Solar Powered Hydroponic Control System integrates hydroponics, renewable energy, and embedded automation. The system consists of an ESP32 controller, environmental sensors, water-level sensor, solar panel, battery, cooling fans, and an LCD display. The ESP32 monitors environmental conditions and automatically controls ventilation to maintain optimal growth conditions. The solar-battery setup ensures sustainable power supply. The integration of these technologies supports resource conservation, reduces manual effort, and promotes sustainable agriculture.



2. LITERATURE SURVEY

Resh et al. [1] (2005) explained the fundamentals of hydroponic farming and demonstrated that plants can grow efficiently in nutrient-rich water without soil, improving crop yield and reducing water usage.

Jones et al. [2] (2007) studied hydroponic crop production and showed that controlled nutrient delivery systems help increase plant growth rate and productivity compared to traditional soil farming.

Despommier et al. [3] (2010) discussed modern vertical farming and hydroponic systems as a sustainable solution for urban agriculture and food production.

Sharma et al. [4] (2011) analysed hydroponic techniques and reported that hydroponics requires less water and land while providing faster plant growth.

Raviv and Lieth et al. [5] (2012) studied soilless cultivation systems and highlighted the advantages of hydroponic nutrient management and controlled plant environments.

Putera et al. [6] (2015) developed a solar-powered hydroponic instrument using photovoltaic panels and microcontrollers to supply energy for pumps and monitoring devices.

Björk and Nielsen et al. [7] (2015) investigated solar photovoltaic systems and demonstrated their efficiency in providing renewable energy for small automated agricultural systems.

Aruna et al. [8] (2018) designed a solar hydroponic system that simplifies plant cultivation by integrating automated control and nutrient circulation.

Hoe et al. [9] (2018) proposed solar-powered control systems using MPPT technology to improve power efficiency in automated agricultural applications.

Singh et al. [10] (2019) studied automated hydroponic systems and reported that sensors and microcontrollers can effectively monitor environmental conditions.

Patel et al. [11] (2020) proposed a smart hydroponic monitoring system that measures temperature, humidity, and nutrient levels using embedded systems.

Mohammad et al. [12] (2021) developed an automatic hydroponic system powered by solar panels and batteries for maintaining pH and nutrient concentration.

Kamarulzaman et al. [13] (2021) designed a solar-powered hydroponic monitoring system using Arduino and sensors to measure water level, pH, and temperature.

Saeed et al. [14] (2022) proposed smart hydroponic farming integrated with IoT technology to monitor plant growth conditions remotely.

Aquaponics et.al [15] (2022) developed a solar-powered aquaponic prototype for sustainable food production using renewable energy.

3. PROPOSED METHODOLOGY

The proposed Solar Powered Hydroponic Control System integrates hydroponic cultivation, renewable solar energy, sensor-based monitoring, and automatic control using an ESP32 microcontroller. The main objective of the system is to maintain suitable environmental conditions for hydroponic plants while reducing manual monitoring, energy consumption, and dependence on conventional electricity. The system continuously monitors temperature, humidity, and water level and responds automatically according to predefined conditions.

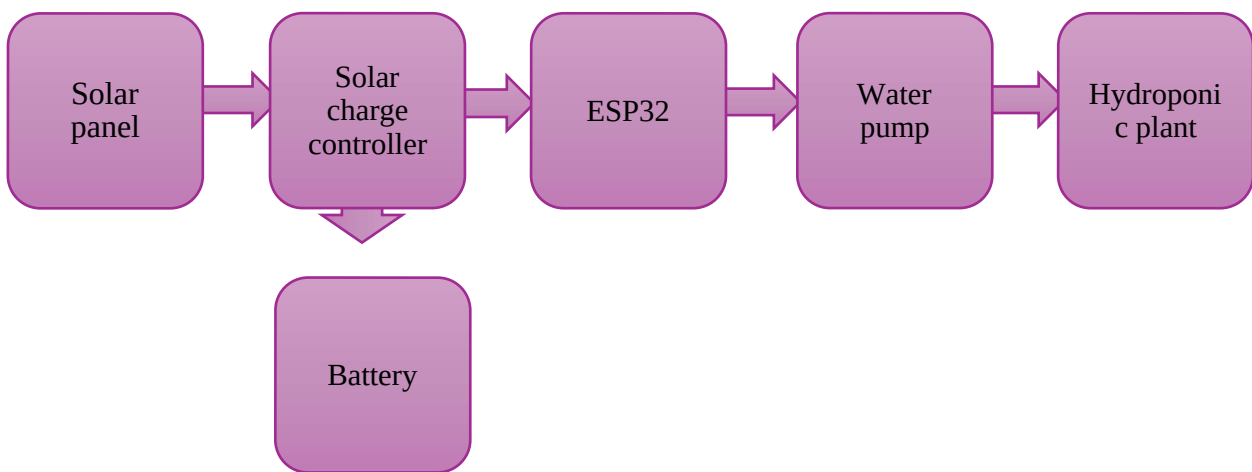


Figure 1.1 Block Diagram of Proposed System

The above figure shows the flow of working of the integrated system. The solar panel acts as the primary energy source of the system. It converts sunlight into electrical energy, which is supplied to the control system through a suitable charging and power-management circuit. During sunlight hours, the generated energy is used to operate the ESP32, sensors, LCD display, and cooling fan while also charging the rechargeable battery. The battery stores the generated energy and supplies power when sunlight is insufficient, such as during cloudy conditions or nighttime. This combination of solar panel and battery provides a renewable and reliable power source for the hydroponic control system.

The hydroponic section consists of plants supported without conventional soil and supplied with a nutrient-rich water solution. The nutrient solution provides the required water and nutrients directly to the plant roots. The system can be used for suitable vegetables, herbs, and other



hydroponic plants. Since the plants are grown in a controlled environment, important conditions such as temperature, humidity, and water availability need to be monitored continuously to support healthy plant growth.

A temperature and humidity sensor is installed near the hydroponic plants to measure the environmental conditions. Temperature affects plant metabolism, photosynthesis, transpiration, and nutrient absorption, while humidity affects water loss and the surrounding growing environment. The sensor continuously sends temperature and humidity readings to the ESP32. The controller compares these readings with predefined threshold values. When the temperature or humidity becomes higher than the desired level, the ESP32

activates the cooling fan to improve air circulation around the plants. When the conditions return to the acceptable range, the fan is switched OFF.

A water-level sensor is installed inside the nutrient-solution reservoir to monitor the availability of water for the plants. The sensor continuously detects the water level and provides the information to the ESP32. When the water level is sufficient, the system operates normally. If the water level decreases below the predefined minimum level, the ESP32 detects the condition and provides a warning through the LCD display. This allows the user to refill the reservoir before insufficient water availability affects the plants.

The ESP32 functions as the central control unit of the complete system. It receives data from the temperature, humidity, and water-level sensors and processes the collected information according to the programmed control logic. The controller determines whether the cooling fan needs to be operated and updates the LCD display with the latest sensor readings. The ESP32 continuously repeats this monitoring and control process, allowing the system to respond automatically to changes in the hydroponic environment.

The cooling fan is used to regulate airflow around the hydroponic plants. The fan is connected to the ESP32 through a suitable switching or driver circuit. When the measured temperature or humidity exceeds the specified threshold, the ESP32 sends a control signal to activate the fan. The fan increases air circulation and helps remove excessive heat and moisture from the growing area. When the measured conditions return to the desired range, the fan is automatically turned OFF. This method avoids unnecessary fan operation and helps conserve the energy stored in the battery.

An LCD display is incorporated into the system to provide real-time information to the user. The ESP32 sends the sensor readings and system status to the display. The LCD can show the current temperature, humidity, water-level condition, fan status, and other relevant system information. For example, during normal operation, the LCD can display the measured temperature and humidity along with a normal water-level status. If the temperature becomes high, the display can indicate that the fan is ON, while a low water level can be indicated through a warning message. Thus, the LCD provides a simple and convenient interface for monitoring the system.



The complete system works as a continuous feedback and control process. First, the solar panel generates electrical energy and charges the battery. The stored energy supplies power to the ESP32 and other components whenever required. The temperature and humidity sensor measures the environmental conditions around the plants, while the water-level sensor monitors the nutrient solution in the reservoir. These sensor readings are transferred to the ESP32, where they are processed and compared with predefined threshold values.

Based on the processed information, the ESP32 controls the cooling fan and updates the LCD display. If the temperature or humidity exceeds the selected limit, the fan is switched ON to improve ventilation. When the environmental conditions return to the desired range, the fan is switched OFF. If the water level becomes low, a warning is displayed so that the user can add the required nutrient solution. The monitoring process continues repeatedly throughout system operation.

Thus, the proposed methodology combines solar power generation, battery storage, hydroponic cultivation, sensor-based monitoring, ESP32 control, automatic fan operation, and LCD-based display into one integrated system. The system reduces the need for continuous human intervention and promotes efficient use of water and electrical energy.

4. RESULT

The developed Solar Powered Hydroponic Control System was tested for monitoring and controlling the major environmental parameters required for hydroponic plant cultivation. The system successfully integrated the ESP32 microcontroller, temperature and humidity sensor, water-level sensor, solar panel,

rechargeable battery, cooling fan, LCD display, and hydroponic plants. The system operated as a continuous monitoring unit and provided the required sensor information through the LCD display.

The temperature and humidity sensor successfully detected the environmental conditions around the hydroponic plants and transmitted the measured values to the ESP32. The ESP32 processed the sensor readings and displayed the temperature and humidity values on the LCD. The readings changed according to the surrounding environmental conditions, confirming the proper operation of the sensing and monitoring section.

The temperature-control function was also successfully obtained. When the measured temperature exceeded the predefined threshold, the ESP32 activated the cooling fan. The fan increased the airflow around the plants and continued operating until the measured temperature returned to the specified operating range. When the temperature reached the acceptable range, the fan was automatically switched OFF. This confirmed the successful operation of the automatic temperature-based control mechanism.

The humidity monitoring section continuously measured the relative humidity around the plants. The measured humidity values were received by the ESP32 and displayed on the LCD. When the



humidity reached a higher level than the selected threshold, the cooling fan was activated to provide ventilation. The system therefore responded automatically to changes in the humidity conditions.

The water-level sensor successfully monitored the nutrient solution present in the hydroponic reservoir. When the water level was sufficient, the system indicated a normal condition on the LCD. When the water level decreased below the predefined minimum level, the ESP32 detected the condition and generated a low-water warning on the display. This confirmed that the system could identify changes in the water level and provide an appropriate indication to the user.

The LCD display successfully provided real-time information about the system operation. Temperature, humidity, water-level status, and fan status were displayed according to the current operating condition. The display allowed the user to observe the system parameters directly and verify the operation of the sensors and fan.

The solar power section successfully supplied electrical energy to the system during sunlight hours. The solar panel generated electrical energy and supplied power to the system while also charging the rechargeable battery. The stored battery energy was available for operating the system when direct solar energy was not sufficient. The solar panel and battery combination therefore provided the required electrical supply for the low-power control components.

The ESP32 successfully performed the central control functions of the system. It received signals from the temperature, humidity, and water-level sensors, processed the data, controlled the cooling fan, and updated the LCD display. The complete sensing and control process was performed automatically according to the programmed conditions.

The hydroponic plants were maintained using the nutrient-water solution under the monitored environmental conditions. The system provided continuous monitoring of the growing environment and maintained the required water-level condition through regular observation. The operation of the cooling fan helped maintain airflow around the plants when the measured environmental conditions crossed the selected limits.

The overall test results confirmed the successful integration of all major system components. The temperature and humidity sensor provided environmental measurements, the water-level sensor detected reservoir conditions, the ESP32 processed the sensor data, the cooling fan responded automatically, the LCD displayed real-time information, and the solar panel with battery supplied electrical energy to the control system.

The experimental results confirm that the proposed Solar Powered Hydroponic Control System successfully performs its intended functions of environmental monitoring, automatic fan control, water-level detection, real-time display, and solar-powered operation. The integration of the ESP32 with the sensors and output devices provides continuous and automatic operation of the hydroponic control system.

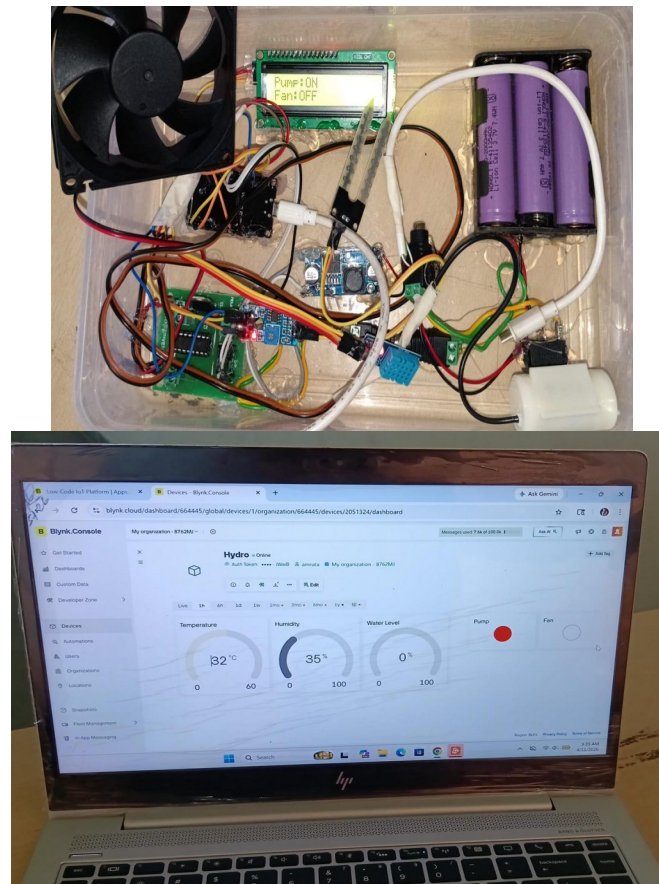


Fig 1.2 Hardware and Software Result Display

5. DISCUSSION

Figure 1.2 shows the hardware and software outputs of the proposed system. The solar-powered hydroponic control system represents a modern and sustainable approach to agriculture by combining renewable energy with soilless farming techniques. In this system, solar panels generate electrical energy, which is stored in batteries and used to power all components, making it independent of conventional electricity sources. The integration of a microcontroller such as the ESP32 allows the system to function automatically by continuously monitoring environmental and nutrient conditions. This automation reduces manual effort and ensures that plants receive optimal care at all times, making the system highly efficient and suitable for smart farming applications.

A key strength of this system lies in its use of multiple sensors to maintain ideal growing conditions. Temperature, humidity, and water level sensors provide real-time data to the controller, which then makes decisions to control devices like fans and lights.

In addition to improving efficiency, the system is also environmentally friendly and resource efficient. It significantly reduces water consumption compared to traditional soil-based farming, as water is recycled within the system. The use of solar energy minimizes carbon emissions and



lowers operating costs over time. Furthermore, the system can be connected to IoT platforms for remote monitoring and control, allowing users to track system performance from anywhere. Although the initial setup cost may be relatively high, the long-term benefits such as energy savings, reduced labor, higher productivity, and sustainability make the solar-powered hydroponic control system a highly promising solution for future agricultural practices.

6. CONCLUSION

The Solar Powered Hydroponic Control System combines hydroponic cultivation, renewable solar energy, and IoT-based automation into a single intelligent farming solution. The ESP32 continuously monitors temperature, humidity, and water level using sensors and automatically controls the cooling fan to maintain a suitable environment for plant growth. The LCD provides real-time system information, while the solar panel and rechargeable battery ensure uninterrupted operation. The proposed system reduces water consumption, lowers electricity costs, minimizes human intervention, and promotes sustainable agriculture.

It provides an efficient, eco-friendly, and scalable solution capable of meeting the increasing demand for modern smart farming technologies

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