

**REVIEW OF SOLAR POWERED HYDROPONIC CONTROL SYSTEM***Prof. S. K. Godase**Assistant Professor, Department of Electronics and Telecommunication Engineering
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The increasing population, rapid urbanization, depletion of agricultural land, water scarcity, and changing climatic conditions have created a growing demand for sustainable and efficient agricultural technologies. Hydroponics is an advanced cultivation technique that enables plants to grow without soil by supplying essential nutrients through a water-based solution. Compared with conventional agriculture, hydroponic cultivation can reduce water consumption, improve control over plant-growing conditions, and enable crop production in areas where suitable agricultural land is limited. However, maintaining suitable environmental conditions such as temperature, humidity, and water availability is essential for successful hydroponic plant growth. Continuous manual monitoring of these parameters is time-consuming and may result in delayed corrective actions. The integration of embedded systems and renewable energy provides an opportunity to develop automated and sustainable hydroponic systems.

This review paper focuses on the development and technological aspects of a Solar Powered Hydroponic Control System based on the ESP32 microcontroller. The proposed concept integrates temperature and humidity sensing, water-level monitoring, solar photovoltaic panels, rechargeable battery storage, cooling fans, and an LCD display for real-time monitoring and control. The ESP32 acts as the central controller, processing sensor information and controlling the ventilation system according to predefined environmental conditions. Solar panels provide renewable electrical energy, while the battery supplies stored energy during periods of insufficient sunlight. The review discusses the role of hydroponics, sensor-based environmental monitoring, IoT-enabled agriculture, solar-powered agricultural systems, and microcontroller-based automation. It also identifies current limitations, including the need for improved nutrient monitoring, pH and electrical conductivity measurement, remote monitoring, energy optimization, and intelligent control. The study highlights the potential of combining hydroponics, renewable energy, and



embedded automation to develop sustainable, low-power, and resource-efficient agricultural systems.

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

1. INTRODUCTION

Agriculture plays a vital role in ensuring food security, supporting economic development, and providing raw materials for various industries. However, conventional agricultural practices are increasingly affected by several challenges, including limited availability of cultivable land, increasing water requirements, soil degradation, population growth, urbanization, and changing climatic conditions. The continuous increase in population has created a greater demand for food production, while natural resources required for conventional agriculture are becoming increasingly limited. Therefore, there is a growing need for alternative agricultural techniques that can produce crops efficiently while making better use of available land, water, and energy resources. In this context, hydroponic farming has emerged as an important modern agricultural technique that can provide controlled plant cultivation without depending on conventional soil.

Hydroponics is a method of growing plants without soil in which the required nutrients are supplied directly to the plant roots through a nutrient-rich water solution. In a conventional farming system, soil provides physical support as well as water and nutrients to plants. In hydroponic cultivation, these functions are achieved through a controlled water and nutrient supply system. This method allows plants to receive nutrients in a more controlled manner and can reduce the requirement for large areas of fertile agricultural land. Hydroponic systems can be implemented in greenhouses, rooftops, urban farms, laboratories, indoor growing environments, and locations where conventional soil-based agriculture is difficult. The controlled nature of hydroponic cultivation also makes it possible to monitor and manage important environmental conditions around the plants.

One of the major advantages of hydroponic cultivation is efficient utilization of water. In suitable hydroponic arrangements, water containing nutrients can be circulated or reused, reducing unnecessary water loss compared with some conventional agricultural practices. The absence of soil also eliminates several soil-related limitations and allows cultivation in areas where fertile soil is not readily available. However, hydroponic cultivation requires careful control of several environmental and operational parameters. Temperature, humidity, water level, nutrient availability, and other conditions can influence plant growth and the overall performance of the system. Therefore, monitoring these parameters is essential for maintaining an appropriate growing environment.

Temperature is an important environmental parameter because it affects various physiological activities of plants, including photosynthesis, respiration, transpiration, and nutrient absorption. Excessively high or low temperatures can create unfavourable conditions for plant growth.



Similarly, humidity affects the rate of water loss from plants and influences the moisture conditions surrounding the leaves and growing area. Maintaining suitable temperature and humidity conditions is therefore important for maintaining a stable hydroponic environment. In a manually operated system, these parameters may need to be checked regularly, which increases human effort and may result in delayed response to environmental changes. A sensor-based monitoring system can overcome this limitation by continuously measuring environmental conditions and providing timely information to the control unit.

Water availability is another important factor in hydroponic cultivation because the plant roots directly depend on the nutrient solution for water and nutrient supply. A reduction in the reservoir water level can affect the availability of the solution to the plants. Therefore, continuous monitoring of the water level is necessary to identify low-water conditions. A water-level sensor can detect changes in the quantity of nutrient solution and transmit the information to a microcontroller. When the water level becomes lower than the required limit, the system can provide an indication to the user. Such monitoring helps maintain the required water availability and reduces the possibility of prolonged operation under insufficient water conditions.

The development of embedded systems and microcontroller technology has provided new opportunities for automation in agriculture. Microcontrollers can collect information from sensors, process the received data, and control different devices according to programmed conditions. Among the available microcontroller platforms, the ESP32 is suitable for smart monitoring and control applications because of its processing capability, low-power operation, multiple input/output interfaces, and integrated wireless communication features. In a hydroponic control system, the ESP32 can receive information from temperature, humidity, and water-level sensors and process the measurements continuously. Based on predefined threshold conditions, it can control devices such as cooling fans and provide information through an LCD display.

The use of automatic control can reduce the requirement for continuous human intervention. For example, when the temperature of the hydroponic growing area increases beyond a selected limit, the ESP32 can activate a cooling fan. The fan increases air circulation around the plants and helps in managing excessive heat. Similarly, changes in humidity can be monitored and ventilation can be provided when required. When the measured conditions return to the desired operating range, the controller can switch the fan OFF. This automatic operation allows the cooling device to operate according to actual environmental requirements rather than running continuously, thereby supporting efficient utilization of electrical energy.

An LCD display can also be incorporated into the hydroponic control system to provide real-time information to the user. The ESP32 can send processed sensor data to the display, allowing the user to



observe temperature, humidity, water-level status, and fan operation. The display provides a simple local monitoring interface and makes it easier to identify the current operating condition of the system. When the

water level becomes low or the cooling fan is activated, the corresponding status can be displayed. Thus, the combination of sensors, ESP32, and LCD provides both automatic control and convenient monitoring of the hydroponic environment.

Another important consideration in an automated agricultural system is the availability and reliability of electrical power. The operation of microcontrollers, sensors, displays, cooling fans, and other electronic components requires a continuous electrical supply. Dependence entirely on conventional grid electricity can increase operating costs and may limit the use of automated systems in remote or off-grid agricultural locations. The integration of renewable energy can provide an alternative solution to this problem. Solar photovoltaic technology converts sunlight directly into electrical energy and can therefore be used as a renewable power source for low-power agricultural control systems.

In the proposed system, solar panels are used to generate electrical energy required for operating the hydroponic control unit. The generated electrical energy can be supplied to the electronic components and used to charge a rechargeable battery. The battery stores energy generated during periods of sunlight and provides power when solar radiation is insufficient, such as during nighttime or cloudy conditions. The combination of solar panels and battery storage provides a suitable power arrangement for a small-scale automated hydroponic system. It also supports the use of renewable energy and reduces dependence on conventional electrical sources.

The Solar Powered Hydroponic Control System therefore combines hydroponic cultivation, renewable energy, sensor-based monitoring, and embedded automation into a single integrated system. The proposed system consists of hydroponic plants, an ESP32 microcontroller, temperature and humidity sensor, water-level sensor, solar panel, rechargeable battery, cooling fan, and LCD display. The sensors continuously monitor the environmental conditions and provide the measured information to the ESP32. The controller processes the sensor readings and compares them with predefined operating limits. According to the measured conditions, the cooling fan is automatically controlled. The water-level condition is also monitored and indicated through the LCD display.

The operation of the system follows a continuous sensing and control process. The solar panel generates electrical energy and supplies power to the system while charging the battery. The temperature and humidity sensor measures the environmental conditions surrounding the hydroponic plants, while the water-level sensor monitors the nutrient solution reservoir. These sensor signals are provided to the ESP32, which processes the information and determines the appropriate control action. When the environmental conditions remain within the selected limits, the system continues normal operation. When the temperature or humidity exceeds the specified



threshold, the cooling fan is activated to improve air circulation. If the water level decreases below the required level, the system provides an indication through the LCD. The measured parameters and system status can be continuously displayed for user observation.

The integration of renewable energy and automated monitoring provides several benefits for hydroponic cultivation. Sensor-based monitoring allows environmental conditions to be observed continuously, while automatic control reduces the need for frequent manual intervention. Solar energy provides a renewable source of electrical power, and battery storage supports operation when direct solar energy is unavailable. Water-level monitoring helps maintain the availability of nutrient solution, while automatic fan control helps maintain suitable airflow according to the monitored conditions. These features together contribute to efficient operation of the hydroponic system.

The proposed system is particularly relevant to sustainable and controlled agriculture because it combines resource-efficient cultivation with renewable energy and embedded automation. Hydroponics can be used where agricultural land is limited, while solar energy can provide electrical power without continuous dependence on the conventional grid. The use of sensors and an ESP32 enables important environmental parameters to be monitored automatically, making the system more systematic and reliable than a purely manual monitoring arrangement.

Therefore, the Solar Powered Hydroponic Control System represents an integrated approach to modern agricultural automation. By combining hydroponic plants with temperature and humidity monitoring, water-

level detection, automatic fan control, LCD-based monitoring, solar energy generation, and battery storage, the system provides a controlled environment for plant cultivation while utilizing renewable energy. The methodology demonstrates how embedded electronics and solar power can be integrated with hydroponic agriculture to create a practical, automated, and energy-conscious cultivation system.

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 is developed by integrating hydroponic cultivation, renewable solar energy, sensor-based monitoring, and automatic environmental control using an ESP32 microcontroller. The main objective of the system is to provide a controlled and monitored environment for hydroponic plants while reducing manual intervention and dependence on conventional electrical power. The system continuously observes important parameters such as temperature, humidity, and water level and uses the collected information to control the cooling fan automatically. The complete system consists of a solar panel, rechargeable battery, ESP32 microcontroller, temperature and humidity sensor, water-level sensor, cooling fan, LCD display, nutrient-water reservoir, and hydroponic plants. All these components work together to provide continuous monitoring and control of the hydroponic growing environment.

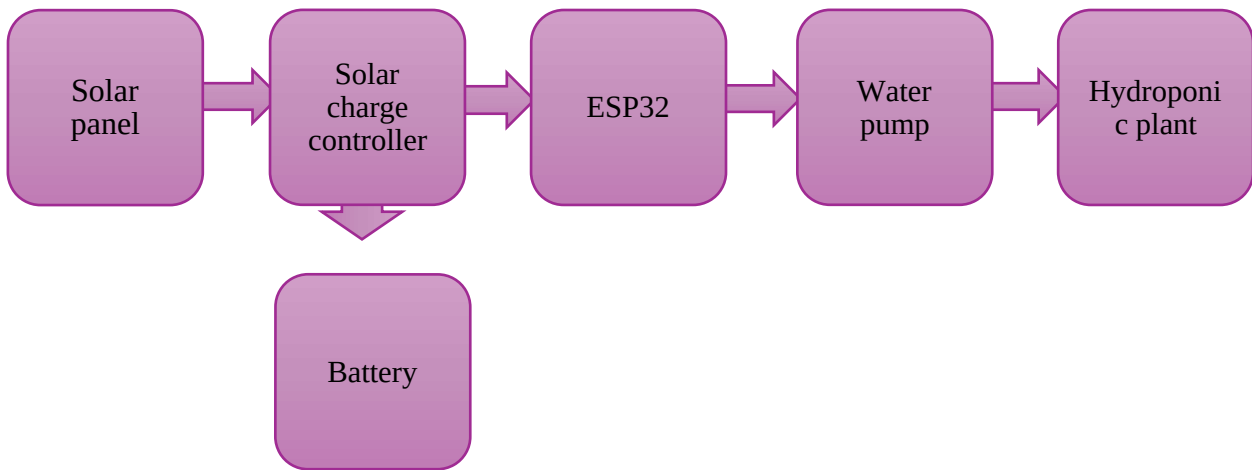


Figure 1 Block Diagram of Proposed System

Figure 1 shows the block diagram and the flow of working of the system. The solar panel acts as the primary source of electrical energy for the system. It converts solar radiation into electrical energy through the photovoltaic effect. The generated energy is supplied to the control system through a suitable charging and power-management arrangement. During periods of sufficient sunlight, the solar panel supplies the required energy to the electronic components and simultaneously charges the rechargeable battery. The battery stores the generated electrical energy and provides power when direct solar energy is insufficient, such as during nighttime or periods of reduced sunlight. This combination of solar energy generation and battery storage supports continuous operation of the system and reduces dependence on conventional grid electricity. The power generated by the solar panel is utilized according to the requirements of the ESP32, sensors, LCD display, and cooling fan.

The hydroponic section provides the growing environment for the selected plants. In this system, plants are cultivated without conventional soil and are supported using a suitable growing structure or medium. The plant roots receive water containing the required nutrients from the hydroponic reservoir. The nutrient solution acts as the primary source of water and nutrients for plant growth. The plants are positioned in a controlled environment where the surrounding temperature, humidity, and water availability can be monitored. The hydroponic arrangement enables the plants to obtain nutrients directly from the water-based solution and provides a suitable platform for integrating electronic monitoring and control technologies.

Temperature and humidity monitoring is performed using a suitable temperature and humidity sensor positioned near the hydroponic plants. The sensor continuously measures the environmental conditions surrounding the plants and provides the measured values to the ESP32. Temperature is an important parameter because changes in temperature can affect plant growth, transpiration,



metabolism, and nutrient absorption. Humidity also influences the water balance of plants and the surrounding growing environment. Since these parameters can vary during different periods of the day, continuous monitoring provides more reliable information about the actual conditions of the hydroponic environment. The ESP32 receives the sensor readings and compares them with predefined threshold values programmed into the controller.

When the measured temperature remains within the selected operating range, the cooling fan remains switched OFF. If the temperature rises above the predefined threshold, the ESP32 generates a control signal to activate the cooling fan. The operating fan increases airflow around the hydroponic plants and assists in reducing excessive heat. Humidity is also monitored by the same sensing unit. When the humidity becomes higher than the selected operating condition, the fan can be activated to provide additional ventilation around the plants. Once the measured environmental conditions return to the acceptable range, the ESP32 automatically switches the fan OFF. This method provides automatic environmental control without requiring the user to operate the fan manually.

The water-level sensor is installed inside the hydroponic nutrient-solution reservoir to continuously monitor the available water level. The plants depend on the nutrient solution for their water and nutrient

requirements, making water-level monitoring an important part of the system. The sensor detects whether the reservoir contains enough nutrient solution and sends the corresponding information to the ESP32. When the water level is above the predefined minimum level, the system continues normal operation. When the water level decreases below the specified level, the ESP32 identifies the low-water condition and provides a warning through the LCD display. This allows the user to observe the reservoir condition and add the required nutrient solution when necessary.

The ESP32 acts as the central processing and control unit of the complete system. It receives information from the temperature and humidity sensor and water-level sensor and processes the collected data according to the programmed control conditions. The microcontroller continuously compares the sensor readings with the predefined threshold values and determines the required system response. Based on the temperature and humidity conditions, it controls the operation of the cooling fan. At the same time, it processes the water-level information and communicates the condition to the user through the LCD display. The ESP32 therefore establishes communication between the sensing section, control section, and display section and enables automatic operation of the system.

The cooling fan is connected to the ESP32 through an appropriate switching or driver circuit. Since the fan requires more current than a microcontroller output can normally provide, the driver circuit is used to safely control its operation. During normal environmental conditions, the fan remains OFF to avoid unnecessary energy consumption. When the temperature or humidity exceeds the selected limit, the ESP32 sends a control signal to the driver circuit, which switches the fan ON.



The fan increases air circulation within the growing area and helps maintain suitable environmental conditions. When the measured parameters return to the required range, the ESP32 removes the control signal and the fan is switched OFF. The automatic operation of the fan helps in maintaining the environmental conditions while utilizing electrical energy only when ventilation is required.

An LCD display is incorporated into the system for real-time monitoring of the hydroponic environment. The ESP32 sends the processed sensor information to the LCD, where the user can observe the current temperature, humidity, water-level condition, and fan status. The display provides a simple interface for checking the system without requiring an external computer or monitoring device. Under normal conditions, the LCD displays the current sensor values and operating status. If the water level becomes low, the display provides a warning to the user. Similarly, the fan status can be displayed when the controller activates or deactivates the cooling system. This makes the operation of the system easier to observe and verify.

The complete system operates as a continuous sensing, processing, and control cycle. When the system is powered, the ESP32 initializes the connected sensors, LCD display, and fan-control circuit. The solar panel generates electrical energy and charges the battery during sunlight hours, while the battery supplies stored energy whenever the solar source is insufficient. After initialization, the temperature and humidity sensor measures the environmental conditions around the hydroponic plants, while the water-level sensor monitors the nutrient solution in the reservoir. The sensor data is continuously transferred to the ESP32 for processing.

The ESP32 analyses the received sensor readings and compares them with the predefined operating limits. If the temperature and humidity remain within the desired range, the cooling fan remains OFF and the system continues normal operation. If the temperature or humidity exceeds the selected limit, the ESP32 activates the fan to improve ventilation. The controller continues monitoring the environmental parameters while the fan is operating. When the measured conditions return to the acceptable range, the fan is automatically switched OFF. At the same time, the water-level sensor continuously monitors the nutrient reservoir. If the water level becomes lower than the required level, the ESP32 detects the condition and displays an appropriate warning on the LCD.

The methodology therefore functions as an integrated feedback-based control system in which sensor measurements are continuously collected and processed by the ESP32. The controller uses the measured information to determine the operation of the cooling fan and provides real-time information through the LCD display. The solar panel and battery provide the required electrical energy for the control system, while the hydroponic section provides the environment for plant cultivation. The continuous interaction between these sections allows the system to automatically monitor the important environmental conditions surrounding the hydroponic plants.

Overall, the proposed methodology integrates renewable energy, hydroponic cultivation, embedded control, environmental sensing, automatic ventilation, and real-time display into a



single system. The use of the ESP32 enables centralized processing of sensor data and automatic control of the cooling fan. The temperature and humidity sensor provides information about the growing environment, while the water-level sensor monitors the availability of nutrient solution. The LCD provides direct information to the user, and the solar panel with rechargeable battery supplies electrical power to the system. Through the continuous sensing and control process, the proposed system provides an automated and energy-efficient approach for maintaining a monitored hydroponic growing environment.

4. 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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