International Journal of
AI Electronics and Nexus Energy
Peer Reviewed, Referred & Indexed Journal
ISSN: 3070-0515 www.zesterapublications.com Original Research Paper

Design and Implementation of an IoT-Enabled Solar Hydroponic Farming System

Arshad Khan[1], Marla Sainath[1], Samala Rishitha[1], Dubapalli Rajesh Reddy[1], P. Vasudha[1]
[1]Department of Electronics and Communication Engineering, [1]Sree Dattha Institute of Engineering and Science, Sheriguda, Ibrahimpatnam, 501510, Telangana, India.

ABSTRACT

This project presents an IoT-based smart indoor farming system developed to enhance sustainable agriculture through automation, environmental monitoring, and efficient resource management. The system is implemented using an ESP32 microcontroller integrated with multiple sensors, including a DHT11 sensor for temperature and humidity monitoring and a soil moisture sensor for irrigation management. The proposed system continuously monitors environmental conditions and automatically controls essential farming operations such as water pumping, ventilation through fan control, and alert generation using a buzzer. Real-time sensor data is displayed on an LCD module and transmitted to an IoT cloud platform through Wi-Fi connectivity for remote monitoring and analysis. The automated control mechanism maintains suitable environmental conditions for plant growth, reducing human intervention and improving farming efficiency. The system also supports smart irrigation by detecting soil moisture levels and activating the water pump only when required, thereby conserving water resources. This low-cost and energy-efficient solution is suitable for indoor farming and smart agriculture applications, addressing challenges such as limited agricultural land, climate variations, and efficient crop management while promoting modern eco-friendly farming practices.

Keywords: IoT, Smart Indoor Farming, ESP32 Microcontroller, DHT11 Sensor, Soil Moisture Monitoring, Smart Irrigation System, Environmental Monitoring, Automated Farming, Wi-Fi Communication, IoT Cloud Platform, Sustainable Agriculture, Precision Agriculture, Sensor-Based Automation, Smart Agriculture, Remote Monitoring.

1. INTRODUCTION

As the global population continues to grow, the demand for sustainable agricultural practices is increasing. Conventional farming methods face challenges such as limited arable land, unpredictable weather conditions, and significant water consumption. To address these issues, hydroponic farming has emerged as a viable solution. Hydroponics allows plants to grow without soil, using nutrient-rich water solutions. This method offers several advantages, including efficient water use, faster plant growth, and the ability to cultivate crops in urban environments. This project aims to develop an IoT-enabled solar-powered hydroponic indoor farming and plant growth chamber that provides a controlled environment for optimal plant growth. By integrating solar power and IoT technology, the system ensures energy efficiency and sustainability, reducing reliance on conventional power sources. The use of IoT technology enables real-time monitoring and automation of environmental factors, leading to improved plant growth conditions and resource optimization.

The system is designed to operate in both Manual and Automatic modes. In Manual Mode, users can remotely control the irrigation pump via an IoT platform, allowing for flexibility and user intervention when necessary. In Automatic Mode, the system autonomously adjusts water and nutrient flow based on real-time sensor data, minimizing human intervention and ensuring optimal plant growth conditions. Key components of the system include temperature, humidity, and nutrient sensors, a water level sensor, a 16x2 LCD display, a buzzer for alerts, and an AC water pump for automated irrigation. The ESP32 microcontroller serves as the central unit for real-time monitoring and automation, continuously uploading sensor readings to an IoT cloud platform for remote monitoring and analysis. By leveraging solar energy, the system reduces energy consumption and promotes sustainable indoor farming practices. The automated control of environmental factors enhances plant growth conditions, leading to improved yield and resource optimization. This smart hydroponic solution not only supports sustainable agriculture but also contributes to food security and the efficient use of natural resources.

2. LITERATURE REVIEW

Ankita Patil, et al. [1] proposed a smart farming system using Arduino and data mining techniques to improve agricultural productivity through wireless sensor technology and automated plant watering mechanisms. The system enabled farmers to monitor soil moisture, weather conditions, fertilizers, and crop-related information through a smartphone application. Muhammad Faris Hilmi Ameran, et al. [2] proposed an IoT-integrated dual-sensor monitoring system for hydroponic cultivation that continuously monitored root growth, nutrient levels, pH, and temperature conditions to optimize hydroponic farming performance. Pradnya Vishram Kulkarni, et al. [3] proposed sensing methodologies for hydroponic farming using IoT and sensor networks to monitor nutrient concentration, pH levels, and environmental parameters for achieving optimal plant growth and improved crop quality. Minwoo Ryu, et al. [4] proposed a connected smart farming system using IoT technology, where wireless sensors and actuators were integrated to monitor and control agricultural environmental conditions through smartphones and remote communication platforms.

Glenn Dbritto [5] proposed an AI-based hydroponic farm monitoring system that utilized automated nutrient delivery and environmental sensing technologies to support efficient crop cultivation without soil in controlled farming environments. Urmila Pilania, et al. [6] proposed an automated hydroponic monitoring system using IoT and cloud-based technologies for sustainable agriculture by continuously monitoring water level, nutrient concentration, temperature, and humidity parameters.

Archana Bhamare, et al. [7] proposed an AI-based plant growth monitoring system using computer vision techniques to analyze plant growth parameters such as leaf area, biomass, and height for efficient crop management and yield improvement. Shreya P Patil, et al. [8] proposed an AI-driven hydroponic farming system for Lemon Basil cultivation that integrated advanced monitoring and automated control techniques to optimize plant growth and resource utilization.

Pooja Mahajan, et al. [9] proposed an automated hydroponic system that incorporated sensors, nutrient delivery mechanisms, and climate control technologies to improve efficiency, sustainability, and crop yield in modern farming applications. S. Boopathy, et al. [10] proposed an IoT-based hydroponic fertigation system for organic vegetable cultivation, where sensors and IoT communication technologies were used to automate nutrient supply and monitor plant growth conditions.

Thalwatte A. M. et al. [11] proposed a fully automatic hydroponic cultivation system integrated with sensors and actuators for monitoring temperature, light intensity, water level, and CO2 concentration in smart greenhouse environments.

A. Sharmila Agnal, et al. [12] proposed an automated IoT indoor hydroponic farming system that monitored environmental parameters such as temperature, humidity, and light intensity while automating nutrient and water delivery processes. Bernard Juk Jangan, et al. [13] proposed an IoT-based hydroponic monitoring system to analyze the effects of water level, temperature, and humidity on plant growth using real-time environmental data collection techniques.

International Journal of
AI Electronics and Nexus Energy
Peer Reviewed, Referred & Indexed Journal
ISSN: 3070-0515 www.zesterapublications.com Original Research Paper

Lovina Siechrist T. Agbayani, et al. [14] proposed a ThingSpeak-based IoT monitoring system for hydroponics that enabled real-time monitoring of parameters such as temperature, pH, and electrical conductivity for efficient crop management. Muhammad Irfan Syauqi, et al. [15] proposed an IoT device-based website monitoring system for water-media plant cultivation that collected and analyzed environmental data to improve hydroponic farming and maintenance processes. Sneha Dhanan, et al. [16] proposed a LoRa technology-based hydroponic farm monitoring system that used wireless sensor networks to measure temperature, humidity, and pH levels for efficient remote agricultural monitoring.

3. PROPOSED SYSTEM

The proposed IoT-based smart indoor farming system is designed around an ESP32/Arduino microcontroller that acts as the central processing unit for monitoring and automation tasks. The architecture integrates multiple sensors, communication modules, and actuator devices to maintain optimal environmental conditions for plant growth. Temperature and humidity values are continuously monitored using the DHT11 sensor, while the soil moisture sensor detects the water content in the growing medium for intelligent irrigation management. The sensed data is processed by the microcontroller and displayed in real time on an LCD module for local monitoring. The system incorporates automated control mechanisms where the fan is activated whenever the temperature or humidity exceeds predefined threshold values, ensuring proper climate regulation. Similarly, the water pump is automatically controlled based on soil moisture conditions to support efficient irrigation and water conservation. A buzzer unit is included to provide alert notifications during abnormal environmental conditions. As illustrated in Figure 1, the system also includes Wi-Fi-based IoT connectivity using AT command communication, enabling remote monitoring and cloud data uploading through the ThingSpeak platform.

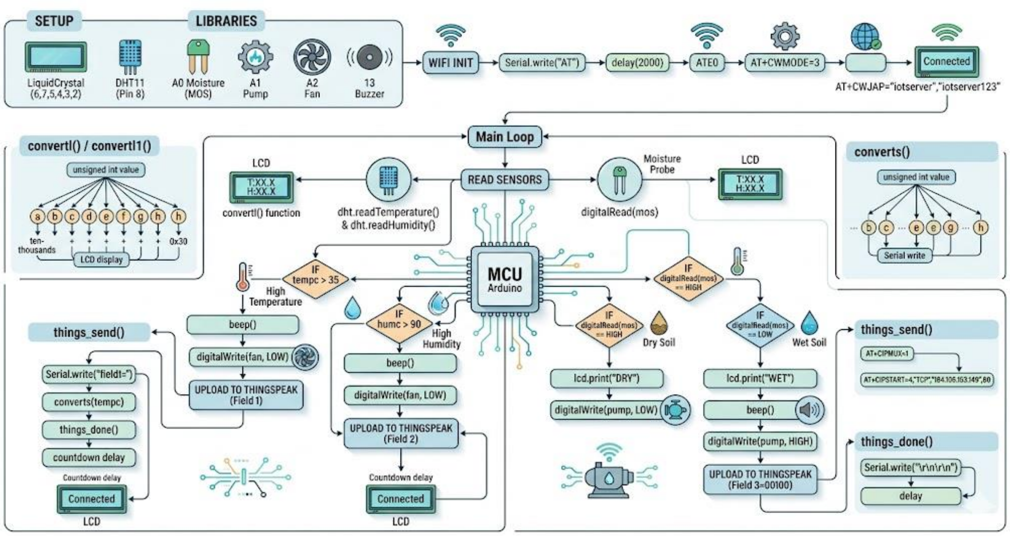

Figure 1: The proposed IoT-based smart indoor farming system.

The architecture supports continuous real-time operation through the main loop execution cycle, where sensor acquisition, decision-making, actuator control, and cloud communication are performed simultaneously. Data conversion and formatting functions are incorporated for LCD visualization and serial transmission to the IoT server. The overall system architecture provides a low-cost, energy-efficient, and automated solution for smart indoor farming applications by integrating sensing, control, communication, and monitoring functionalities into a unified embedded platform.

Received: 06-05-2026 | Accepted: 13-06-2026 | Published: 22-06-2026

International Journal of
AI Electronics and Nexus Energy
Peer Reviewed, Referred & Indexed Journal
ISSN: 3070-0515 www.zesterapublications.com Original Research Paper

4. RESULTS AND DISCUSSION

The Results and Discussion section evaluates the performance of the proposed IoT-based smart irrigation and environmental monitoring system under real-time operating conditions. The integrated sensors accurately monitored soil moisture, temperature, and humidity, while the control unit effectively managed irrigation and cooling operations based on sensed parameters. The collected data were successfully transmitted to the cloud platform and visualized through a web-based dashboard for remote monitoring. Experimental observations confirmed reliable system operation, timely decision-making, and efficient resource utilization.

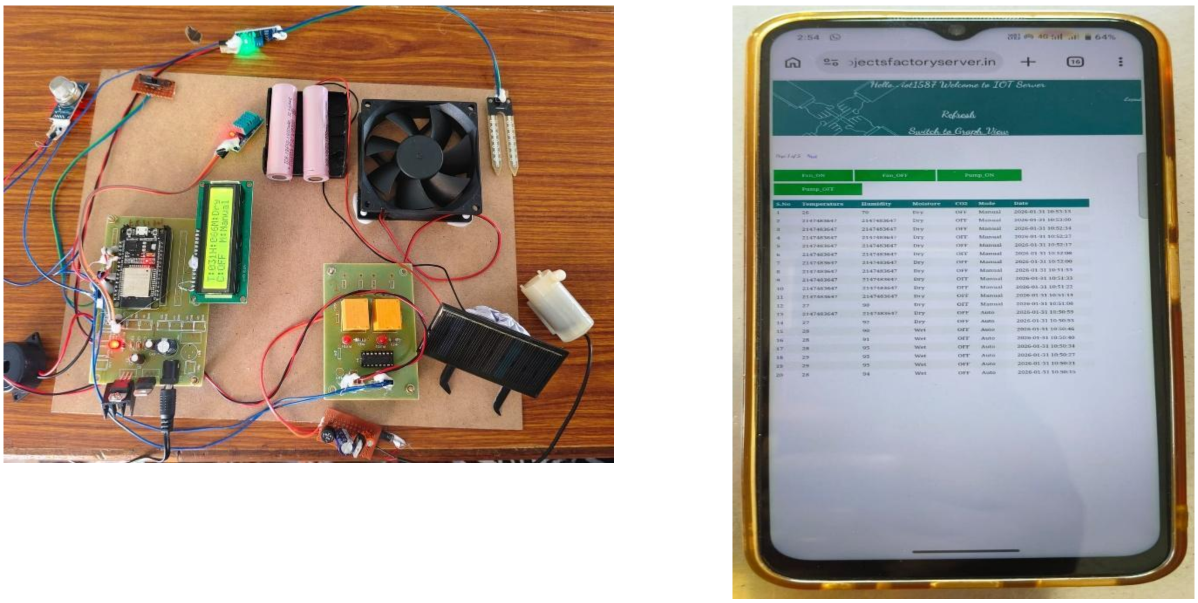

Figure 2. Experimental Prototype and IoT monitoring dashboard of the smart irrigation system

Figure 2 presents the developed IoT-enabled smart irrigation and environmental monitoring system along with its web-based monitoring dashboard. The hardware prototype integrates an ESP32 microcontroller, soil moisture sensor, temperature and humidity sensor, water pump, cooling fan, solar panel, battery unit, relay control module, and LCD display for real-time agricultural monitoring. Sensor data are continuously collected and transmitted to a cloud-based platform through wireless communication. The web dashboard provides remote access to environmental parameters, soil conditions, motor status, and historical records, enabling effective monitoring and management of irrigation activities. Experimental results demonstrate reliable data acquisition, automated irrigation control, and successful remote visualization, highlighting the system's suitability for intelligent and sustainable agriculture applications.

5. CONCLUSION

The hydroponics system utilizing an ESP-32 microcontroller ensures efficient plant growth by automating key environmental controls. Powered by a solar-charged battery, the system continuously monitors temperature, humidity, and soil moisture levels through dedicated sensors, optimizing irrigation and nutrient delivery. The integration of an automatic/manual switch provides flexibility in operation, while real-time data visualization is achieved via an LCD monitor. An IoT module enables remote monitoring and control, ensuring precision in resource management. The system efficiently regulates an AC pump for nutrient circulation and employs a buzzer for alerts, enhancing reliability. By leveraging smart automation,

International Journal of
AI Electronics and Nexus Energy
Peer Reviewed, Referred & Indexed Journal
ISSN: 3070-0515 www.zesterapublications.com Original Research Paper

hydroponics cultivation becomes more sustainable, conserving water and nutrients while improving crop yield.

REFERENCES:

[1] Ankita Patil, Akshay Naik, Mayur Beldar, Sachin Deshpande. (2016). “Smart Farming using Arduino and Data Mining”Divya Sai. K et al 2016 3rd International Conference on Computing for Sustainable Global Development (INDIACom)

[2]Muhammad Faris Hilmi Ameran, Rina Abdullah, Nuraiza Ismail, Rosmawati Shafie, Suziana Omar, Siti Aisyah Che Kar, "Design and Implementation of an IoT Integrated Dual Sensors for Hydroponic Cultivation Root Growth Monitoring System", 2024 IEEE

[3] Pradnya Vishram Kulkarni, Vinaya Gohokar, Kunal Kulkarni, "Sensing Methodologies in Hydroponics for Optimal Growth and Nutrient Monitoring"2024IEEE

[4] Minwoo Ryu, Jaeseok Yun, Ting Miao, Il-Yeup Ahn, Sung-Chan Choi, Jaeho Kim. (2015). “Design and Implementation of a Connected Farm for Smart Farming System”. 2015 IEEE SENSORS

[5] Glenn Dbritto An AI Based System Design to Develop and Monitor a Hydroponic Farm 2018 (ICSCET)

[6] Urmila Pilania, Manoj Kumar, "Automated Monitoring of Hydroponic System using IoT and Cloud based Technology for Sustainable Agriculture", 2024 1st International Conference on Advanced Computing and Emerging Technologies (ACET)

[7] Archana Bhamare, Vivek Upadhyay, Payal Bansal, "AI based Plant Growth Monitoring System using Computer Vision", 2023 IEEE

[8] Shreya P Patil, Lincy Meera Mathews, Arvind Kumar G, Sanchi B Motgi, Utkarsh Sinha, "AI-Driven Hydroponic Systems for Lemon Basil", *2023 International Conference on Network, Multimedia and Information Technology (NMITCON*)

[9]Pooja Mahajan, Sanyam Gupta, Sameer Sachdeva, "Automation in Hydroponic Systems: A Sustainable Pathway to Modern Farming", 2022 IEEE International Conference on Service Operations and Logistics, and Informatics (SOLI)

[10]S Boopathy, K R Gokul Anand, E L Dhivya Priya, A Sharmila, S.A. Pasupathy, "IoT based Hydroponics based Natural Fertigation System for Organic Veggies Cultivation", 2021 Third International Conference on Intelligent Communication Technologies and Virtual Mobile Networks (ICICV)

[11] Thalwatte A. M.; Ranasinghe U. G. K. L. P. S Fully Automatic Hydroponic Cultivation Growth System 2021 3rd International Conference on Advancements in Computing (ICAC)

[12] A Sharmila Agnal; V P Sanaadhani; L Reshma Automated IoT Indoor Hydroponic Farm 2024 International Conference on Power, Energy, Control and Transmission Systems (ICPECTS)

[13] 13. Bernard Juk Jangan, Nina Korlina Madzhi, "IoT based Monitoring and Investigation of the Effect of Water Level, Temperature and humidity to the Hydroponic based plant", 2024 IEEE

[14] Lovina Siechrist T. Agbayani, Jocelyn Flores Villaverde, "Thingspeak Based Monitoring IoT System for Hydroponics System", 2024 7th International Conference on Information and Computer Technologies (ICICT)

[15] Muhammad Irfan Syauqi, Ahmad Nurul Fajar, "Development of Monitoring System Website Based on IoT Devices as a Solution to Plant Planting and Maintenance Process in Water Media", 2023 10th International Conference on ICT for Smart Society (ICISS)

[16] Sneha Dhanan; S Sri Harsha; Shivam Choudhary; Sharmila K PLoRa Technology Based Hydroponic Farm Monitoring System 2021 2nd International Conference on Smart Electronics and Communication (ICOSEC)