International Journal of
DATA SCIENCE AND IOT MANAGEMENT SYSTEM
Peer Reviewed, Referred & Indexed Journal
ISSN: 3068-272X www.ijdim.com Original Research Paper

IoT-Enabled Intelligent Hydroponic System for Smart Indoor Farming and Real-Time Environmental Monitoring

B. Ravi Kumar[1*], Kusumanchi Baji Baba[1], Essampally Supriya[1], Kusumanchi Karishma[1], Kola Sathvika, Mulagalapati Ramanaga Vignesh[1]
[1]Department of Electronics and Communication Engineering, Mother Teresa Institute of Science and Technology, Sanketika Nagar, Kothuru, Sathupally, Khammam, 507303, Telangana, India
*Correspondence: B. Ravi Kumar

ABSTRACT

With the rising emphasis on sustainable agriculture, hydroponic farming has become a highly efficient alternative to traditional methods, enabling soil-less cultivation while significantly reducing water usage and enhancing nutrient management. This project introduces an IoT-enabled, solar-powered hydroponic indoor farming and plant growth chamber designed to maintain a controlled environment that promotes optimal plant development. The system is powered by a solar-based energy supply and integrates the ESP32 microcontroller to facilitate real-time monitoring and automated operations. Core components include sensors for temperature, humidity, water level, and nutrient concentration, along with a 16x2 LCD display, a buzzer for alert notifications, and an AC water pump for automated irrigation. It features two operational modes: Manual and Automatic. In Manual Mode, users can remotely control the irrigation pump via an IoT platform. In Automatic Mode, the system independently regulates water and nutrient delivery based on continuous sensor input. All sensor data is transmitted to an IoT cloud platform for remote monitoring and analysis. By utilizing solar power, the system ensures energy efficiency and promotes sustainability by minimizing reliance on conventional electricity sources. Automated control of environmental parameters fosters ideal growing conditions, improving crop yield and maximizing resource efficiency. This smart hydroponic system reduces the need for manual intervention, enhances the use of water and nutrients, and supports eco-friendly indoor farming practices.

KEYWORDS: IoT, Hydroponics, Indoor Farming, Plant Growth Chamber, Cloud Computing

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

2.1 Smart Farming and IoT-Based Agricultural Systems

Ankita Patil *et al.* [1] proposed a smart farming system using Arduino and data mining techniques, integrating wireless sensors and mobile applications to automate irrigation and provide agricultural insights such as soil moisture and weather conditions. Similarly, Minwoo Ryu *et al.* [4] developed a connected farm system using IoT-enabled sensors and actuators to monitor environmental parameters and allow remote farm management, improving productivity and reducing resource wastage.

2.2 IoT-Based Hydroponic Monitoring Systems

Muhammad Faris Hilmi Ameran *et al.* [2] designed an IoT-integrated dual-sensor system for monitoring root growth in hydroponic environments, focusing on parameters such as nutrient levels, pH, and temperature for optimized crop production. Likewise, Bernard Juk Jangan *et al.* [13] investigated the impact of environmental parameters like water level, temperature, and humidity on hydroponic plant growth using IoT-based monitoring systems.

2.3 Sensor-Based Nutrient and Growth Optimization

Pradnya Vishram Kulkarni *et al.* [3] explored sensing methodologies for monitoring nutrient levels and environmental conditions in hydroponic systems, emphasizing precise control for optimal plant growth. Additionally, Lovina Siechrist T Agbayani *et al.* [14] implemented a ThingSpeak-based IoT monitoring system to track parameters such as temperature, pH, and electrical conductivity for improved crop health.

2.4 AI-Based Hydroponic and Smart Farming Systems

Glenn Dbritto *et al.* [5] developed an AI-based hydroponic farming system that automates nutrient delivery and water supply, improving efficiency and reducing dependency on soil-based cultivation. Similarly, Shreya P Patil *et al.* [8] introduced an AI-driven hydroponic system for lemon basil cultivation, demonstrating enhanced yield and reduced resource consumption through intelligent monitoring.

2.5 Automation and Cloud-Based Hydroponic Systems

Urmila Pilania *et al.* [6] proposed an automated hydroponic monitoring system using IoT and cloud computing, enabling real-time tracking and decision-making based on environmental conditions. In addition, Pooja Mahajan *et al.* [9] highlighted the importance of automation in hydroponic systems, focusing on nutrient delivery and climate control to enhance sustainability and efficiency.

2.6 Computer Vision and AI in Plant Monitoring

Archana Bhamare *et al.* [7] developed an AI-based plant growth monitoring system using computer vision techniques to analyze plant features such as height, leaf area, and biomass, reducing manual intervention and improving monitoring accuracy.

2.7 Fully Automated and Smart Greenhouse Systems

Thalwatte A M *et al.* [11] designed a fully automated hydroponic system integrated with greenhouse technology, using sensors to monitor environmental factors such as temperature, CO_2 levels, and light intensity. The system also incorporates machine learning for disease detection and yield prediction.

2.8 IoT-Based Indoor and Wireless Monitoring Systems

A Sharmila Agnal *et al.* [12] presented an automated indoor hydroponic system using IoT and cloud platforms for real-time monitoring and control. Similarly, Sneha Dhanan *et al.* [16] proposed a LoRa-based hydroponic monitoring system that enables long-range communication and efficient data transmission for large-scale farming environments.

2.9 Web-Based and IoT Monitoring Platforms

Muhammad Irfan Syauqi *et al.* [15] developed a web-based monitoring system integrated with IoT devices to track environmental parameters in water-based cultivation systems, enabling better plant maintenance and decision-making.

3. PROPOSED SYSTEM

The proposed system for an IoT-based solar-powered hydroponic indoor farming and plant growth chamber aims to enhance the efficiency and effectiveness of plant cultivation by integrating advanced technologies. Here are some key features and components of the proposed system:

1. **Solar Power Integration**: The system will utilize solar panels to generate renewable energy, reducing dependency on conventional power sources and making the system more sustainable.
2. **Advanced Sensors**: The system will incorporate a variety of sensors to monitor and control environmental conditions, including:
    - **Temperature and Humidity Sensors**: To maintain optimal growing conditions.
    - **pH and EC Sensors**: To monitor and adjust the nutrient solution.
    - **Light Sensors**: To regulate artificial lighting based on natural light availability.
    - **Water Level Sensors**: To ensure a consistent water supply.
3. **Automated Control System**: The system will use IoT technology to automate various processes, such as:
    - **Nutrient Delivery**: Automated pumps will deliver the right amount of nutrients to the plants.
    - **Water Circulation**: Automated water pumps will ensure proper water circulation.
    - **Lighting Control**: LED lights will be controlled based on the plants' needs and natural light availability.
4. **Data Collection and Analysis**: The system will collect data from sensors and use cloud-based platforms for real-time monitoring and analysis. This data will help optimize growing conditions and improve crop yield.
5. **Remote Monitoring and Control**: Users will be able to monitor and control the system remotely using a smartphone or computer. This feature will provide convenience and flexibility in managing the farming system.
6. **User-Friendly Interface**: The system will have an intuitive interface that allows users to easily monitor and adjust settings. This interface will display real-

time data and provide alerts for any issues that need attention.

This proposed system aims to provide a controlled and efficient environment for indoor farming, leveraging the power of IoT and renewable energy to optimize plant growth and resource usage.

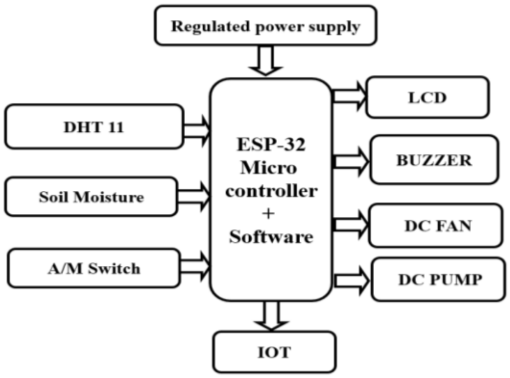

Fig 1. Block Diagram of smart hydroponic system

As shown in fig 1 the block diagram illustrates an IoT-based smart irrigation system powered by an ESP-32 microcontroller. A solar panel charges a battery, which supplies power to the system. The ESP-32 receives input from multiple sensors, including temperature, humidity, and soil moisture sensors, to monitor environmental conditions. An automatic/manual (A/M) switch allows users to toggle between automated and manual control of the irrigation process. Based on the sensor data and selected mode, the ESP-32 controls various output devices such as an AC pump for irrigation, an LCD monitor for displaying real-time data, a buzzer for alerts, and an IoT module for remote monitoring and control. This setup ensures efficient water management by automating irrigation based on soil moisture levels and environmental conditions.

ESP32 is the SoC (System on Chip) microcontroller which has gained massive popularity recently. Whether the popularity of ESP32 grew because of the growth of IoT or whether IoT grew because of the introduction of ESP32 is debatable. If you know 10 people who have been part of the firmware development for any IoT device, chances are that 7−8 of them would have worked on ESP32 at some point.

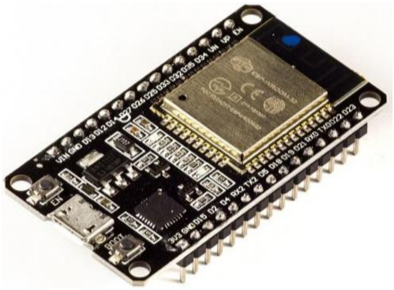

Fig 2. ESP32 WROOM 32 variant

Before we delve into the actual reasons for the popularity of ESP32, let's take a look at some of its important specifications. The specs listed below belong to the ESP32 WROOM 32 variant.−

- Integrated Crystal− 40 MHz
- Module Interfaces− UART, SPI, I2C, PWM, ADC, DAC, GPIO, pulse counter, capacitive touch sensor
- Integrated SPI flash− 4 MB
- ROM− 448 KB (for booting and core functions)
- SRAM− 520 KB
- Integrated Connectivity Protocols− WiFi, Bluetooth, BLE
- On−chip sensor− Hall sensor
- Operating temperature range− −40 − 85 degrees Celsius
- Operating Voltage− 3.3V
- Operating Current− 80 mA (average)

With the above specifications in front of you, it is very easy to decipher the reasons for ESP32's popularity. Consider the requirements an IoT device would have from its microcontroller (μC). If you've gone through the previous chapter, you'd have realized that the major operational blocks of any IoT device are sensing, processing, storage, and transmitting. Therefore, to begin with, the μC should be able to interface with a variety of sensors. It should support all the common communication protocols required for sensor interface: UART, I2C, SPI. It should have ADC and pulse counting capabilities. ESP32 fulfills all of these requirements. On top of that, it also can interface with capacitive touch sensors. Therefore, most common sensors can interface seamlessly with ESP32.

Secondly, the µC should be able to perform basic processing of the incoming sensor data, sometimes at high speeds, and have sufficient memory to store the data. ESP32 has a max operating frequency of 40 MHz, which is sufficiently high. It has two cores, allowing parallel processing, which is a further add-on. Finally, its 520 KB SRAM is sufficiently large for processing a large array of data onboard. Many popular processes and transforms, like FFT, peak detection, RMS calculation, etc. can be performed onboard ESP32. On the storage front, ESP32 goes a step ahead of the conventional microcontrollers and provides a file system within the flash. Out of the 4 MB of onboard flash, by default, 1.5 MB is reserved as SPIFFS (SPI Flash File System). Think of it as a mini−SD Card that lies within the chip itself. You can not only store data, but also text files, images, HTML and CSS files, and a lot more within SPIFFS. People have displayed beautiful WebPages on WiFi servers created using ESP32, by storing HTML files within SPIFFS.

4. 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, 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"2024 IEEE

[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]. 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]. Viswanathan, V. (2023). AI-Augmented Decision Intelligence for Enterprise Systems: Integrating Cognitive Analytics for Resource and Talent Optimization.

[15]. 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)

[16]. 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)

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