
**IOT ENABLED HYDROPONIC INDOOR FARMING FOR SUSTAINABLE
AGRICULTURE**

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ABSTRACT

This paper presents an IoT-enabled hydroponic indoor farming system designed to revolutionize sustainable agriculture through intelligent automation and resource optimization. The system integrates ESP-32 microcontroller technology with multiple environmental sensors including DHT11 for temperature and humidity monitoring, soil moisture sensors for nutrient solution management, CO2 sensors for atmospheric control, and automated mode selection capabilities. Real-time data monitoring and control are facilitated through IoT connectivity, enabling remote farm management and data analytics for optimal crop growth conditions. The system autonomously controls critical parameters including irrigation through pump automation, climate regulation via fan control, environmental alerts through buzzer notifications, and comprehensive data visualization on LCD displays. This integrated approach addresses contemporary challenges in agriculture including water scarcity, land limitations, climate variability, and food security concerns while promoting eco-friendly farming practices.

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

1. INTRODUCTION

1.1 INTRODUCTION

The rapid growth of the global population, combined with increasing urbanisation and the progressive degradation of arable farmland, has necessitated a fundamental rethinking of conventional agricultural practices. Traditional soil-based farming is heavily constrained by seasonal weather patterns, geographic limitations, water scarcity, and exposure to soil-borne pathogens — all of which significantly reduce yield predictability and operational efficiency. Hydroponics, a method of cultivating plants in a nutrient-rich aqueous solution without the use of soil, has emerged as one of the most promising alternatives to address these challenges. By delivering precisely calibrated

nutrients directly to plant roots, hydroponic systems enable faster plant growth, higher crop density, and substantially reduced water consumption compared to conventional farming methods.

Indoor hydroponics takes this concept a step further by establishing a fully controlled growing environment, independent of external climate conditions. Plants are cultivated under artificial lighting, regulated temperature and humidity, and optimised nutrient delivery — creating ideal growing conditions year-round. However, maintaining the precise environmental parameters required for healthy plant growth is a labour-intensive task that demands continuous monitoring and timely intervention. Any deviation in temperature, humidity, soil moisture, or carbon dioxide concentration can lead to crop

stress, reduced yield, or total crop failure. This is where the integration of the Internet of Things (IoT) becomes transformative, enabling autonomous, real-time monitoring and control of all critical farming parameters through connected sensors and actuators managed by a centralised microcontroller.

This paper presents the design and implementation of an IoT-enabled hydroponics indoor farming system built around the ESP-32 microcontroller. The system integrates a DHT11 sensor for ambient temperature and humidity measurement, a soil moisture sensor for root-zone hydration monitoring, a CO₂ sensor for air quality and plant respiration management, and an Automatic/Manual (A/M) mode selector for flexible operation. Based on real-time sensor data, the ESP-32 autonomously controls a water pump, a ventilation fan, an LCD status display, and a buzzer alert system. All operational data is transmitted wirelessly to an IoT cloud dashboard, enabling remote monitoring and control from any internet-connected device. The result is a scalable, energy-efficient, and intelligent farming platform suitable for urban households, research institutions, and commercial indoor farms.

1.2 OBJECTIVE OF THE PROJECT

The primary objective of this project is to design, develop, and validate an IoT-enabled hydroponics indoor farming system that eliminates the need for manual monitoring by automating all critical environmental control tasks through an integrated sensor-actuator network managed by an ESP-32 microcontroller. Specifically, the system aims to maintain optimal growing conditions for indoor crops by continuously monitoring ambient temperature, relative humidity, root-zone soil moisture, and atmospheric CO₂ concentration, and responding autonomously to any deviations from preset threshold values. The pump activation mechanism ensures that plants receive water and nutrients precisely when needed, preventing both

over-irrigation and dehydration, while the fan control system regulates air circulation and temperature to prevent heat stress and CO₂ depletion. An audio-visual alert subsystem notifies operators of critical environmental anomalies that require human intervention. Beyond local automation, the system targets seamless IoT cloud integration to deliver real-time remote monitoring, historical data logging, and remote actuation through a web or mobile dashboard, making precision farming accessible from any location at any time.

A secondary objective is to provide operational flexibility through an Automatic/Manual mode switch, allowing users to override automated decisions and manually control actuators when needed — for example, during system maintenance, calibration, or crop-specific growing experiments. The system is also designed with scalability in mind, using modular hardware and standard communication protocols so that additional sensors, grow chambers, or remote nodes can be incorporated without significant redesign. Ultimately, the project aims to demonstrate that IoT-driven precision agriculture can deliver higher crop yields, reduced resource consumption, and lower operational costs compared to traditional manual farming approaches, providing a replicable, low-cost platform that is accessible to small-scale urban farmers and large commercial producers alike.

1.3 PROBLEM STATEMENT

Despite the well-documented agronomic advantages of hydroponics, widespread adoption of indoor hydroponic farming continues to be hindered by several practical and technological challenges. The most significant barrier is the requirement for constant manual monitoring of multiple environmental parameters simultaneously. Variables such as ambient temperature, relative humidity, root-zone moisture, and atmospheric CO₂ concentration

must be kept within narrow optimal ranges at all times — ranges that can shift within minutes due to changes in lighting, plant transpiration, or HVAC performance. In the absence of automated control systems, farm operators must conduct frequent physical inspections and manual adjustments, making the process labour-intensive, error-prone, and economically unscalable. A momentary lapse in monitoring can result in plant wilting, root rot, CO₂ toxicity, or complete crop loss, all of which represent significant financial and food-security consequences.

Existing commercial hydroponics monitoring solutions are predominantly proprietary, expensive, and designed for large-scale industrial operations, placing them well beyond the reach of small-scale urban farmers, educational institutions, and research labs. There is a clear and growing need for an affordable, open-architecture, microcontroller-based monitoring and control system that can deliver industrial-grade automation at a fraction of the cost. Furthermore, current systems often lack robust remote accessibility, meaning that farmers must be physically present to respond to alerts or adjust system parameters — an impractical requirement in modern distributed farm management scenarios. The absence of integrated IoT connectivity in low-cost hydroponics solutions means that data-driven decision-making, historical trend analysis, and remote intervention remain out of reach for the majority of small and mid-scale operators. This project directly addresses these gaps by providing a fully integrated, IoT-connected, autonomous hydroponics control system that is low-cost, open-source, and easily deployable across a wide range of indoor farming contexts.

1.4 SYSTEM OVERVIEW

The IoT-enabled hydroponics indoor farming system is architected around the ESP-32 dual-core microcontroller, which serves as the central

processing and wireless communication hub for the entire platform. The ESP-32 was selected for this application due to its integrated 802.11 b/g/n WiFi and Bluetooth Low Energy (BLE) capabilities, its dual Tensilica LX6 cores operating at up to 240 MHz, its extensive GPIO peripheral set, and its low power consumption profile — all essential attributes for a continuously operating embedded IoT device. The microcontroller interfaces with four primary sensing subsystems: the DHT11 digital temperature and humidity sensor, which provides calibrated measurements of ambient air temperature and relative humidity critical for preventing heat stress and fungal disease; the capacitive soil moisture sensor, which monitors the water content at the plant root zone and drives the irrigation pump in closed-loop feedback; the MQ-series CO₂ and gas sensor, which tracks atmospheric carbon dioxide levels essential for photosynthesis optimisation; and a manual/automatic mode selector switch, which allows human operators to override autonomous control decisions when required.

On the actuation side, the ESP-32 drives four output subsystems based on sensor data and pre-programmed threshold logic. The water pump is activated via a relay module whenever soil moisture falls below the configured lower threshold, providing precise on-demand irrigation without human intervention. The ventilation fan is similarly controlled by a relay, activating whenever ambient temperature or CO₂ levels exceed their respective upper thresholds to restore optimal growing conditions through active air circulation and gas exchange. The LCD display module provides operators with a real-time local readout of all key parameters, including temperature, humidity, moisture level, CO₂ concentration, and current system mode, eliminating the need for a dedicated monitoring computer on-site. The buzzer alert system generates an audible alarm whenever any

parameter reaches a critical out-of-range condition that requires immediate human attention. All sensor readings and actuator states are transmitted over WiFi to an IoT cloud platform — such as Blynk, ThingSpeak, or a custom MQTT broker — enabling real-time remote monitoring, data logging, and remote control from any web browser or mobile application worldwide.

The system operates in two distinct modes selectable via the A/M switch. In Automatic Mode, the ESP-32 executes the full closed-loop control algorithm, making all irrigation and ventilation decisions autonomously based on live sensor data and programmed threshold values, with all actuator states reported to the IoT dashboard in real time. In Manual Mode, the automation logic is suspended and actuators are controlled directly through the IoT dashboard or physical controls, giving the operator full override capability for maintenance, calibration, or experimental crop protocols. This dual-mode architecture ensures that the system is both fully autonomous for unattended operation and fully flexible for hands-on management, making it adaptable to the diverse operational requirements of modern indoor farming environments. The entire platform is powered through a regulated power supply (RPS), ensuring stable 3.3V and 5V rails for the ESP-32, sensors, relay modules, and peripheral displays regardless of load variations.

2. LITERATURE REVIEW

1. **Ankita Patil, Akshay Naik, Mayur Beldar, Sachin Deshpande. (2016). "Smart Farming using Arduino and Data Mining"** Divya Sai. K et al (2021) The paper "Smart Farming using Arduino and Data Mining" presented at the 2016 INDIACom conference discusses the use of wireless sensor technology and Arduino-based systems to improve farming practices. It

introduces an automatic plant watering system controlled via a smartphone application¹. The app provides farmers with crucial agricultural information, such as seed costs, soil moisture levels, weather forecasts, and recommended fertilizers and pesticides. The goal is to enhance crop yield and reduce resource wastage by leveraging modern technology¹. This approach aims to address the challenges faced by Indian agriculture, such as erratic weather and crop loss.

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** The paper "Design and Implementation of an IoT Integrated Dual Sensors for Hydroponic Cultivation Root Growth Monitoring System" presented at the 2024 IEEE I2CACIS conference discusses the development of a dual-sensor system for monitoring root growth in hydroponic cultivation. The system integrates IoT technology to provide real-time data on root health and growth conditions. It aims to optimize hydroponic farming by ensuring precise control over environmental factors. The sensors monitor parameters such as nutrient levels, pH, and temperature. This approach enhances crop yield and quality by providing accurate and timely information to farmers.
3. **Pradnya Vishram Kulkarni, Vinaya Gohokar, Kunal Kulkarni, "Sensing**

Methodologies in Hydroponics for Optimal Growth and Nutrient Monitoring²⁰²⁴ The paper "Sensing Methodologies in Hydroponics for Optimal Growth and Nutrient Monitoring" explores the use of IoT and sensor networks to optimize hydroponic farming. It focuses on monitoring parameters such as pH levels, temperature, and nutrient requirements for various plants¹. The study highlights the importance of precise control over environmental factors to ensure optimal growth. It also discusses the challenges and open issues in the field of hydroponics¹. The goal is to enhance crop yield and quality by leveraging modern technologies.

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.** The paper "Design and Implementation of a Connected Farm for Smart Farming System" presented at the 2015 IEEE SENSORS conference discusses the development of a smart farming system using IoT technology. The system aims to enhance agricultural productivity by integrating wireless sensor devices and actuators to monitor and control environmental conditions¹. The connected farm allows farmers to remotely manage their farms using smartphones or tablets. This approach aims to improve efficiency and reduce resource wastage in agriculture¹. The paper highlights the potential of IoT as a disruptive technology in the agricultural sector.

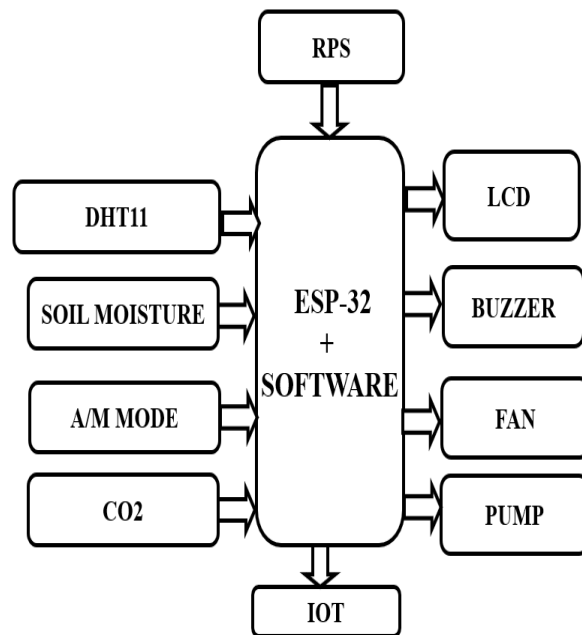
5. **Glenn Dbritto An AI Based System Design to Develop and Monitor a Hydroponic Farm 2018 (ICSCET)** The paper "An AI Based System Design to Develop and Monitor a Hydroponic Farm" presented at the 2018 ICSCET conference discusses the development of an AI-based system for hydroponic farming. The system aims to address issues like soil erosion and overuse of fertilizers by growing crops without soil in a controlled environment¹. It uses sensors to automatically deliver a mix of water and nutrient solutions directly to the roots of plants. The study focuses on the growth rate of Tomato F1 Hybrid Suhyana seeds and compares it with soil-grown plants¹. This approach helps conserve water and reduce losses due to drought and flooding

3. PROPOSED SYSTEM

The proposed system introduces a fully automated, solar-powered IoT architecture that transforms hydroponic farming into an intelligent, self-sustaining ecosystem with minimal human intervention requirements. At its core, the ESP-32 microcontroller processes inputs from DHT11 temperature-humidity sensors, soil moisture detectors, CO₂ level monitors, and automatic/manual mode selectors to make real-time decisions. Solar panels integrated with the system provide renewable energy, ensuring uninterrupted operation while significantly reducing electricity costs and environmental impact. The IoT connectivity enables remote monitoring and control through cloud-based platforms, allowing farmers to manage their operations from anywhere using smartphones or computers. Automated actuators including water pumps, ventilation fans, and alert buzzers respond instantaneously to sensor

readings, maintaining ideal growing conditions throughout the day and night. An LCD display provides on-site visualization of all critical parameters, while comprehensive data logging facilitates trend analysis and predictive maintenance. This intelligent system optimizes resource utilization, maximizes crop yields, minimizes operational costs, and represents a scalable solution for future sustainable agriculture.

3.1 BLOCK DIAGRAM:

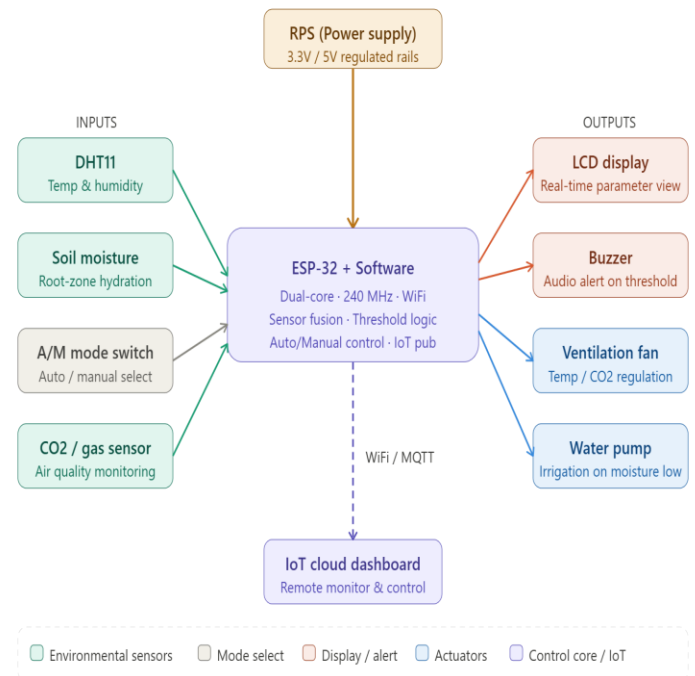


3.2 BLOCK DIAGRAM EXPLANATION

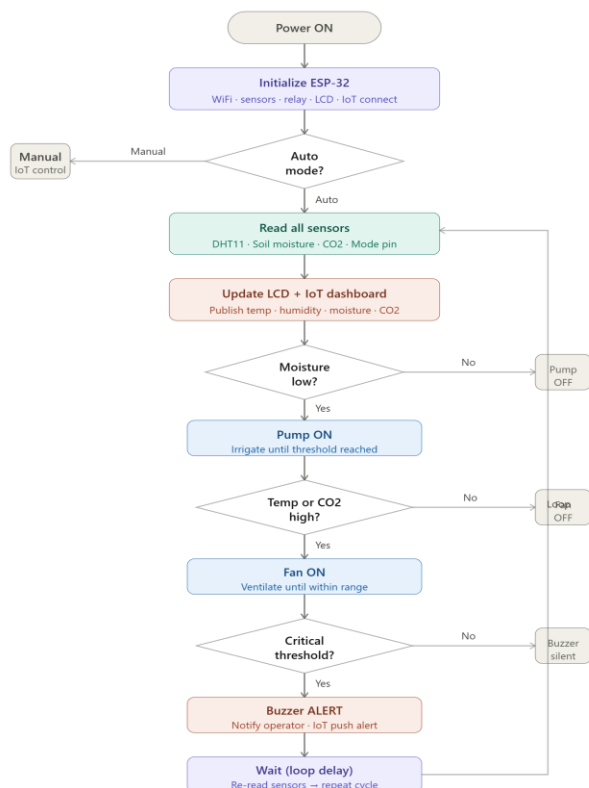
The block diagram illustrates a centralized architecture with ESP-32 microcontroller and embedded software forming the system's intelligent core for processing and decision-making. Input sensors positioned on the left include DHT11 for ambient temperature and humidity measurement, soil moisture sensor for monitoring nutrient solution levels, automatic/manual mode selector for operational flexibility, and CO2 sensor for atmospheric quality assessment. Solar panels mounted at the top provide sustainable power generation, converting sunlight into electrical energy for

system operation and battery charging. Output actuators positioned on the right include an LCD display for real-time parameter visualization, buzzer for audio alerts during threshold violations, cooling fan for temperature and air circulation management, and water pump for automated irrigation and nutrient delivery. The ESP-32 microcontroller continuously reads sensor data, executes control algorithms, and triggers appropriate actuator responses based on predefined thresholds and operational modes. IoT connectivity at the bottom enables cloud integration for remote monitoring, data analytics, and smartphone-based control, creating a comprehensive smart farming ecosystem.

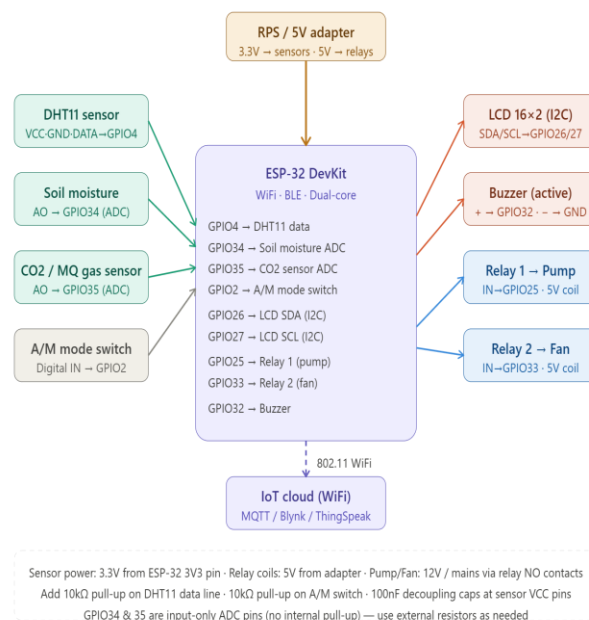
3.3 SYSTEM ARCHITECTURE



3.4 FLOW CHART



3.5 SCHEMATIC DIAGRAM



4. RESULTS

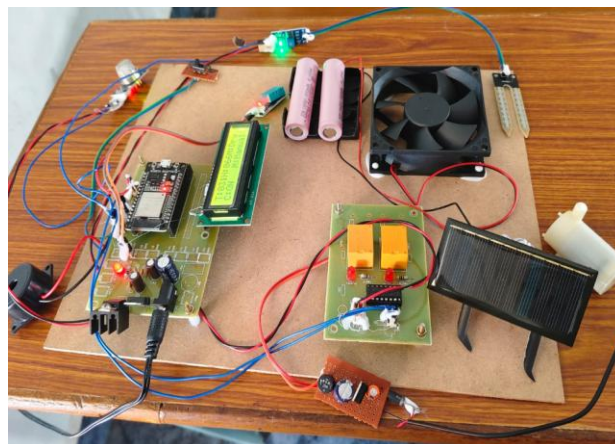


Fig 1: Entire Hardware Implementation of a prototype

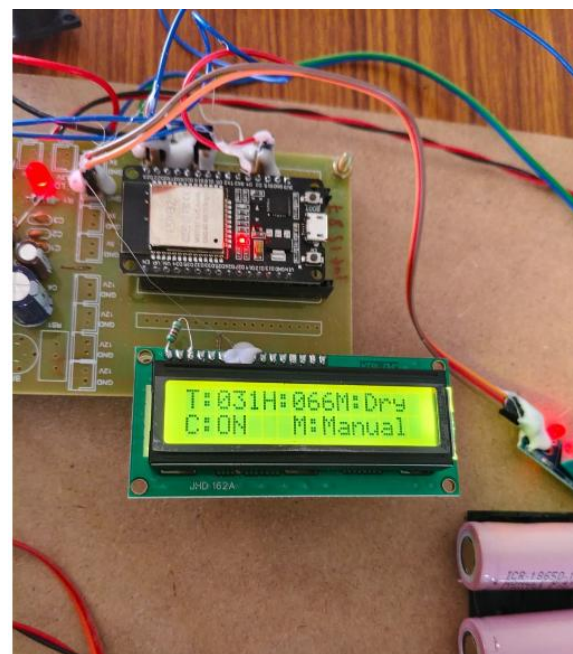


Fig 2 : values Displaying on LCD



Fig 3: Title Displaying on LCD

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

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