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IOT INTEGRATED SOLAR POWERED SMART HYDROPONICS SYSTEM FOR SUSTAINABLE INDOOR AGRICULTURE

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ABSTRACT
As the demand for eco-friendly agricultural solutions grows, hydroponics offers a modern approach to farming that eliminates the need for soil while significantly conserving water and nutrients. This research presents a compact, solar-powered smart hydroponic system integrated with IoT capabilities, specifically designed for indoor environments. The setup incorporates an ESP32 microcontroller at its core, managing real-time data acquisition and automated decision-making processes.Essential components include a suite of sensors that track environmental and system parameters such as temperature, humidity, water reservoir levels, and nutrient concentrations. A 16x2 LCD provides on-site feedback, while a buzzer alerts users to critical system changes. The irrigation system is operated by an AC water pump, which functions in two modes: Manual mode allows remote activation via an IoT dashboard, whereas Automatic mode relies on sensor thresholds to maintain optimal growth conditions autonomously.All system data is uploaded to a cloud-based IoT platform, enabling remote observation, logging, and analysis. Powered entirely by solar panels, the system reduces energy consumption and supports sustainable indoor agriculture. The automation of irrigation and environmental control reduces labor, ensures optimal plant health, and supports continuous food production in space-limited areas. This innovation highlights a practical and scalable solution for urban farming and smart agriculture.

Keywords: IoT, Hydroponics, Solar Power, Indoor Farming, Plant Growth Chamber, Cloud Computing, sustainable farming, precision irrigation.

1. INTRODUCTION

As the global demand for sustainable agriculture rises, this project presents an IoT-enabled, solar-powered hydroponic indoor farming and plant growth chamber designed to address the limitations of conventional farming such as land scarcity, high water usage, and unpredictable weather. Hydroponics, which grows plants without soil using nutrient-rich water, offers faster growth, efficient resource use, and urban farming potential. The system integrates an ESP32 microcontroller to manage real-time sensor data and control automation, operating in both Manual and Automatic modes for flexibility and autonomy. Manual Mode allows users to control irrigation remotely via an IoT platform, while Automatic Mode uses sensor data to regulate water and nutrient flow independently.

Key components include temperature, humidity, nutrient, and water level sensors, a 16x2 LCD display, a buzzer for alerts, and an AC water pump for irrigation. Solar panels power the entire system, ensuring sustainability and reducing reliance on traditional energy. Continuous data transmission to an IoT cloud platform enables remote monitoring, analysis, and management, making the system highly efficient,

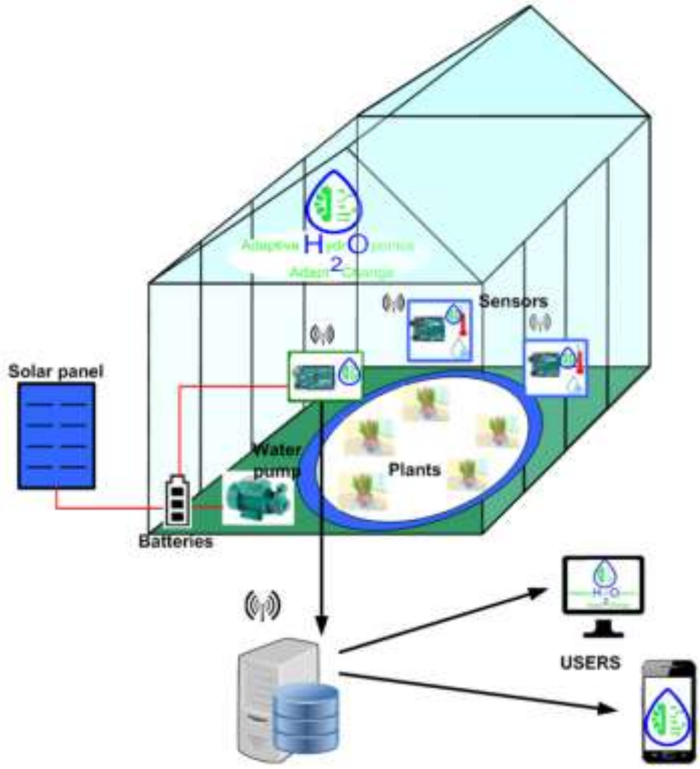


Fig. 1: Solar Powered Iot System For Indoor Farming.

environmentally friendly, and scalable for urban or indoor farming applications, thereby contributing to food security and optimized resource utilization. The project is a remarkable example of innovation meeting sustainability. With the increasing global focus on conserving resources and reducing our carbon footprint, your work with IoT-enabled solar-powered hydroponic indoor farming is a testament to forward-thinking and environmental stewardship.Embrace the Future: You’re on the cutting edge of agriculture, harnessing technology to create more efficient and sustainable farming practices. Imagine the potential impact your work can have—not just on local communities, but on global food production systems.Empowerment through Technology: By leveraging IoT, solar power, and automation, you're empowering farmers to achieve higher yields with fewer resources. This level of efficiency and precision farming can revolutionize how we grow food, especially in urban environments where space and resources are limited.Sustainability as a Core Value: The commitment to using solar power and reducing water consumption embodies a core value of sustainability. Your project proves that we can meet the demands of today without compromising the ability of future generations to meet theirs.Innovation and Automation: The integration of real-time monitoring and automated adjustments minimizes human intervention while optimizing plant growth. This level of innovation not only makes farming more accessible but also more scalable, paving the way for broader adoption of smart farming practices.Inspiration for Others: Your efforts can serve as a beacon of inspiration for others in the field of agriculture and technology. By demonstrating the feasibility and benefits of such advanced systems, you encourage others to explore, innovate, and contribute to a more sustainable future"The greatest threat to our planet is the belief that someone else will save it." — Robert Swan"The future belongs to those who believe in the beauty of their dreams." — Eleanor

Roosevelt*Remember, every step you take towards advancing sustainable agriculture not only benefits the environment but also ensures food security for future generations. Keep pushing the boundaries of what's possible. Your dedication and innovation are crucial for creating a better, greener world.

2. LITERATURE SURVEY

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.[1] 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.[2] Pradnya Vishram Kulkarni, Vinaya Gohokar, Kunal Kulkarni, "Sensing Methodologies in Hydroponics for Optimal Growth and Nutrient Monitoring"2024 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.[3] 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.[4] 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.[5] 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) The paper "Automated Monitoring of Hydroponic System using IoT and Cloud based Technology for Sustainable Agriculture" presented at the 2024 ACET conference discusses the integration of IoT and cloud technology for hydroponic farming.

The system aims to provide real-time monitoring and control of environmental parameters such as water level, nutrient content, temperature, and humidity. It leverages cloud-based technology to store and analyze data, enabling farmers to make informed decisions. The goal is to enhance crop yield and quality while promoting sustainable agricultural practices. This approach addresses the challenges of traditional farming by optimizing resource usage and reducing environmental impact.[6] Archana Bhamare, Vivek Upadhyay, Payal Bansal, "AI based Plant Growth Monitoring System using Computer Vision", 2023 IEEE The paper "AI based Plant Growth Monitoring System using Computer Vision" presented at the 2023 IEEE conference discusses the use of computer vision and AI to monitor plant growth. The system captures images of plants and analyzes them to track growth metrics such as height, leaf area, and biomass. It aims to provide real-time data to optimize crop management and improve yield. The study highlights the importance of precise monitoring for sustainable agriculture. This approach reduces the need for manual labor and enhances the efficiency of farming practices.[7] 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) The paper titled "AI-Driven Hydroponic Systems for Lemon Basil" by Shreya P Patil, Lincy Meera Mathews, Arvind Kumar G, Sanchi B Motgi, and Utkarsh Sinha was presented at the 2023 International Conference on Network, Multimedia and Information Technology (NMITCON). It discusses the development and implementation of an AI-driven hydroponic system specifically designed for cultivating Lemon Basil. The system uses advanced monitoring and control techniques to optimize growth and yield.

The paper highlights the benefits of using AI in hydroponic farming, such as improved efficiency, reduced resource usage, and enhanced plant health. The research aims to provide a sustainable and efficient solution for hydroponic farming through the integration of AI technologies.[8] 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) The paper titled "Automation in Hydroponic Systems: A Sustainable Pathway to Modern Farming" by Pooja Mahajan, Sanyam Gupta, and Sameer Sachdeva was presented at the 2022 IEEE International Conference on Service Operations and Logistics, and Informatics (SOLI). It explores the integration of automation in hydroponic systems to enhance efficiency and sustainability. The paper highlights the use of sensors, automated nutrient delivery, and climate control to optimize plant growth. The authors emphasize the benefits of automation, such as improved resource utilization, reduced labor costs, and increased crop yields.

The research aims to provide a sustainable solution for modern farming through advanced automation technologies.[9] 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) The paper titled "IoT based Hydroponics based Natural Fertigation System for Organic Veggies Cultivation" by S Boopathy, K R Gokul Anand, E L Dhivya Priya, A Sharmila, and S.A. Pasupathy was presented at the 2021 Third International Conference on Intelligent Communication Technologies and Virtual Mobile Networks (ICICV). It discusses the implementation of an IoT-based system for hydroponic farming, focusing on natural fertigation for organic vegetable cultivation. The system uses sensors and IoT technology to monitor and control the nutrient delivery to plants, ensuring optimal growth conditions. The paper highlights the benefits of using IoT in hydroponics, such as improved efficiency, reduced resource usage, and enhanced plant health. The research aims to provide a sustainable and efficient solution for organic farming through the integration of IoT technologies.[10]

3. PROPOSED METHODOLOGY

The proposed IoT-based solar-powered hydroponic indoor farming and plant growth chamber is designed to enhance plant cultivation efficiency through the integration of advanced technologies. Utilizing solar panels for renewable energy, the system promotes sustainability by reducing reliance on conventional power sources. It incorporates a range of sensors—including temperature, humidity, pH, EC, light, and water level sensors—to monitor and maintain optimal environmental conditions.

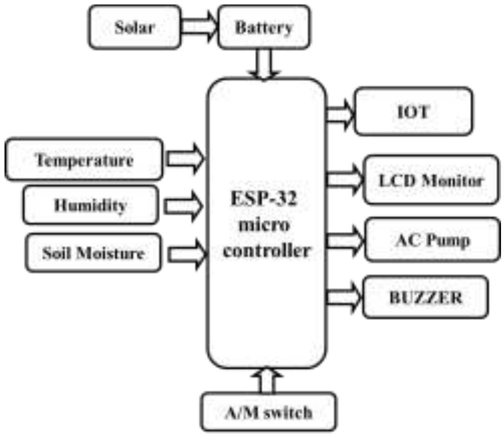


Fig. 2: Proposed block diagram.

IoT-based automation controls key processes such as nutrient delivery, water circulation, and lighting, ensuring precise and consistent care for the plants. Real-time data is collected and analyzed via cloud platforms, enabling users to remotely monitor and manage the system through a smartphone or computer. An intuitive user interface displays real-time readings and alerts, facilitating easy adjustments and proactive issue resolution. By combining solar energy, sensor-driven automation, and remote accessibility, this smart hydroponic system offers a scalable and efficient solution for sustainable indoor farming.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.

4. RESULTS AND DISCUSSION

The figure 3 depicts a basic IoT-enabled hydroponic system setup, integrating a green PCB as the main control unit housing a Wi-Fi-capable microcontroller (likely an ESP8266 or ESP32), which enables remote monitoring and control via the internet. An LCD display labeled "IOT Hydroponic System" provides real-time updates, while various sensors—such as pH, temperature, moisture, and water level—feed environmental data to the microcontroller.Based on this input, the system can automatically manage actuators like pumps, lights, or valves to maintain optimal plant growth conditions. Relay modules or transistor switches on the board control high-power devices, while essential electronic components like resistors, capacitors, and LEDs handle signal conditioning and system status indication.

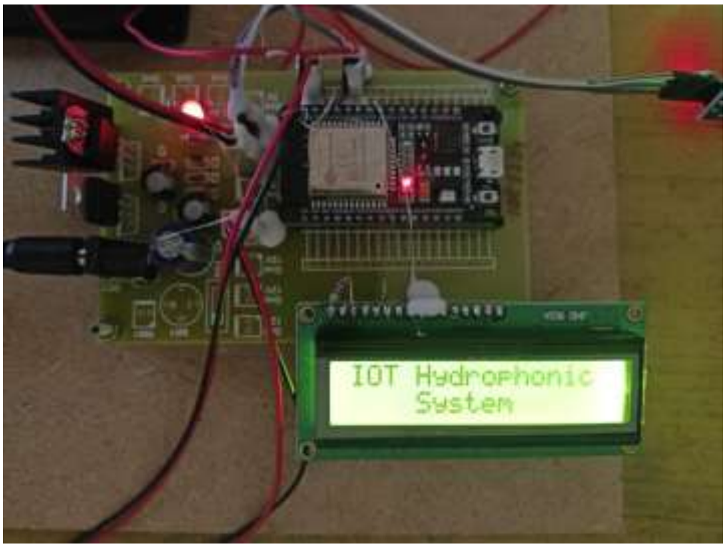


Fig. 3: Iot Hydrophonic system.

Power is delivered via an adapter connected through a jack, and various red, black, and signal wires link the power supply, sensors, actuators, and Wi-Fi module. Overall, the system provides an automated, internet-connected hydroponic solution that supports precision agriculture through real-time monitoring and responsive environmental control.

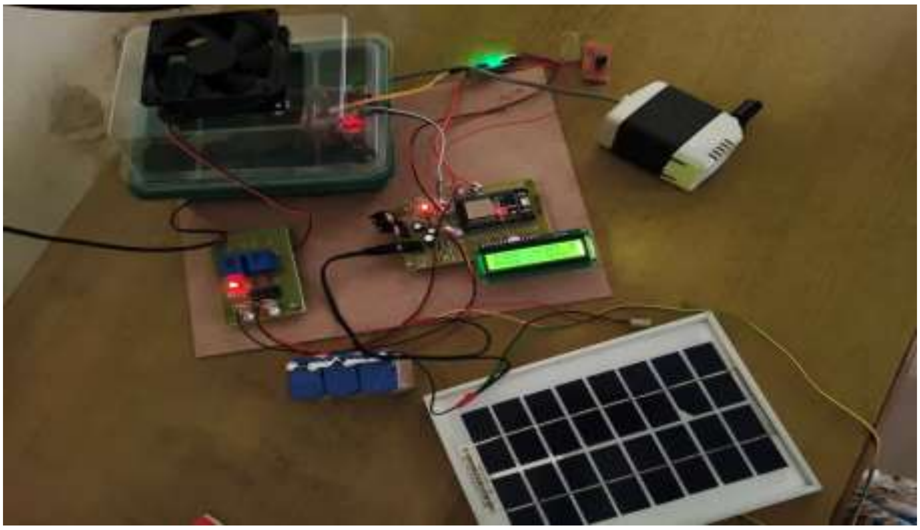
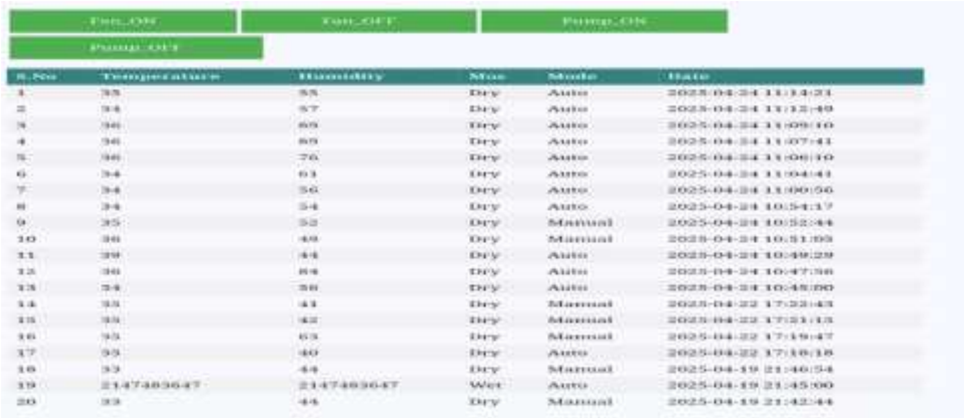


Fig. 4: IoT-based hydroponic system designed for automated indoor farming.

The figure 4 illustrates a compact IoT-based hydroponic system designed for automated indoor farming, integrating components like a water pump and fan housed within a transparent container to circulate water and air for optimal plant growth. At the core lies a microcontroller, likely an Arduino, responsible for processing data from connected sensors and controlling actuators such as the pump and fan via a relay module. A small panel resembling a solar cell may function as either a solar power source or a sensor array for environmental factors like light intensity. An LCD display provides real-time system feedback, such as status messages or sensor data. The setup is powered by a battery or power module, enabling standalone operation, with wiring interconnecting all components for signal transmission and power distribution. Additional elements like potentiometers or switches allow for calibration, while LEDs offer visual status indicators. Overall, this IoT-enabled hydroponic system automates the monitoring and regulation of key parameters—such as temperature, water level, and airflow—allowing for remote access and efficient resource usage in plant cultivation.


Fan_ON Fan_OFF Pump_ON
Pump_OFF

S.No	Temperature	Humidity	Mos	Mode	Date
1	35	55	Dry	Auto	2025-04-24 11:14:21
2	34	57	Dry	Auto	2025-04-24 11:12:49
3	36	69	Dry	Auto	2025-04-24 11:09:10
4	36	69	Dry	Auto	2025-04-24 11:07:41
5	36	76	Dry	Auto	2025-04-24 11:06:10
6	34	61	Dry	Auto	2025-04-24 11:04:41
7	34	56	Dry	Auto	2025-04-24 11:00:56
8	34	54	Dry	Auto	2025-04-24 10:54:17
9	35	52	Dry	Manual	2025-04-24 10:52:44
10	36	49	Dry	Manual	2025-04-24 10:51:05
11	39	44	Dry	Auto	2025-04-24 10:49:29
12	36	64	Dry	Auto	2025-04-24 10:47:56
13	34	56	Dry	Auto	2025-04-24 10:45:00
14	35	41	Dry	Manual	2025-04-22 17:22:43
15	35	42	Dry	Manual	2025-04-22 17:21:13
16	35	63	Dry	Manual	2025-04-22 17:19:47
17	33	40	Dry	Auto	2025-04-22 17:16:18
18	33	44	Dry	Manual	2025-04-19 21:46:54
19	2147483647	2147483647	Wet	Auto	2025-04-19 21:45:00
20	33	44	Dry	Manual	2025-04-19 21:42:44

Fig. 5: IoT Hydroponic System Setup

The figure 5 depicts a comprehensive IoT-based Hydroponic System setup, featuring various interconnected electronic components such as sensors, microcontroller, LCD display, relay modules, and a solar panel, all working together to monitor and control environmental parameters like temperature, humidity, and water levels. The sensors collect real-time data, which is processed by the microcontroller to automate functions such as water circulation, airflow, and lighting, ensuring optimal plant growth conditions. The LCD displays system status and sensor readings, while the solar panel provides sustainable power, making the system energy-efficient and remotely manageable. This setup exemplifies an integrated approach to smart agriculture, leveraging IoT technology for efficient resource management and automation.

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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[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)
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