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HYDROPONIC SOLUTION FOR SOILLESS AGRICULTURE WITH ADVANCED TECHNIQUES AND SMART PERSPECTIVES

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ABSTRACT
Hydroponics is quickly becoming a preferred method of growing food, especially in places where traditional farming faces serious limitations. As cities expand and climate conditions worsen, the availability of fertile land and clean water is steadily decreasing. In response to these challenges, hydroponics offers a way to cultivate crops without soil, using nutrient-rich water instead. However, keeping track of all the environmental factors needed for plant growth can be time-consuming and difficult to manage manually. This paper discusses the hardware development and the experimental setup for automation of hydroponics using IOT technologies. This project introduces a smart hydroponic system that uses Internet of Things (IoT) technology to monitor and control important parameters like pH, temperature, humidity, and light. By connecting various sensors to a central controller, the system can adjust growing conditions automatically and share live data with users through a mobile app or website. The goal is to create a reliable and low-maintenance solution that makes urban farming more accessible, sustainable, and productive.
Keywords: Hydroponic, Soilless, Land, Cultivable, IOT, Arduino, pH, Temperature, Humidity, Automation etc.

I. Introduction
The world is facing a growing challenge when it comes to food production. As global population numbers climb and urban areas continue to expand, the demand for fresh, locally grown food is rising sharply. At the same time, the amount of cultivable land available for traditional farming is shrinking, making it harder to meet this growing need through conventional agricultural methods alone. Climate change, erratic weather patterns, soil degradation, and increasing water scarcity are adding even more pressure to already strained food systems.
In response to these concerns, new and innovative approaches to agriculture are gaining attention. Among them, hydroponics has emerged as a highly promising method for growing crops without soil. Instead of relying on fertile ground, hydroponic systems use water enriched with nutrients to feed plants directly. This allows crops to grow faster and in more controlled conditions, without many of the problems that plague soil-based farming such as pests, diseases, and poor drainage. Because hydroponics is not limited by location or weather, it can be used in urban areas, deserts, and even indoors, making it a flexible option for sustainable food production.
However, managing a hydroponic setup still requires close attention to detail. Factors like water temperature, pH levels, nutrient balance, humidity, and light all play a role in plant health and productivity. In larger or commercial-scale systems, constant manual monitoring becomes time-consuming and labor-intensive, and even small oversights can lead to reduced yields or plant loss.
This is where technology can make a real difference. The integration of Internet of Things (IoT) solutions into hydroponic systems offers a way to automate and streamline the entire growing process. By using sensors to monitor environmental and nutrient conditions in real-time, and microcontrollers to respond to changes automatically, an IoT-enabled system can keep everything

running smoothly with minimal human intervention. Data collected from these sensors can be sent to cloud platforms, where it can be viewed on mobile apps or web dashboards, allowing users to check on their system anytime, from anywhere.
In this paper, we present the design and development of a smart hydroponic system that utilizes IoT to improve efficiency and reduce the need for manual labor. Our project includes a combination of hardware such as pH, temperature, humidity, and light sensors and software, including mobile and web-based interfaces for real-time monitoring and control. The system is built on a low-cost microcontroller platform (Arduino Mega and ESP32) and uses cloud-based communication to enable remote access and automation.
By developing and testing this system, we aim to show how technology can play a key role in making hydroponic farming more accessible, sustainable, and productive especially in areas where traditional agriculture is no longer practical. This approach not only addresses the immediate need for efficient food production but also contributes to long-term goals of environmental sustainability, resource conservation, and smart urban living.

II. CURRENT WORK:

Hydroponic farming has gained significant attention in recent years as a solution to the mounting challenges of conventional agriculture, including diminishing arable land, climate variability, and unsustainable resource usage. A wide range of studies have explored both the technical and socio-economic dimensions of hydroponic systems, particularly in the context of integrating automation and smart technologies.
Sharma et al. (2018) examined the increasing relevance of hydroponic cultivation in regions constrained by poor soil quality and limited land availability. Their work emphasized the system's potential to support fast-growing crops like leafy vegetables throughout the year, even within confined urban environments. They further advocated for the development of low-cost, user-friendly, and automated hydroponic systems to improve accessibility for small and medium-scale Indian farmers, particularly in low-income communities where agricultural labor is scarce or expensive.
Molin and Martin (2019) compared vertical hydroponic farming with traditional agricultural systems in the context of urban climates, especially in northern European regions. Their findings highlighted the resilience of vertical farms to environmental conditions and seasonal fluctuations. While energy consumption remains a concern due to artificial lighting and climate control systems, the overall reduction in water usage, land footprint, and pesticide dependency marks these systems as environmentally and socially promising, especially for urban employment and food security.
Nguyen et al. (2017) presented a lab-oriented hydroponic system used in both academic and commercial settings, specifically targeting research in plant mineral nutrition. Their methodology detailed a cost-effective approach to nutrient solution control, enabling precise studies on plant responses to essential and toxic mineral elements. This work demonstrated hydroponics as a flexible and scalable model, useful for both basic scientific research and practical agricultural innovation.
Sambo et al. (2019) explored the potential of hydroponics within smart agriculture frameworks, emphasizing its value in regions affected by soil degradation, salinization, and water scarcity. Their review focused on techniques for optimizing nutrient uptake such as adjusting electrical conductivity and nitrate levels in nutrient solutions and underscored the environmental benefits of hydroponics, particularly its ability to reduce chemical inputs and waste.
In a continuation of this line of inquiry, Sambo et al. (2020) expanded their analysis to include the integration of intelligent sensors and feedback systems into hydroponic setups. They highlighted the role of real-time monitoring and automated control mechanisms in improving plant health and resource efficiency. Their work confirmed that properly managed hydroponic systems could meet both productivity and sustainability objectives, particularly in the face of climate-related agricultural disruptions.

Daryadar et al. (2016) contributed to the field by demonstrating hydroponics' suitability for medicinal and aromatic crops, specifically peppermint. Their study emphasized the advantages of hydroponic systems in maintaining a clean growing environment with minimal pesticide use, alongside improved nutrient absorption and accelerated plant growth. The research highlighted hydroponics as a promising method not only for food crops but also for high-value specialty plants within eco-friendly farming models.

Collectively, these studies present a compelling case for the adoption of hydroponic systems in both research and commercial agriculture. Across diverse environments from controlled laboratory settings to urban rooftops hydroponics has demonstrated its adaptability, efficiency, and compatibility with digital agriculture technologies. As environmental pressures continue to challenge conventional farming, hydroponics, especially when enhanced through IoT and automation, offers a scalable path toward resilient, sustainable, and localized food production.

III. METHODOLOGY:

To build a reliable and efficient hydroponic automation system, the development process was organized into a set of carefully planned stages. Each phase was designed to build on the last, ensuring the work progressed logically while minimizing the chance of errors. The following is an overview of the steps taken during the project:

3.1 Initial Research and Component Selection

The process began with a detailed review of existing literature and technologies related to hydroponics and smart agriculture. This helped identify gaps in current solutions and offered insight into the best practices. At the same time, a thorough market survey was conducted to choose the most appropriate sensors, control hardware, and platforms for our intended design.

3.2 IoT Protocol Design

Next, a custom communication protocol was developed to ensure smooth data flow between the hydroponic system and the cloud interface. The aim was to enable real-time monitoring and reliable control through both mobile and web-based applications.

3.3 pH Monitoring Integration

Maintaining the correct pH level is essential for healthy plant growth. A pH sensor was incorporated to track acidity levels in the nutrient solution. The system uses this data to decide when to adjust nutrient levels, keeping the growing environment within ideal parameters.

3.4 Temperature and Humidity Control

Using a DHT11 sensor, the system continuously records temperature and humidity inside the growing area. When these values stray beyond set limits, automatic mechanisms like fans or humidifiers are activated to maintain a stable environment.

3.5 Central Data Collection and Cloud Sync

All the sensor data pH, temperature, humidity, and light is sent to a main controller, which compiles the information and uploads it to a cloud dashboard. This gives users the ability to track system performance from a smartphone or computer, anytime and anywhere.

3.6 Implementation of Automation Logic

Smart algorithms were developed to analyze incoming sensor data and make real-time decisions, such as activating lights, adjusting nutrient flow, or regulating temperature all without manual input. These routines form the intelligence behind the system's automated behavior.

3.7 System Hardware Planning

This stage involved designing the physical layout of the system, including circuit diagrams and the arrangement of components. The goal was to create a practical and expandable hardware setup, ready for final board development.

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3.8 PCB Fabrication and Assembly

After finalizing the design, a custom PCB (Printed Circuit Board) was produced. The electronic parts including microcontrollers, relays, and sensors were then soldered and mounted. Basic functionality tests were carried out to confirm correct operation before software was installed.

3.9 Front-End and Software Interface Development

While the hardware was being assembled, the user interface was built using web technologies and mobile app development tools. These interfaces were designed to display real-time data in a clean, user-friendly layout, making it easy for growers to monitor and control the system.

2.10 Mobile App Integration

A dedicated mobile app was created to extend system access on the go. This app connects directly with the backend cloud system, allowing users to view sensor readings and toggle key components like pumps or lights from their smartphones.

3.11 System Programming and Integration

With both hardware and software in place, the system was programmed to bring everything together. The code handled data collection, automated decision-making, and the exchange of information between devices and the cloud.

3.12 Testing and Final Optimization

In the last stage, the full setup was tested in a live environment to check its performance and responsiveness. Based on the results, small tweaks were made to improve efficiency, ensure accuracy, and enhance the user experience. These final adjustments helped prepare the system for reliable long-term use.

The proposed architecture Diagram of the system is given below:

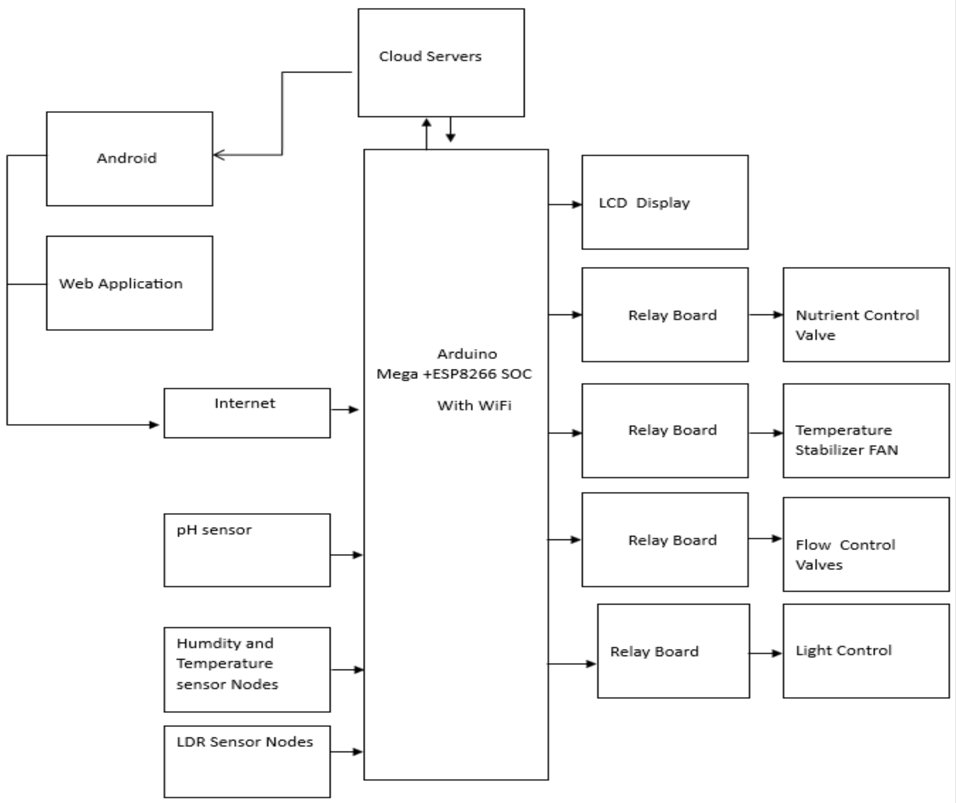

Figure 1: Proposed System Architecture

The block diagram above outlines the core structure of the proposed hydroponic automation system. At its heart, the setup brings together a range of environmental sensors and a central control unit that work in sync to monitor, automate, and fine-tune conditions for growing crops without soil.

The system is essentially made up of two parts:

1. **The smart hydroponic hardware** that directly interacts with the plants, and
2. **The IoT-powered software platform** that lets users check in remotely.

The smart component is responsible for keeping tabs on vital parameters like the pH level of the nutrient solution. If anything falls outside the optimal range, the system can automatically adjust things like nutrient dosing using a control valve to bring conditions back in line for healthy plant growth.

Meanwhile, sensors keep a continuous watch on the environment, measuring light, temperature, and humidity. These readings are constantly processed by the control unit, which adjusts lighting, cooling, or water flow as needed no manual work required. All sensor data is sent online in real time, so farmers or users can track how things are going through a mobile app or website. Whether you're across town or halfway around the world, you can monitor the system and make changes if necessary. This kind of remote access not only saves time but also allows for quicker response to any unexpected changes, making the entire setup more efficient and reliable.

IV. RESULTS AND DISCUSSION:

The proposed hydroponic automation system using IoT was successfully implemented and tested in a controlled environment. The system monitored and regulated key plant growth parameters pH, temperature, humidity, and light intensity with real-time control enabled through cloud and mobile applications. Key outcomes are summarized below:

Parameter	**Optimal Range**	**Measured Range (Test)**	**System Response**
pH Level	5.5 – 6.5	5.4 – 6.7	Adjusted nutrient valve to maintain balanced pH
Temperature (°C)	18°C – 26°C	17.8°C – 26.3°C	Activated fan or heater based on readings
Humidity (%)	50% – 70%	49% – 71%	Triggered fan or humidifier to stabilize environment
Light Intensity (LUX)	Mapped in 0-100%	0-100%	Auto-switched grow light on/off via LDR-based relay

Table 1: Results Obtained

Figure 2: Complete Experimental Setup

The figure 2 above shows the complete experimental setup of the project. The experimental setup designed is for three plants and consists of a hydroponic setup along with tank , pumping unit , automation control panel and power supply.

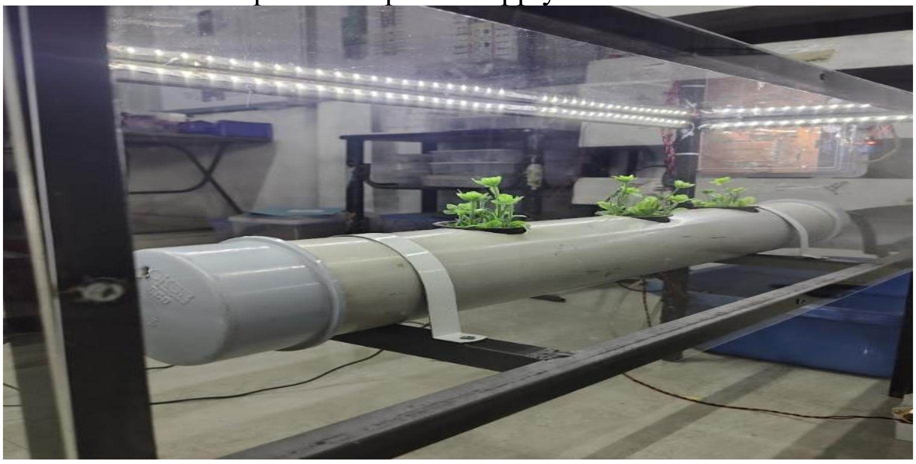

Figure 3: Setups with Plants

The figure 3 below shows the plants in the hydroponic setup we have developed.The Different parameters are read and displayed on the lcd display as well as the IOT cloud panel developed. As shown in figure 4 and figure 5. In addition to we web panel the android app is also developed in the proposed system so that the farmer can remotely monitor and the control the farm from anywhere.

Figure 4: LCD display and readings

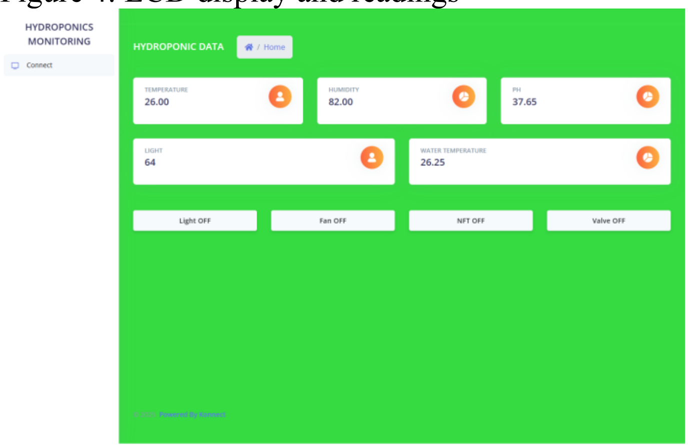

Figure 5: IOT cloud panel developed.

V. CONCLUSION:

This project successfully demonstrates how integrating IoT technology into hydroponic systems can create an efficient, hands-free method of growing plants. By automating key aspects like nutrient delivery, temperature control, and humidity management, the system reduces the need for constant manual oversight. Real-time monitoring through sensor nodes and cloud connectivity allows users to check on their crops and make adjustments from virtually anywhere. This level of control not only simplifies the growing process but also helps maintain ideal conditions for better crop yield and resource efficiency.

Beyond the technical benefits, this approach offers real promise for the future of sustainable agriculture, especially in urban or resource-limited settings. With land becoming scarce and climate unpredictability on the rise, smart hydroponic systems provide a scalable, environmentally friendly alternative to traditional farming. The system we've built lays the foundation for more advanced, accessible farming methods that can be adapted for homes, schools, and commercial operations alike paving the way for a greener, tech-driven approach to feeding the world.

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