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IoT-Based Hydroponic Plant Grow Cabinet

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Abstract: As the strain on food systems increases due to population growth and climate change, sustainable farming practices have become essential. By giving plants nutrient-rich water in regulated conditions, hydroponics provides an effective soilless method. An ESP32 microcontroller-based IoT-based hydroponic plant growing cabinet is presented in this paper. Temperature, humidity, water level, pH, and total dissolved solids (TDS) are among the important parameters that the system tracks. Real-time data transmission to a cloud platform allows for remote control and analysis. The ideal conditions for plant growth are maintained by automated processes like light regulation, nutrient dosing, and water circulation. Significant water savings, low latency, and dependable performance are all displayed by the suggested system. Sustainable urban agriculture is supported by the precise environmental management made possible by the IoT's integration with hydroponics.
Keywords: IoT, Hydroponics, ESP32, Smart Agriculture, Sensor Monitoring, Nutrient Control, Water Management.

I. INTRODUCTION

Contemporary agriculture encounters many challenges such as limited arable land, water limitations, and the seasonal effects of weather. Hydroponics try to alleviate these problems by using a nutrient solution in lieu of soil so you are able to provide the necessary minerals directly to the roots of the plant in a small area. Hydroponics enhance the use of resources, such as lights, water, and nutrients.

The Internet of Things (IoT) also improves hydroponic systems by allowing constant monitoring and management of growing conditions remotely. An IoT system links sensors to microcontrollers and a communication means, allowing for automation of plant care and higher productivity. The ESP32 is a low-cost and high-performance microcontroller with built-in Wi-Fi and Bluetooth capabilities. It has been demonstrated to be useful in agriculture and automation due to its speed and energy savings.

This paper details the design and implementation of a compact Hydroponic Plant Growing Cabinet with IoT capabilities that enables automatic control of temperature, humidity, and nutrient levels. The goal is to provide a consistent growing environment for plants while reducing labor and waste of resources.

II. PROBLEM DEFINITION / NEED OF SYSTEM

Typical soil farming uses a lot of space and water, which makes it impractical in urban situations. Most hydroponic systems on the market allow growers to manually observe temperature, water levels, and nutrient levels, resulting in inconsistencies in plant growth.

An automated, IoT-based hydroponic cabinet can eliminate this problem, and enable precise, real-time monitoring and control of the hydroponic system. This will lead to optimum growth conditions for the plants, and significantly reduce the water and fertilizer that is wasted through inefficient use. The cabinet will allow for sustainable home-based food production. By installing microprocessors with sensors and intelligent control, the performance of the plants can be monitored using mobile or web-enabled technology.

III. SYSTEM COMPONENTS / SPECIFICATIONS

Microcontroller: ESP32 (Dual-core processor, 240 MHz, built-in Wi-Fi/Bluetooth)

A. Sensors

- DHT22 (for measuring temperature and humidity)
- pH sensor (for acidity of nutrient solution)
- TDS sensor (to measure nutrient concentration)
- Ultrasonic sensor (to detect water level)
- LDR (to detect ambient light intensity)

B. Actuators

- Submersible pump (for nutrient delivery)
- Solenoid valve (for controlling water)
- LED grow lights (to help with photosynthesis)
- Cooling fan (for ventilation)

IoT Platform: Blynk or ThingSpeak cloud (for visualizing live data)
Power: 12 V regulated DC power source

IV. METHODOLOGY

1) Data Collection: Sensors on the ESP32 were used to take the environmental measurements internally to the cabinet.
2) Processing: The data the sensors took, will be processed in real-time, and evaluated against threshold parameters and/or limits in the firmware on the controller.
3) Control Action: The actuator will autonomously act based on what is detected. For example, if the temperature is too hot, the exhaust fan will turn on, if the water level is getting low, the pump will bring the tank back up, and if the light is low, the LED lights will be turned on.
4) IoT Integration: The ESP32 will upload the sensor data to the cloud platform through Wi-Fi, and will allow users to monitor and control their cabinet from any smartphone or web dashboard.
5) Feedback and Alerts: The user will receive alerts on abnormal conditions (such as low water level, or high pH) as feedback loop for quick user response time.

This approach builds on the findings of Fadillah et al. [1] demonstrating automous control in real-time with ESP32 and Blynk.

V. LITERATURE SURVEY

Fadillah et al. (2022) developed a hydroponics system using IoT technology with an ESP32 microcontroller and TDS and pH sensors, allowing the system to be showcased in real-time using the Blynk app [1]. The authors state that automatic supervision is capable of maintaining optimum health and consistent plant growth. Similarly, Untoro and Hidayah (2023) created a control system for hydroponic cultivation that also made use of IoT technology, can provide very precise regulation of environmental parameters, with measurement errors below 7% for pH and nutrient concentration [2]. In 2023, the journal MethodsX published a paper developing a smart hydroponic monitoring system using ESP32 interfaced with multiple sensors for TDS, water level and temperature [3]. The authors highlighted that using the IoT platform showed an improvement in both yield and productivity.
Together, these articles demonstrate that making irrigation systems with an ESP32 based IoT easily provides a very sound basis for intelligent agricultural systems and hydroponic cabinet described this paper.

VI. PROPOSED SYSTEM

The Hydroponic Plant Growing Cabinet leverages IoT to collect and manage environmental measurements from within a closed system.

1) Measurement: Sensors all take measurements of temperature, humidity, water level, pH and TDS.
2) Processing: The ESP32 will process the sensor readouts and determine if corrective action is necessary.
3) Actuation: If corrective action is required, the ESP32 will activate a correction device, such as a pump, solenoid valve, fan or lights.
4) IoT-Enabled: Sensor measurements are uploaded to the cloud in real time. A user can view the data via the Blynk or ThingSpeak interface.
5) Alerts: If the conditions change beyond acceptable set tolerance, the mobile application will instigate alerts to the user's mobile phone for constant monitoring without requiring them to be physically present.

This modular design also supports scalability and would allow future expansion to integrate machine learning algorithms.

VII. RESULTS / OUTPUT DISCUSSION

Experiments were conducted utilizing leafy vegetables as the sample crop and the chamber meant to maintain a temperature of 24 - 28 °C, a humidity of 60 - 70%, and a pH level of 6.0 - 6.5. Transmission data was delayed for less than two seconds.
The automated system generated optimal conditions for growth without any human intervention, while plants inside the automated system grew a healthy foliage and as compared to an uncontrolled environment they had faster growth.

The results are in accordance with the metrics used by Untoro and Hidayah [2], and provide an assurance of the reliability of ESP32 for hydroponic automation and monitoring.

VIII. FUTURE SCOPE

1) AI-Driven Prediction: Machine learning can be used to predict nutrient needs and determine stress indications at an early state.
2) Renewable Energy Integration: the use of renewable energy sources could help improve sustainability.
3) Use of Computer Vision for Monitoring: By tracking growth with images, harvest estimation could be automated.
4) Mobile App Modification: a dedicated Android/iOS app can be customised to allow for interactive analytics and backup to the cloud.

IX. CONCLUSION

The presented Hydroponic Plant Growing Cabinet enabled with IoT provides a financially responsible and efficient smart farming option. The user can monitor and study the temperature, humidity, water level, and nutrient quality in real time with the ESP32 supporting microcontroller. The experimental results show reasonable plant growth with efficient resource consumption. The integration of IoT with hydroponics is a viable approach to address sustainable farm practices in urban communities and educational research.

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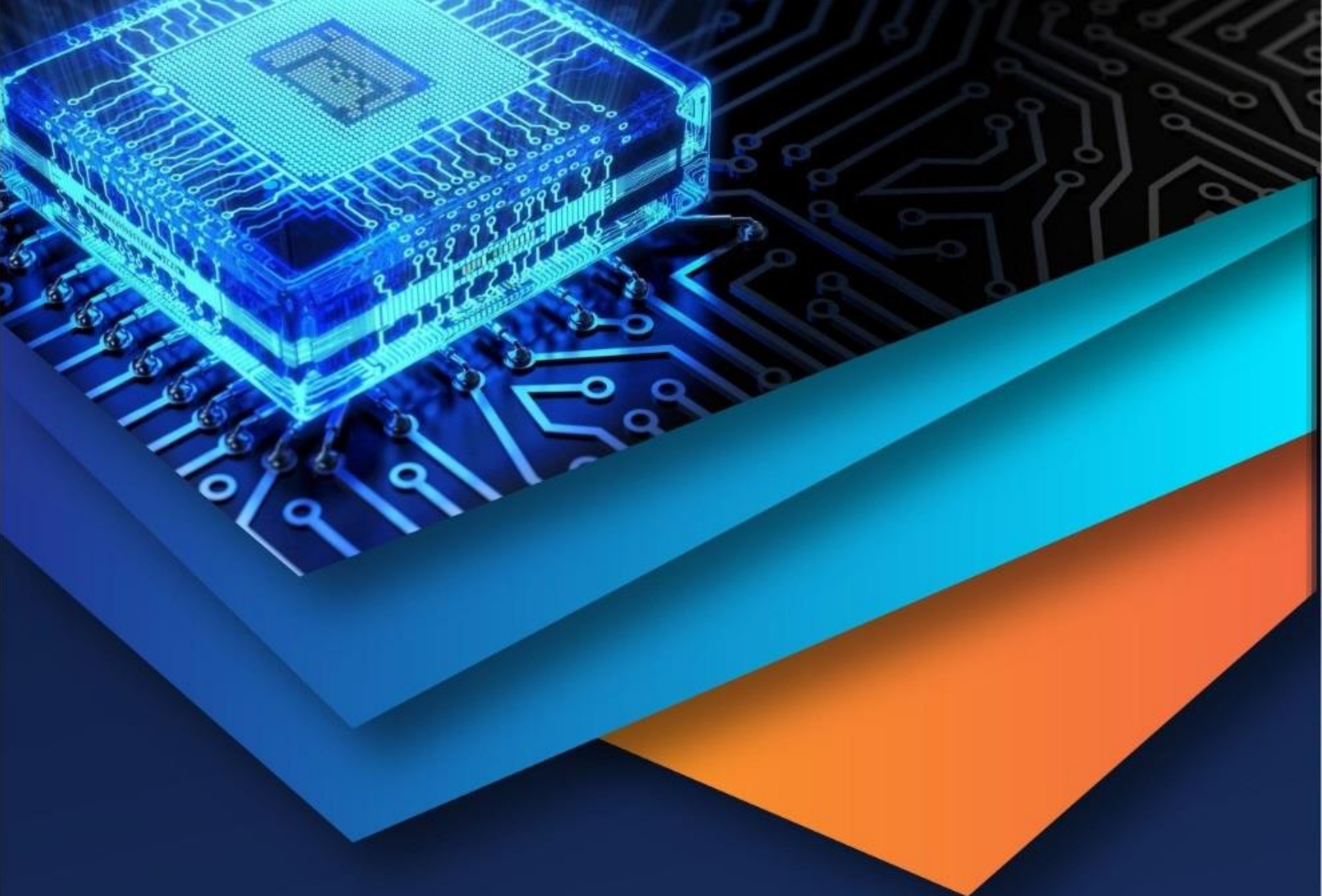

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