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Automated Hydroponic System Based on Mobile Application

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***Abstract*: Hydroponics offers a modern farming solution that eliminates soil usage, enabling water conservation and higher crop productivity. It serves as a more sustainable approach compared to traditional agriculture. Ensuring healthy plant development requires consistent monitoring of nutrient supply, temperature, and solution balance. This paper presents an Automated Hydroponic Nutrient Control System (AHNCS) that utilizes ESP32, sensors, and actuators to observe and manage conditions. Real-time data analysis drives automatic responses, reducing manual effort while improving accuracy, plant health, and overall efficiency.**

***Keywords*: Hydrophonic, plant, real time.**

1. Introduction

Over the past 12,000 years, the world's population has multiplied approximately 1,860 times, introducing serious challenges in the global food supply. Issues such as urban growth, climate shifts, soil exhaustion, and reduced agricultural land have undermined the effectiveness of traditional cultivation. To address increasing food demands, new agricultural strategies are becoming essential. One such approach is hydroponics—a technique that grows plants in nutrient-rich water without soil—offering a sustainable way to conserve resources and enhance productivity. It supports vertical farming, automation, and minimizes human labor.

Smart farming technologies driven by IoT and artificial intelligence allow for continuous tracking and control of plant environments. For hydroponics to be successful, it is important to regulate parameters including pH, electrical conductivity (EC), total dissolved solids (TDS), and the temperature of the water. Monitoring these aspects manually can be both tedious and error-prone.

Automation in hydroponic systems offers a solution, maintaining stable growing conditions and potentially reducing maintenance costs by 23% to 70%.

This paper presents an Automated Hydroponic Nutrient Control System (AHNCS) designed to meet these challenges. The system incorporates sensors, a Raspberry Pi 4 microcontroller, and actuators for smart nutrient and temperature management. With IoT connectivity, it enables cloud-based monitoring and remote access. The goal of this proposed system is to enhance efficiency, improve crop quality.

2. Methodology

A. Design Framework

The core of the Automated Hydroponic Nutrient Control System (AHNCS) is the ESP32 microcontroller, which supervises sensor input readings and controls output to actuators. It utilizes LM35 sensors for temperature, DHT11 for humidity, pH probes, and water level sensors to gather essential data. This information is interpreted by the ESP32 to assess system conditions. When sensor values exceed predefined limits, control signals are sent to devices like water pumps, buzzers, and cooling fans. Relays facilitate switching these devices as needed. This setup offers automated responsiveness to environmental shifts, promoting consistent and efficient hydroponic system performance.

B. Feedback Mechanism

This system features a continuous feedback loop that monitors critical parameters in real time—such as humidity, pH level, temperature, and water availability. For example, when the temperature surpasses the defined limit, a fan is activated automatically. A drop in humidity sets off a buzzer alert. Likewise, water levels trigger the pump, and pH fluctuations cause an LED to signal abnormalities.

C. Data processing and Analysis

The ESP32 microcontroller collects and evaluates sensor data in real time. Outputs from analog sensors, such as LM35 and the water level detector, are first digitized using an ADC before processing. Digital inputs like the DHT11 provide temperature and humidity readings directly. The embedded logic compares each sensor's data to preset thresholds determined by the user. Based on this evaluation, the system decides whether to switch actuators on or off, ensuring that the growing environment consistently remains within ideal parameters.

D. Software Implementation

The ESP32 is programmed using Micro Python, which facilitates communication between the microcontroller and sensors. GPIO functions are employed to manage outputs like fans, water pumps, buzzers, and indicator LEDs. An LCD screen presents real-time readings from all sensors.

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Additionally, the system incorporates cloud capabilities for storing data and enabling remote supervision, thereby improving monitoring and data access. The primary algorithm runs in a continuous loop on the ESP32, reading sensor inputs, making control decisions, and triggering actuators for complete automation.

3. Background and Related Work

Numerous studies have focused on advancing smart agricultural practices and automating hydroponic systems. One such approach featured an Arduino-based setup that utilized pH and EC sensors along with Xbee modules and GBoards to enable wireless operation and real-time environmental monitoring. Another research initiative controlled water flow using flow sensors and servo motors, which ensured precise distribution of nutrient solutions. These implementations reflect the increasing adoption of automation and IoT technologies in modern farming systems. In addition, autonomous robots powered by artificial intelligence have been used to monitor plant growth in hydroponics, increasing accuracy and reducing the reliance on manual effort. Many current systems also integrate cloud platforms to facilitate remote monitoring and management, thereby improving accessibility and data traceability.

As a method that replaces soil with water-based nutrients, hydroponics demands accurate monitoring of environmental and nutrient variables. Studies have consistently indicated that controlling factors such as pH, electrical conductivity, temperature, and water levels plays a vital role in ensuring healthy plant growth and maximizing yield. Common sensors applied include LM35 for temperature, DHT11 for humidity, and various types of pH sensors for evaluating solution quality. These devices, when linked to microcontrollers like Arduino or ESP32, enable automated operations that react to real-time data. Such integrations have established a strong foundation for the current generation of intelligent, sensor-driven agricultural technologies.

With IoT becoming more prevalent, hydroponic setups are becoming increasingly efficient and adaptable. The use of cloud storage, mobile apps, and web dashboards allows growers to access and control their systems remotely. In recent developments, artificial intelligence techniques have been employed to enhance decision-making and diagnostic precision. Deep learning models are being used to identify nutrient imbalances and detect plant health issues using sensor data and image recognition. These innovations help cut labor costs while boosting productivity and crop reliability. The Automated Hydroponic Nutrient Control System (AHNCS) introduced here expands on past work by incorporating ESP32-driven sensor networks, feedback control, LCD status displays, and cloud connectivity. This system is designed to provide accuracy, scalability, and minimal user intervention in hydroponic farming.

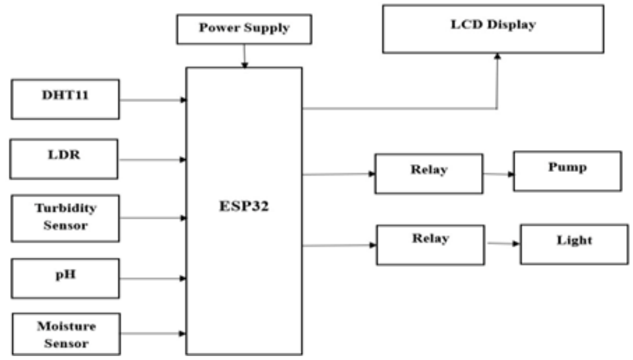

Fig. 1. Block diagram

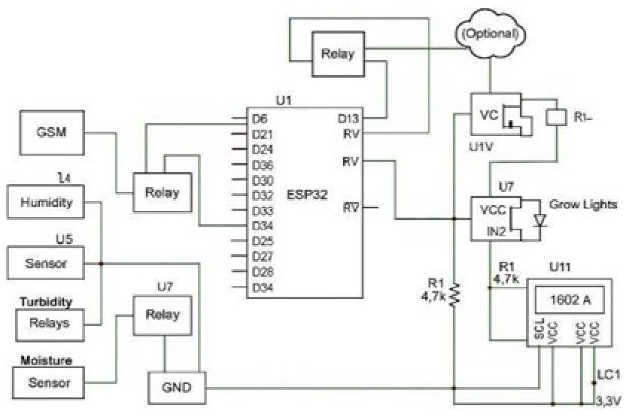

Fig. 2. Block diagram

4. Result and Analysis

A. Sensor Initialization and Control Logic

The system initiates its process by powering all connected sensors. Once activated, each sensor—responsible for temperature, humidity, water level, and pH—transmits values to the LCD display. Actuators and sensors function according to preset thresholds, updating the display with current data. Hydroponics depends on efficient nutrient circulation through water, which the system manages by continuously cycling water to prevent stagnation and nutrient layering.

B. Temperature and Water Level Monitoring

The ESP32 regularly evaluates inputs from all sensors and acts accordingly. For temperature regulation, a limit of 35 °C is established, within the general range of 25–35 °C based on plant needs. If this threshold is crossed, the fan starts automatically. Likewise, if the main reservoir's water level drops below 300 units, the motor is switched on to refill it using water from the secondary container.

C. pH and Nutrient Regulation

To ensure optimal nutrient absorption, the solution's pH must remain between 6 and 8. A dedicated sensor constantly checks the pH and shows readings on the LCD panel. If the value strays from the acceptable range, the system issues an alert. This feature helps minimize human involvement while maintaining consistent plant care, even during the absence of the cultivator or system operator.

D. Dual-Tank Water Management

This hydroponic system consists of two separate water tanks. Plant roots are immersed in a solution enriched with nutrients. A water level sensor is embedded in the primary tank to track levels. If the level drops, water is transferred automatically from the secondary unit. This ensures a continuous supply of nutrients, allowing the system to support plant growth for extended durations without user intervention.

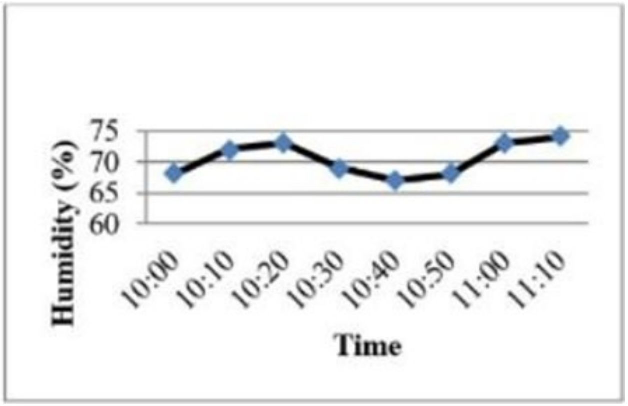

Fig. 3. Sensor data of humidity with time

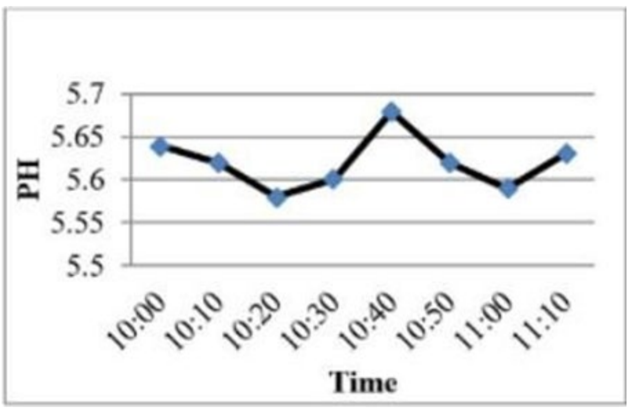

Fig. 4. Sensor data of pH with time

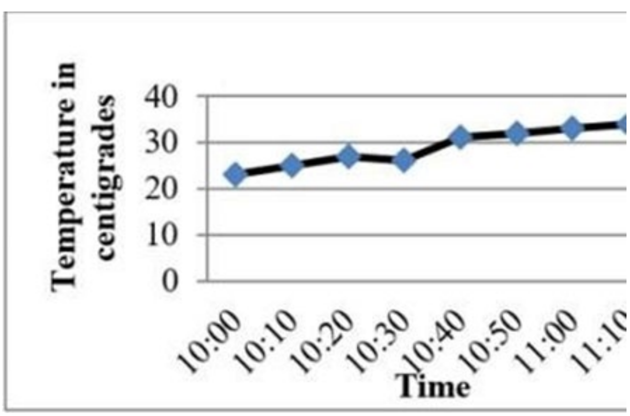

Fig. 5. Sensor data of temperature

E. Humidity Management

Humidity levels fluctuate based on plant transpiration and surrounding environmental variables. In this system, humidity is maintained in the optimal range of 50% to 80%, typically varying between 67% and 74%. Whenever values drop below or rise above this band, a buzzer or fan responds. This keeps atmospheric conditions consistent and promotes a healthy growing environment for hydroponic cultivation with time.

F. Comparative System Performance

The performance of the proposed Automated Hydroponic Nutrient Control System (AHNCS) is evaluated against a Conventional Hydroponic Nutrient Control System (CHNCS). Key metrics include accuracy, delay, and efficiency. Graphs show that AHNCS consistently outperforms CHNCS in all aspects.

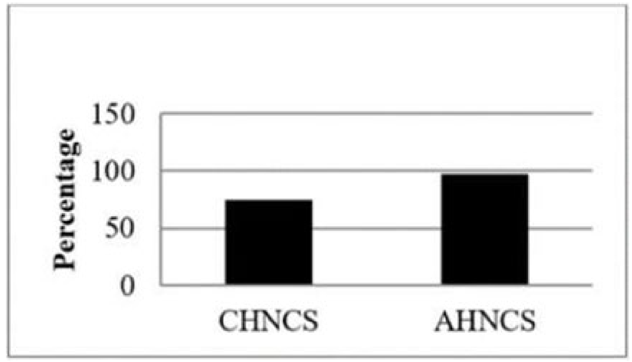

Fig. 6. Accuracy analysis

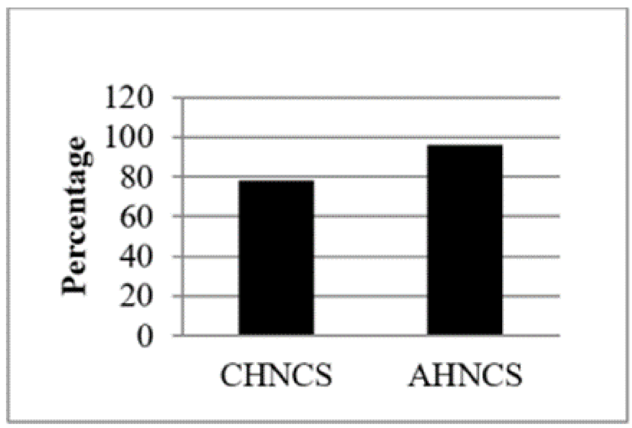

Fig. 7. Efficiency analysis

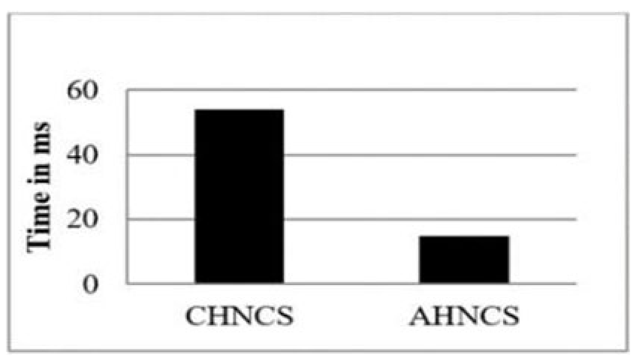

Fig. 8. Delay analysis

5. Conclusion

This project effectively demonstrates the development and implementation of an Automated Hydroponic Nutrient Control System designed for smart agriculture using IoT and sensor-based technologies. The integration of sensors such as temperature, humidity, pH, and water level, along with actuators controlled by a Raspberry Pi, enables real-time monitoring and management of the hydroponic environment.

The system maintains optimal growing conditions by automatically activating devices such as cooling fans, water pumps, and buzzers based on threshold values predefined for each parameter. These thresholds ensure that plants receive the appropriate amount of nutrients, temperature control, and moisture levels for healthy and consistent growth.

With a user-friendly LCD display, the system allows real-time visualization of environmental parameters, reducing the need for manual supervision. The dual-tank mechanism ensures continuous water supply, enhancing system reliability even during extended periods of absence.

Performance analysis using metrics such as accuracy, delay, and efficiency confirms that the Automated Hydroponic Nutrient Control System (AHNCS) outperforms conventional systems (CHNCS). The results indicate higher precision, faster response times, and greater energy efficiency, all contributing to improved agricultural productivity.

Furthermore, environmental data trends for humidity, pH, and temperature across time validate the system's ability to operate within optimal ranges, ensuring a stable and controlled hydroponic environment.

This project sets a solid foundation for scalable, remote, and intelligent farming solutions. Future enhancements can include integration with mobile applications, machine learning for adaptive nutrient control, and solar-powered energy systems for increased sustainability.

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