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Integrating smart technologies for sustainable crop management in hydroponics

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ABSTRACT

Hydroponics has become a game-changing technique in agriculture's constantly changing terrain, upending traditional soil-based farming. The smart hydroponics management system, a cutting-edge method intended to maximize plant development and resource use, is presented in this study. The approach aims to push the limits of conventional farming, drawing inspiration from sustainable horticultural concepts as well as the principles described in Howard M. Resh's book on hydroponic production. This abstract integrates cutting-edge sensor technology and automation methodologies to capture the core of the smart hydroponics management system. It presents the system as a complete answer to the problems facing modern agriculture, rather than just a technique of cultivation. By drawing comparisons with seminal works in computer vision, the unique character of the system is highlighted, demonstrating a dedication to advanced and flexible agricultural techniques.

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1. INTRODUCTION

Hydroponics has become a game-changing technique in agriculture's constantly changing terrain, upending traditional soil-based farming. The Smart Hydroponics Management System, a cutting-edge method intended to maximize plant development and resource use [1]. The approach aims to push the limits of conventional farming, drawing inspiration from sustainable horticultural concepts as well as the principles described in Howard M. Resh's book on hydroponic production. This abstract integrates cutting-edge sensor technology and automation methodologies to capture the core of the Smart Hydroponics Management System. It presents the system as a complete answer to the problems facing modern agriculture, rather than just a technique of cultivation. By drawing comparisons with seminal works in computer vision, the unique character of the system is highlighted, demonstrating a dedication to advanced and flexible agricultural techniques. Hydroponics: potential for augmenting sustainable food production in non-arable regions" by Treftz and Omaye [2]. "A review on plant without soil - Hydroponics" edited by Sardare and Admane [3]. "Impact of hydroponic nutrient management on crop quality and yield" by Jones *et al.* [4].

2. RESEARCH METHOD

2.1. Using sensors in hydroponics

Hydroponic systems rely on precise control of environmental factors to maximize plant growth [5]. The smart hydroponics management system enhances this control by using an advanced network of sensors that provide real-time data on key factors. This real-time monitoring increases the flexibility and efficiency of hydroponic farming, leading to better overall results [6]. The system is designed to support medium-scale hydroponic setups, capable of managing up to 100 plants simultaneously, with a water reservoir capacity of 50 litres and a nutrient reservoir of 10 litres.

2.1.1. Using sensors in hydroponics

The nutrition management system's essential component is the total dissolved solids (TDS) sensor. This sensor provides unmatched precision in determining nutrient levels by using cutting-edge technology to monitor the concentration of dissolved compounds in the water stream [7]. The technology guarantees that plants receive the right combination of nutrients through consistent calibration and a predetermined threshold. The sensor initiates automatic responses when TDS levels go below this threshold, signifying a nutritional deficit. This involves turning on a DC pump to provide nutritional solutions, effectively and quickly treating the shortfall. Incorporating the TDS sensor reduces the possibility of overfeeding, which is a typical issue in hydroponic systems, in addition to preventing under-fertilization [8]. The system supports nutrient delivery for up to 100 plants, ensuring efficient and consistent feeding even under heavy load conditions.

2.1.2. Humidity and temperature sensors

Plant development is greatly influenced by environmental parameters, and hydroponic systems need exact control over elements like humidity and temperature [9]. These factors are continually monitored by dedicated sensors, which provide the system with real-time data it needs to make choices. The hydroponic environment's ambient temperature is measured by the temperature sensor [10]. This data is essential for modifying the environment to within the optimal range for plant development. Corrective measures, including limiting the operation of environmental control systems or reducing the intensity of artificial lighting, can be implemented by the system [11]. The system is capable of maintaining stable temperatures for setups operating over a 20 square meter area, demonstrating its scalability and effectiveness. Conversely, humidity sensors keep an eye on the amount of moisture in the air. This information is essential for controlling transpiration rates in plants and preventing problems like the growth of mildew [12]. The device lowers the danger of illnesses linked to excessive wetness and promotes overall plant health by guaranteeing that humidity levels remain within the intended range [13]. In larger setups, these sensors allow centralized control, making the system well-suited for greenhouse or urban farming applications.

2.1.3. pH sensors

In hydroponic systems, pH levels significantly impact plant nutrient uptake, alongside TDS [14]. To effectively monitor and adjust the pH of the nutrient solution, the inclusion of pH sensors is crucial. By maintaining an optimal pH range, the system ensures that essential nutrients remain in a form that plants can easily absorb, thereby enhancing nutrient absorption efficiency [15]. The system is designed to maintain pH levels within a range of 5.5 to 6.5, ideal for most hydroponic crops.

2.2. Techniques for automation

2.2.1. NodeMCU microcontroller

The Smart Hydroponics Management System is powered by the NodeMCU microcontroller. This sophisticated gadget controls the whole automation process by communicating with a variety of sensors and actuators. Its programming logic is fine-tuned to handle input from various sensors in real time, resulting in quick and precise reactions to changing environmental circumstances. For example, the NodeMCU continually monitors TDS sensor data and immediately initiates remedial measures when nutrient levels fall below specified thresholds. It also analyses data from temperature and humidity sensors to ensure that the air conditions are appropriate for plant development [16]. The NodeMCU's adaptability allows the system to adjust dynamically to fluctuations in weather patterns, diurnal cycles, and seasonal shifts, resulting in constant and resilient performance [17].

2.2.2. Control of DC pump

The NodeMCU is programmed to carry out instructions that regulate the DC pump in addition to interpreting data from sensors. The pump is turned on by the microcontroller to supply the hydroponic system with the nutrients it needs when the levels of nutrients are too low. This automation lowers the need for human involvement, lowers the possibility of human mistake, and guarantees a steady delivery of nutrients that are essential for plant growth [18]. In addition to monitoring the pump's state, the Node MCU communicates with the DC pump to activate it. The Arduino can start remedial action or create maintenance alerts if abnormalities or faults (such a blockage or erratic flow) are found [19].

3. RESULTS AND DISCUSSION
3.1. Block diagram
Figure 1 shows the block diagram of a system that uses an ESP8266 microcontroller with WiFi to monitor and control environmental parameters. A DHT-11 sensor provides digital data for temperature and humidity, while a TDS sensor gives analog data for water purity. The microcontroller processes this data, controls a pump, displays information on an LCD, and sends data to a mobile phone using the Blynk app for remote monitoring and control [20].

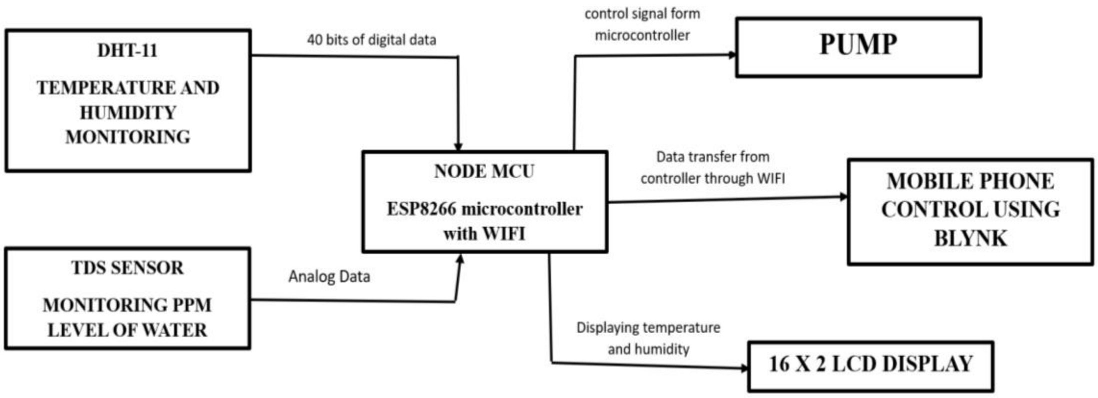

Figure 1. Block diagram

3.2. Median filtering algorithm
The median filter is a frequently used noise reduction technique in digital signal processing and image processing, and this algorithm is a straightforward implementation of it. Let's dissect the algorithm in detail:

a) Function Definition: The function getMedianNum accepts two inputs: an integer iFilterLen, which represents the length of the filter (often an odd number), and an array of numbers, bArray[].
b) Copying Array: The first iFilterLen items of bArray[] are copied into a new local array called bTab[], which has a length of iFilterLen.
c) Sorting: Next, the program uses a straightforward bubble sort technique to arrange the elements of bTab[] in ascending order. The components of bTab[] are bubble sorted by this nested loop structure until they are put in ascending order [21].

3.2.1. Explanation
– To prevent changing the original array, the technique first copies the input array into a local array. It then uses a straightforward sorting algorithm, such as bubble sort, to sort the copied array.
– Bubble sort is a simple sorting algorithm that performs well in this situation; however, it is not the most efficient for huge arrays.
– Based on the filter's length, the median value is ascertained following sorting. The centre element is the median if the filter length is odd. The median is the average of the two middle parts when the length is even.
– The function then returns the median number as its output.

Overall, this algorithm calculates the median value of a window of data represented by the input array bArray[] using the median filter technique, which helps in reducing noise while preserving the important features of the data.

3.3. Formula

$$\boldsymbol{TDS_{Value}} = \left(133.42 * Compensation_{Voltage}{}^{3} - 255.86 * Compensation_{Voltage}{}^{2} + 857.39 * Compensation_{Voltage}\right) * 0.5$$

$$Compensation_{Voltage} = \frac{Average_{Voltage}}{Compensation_{Coefficient}}$$

$$Compensation_{coefficient} = 1.0 + 2.0(temperature - 25.00)$$

3.4. Behaviour of TDS with temperature

Figure 2 shows the graph of variation of TDS in parts per million (PPM) with respect to temperature in degrees Celsius (°C). The black line represents the TDS variation without compensation, which significantly increases with temperature, while the blue line represents the TDS variation with compensation, remaining relatively constant across the temperature range. This indicates that compensation effectively stabilizes TDS measurements despite temperature changes, making it relevant for accurate water quality monitoring [22].

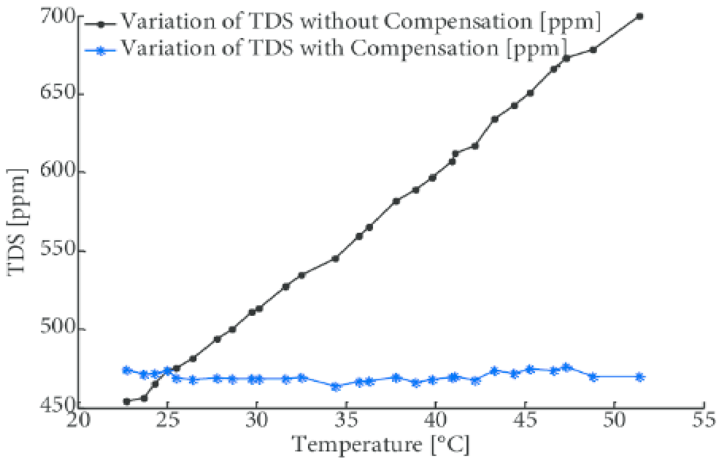

Figure 2. Graph TDS vs temperature

3.5. Behaviour of TDS levels with and without the temperature compensation algorithm without temperature adjustment

- The TDS sensor monitors the solution's conductivity, which is directly impacted by temperature, in the absence of temperature adjustment.
- Most solutions become more conductive as the temperature rises. This means that, even in the case when the actual concentration of dissolved solids is constant, the TDS readings would generally tend to be greater at higher temperatures and lower at lower temperatures in the absence of compensation [23]. Therefore, in the absence of correction, temperature-dependent variations in TDS readings might result in imprecise observations.

With Temperature Compensation

- The goal of the temperature compensation method is to account for how conductivity is affected by temperature.
- To produce a more precise estimate of the TDS level, it modifies the recorded voltage in response to temperature changes. For the particular solution under measurement, the compensation algorithm often employs a formula that accounts for the established link between temperature and conductivity [24].
- This adjustment makes the TDS values less susceptible to temperature variations, leading to results that are more consistent and precise.
- By adjusting the TDS measurements to what they would be at a normal temperature (often 25°C or 77°F), temperature correction creates a more uniform foundation for comparison under various circumstances [25].

3.6. Plants and their TDS levels

Table 1 outlines the PPM ranges for various plants, providing essential information for nutrient management. For example, tomatoes thrive within a PPM range of 1400 to 3500, while broccoli prefers a range of 1960 to 2450 PPM. Similarly, cabbage grows best with nutrient concentrations between 1750 and 2100 PPM. These values reflect the nutrient or substance concentrations necessary for optimal growth in each plant species.

Table 1. Plants and their PPM

PLANT	PPM (parts per million)
Tomato	1400-3500
Broccoli	1960-2450
Cabbage	1750-2100
Cauliflower	1050-1400
Cucumber	1190-1750
Garlic	960-1260
Lemon	600-730
Strawberry	1260-1540

4. CONCLUSION

This project's hydroponics management system effectively automated the hydroponic system's maintenance procedure, saving labour and guaranteeing steady, ideal plant development. The hydroponic system was continuously monitored and maintained by the system through the use of sensors that tracked temperature, humidity, and TDS levels. This assured that the plants were growing in the best possible circumstances and receiving the nutrients they needed. The hydroponics management system may lessen manual labour, increase the effectiveness and dependability of hydroponic systems, and give farmers important information about the hydroponic system's environmental parameters. The technology may be further enhanced to increase its scalability and applicability to other hydroponic systems.

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C : **C**onceptualization
M : **M**ethodology
So : **So**ftware
Va : **Va**lidation
Fo : **Fo**rmal analysis
I : **I**nvestigation
R : **R**esources
D : **D**ata Curation
O : Writing - **O**riginal Draft
E : Writing - Review & **E**diting
Vi : **Vi**sualization
Su : **Su**pervision
P : **P**roject administration
Fu : **Fu**nding acquisition

CONFLICT OF INTEREST STATEMENT

Authors state no conflict of interest.

DATA AVAILABILITY

The data that support the findings of this study are openly available in IOT_Hydroponic Management at https://github.com/Poornavikash7373/IOT_HydroponicsManagement.git, reference number: 1003813.

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