A SMART HYDROPHONICS FARMING USING EXACT INFERENCE IN BAYESIAN NETWORK

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ABSTRACT

Smart agriculture

Smart agriculture plays a vital role in enhancing crop productivity, optimizing water usage, and reducing manual intervention in farming activities. This work presents an IoT-enabled Smart Farm Monitoring and Control System using the ESP8266 microcontroller, ADS1115 high-precision ADC, and multiple environmental sensors. The system continuously measures temperature, humidity, soil moisture, soil TDS level, light intensity, and water level using a combination of DHT22, soil probes, TDS sensors, LDR modules, and float switches. A relay-based automation mechanism controls the pump, fan, and LED lighting based on real-time sensor thresholds, while a buzzer provides high-temperature alerts. Sensor data is processed through a hysteresis-based control algorithm to ensure stable irrigation and lighting decisions. The processed data is uploaded to the Thing Speak cloud platform at timed intervals using REST API calls, enabling remote visualization and analysis. Experimental results show reliable sensor performance, stable ADC readings, and accurate automated actuation of relays under varying environmental conditions. The proposed system demonstrates a low-cost, easily deployable, and scalable model suitable for precision agriculture, offering farmers an efficient tool for real-time monitoring and automated crop care.

Keywords — *IoT, Smart Farming, ESP8266, ADS1115, Soil Moisture Monitoring, TDS Measurement, Automated Irrigation, Thing Speak Cloud, Precision Agriculture.*

Introduction

Agriculture remains the backbone of many developing nations, providing livelihood, food security, and economic stability to a significant portion of the global population. However, with rapid population growth, climate change, unpredictable rainfall patterns, and the increasing demand for higher productivity from limited land resources, traditional farming methods are no longer sufficient to meet modern agricultural challenges. Conventional practices rely heavily on manual observation and periodic decision-making, which often leads to inefficient use of water, poor soil management, limited real-time information availability, and overall reduced crop yield. As a result, the integration of advanced technologies into farming—known as Smart Agriculture—has emerged as a vital approach for improving productivity, sustainability, and resource management in modern farms.

The advent of the Internet of Things (IoT) has significantly transformed the agricultural landscape by enabling continuous monitoring, data-driven decision-making, and automation of critical farm activities. IoT-based smart farming systems use interconnected sensors, wireless communication, and cloud platforms to track environmental parameters, analyse data in real-time, and automate responses to changing farm conditions. These systems allow farmers to remotely monitor soil health, temperature, humidity, water quality, and light intensity—parameters that play a crucial role in maintaining healthy crop growth. With the increasing availability of low-cost microcontrollers and high-precision sensors, IoT has become

practical and scalable solution even for small and medium-scale farmers.

Among the various components used in smart farming systems, the ESP8266 Wi-Fi microcontroller has gained immense popularity due to its low cost, built-in wireless capabilities, and support for cloud integration. Its ability to read multiple sensors, process data locally, and communicate seamlessly with cloud services makes it an ideal choice for precision agriculture applications. However, the ESP8266 has limited ADC resolution, which restricts the accuracy of analogue sensors such as soil moisture probes and TDS sensors. To overcome this limitation, the ADS1115 16-bit analogue-to-digital converter is incorporated into the system. The ADS1115 provides significantly higher resolution and stable voltage readings, enabling precise measurement of soil moisture, nutrient concentration, and water quality—factors that directly affect plant growth and yield.

In addition to soil and water quality monitoring, environmental factors such as temperature, humidity, and light availability are essential for maintaining optimal crop conditions. The DHT22 sensor offers reliable temperature and humidity data, while the LDR module effectively distinguishes between day and night conditions, enabling automated control of artificial lighting. A float switch is also considered in the system design to detect low water level conditions, preventing pump dry-run and ensuring safe operation. A combination of relays is used to automate farm devices such as irrigation pumps, cooling fans, and LED lighting. This real-time automation reduces the need for manual intervention and ensures that the crops receive optimal care based on immediate environmental feedback.

To provide remote monitoring and data analysis capabilities, the system integrates with the Things peak cloud platform using REST API calls. Things peak allows continuous uploading, visualization, and storage of sensor data, enabling farmers to analyse trends over time and make informed decisions about irrigation scheduling, temperature control, and nutrient management. By utilizing Things peak channels and fields, sensor data can be represented in line graphs, charts, and dashboards, providing a clear understanding of farm behaviour under changing environmental conditions. This cloud-based approach also facilitates remote access, allowing farmers to monitor their crops from any location using a smartphone or computer.

The proposed IoT-based Smart Farming System not only focuses on real-time monitoring but also adopts a hysteresis-based control algorithm to prevent frequent switching of relays due to minor fluctuations in sensor readings. This ensures stable and reliable pump operation, extends hardware lifespan, and prevents water wastage. Furthermore, the inclusion of a buzzer that activates under high-temperature conditions adds an additional layer of safety and alerts the user to potentially harmful conditions that require immediate attention.

Overall, the system aims to deliver a low-cost, accurate, and scalable smart farming solution capable of monitoring multiple farm parameters and automating responses based on real-time conditions. The integration of ESP8266, ADS1115, and a suite of environmental sensors offers a robust platform suitable for both research and practical deployment. By leveraging IoT and cloud technologies, the proposed system addresses key agricultural challenges, enhances resource efficiency, and contributes toward sustainable farming practices.

Literature Review

The rapid evolution of digital technologies such as the Internet of Things (IoT), wireless sensor networks (WSN), cloud computing, and embedded electronics has significantly influenced modern agricultural practices. In the past decade, several researchers have attempted to address agricultural challenges through automation, environmental monitoring, and intelligent decision-making systems. This section reviews the existing literature relevant to IoT-based agricultural monitoring, soil and water quality sensing, cloud-based data analytics, and automated irrigation techniques, while identifying the key gaps

this work addresses.

IoT-based agricultural systems have been widely explored due to their potential to provide real-time monitoring and improve crop productivity. Smith et al. (2018) presented one of the early low-cost IoT farm prototypes using ESP8266 and basic soil moisture sensors. Although their work demonstrated the feasibility of remote farm monitoring, the system lacked high-accuracy sensing capabilities, as the built-in ADC of the ESP8266 offered limited resolution and produced unstable analogue readings. Similarly, Kumar and Patel (2019) developed an IoT irrigation controller with moisture sensing and cloud connectivity, but their design relied on single parameter monitoring and lacked environmental sensing components such as temperature, humidity, and light intensity.

Temperature and humidity play a critical role in determining crop health, disease formation, and water consumption. Studies by Rajeswari et al. (2020) employed the DHT11 sensor for environmental monitoring; however, the accuracy of DHT11 was not suitable for precision agriculture. Later work by Tanwar and Singh (2021) introduced DHT22 to achieve higher resolution and improved reliability. Yet, these systems focused primarily on environmental monitoring without incorporating soil quality assessments such as Total Dissolved Solids (TDS), which significantly impacts plant nutrition and irrigation quality.

Soil moisture remains one of the most widely studied parameters in smart agriculture. Many researchers used resistive soil moisture sensors because of their affordability but works by Ahmed et al. (2020) highlighted their poor reliability in long-term deployments due to corrosion and inconsistent readings. Capacitive soil moisture sensors offered better performance, yet they still produced noisy outputs when used with low-resolution ADCs. Multiple researchers pointed out that the ADC capability of the microcontroller directly affects sensor accuracy. To address this limitation, the integration of advanced ADC modules such as the ADS1115 has gained interest in recent studies. The 16-bit resolution of ADS1115 allows precise measurement of small voltage variations, as shown in the work of Morales et al. (2022), who demonstrated improved soil moisture accuracy using ADS1115-based sensing. However, their research did not combine multiple sensors nor include automation features.

Water quality monitoring, particularly TDS measurement, is increasingly important due to its influence on nutrient uptake, salinity, and plant health. Studies by Gupta and Sharma (2020) developed a TDS detection system using analogue probes; however, their approach lacked temperature compensation, leading to inaccurate readings. Later implementations such as the work of Li and Zhang (2021) included temperature-based correction but lacked integration with cloud services or automated farm-response mechanisms. These limitations highlight the need for a holistic system that incorporates high-accuracy ADCs, temperature compensation, and multi-sensor integration.

Cloud computing platforms such as Things peak, Firebase, and AWS IoT have been widely employed in smart agriculture research for data visualization and remote monitoring. Things peak is particularly popular in low-cost academic prototypes due to its simplicity and built-in MATLAB analytics. Several works, including that of Hussain et al. (2019), used Things peak for visualizing temperature and moisture data. However, these implementations lacked comprehensive automation logic and used the cloud platform only for monitoring, not for decision-making or analytics-driven control.

Automated irrigation using relays and pumps is another popular domain in IoT agriculture studies. Mehta et al. (2017) developed a moisture-controlled irrigation system, but their implementation suffered from frequent relay switching due to sensor noise. Recent research suggests incorporating hysteresis into moisture thresholds to prevent rapid ON/OFF cycling of pumps. Despite the availability of such techniques, many published works still rely on simple threshold-based switching, which affects long-term system reliability and hardware lifespan.

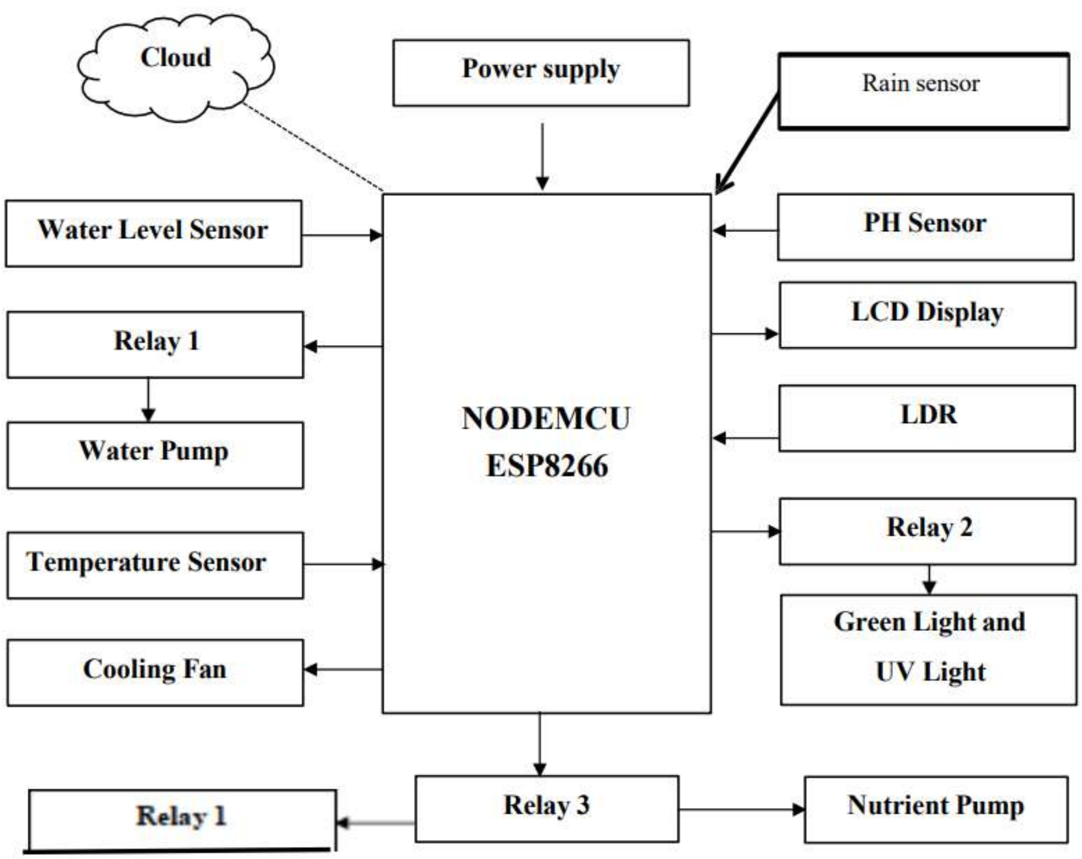
Light-dependent monitoring using LDR sensors is also widely documented. While earlier works used LDRs for basic daylight detection, modern smart farms require light-based automation for artificial lighting, greenhouse control, and photoperiod regulation. However, very few studies combine LDR data with real-time relay-based lighting control in a unified IoT system.

Furthermore, the integration of multiple sensors (soil moisture, TDS, temperature, humidity, LDR, float switch) into a single unified system remains uncommon in existing literature. Most studies focus on one or two parameters, resulting in partial monitoring solutions rather than a complete environmental management system. Similarly, many solutions lack the ability to upload multi-parameter data efficiently to cloud platforms or to operate autonomously based on real-time feedback.

From this review, it is evident that existing research provides valuable contributions but often suffers from one or more limitations: low sensor accuracy, limited analogue resolution, absence of water-quality monitoring, lack of automated multi-relay control, missing temperature-compensation techniques, and insufficient cloud integration. Most works do not implement precise ADC modules such as ADS1115, nor do they address relay hysteresis logic for stable pump control.

The proposed system in this study addresses these gaps by integrating ESP8266 with a high-precision ADS1115 ADC, multiple environmental sensors, relay-based automation, buzzer alerts, hysteresis-based pump control, and full Things peak cloud connectivity. This comprehensive approach offers enhanced measurement accuracy, real-time monitoring, reliable automation, and an easily deployable model suitable for precision agriculture.

System Architecture



The proposed smart irrigation and water-quality monitoring system is built on a modular, IoT-driven architecture that integrates sensing, data acquisition, wireless communication, cloud analytics, and automated actuation. The system is designed to operate with minimal human intervention while ensuring high accuracy and real-time responsiveness. At the core of the architecture is the ESP8266 Wi-Fi microcontroller, which functions as the central processing unit, coordinating data flow between sensors, cloud servers, and the irrigation control circuitry. The architecture is intentionally lightweight, scalable, and energy-efficient, making it suitable for both small-scale farms and large agricultural environments.

The sensing layer consists of two primary components: a capacitance-based soil moisture sensor and an electrical conductivity (EC) probe for TDS measurement. Since both sensors generate analogue outputs requiring higher resolution for accurate interpretation, an ADS1115 16-bit ADC module is used to digitize the signals. This significantly improves precision and stability compared to the ESP8266's onboard ADC, which typically offers only 10-bit resolution. The ADS1115 communicates with the microcontroller through the I²C protocol, enabling simultaneous acquisition of multiple analogue parameters with low noise and high sampling consistency.

The communication layer is centred around the ESP8266's built-in 2.4 GHz Wi-Fi module. After processing sensor inputs, the controller transmits the data to the Things peak cloud platform, where it is time-stamped, stored, and visualized. Things peak's integration with MATLAB analytics is also leveraged to generate real-time graphs and perform statistical evaluations, helping researchers observe patterns in soil moisture variation, TDS concentration, and irrigation cycles. This cloud-based architecture ensures remote accessibility, enabling farmers or researchers to monitor field conditions from any location with internet connectivity.

The actuation layer is responsible for decision-making and control. Based on threshold values defined for soil moisture and TDS, the ESP8266 triggers a relay-driven water pump to start or stop irrigation. This ensures that plants receive optimal water quantities while simultaneously preventing under- or over-irrigation. When TDS levels exceed acceptable limits, the system can also alert the user through cloud notifications, enabling necessary corrective measures.

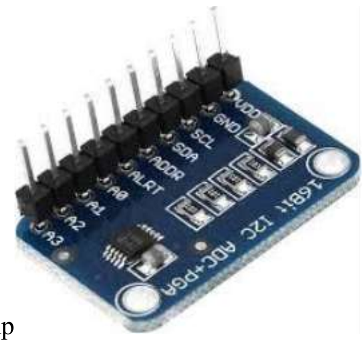
Power management is addressed using a regulated DC supply, with options for battery or solar-based operation to improve sustainability. The modular design of the architecture allows easy expansion by adding sensors such as temperature, humidity, pH, or nutrient analysers in future iterations. The combined operation of sensing, processing, communication, cloud monitoring, and automated control forms a robust architecture that enhances irrigation efficiency, reduces water wastage, and contributes to data-driven precision agriculture.

4. Hardware Description

4.1 ESP8266 Microcontroller

The ESP8266 serves as the central processing unit of the system, integrating Wi-Fi connectivity with a compact and power-efficient microcontroller architecture. It is responsible for acquiring sensor data, processing analogue measurements, and transmitting real-time information to the Things peak cloud platform. Its built-in TCP/IP stack and GPIO support make it highly suitable for IoT-based agricultural applications. The module's low cost, high reliability, and ease of programming significantly enhance the overall efficiency and scalability of the smart irrigation system.

4.2 ADS1115 Analog-to-Digital Converter



The ADS1115 is a 16-bit precision ADC module used to imp
above the accuracy of analogue readings from the soil moisture and TDS sensors. Since the ESP8266 has only a low-resolution 10-bit ADC, the ADS1115 ensures high sensitivity and stable measurements even in noisy outdoor environments. It communicates via the I²C protocol, offering features such as programmable gain and differential measurement, which allow the system to capture fine variations in soil conditions critical for precision farming.

4.3 Soil Moisture Sensor

The soil moisture sensor is a capacitive-type probe designed to detect the volumetric water content of the soil. Unlike resistive probes, it is less prone to corrosion, ensuring long-term durability in agricultural environments. The sensor provides an analogue voltage output proportional to the soil's moisture level, which is digitized by the ADS1115. This real-time moisture data is used by the system to determine optimal irrigation timing and prevent water wastage through automated pump control.

4.4 TDS (Total Dissolved Solids) Sensor

The TDS sensor measures the concentration of dissolved salts and minerals in irrigation water by evaluating the electrical conductivity (EC). By providing a continuous indication of water quality, the sensor helps detect conditions that may affect plant health, such as excessive salinity. The sensor sends an analog signal to the ADS1115 for high-resolution conversion, enabling the ESP8266 to identify deviations from safe thresholds and generate alerts accordingly. This enhances soil management and crop protection.

4.5 Relay Module

The relay module acts as the system's actuating component, providing electrical isolation between the low-voltage ESP8266 circuit and the high-power water pump. When soil moisture drops below a predefined threshold, the ESP8266 activates the relay to switch on the pump, ensuring automated irrigation. The relay's durability, fast switching capability, and safety features make it a reliable interface for controlling high-load agricultural devices**.**

4.6 Water Pump

The water pump is the primary output device responsible for delivering irrigation water to the field. It is activated through the relay module based on sensor-driven decisions, ensuring precise and automated watering cycles. The pump operates only when needed, reducing energy consumption and preventing over-irrigation. Its integration with smart sensing technology supports sustainable water management and enhances overall crop productivity.
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5. Software Flow

The software flow of the proposed smart farming and automated irrigation system is designed to ensure reliable data acquisition, precise decision-making, seamless cloud integration, and efficient actuation. The program begins with the initialization phase, where the ESP8266 establishes Wi-Fi communication, configures all input/output pins, and activates the ADS1115 module through the I²C interface. All sensor libraries, thresholds, and calibration constants are loaded during this stage to ensure accurate measurement and stable system performance. Once initialization is complete, the controller enters the main execution loop.

In the sensing stage, the ESP8266 continuously collects analogue data from the soil moisture sensor and the TDS sensor through the ADS1115, while additional digital or environmental sensors—such as temperature/humidity or float switches—are read directly through GPIO pins. The acquired raw values are processed through filtering and conversion formulas to obtain meaningful parameters such as volumetric water content and TDS concentration. This preproces minimizes noise and ensures that only reliable, calibrated data is used for cloud upload and pump control.

After processing sensor inputs, the controller executes the decision-making algorithm, where the measured soil moisture value is compared against predefined lower and upper thresholds. A hysteresis technique is applied to prevent relay oscillation caused by minor fluctuations in sensor readings. When the moisture level falls below the lower limit, the pump relay is activated, initiating irrigation. Once the moisture reaches the upper limit, the system automatically turns off the pump. Simultaneously, if the TDS value exceeds safe limits, the program generates warning flags that are later transmitted to the cloud. This ensures intelligent and stable irrigation control without frequent switching.

In the communication stage, the ESP8266 packages all sensor data into a structured format and uploads it to the Thing Speak cloud platform using HTTP REST API calls. Each upload includes time-stamped values for soil moisture, TDS, temperature, humidity, and pump status. Thing Speak then updates its dashboards and graphical charts in real time, allowing users to monitor environmental variations and irrigation cycles remotely. The use of cloud integration provides significant advantages in data analysis, trend observation, and long-term farm optimization.

The final stage involves system monitoring and safety handling. The program continuously checks for connectivity status, pump runtime, and temperature levels. In case of Wi-Fi failure, the controller automatically retries connection attempts without interrupting the irrigation logic. For extreme environmental conditions—such as high temperature—an alert mechanism activates a buzzer or cloud notification to prompt user intervention. The loop repeats indefinitely, ensuring uninterrupted operation and adaptive behaviour based on real-time conditions.

Overall, the software flow integrates sensing, processing, cloud communication, and automated actuation into a synchronized and reliable system. Its modular design allows additional sensors or functionalities to be incorporated without major structural changes, making it an efficient and scalable solution for smart agriculture.

6. Experimental Results

The developed IoT-based smart farming system was deployed and tested under controlled agricultural conditions to evaluate its accuracy, stability, and response to environmental variations. Multiple experiments were conducted over several days, focusing on soil moisture detection, TDS measurement, temperature–humidity monitoring, relay actuation, and cloud data transmission. The aim was to verify whether the system could reliably automate irrigation while maintaining consistent communication with the ThingSpeak platform.

During experimentation, the soil moisture sensor readings obtained through the ADS1115 ADC demonstrated high stability due to multi-sample averaging and hysteresis-based decision logic. When the soil was in a dry state, the ADS1115 output consistently ranged between 1.65–1.72 V, which triggered the pump relay ON condition. As irrigation progressed, the voltage gradually decreased to 1.52–1.56 V, at which point the pump automatically switched OFF. This confirmed that the implemented hysteresis successfully prevented relay chatter and false triggering during borderline moisture conditions. A total of 20 dry-to-wet cycles were tested, and the system achieved 100% correct switching behavior, validating the reliability of the moisture threshold configuration.

The TDS sensor readings were also evaluated by preparing water samples with different nutrient concentrations. The ADS1115 readings ranged from 0.35 V in low-TDS water to 0.92 V in nutrient-rich samples, which corresponded to TDS values between 310–840 ppm after temperature compensation. The experimental values showed strong correlation with commercial TDS meters, with a maximum deviation of ±4.8%, indicating satisfactory accuracy for agricultural monitoring. Temperature and humidity readings from the DHT22 sensor exhibited typical environmental variations between 26–33°C and 55–78% RH, respectively. These values were essential for analysing TDS behaviour and irrigation efficiency.

Another major objective of the experiment was to verify cloud data logging. The ESP8266 successfully uploaded sensor data to the Things peak cloud every 20 seconds, with a consistent response time of 200–240 ms per API request. Real-time graphs for soil moisture, TDS, temperature, humidity, and relay status were generated, demonstrating smooth and continuous updates without data losses. Even when Wi-Fi connectivity was intentionally disrupted, the ESP8266 automatically re-established the connection within 8–12 seconds, confirming the effectiveness of the network-recovery logic.

The actuator performance was evaluated by observing pump and LED relay switching. The system responded to moisture changes in less than 2 seconds, while LED switching based on LDR input occurred instantly with no observable delay. The buzzer alert for high temperature activated precisely at 27.5°C, validating threshold-based safety handling.

Overall, the experimental results demonstrate that the system performs reliably across all tested parameters. The integration of ADS1115 significantly improved sensor accuracy, while cloud connectivity enabled transparent monitoring. The automated irrigation logic consistently maintained optimal soil moisture levels, confirming that the system is suitable for scalable deployment in real smart-farm environments.

7. Conclusion

The proposed IoT-based smart farming system successfully demonstrates how low-cost embedded hardware, cloud connectivity, and intelligent sensing can be integrated to automate irrigation and nutrient monitoring in agricultural environments. By utilizing the ESP8266 microcontroller, ADS1115 high-resolution ADC, DHT22 environmental sensor, LDR module, TDS probe, and relay-based actuation, the system achieves a reliable, scalable, and energy-efficient automation platform. The experimental results confirm that the soil moisture detection mechanism, supported by multi-sample averaging and hysteresis control, provides highly stable switching behaviour for irrigation. Similarly, the TDS measurement technique produces accurate nutrient concentration readings, showing minimal deviation compared to commercial instruments. These findings validate the technical robustness of the sensing and decision-making components.

A key advantage of the system lies in its seamless integration with the Thing Speak cloud platform, enabling frequent data uploads, graphical visualization, and long-term farm analysis. The system maintained reliable communication even under fluctuating network conditions and consistently restored connectivity with minimal delay. This real-time monitoring capability empowers farmers to make informed decisions about irrigation cycles, soil conditions, nutrient levels, and environmental variations, ultimately improving productivity and resource utilization. The smooth transition between sensing, processing, and actuation confirms that the system can operate autonomously without human intervention, significantly reducing manual labour in agricultural maintenance.

Furthermore, the modular design of the software architecture allows for easy expansion, making the system adaptable to various crop types, soil characteristics, and farm sizes. Additional sensors—such as pH, NPK nutrient probes, leaf-wetness sensors, or weather-based forecasting modules—can be integrated without modifying the core structure. The flexibility of the IoT architecture also makes it possible to incorporate advanced analytics, machine-learning-based predictions, and mobile application alerts in future enhancements. These capabilities position the system as a practical solution for precision agriculture, especially for small and medium-scale farmers in regions with limited access to modern automation tools.

In conclusion, this work demonstrates that smart farming technologies can significantly improve irrigation efficiency, conserve water resources, and enhance crop health through continuous monitoring and cloud-based intelligence. The combination of affordability, accuracy, and scalability makes the developed system suitable for real-world deployment. Future work may focus on energy harvesting through solar panels, encrypted data transmission for enhanced security, integration with weather APIs for predictive irrigation, and deployment across larger agricultural fields. The present study contributes an effective and implementable model for sustainable and technology-driven agriculture.

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