ADScAI
Applied Data Science & Artificial Intelligence Symposium

End-to-End Smart Agriculture Sensor Network & Analytics Platform

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Keywords—smart agriculture, sensor analytics, precision farming, smart irrigation, data-driven farming

I. Introduction

Agriculture is one of the main global-level industries which provides essential food supplies to the ever-increasing global population. Due to the rapidly growing demand for food, improving agricultural efficiency and productivity has become a critical goal as an industry. Traditional farming practices, reliant on intuition and manual labor, are increasingly inadequate to meet global food demands while preserving ecosystems. Smart agriculture transcends mere automation; it represents a holistic transformation of farming systems. It refers to the use of modern technology, data analytics, and innovative tools to enhance agricultural productivity, efficiency, and sustainability.

The transition to modern farming methods with various sensors, actuators and analytics is a challenge to many ordinary farmers due to huge initial cost, lack of relevant knowledge and accessibility. This research focuses on proposing a cost-effective smart agriculture ecosystem including sensor network and analytics platform to improve the productivity and maximize the yield of selected crops.

II. Literature Review

In recent years, advancements in sensor technologies, data analytics, and automation have revolutionized the way agricultural operations are managed. Real-time monitoring systems, equipped with an array of sensors and automated control mechanisms, offer unprecedented insights into the dynamic interactions between plants, environment, and resources within protected agriculture settings. By continuously measuring and analyzing critical parameters such as temperature, humidity, light intensity, soil moisture, and nutrient levels, these systems empower farmers to make data-driven decisions, optimize resource allocation, and respond promptly to changing conditions.

Usage of soil sensors, such as moisture sensors, pH sensors are widely popular. Recent study shows that moisture data reduces water usage by up to 30% while maintaining the yield. The challenges in deploying sensor technologies and electronic systems for real-time monitoring in precision agriculture. It emphasizes the need for reliable, scalable, and cost-effective solutions to optimize resource use (e.g., water, fertilizers) and improve crop yields through data-driven decision-making. Energy constraints in remote agricultural settings limit the use of continuous monitoring systems. Bridging the gap between raw sensor data and actionable insights for farmers, particularly in real-time applications, is the key factor in efficient technology use.

Another study developed an IoT-based monitoring system for epidemic disease control in precision agriculture applications. This system enables environmental monitoring services that help maintain the crop growing environment in an optimal status and predicts the disease conditions which would cause a disease outbreak. Microsoft's FarmBeats is a comprehensive platform that integrates IoT, AI, and cloud computing to provide data-driven solutions for agriculture. It combines data from various sensors and drones with cloud-based analytics to offer actionable insights. It outlines the system's design, which accounts for weather-related power and internet outages.

III. Methodology

The design of a smart agriculture sensing and analytics system is a multidisciplinary endeavor that integrates IoT (Internet of Things), sensor networks, edge/cloud computing, machine learning, and agronomic expertise. This methodology provides a step-by-step framework for building a scalable, energy-efficient, and farmer-centric system capable of addressing challenges such as resource optimization, crop health monitoring, and yield prediction.

The overall system consists of,

- Sensor network and the main gateway device
- Realtime cloud database and cloud server
- Data analytics and recommendations

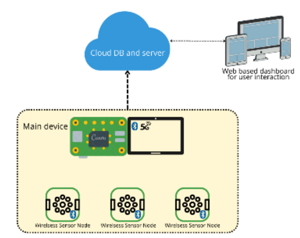

Figure 1: Overall System Architecture

In the proposed system, the sensor setup is placed on the agriculture field with the main device connecting to the cloud via narrow band IoT (NBIoT) communication. There are multiple wireless sensor nodes powered by Bluetooth low energy (BLE) which connect to the main device to expand the area of sensor coverage using grid-based or zone-based deployment strategies. This helps expand the sensor devices across the field to achieve the required precision and spatial distribution. The main device acts as the gateway device which transports the sensor data from the sensor network to the cloud server which stores and processes the obtained sensor data using transport methods such as MQTT.

https://doi.org/10.31705/ADScAI.2025.55

A. Main Device Specifications

The main device serves as the computational and communicative core of the system. Mainly it aggregates data from sensor nodes, pre-processes information, and interfaces with cloud platforms. It also incorporates edge computing capabilities, such as adaptive sampling, allowing them to execute machine learning models locally for immediate decision-making.

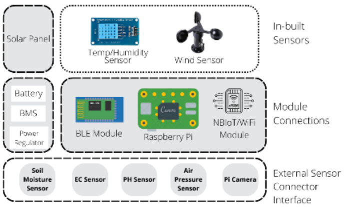

Figure 2: Main Device Components

B. Sensor Node Specifications

Sensor nodes are the backbone of any smart agriculture system, acting as distributed data collection units that monitor environmental, soil, and crop conditions. Covering an agricultural field with multiple sensor nodes is necessary, particularly when the objective is to optimize resource use, monitor crop conditions, and improve yields.

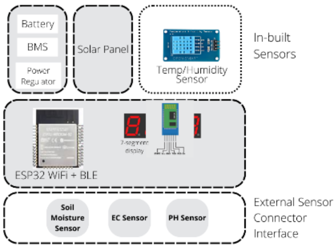

Figure 3: Sensor Node Components

C. Cloud Server and Data storage

In a smart agriculture ecosystem, the cloud server acts as the centralized brain, processing and storing data from distributed sensor nodes and the main device. It enables scalable analytics, long-term trend analysis, and real-time decision-making.

D. Data analytics and insights from collected sensor data

Transforming raw sensor data into actionable insights that can drive informed decision-making is the most crucial role of the proposed system. The sensor data collected from the field is processed using various data analytics techniques to extract patterns, trends, and correlations that

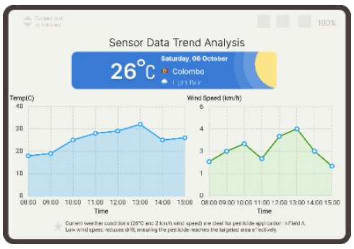

Figure 5: Sensor Analytics Dashboard

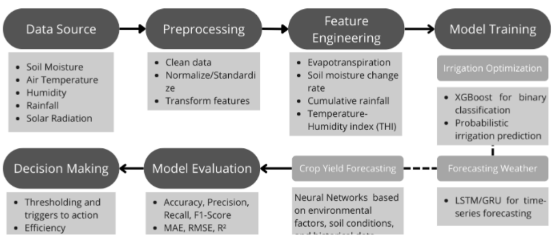

Figure 4: Data analytics and decision-making model

provide valuable insights for farmers as shown in Figure 4. This process involves several stages of data processing, advanced analytics techniques, and predictive modeling, enabling precise decision-making and automation of farm operations as shown in Figure 5.

IV. Experiments And Case Study

Since it is challenging to implement sensor nodes in a remote on-field vegetation environment, a sensor data simulation model was used as shown Figure 6. Aggregated data was used to train the models and evaluate.

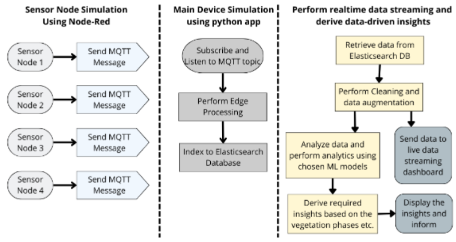

Figure 6: Sensor data simulation case study

V. Results And Discussion

The XGBoost based irrigation optimization model was trained to predict whether irrigation is needed based on environmental factors such as soil moisture, temperature, humidity, and solar radiation. The model was evaluated using several performance metrics such as accuracy which achieved 92%, a precision of 90% and a recall of 85%. The LSTM model was able to capture seasonal variations in weather forecasting, but there was some difficulty in predicting extreme weather events.

VI. Conclusion

The system can be deployed on larger agricultural scales, with integration into actuators such as automated irrigation systems to provide real-time irrigation recommendations, fertilizations based on ongoing environmental conditions.

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