ADVANCEMENTS IN AGRICULTURAL DECISION SUPPORT SYSTEMS: A DATA FUSION APPROACH

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ABSTRACT

At the forefront of precision agriculture, this paper presents an advanced decision support system that integrates a focused dataset from soil sensors measuring pH, temperature, electrical conductivity, and humidity. This research is centered on a rock melon farm, where the aforementioned soil parameters are critical for crop success. By leveraging MQTT for efficient data transmission and Grafana for intuitive data visualization, the system offers real-time insights that guide critical farming decisions. The study demonstrates how this selective data fusion approach can significantly improve the accuracy of soil health assessments, which in turn can lead to enhanced crop yields and reduced operational expenses. The findings provide valuable contributions to the field of agronomy, particularly in the cultivation of rock melons, by offering a refined method for managing agricultural inputs. The practical application of this system is exemplified in its use within a rock melon farming context, proving its versatility and effectiveness in supporting farmers with precise, data-informed strategies to maximize resource efficiency and economic returns.

Keywords: Soil Sensor, Data Fusion, Internet of Things, Precision Agriculture, Decision Support

INTRODUCTION

Agriculture stands as a cornerstone of the global economy, tasked with the monumental challenge of feeding a projected population of 9.7 billion by 2050. This sector, vital for supplying food, fuel, and raw materials, is grappling with formidable challenges such as climate change, water scarcity, soil degradation, and pestilence, which threaten its (Rozenstein et al., 2024). The escalating demand for food necessitates a significant enhancement in agriculture.

The advent of data-driven agriculture has ushered in a new era of precision farming, particularly through the utilization of soil sensors that measure critical parameters such as pH, temperature, electrical conductivity, and humidity. These parameters are pivotal in assessing soil health and informing farming decisions (Ratshiedana et al., 2023). The integration of this data through advanced data fusion techniques equips farmers with actionable insights, enabling informed decisions that optimize crop management and productivity (Kumar et al., 2021).

Data fusion, a method that amalgamates information from various sources, has been instrumental in providing a comprehensive view of the agricultural landscape. By employing MQTT for efficient data transmission and Grafana for effective data visualization, intelligent systems can offer precise recommendations for irrigation, fertilization, and pest control (Mandal et al., 2021). This approach not only improves crop yields but also reduces operational costs, representing a significant leap from traditional farming methods (Abu, Bukhari, Ong, Kassim, et al., 2022).

The application of data fusion in agriculture is well-established, with studies demonstrating its effectiveness in enhancing crop management. For instance, electromagnetic techniques have been used to measure soil electrical conductivity and moisture, providing valuable data for irrigation management in arid environments (Kitchen, 2008). Similarly, dielectric properties-based methods have refined soil water content measurements, essential for precision agriculture.

Beyond immediate crop management, the data collected through these systems can be analyzed by agronomists and researchers to refine agricultural practices and aid in the development of new crop varieties (Melo, Báez and Acuña, 2021).This integration of data sources assists farmers in improving yields and profits and contributes to the advancement of sustainable agricultural practices.

This paper introduces a novel decision support system that leverages data fusion, focusing on rock melon crops. The system is designed to empower farmers with the information needed to make more informed decisions, thereby improving crop yields, increasing profitability, and conserving vital resources. The methodology includes data collection, fusion techniques, real-time recommendations, system testing, data analysis, and system enhancement. The performance evaluation of the system is discussed, highlighting its impact on sustainable agriculture and its potential as a model for future agricultural decision support systems.

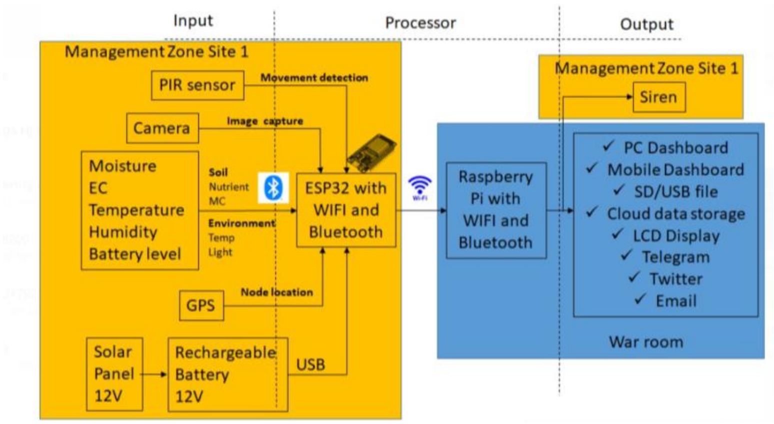
MATERIALS AND METHODS

System Configuration

Figure 1 illustrates the block diagram for the system configuration proposed for agricultural decision support systems. In this system configuration, the data will flow from the input, which is located in the agricultural field, up to the output, which is located remotely, such as in the plantation office or headquarters in the urban area. The input data from the agricultural sites are collected based on multiple sensors based on soil, crops, and environmental monitoring through developed cutting-edge sensor systems (Abu, Bukhari, Ong, Sukhaimie, et al., 2022). In terms of site security, the PIR sensor and integrated CCTV camera can be used to detect any unknown movement through artificial intelligence methods and send the data to the microprocessor such as the ESP32 microcontroller (Kassim, A.M., Jaafar, et al. 2013). The battery level which is supplied inside the sensor is also very important to ensure the sustainability of real-time data collected in the agricultural field (Azam, M.A. et al. 2021).

Moreover, the connection between both areas is through the Internet of Things, where data are transferred to the cloud by using the MQTT gateway. The communication can be done by using WiFi or LoRa transmission such that it can be cover long-range and wide-range communication, which perfectly applied in the plantation and agricultural sites (Kassim, Kamarudin, et al., 2022). On the other hand, the output will be displayed and monitored by the supervisor of the top management and can be viewed through the personal computer and mobile phone dashboards (Kassim, A.M., Jamri, M.S., et al. 2012). The data will be collected and stored through USB and SD cards as hardware storage and in cloud storage, such as an AWS cloud server (Hasim, N., et al. 2012).

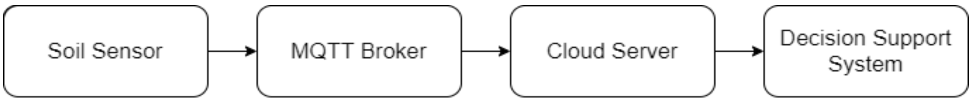
Figure 1: System configuration for agricultural decision support systems



Data Collection

The foundational phase entailed the systematic collection of soil data, focusing exclusively on four critical parameters: pH, temperature, electrical conductivity (EC), and humidity. Data acquisition was automated through soil sensors, with operators using mobile devices to collate data from various points within the rock melon farm (Kassim, Sahak, et al., 2022). The MQTT protocol was harnessed to transmit this data efficiently, ensuring real-time updates and seamless communication between the sensors and the central system (Bin Mohamed Kassim, A., et al. 2015). Figure 2 depicts the MQTT protocol’s role in the data transmission process, illustrating the journey from soil sensor data collection through to the central decision support system.

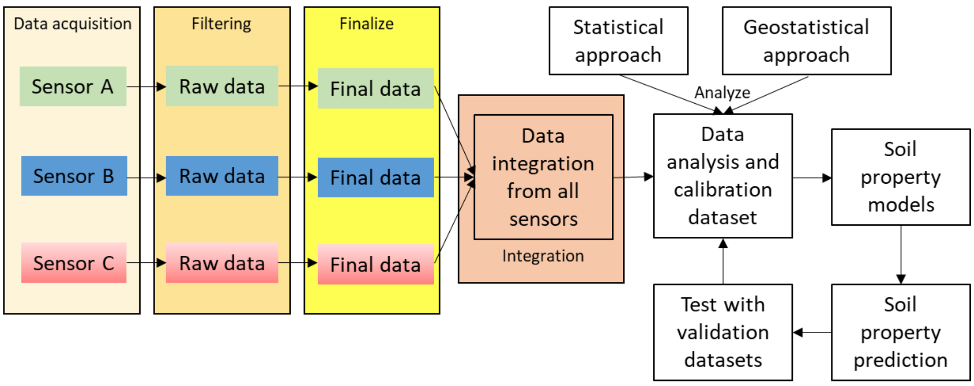
Figure 2: MQTT data transmission flow



Data Fusion

Subsequent to data collection, the integral process of data fusion commenced. The collected multiple soil data, such as moisture and electrical conductivity (EC) with the environmental sensors for the humidity and temperature, were collected and synthesized using advanced algorithms to provide cohesive and comprehensive data and information on the soil and environmental conditions pertinent to the rock melon agricultural site (Nawar. S et al., 2022). The data fusion from all the sensors was instrumental in augmenting the data's precision, facilitating more accurate agricultural decision-making shown in Figure 3.

Figure 3: Data fusion for agricultural decision support system



System Testing

The system underwent rigorous testing within the operational environment of a rock melon farm. The evaluation focused on the system’s capacity to yield actionable insights and its consequential influence on farming outcomes, particularly in terms of irrigation scheduling, fertilization optimization, and pest management strategies (Kassim et al., 2021). Figure 4 illustrates the deployed soil sensor in the field, demonstrating its integration into the rock melon farming system and its role in data collection.

Figure 4: Deployed multi soil and environment sensor

Visualization and Analysis

The implementation of the data fusion-based decision support system has been instrumental in enhancing the management of rock melon cultivation (Ahmad Anas Yusof et al., 2022). The system's utilization of soil sensor data pH, temperature, electrical conductivity, and humidity has provided a detailed view of the soil environment, which is crucial for the precision agriculture of rock melons (Kassim et al., 2021). Figure 5 illustrates the Grafana dashboard interface displaying real-time data of soil pH, temperature, EC, and humidity levels. The dashboard provides a visual representation of the data trends over time, aiding farmers in making informed decisions for crop management.

Figure 5: Grafana soil parameter dashboard

The evaluation involved collecting and synthesizing soil data via the MQTT protocol, which enables real-time transmission, and Grafana for advanced data visualization. This methodology facilitated a thorough analysis of the soil parameters influencing rock melon health and productivity. The system's performance was benchmarked against conventional farming methods, showcasing significant improvements in the precision and promptness of the information delivered to farmers. A key feature of the system was the incorporation of data input by human operators, blending human expertise with sensor data. This synergy ensured that farmers' nuanced understanding of their land was integrated into the decision-making process.

RESULT AND DISCUSSION

Implementation and Results

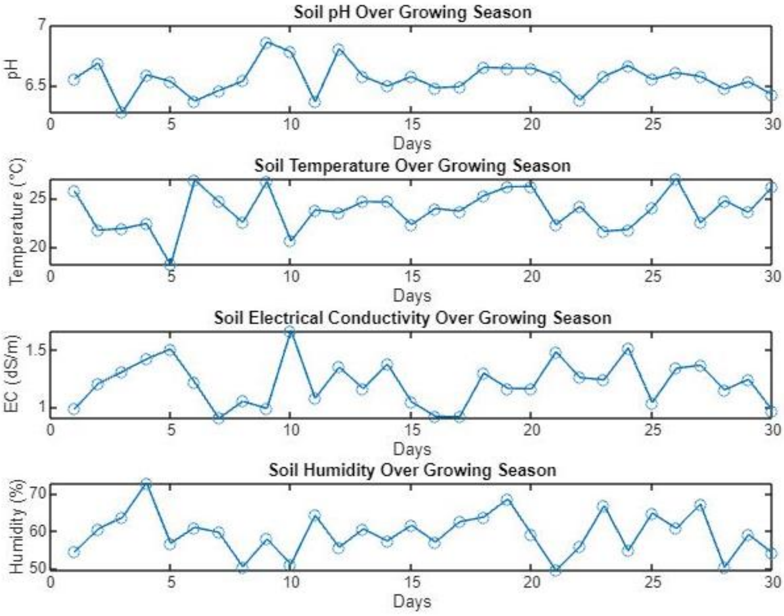
The implementation of the data fusion-based decision support system has been instrumental in enhancing the management of rock melon cultivation. The system's utilization of soil sensor data pH, temperature, electrical conductivity, and humidity has provided a detailed view of the soil environment, which is crucial for the precision agriculture of rock melons. The evaluation involved the collection and synthesis of soil data via the MQTT protocol, enabling real-time transmission, and Grafana for advanced data visualization. This methodology facilitated a thorough analysis of the soil parameters influencing rock melon health and productivity. The system's performance was benchmarked against conventional farming methods, showcasing significant improvements in the precision and promptness of the information delivered to the farmers.

A key feature of the system was the incorporation of data input by human operators, blending human expertise with sensor data. This synergy ensured that farmers' nuanced understanding of their land was integrated into the decision-making process. Table 1 presents the aggregated soil parameter data collected from the sensors and its correlation with the rock melon yield, illustrating the impact of precise soil data on crop management. Figure 6 shows a real-time visualization of soil sensor data, illustrating the fluctuations in soil pH, temperature, EC, and humidity over a growing season.

Table 1. Soil parameter data and correlation with rock melon yield

Soil Parameter	Average Value	Correlation yield
pH	6.5	Positive
Temperature (°C)	24	Positive
Electrical Conductivity (dS/m)	1.2	Negative
Humidity (%)	60	Positive

Figure 6. A mapping tool for location selection and the soil and the crop suitability displays



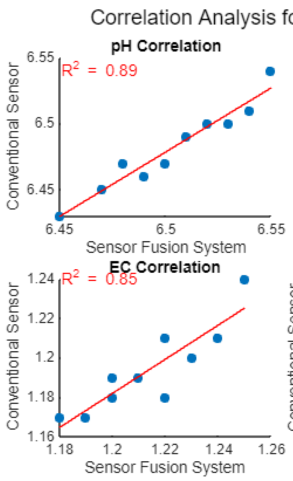
In addition to the existing sensor data, a comparative study was conducted to evaluate the correlation between the sensor fusion system and the Atlas Scientific EC sensor. The study revealed a strong correlation, with an R^2 value demonstrating the sensor fusion system's accuracy in comparison to the conventional sensor. Table 2 presents a comparative average value of the average soil parameter values obtained from the sensor fusion system and the conventional sensor.

Table 2. A comparative average value of sensor fusion with conventional sensor

Soil Parameter	Sensor Fusion	Conventional Sensor
pH	6.5	6.48
Temperature (°C)	24	23.95
Electrical Conductivity (dS/m)	1.2	1.19
Humidity (%)	60	59.8

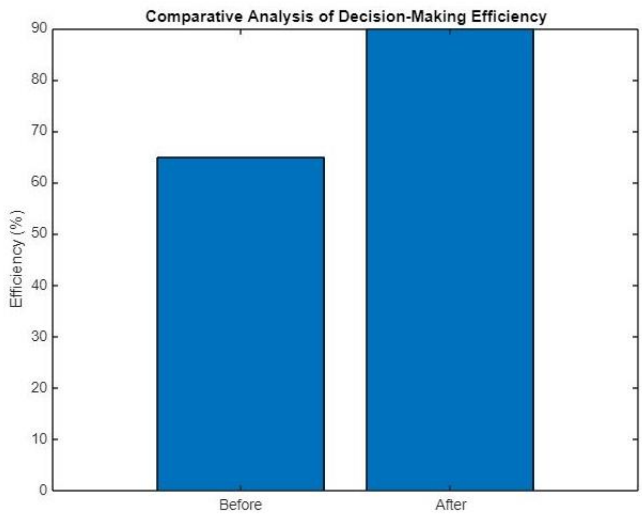
The R^2 values indicate a high degree of correlation between the measurements from the sensor fusion system and the Atlas Scientific EC sensor. The average values for pH (6.5 vs. 6.48, $R^2 = 0.89$), temperature (24°C vs. 23.95°C, $R^2 = 0.93$), electrical conductivity (1.2 dS/m vs. 1.19 dS/m, $R^2 = 0.85$), and humidity (60% vs. 59.8%, $R^2 = 0.90$) are very consistent between the two systems. This strong correlation across all parameters underscores the reliability and precision of the sensor fusion system in providing accurate soil measurements, comparable to those obtained from the Atlas Scientific EC sensor. Figure 7 shows a correlation between sensor fusion systems with conventional sensors.

Figure 7. Correlation between sensor fusion system with conventional sensor



The R² values indicate a high degree of correlation between the measurements from the sensor fusion system and the Atlas Scientific EC sensor. The average values for pH (6.5 vs. 6.48, $R^2 = 0.89$), temperature (24°C vs. 23.95°C, $R^2 = 0.93$), electrical conductivity (1.2 dS/m vs. 1.19 dS/m, $R^2 = 0.85$), and humidity (60% vs. 59.8%, $R^2 = 0.90$) are very consistent between the two systems. This strong correlation across all parameters underscores the reliability and precision of the sensor fusion system in providing accurate soil measurements, comparable to those obtained from the Atlas Scientific EC sensor. Figure 8 shows a correlation between sensor fusion systems with conventional sensors.

Figure 8. Impact on crop management



In summary, this research validates the application of data fusion techniques alongside modern IoT technologies to forge a responsive and intelligent agricultural management system. The confluence of human input with sensor data through MQTT and visualization via Grafana signals a promising trajectory for the future of precision agriculture in rock melon farming. The system enhances the decision-making process and contributes to the sustainable intensification of agriculture.

CONCLUSION

The introduction of a data fusion-based decision support system is a significant advancement in agricultural technology, especially for rock melon farming. This system effectively synthesizes soil data, providing real-time irrigation, fertilization, pest control, and harvest timing recommendations. It brings benefits like improved crop yields, cost savings, and better resource management. Beyond the farm, it aids agronomists and researchers in developing new crop varieties and improving management techniques. This system fosters informed decision-making among farmers, leading to increased profitability and sustainable agriculture. Leveraging data-driven decisions could shape macroeconomic policies, like Malaysia's National Agrofood Policy 2.0, promoting smart agricultural practices. Future efforts should focus on interpreting fused data to maximize IoT platform capabilities. Creating user-friendly interfaces and mobile apps is essential for farmer accessibility and usability, simplifying agriculture and enhancing productivity in a data-centric landscape.

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