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Original Article

Optimizing Agricultural Irrigation in Arequipa - Peru, Through an IoT-Enable Automated Sprinkler Irrigation System

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Abstract *- The Arequipa region in Peru has challenges in agricultural water management due to the erroneous use of water for irrigation and fluctuating climatic features. This research work describes the design and testing of an IoT-based automated sprinkler irrigation system that was developed with the view to facilitate the efficient use of water in irrigation and boost agricultural yield in the area. The system employs a Raspberry Pi 4B as the principal microcontroller board, which communicates with the soil moisture sensors, temperature and humidity sensors, and weather tickers that track the climate parameters in real-time. The collected sensor data is transferred to a Wi-Fi network that stores data in a cloud, provides farmers with the history of data analysis, and grants them the ability to manually control this system through a web or mobile application. The automated system turns on sprinklers when the soil moisture level reaches certain levels and thus cuts on water usage while making the crops healthier. Some of the benefits obtained during the field trials were that they were able to use 30% less water and get 12% more crop yield than with conventional irrigation methods. Further, assessments made by farmers on Microsoft's Product Reaction Cards (MPRC) showed that the system was easy to use, reliable and efficient.*

Keywords *- IoT, Automated irrigation, Sustainable farming, Smart irrigation system, Raspberry Pi.*

1. Introduction

The region of Arequipa, located in southern Peru, is renowned for its rich agricultural tradition and its critical reliance on water availability for crop irrigation. However, the efficient management of water resources poses a significant challenge for local farmers. The inefficient use of water in agriculture, largely due to the lack of automated irrigation systems, presents serious economic and environmental threats.

Currently, agricultural irrigation in Arequipa is predominantly carried out using manual methods or inefficient irrigation systems, resulting in excessive water consumption. This issue not only increases the operational costs for farmers but also depletes local water resources, compromising the long-term sustainability of agriculture in the region [1]. The absence of automated irrigation systems compels farmers to allocate a considerable amount of labor to perform irrigation operations. Moreover, the costs associated with the implementation of conventional irrigation systems can be prohibitive for many farmers, limiting the adoption of advanced technologies. The significant variability in precipitation patterns that Arequipa experiences exacerbates the situation, making precise and adaptable irrigation management critical. The inability to quickly adjust irrigation in response to current climatic conditions leads to inefficient water use and can negatively impact crop yields. Sustainable agriculture is essential for the region's economic well-being and long-term food security. However, the lack of efficient irrigation systems hinders progress towards more sustainable and climate-resilient agriculture. Faced with these challenges, the urgent need arises to develop and adopt automated irrigation systems that employ Internet of Things (IoT) technology to optimize water management in Arequipa's agriculture.

In recent years, IoT-based automated irrigation systems have shown promise in improving water use efficiency and reducing labor costs. For instance, studies have demonstrated the effectiveness of IoT systems in real-time monitoring and control of irrigation processes, leading to significant water savings and improved crop performance [2, 3]. The use of IoT in agriculture allows for precise control over irrigation schedules based on real-time data from soil moisture sensors, weather forecasts, and crop water requirements, thereby enhancing resource management and sustainability [4].

The primary objective of this study is to develop and evaluate an IoT-enabled automated sprinkler irrigation system to optimize agricultural water management in the Arequipa region of Peru. This system aims to improve water use efficiency, reduce operational costs, and promote sustainable agriculture in the region. By leveraging IoT technology, the proposed system seeks to address current issues through the implementation of accessible and effective technological solutions, significantly contributing to the advancement of sustainable agriculture in Arequipa.

2. Related Work

The integration of IoT technologies into agricultural irrigation systems has seen substantial advancements, offering promising solutions to the challenges of efficient water management in agriculture. This section reviews significant contributions in the field that inform the development of an IoT-enabled automated sprinkler irrigation system for Arequipa, Peru. A low-cost, open-source IoT system was developed for smart irrigation, integrating various sensors to monitor soil moisture, temperature, and other environmental factors. The system leverages the FIWARE framework for efficient data management and decision-making processes, supporting both edge and cloud computing for real-time irrigation monitoring and control. The study made by Puig et al.demonstrated the system's capability to optimize water usage and improve crop performance by calculating soil water balance and wet bulb dimensions, which are crucial for determining the most effective irrigation strategies for drip systems [5, 6].

Ananthi et al. [7] developed an IoT-based smart soil monitoring system aimed at improving agricultural productivity. The system integrates various sensors to monitor soil moisture, temperature, and nutrient levels in real-time. Data collected from the sensors is transmitted to a cloud server for processing and analysis, enabling farmers to make informed decisions about irrigation and fertilization. This approach enhances re-source efficiency and crop yields by providing precise and timely information on soil conditions.

Yousif and Abdalgader [8] proposed a real-time monitoring and auto-watering system based on mathematical models integrated into an Arduino IDE. The system uses IoT sensors to measure soil moisture and other environmental parameters, automatically controlling water distribution based on predefined thresholds. This approach reduced water consumption by over 70% and increased crop production efficiency by optimizing irrigation schedules.

Goap et al. [9] developed a smart irrigation management system that integrates IoT with machine learning and open source technologies. The system employs various sensors to monitor soil moisture, temperature, and humidity. Machine learning algorithms are used to analyze the collected data and make real-time irrigation decisions. This system aims to optimize water usage and improve crop yields by providing precise irrigation schedules based on environmental conditions. The use of open-source technologies ensures cost-effectiveness and accessibility for a wider range of users.

Vallejo-Gomez et al. [10] conducted a systematic review of smart irrigation systems, focusing on the use of Artificial Intelligence (AI) and Machine Learning (ML) techniques in both urban and rural agriculture. The review analyzes various AI-based systems that optimize irrigation schedules based on real-time data from soil and environmental sensors. The study concludes that these systems significantly enhance water use efficiency and crop productivity, highlighting their potential to address future food security challenges.

Boursianis et al. [11] provide a comprehensive review of the integration of IoT and UAVs in smart farming. This study explores how IoT technologies and UAVs can work together to enhance precision agriculture by providing detailed monitoring and data collection capabilities. The authors discuss various applications, including crop health monitoring, soil analysis, and efficient water management. The use of UAVs combined with IoT infrastructure helps in real-time data acquisition, leading to more informed decision-making and optimized resource use in agriculture.

Nawandar and Satpute [12] designed a low-cost intelligent module for smart irrigation using IoT. This system leverages neural networks to analyze data from various sensors, including soil moisture, temperature, and humidity sensors, to determine optimal irrigation schedules. By integrating IoT and machine learning, the system significantly enhances water management efficiency and supports remote monitoring and control through mobile applications. This approach not only reduces operational costs but also promotes sustainable agricultural practices by optimizing water usage.

Madushanki et al. [13] review the adoption of IoT in agriculture and smart farming, emphasizing its role in improving productivity and cost-effectiveness through automation. The study analyzes data from 60 peer-reviewed publications, highlighting the importance of IoT in water management, crop management, and smart farming. It reports that water management is the most researched area, with 28.08% of the studies focusing on it, followed by crop management (14.60%) and smart farming (10.11%). The review underscores the need for IoT systems to address scalability, heterogeneity, and security issues to enhance agricultural efficiencies.

These studies collectively emphasize the transformative impact of IoT and automated systems on agricultural irrigation. They illustrate how real-time monitoring, data analysis, and adaptive control can lead to significant improvements in water use efficiency, cost reduction, and crop productivity. As agriculture faces increasing pressures from climate change and water scarcity, adopting such technologies becomes ever more crucial. The proposed research aims to build upon these foundational works, developing a low-cost, IoT-enabled automated sprinkler irrigation system tailored to the specific needs and challenges of the Arequipa region in Peru.

3. Methodology

The development and evaluation of an IoT-enabled automated sprinkler irrigation system for optimizing agricultural irrigation in Arequipa, Peru, involved several critical phases: system design, hardware and software development, implementation, and evaluation.

The project began with a comprehensive analysis of irrigation requirements specific to Arequipa's agricultural landscape, focusing on crop types, soil conditions, and climate patterns. This phase included identifying the specific needs of local farmers, such as water usage, labor constraints, and existing irrigation practices. Based on this analysis, we designed an overall system architecture integrating sensors, microcontrollers, communication modules, and actuators. This architecture ensured reliable data transmission and system control across the irrigation field. The architecture is shown in Figure 1.

For hardware development, we selected appropriate sensors to measure soil moisture, temperature, humidity, and weather conditions. Commonly used sensors included capacitive or resistive soil moisture sensors, DHT22 temperature and humidity sensors, and weather stations. These sensors were strategically deployed across the irrigation field to ensure comprehensive data collection, covering different soil types and microclimates. The connection between a sensor, an actuator and the controller is shown in the schematic in Figure 2.

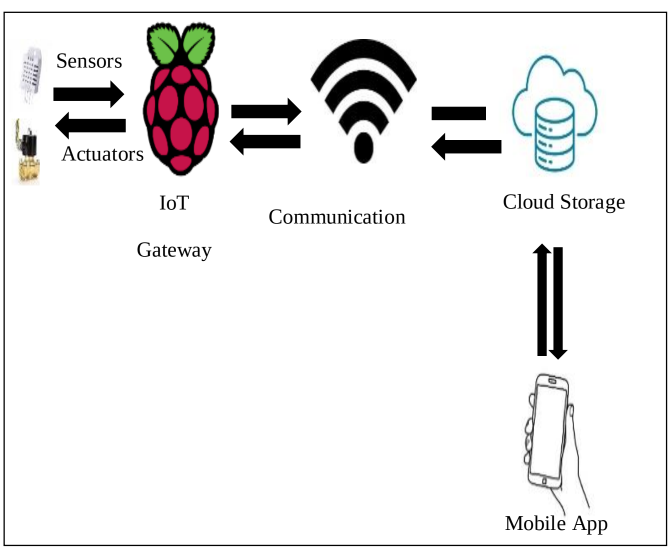

Fig. 1 Simple IoT architecture

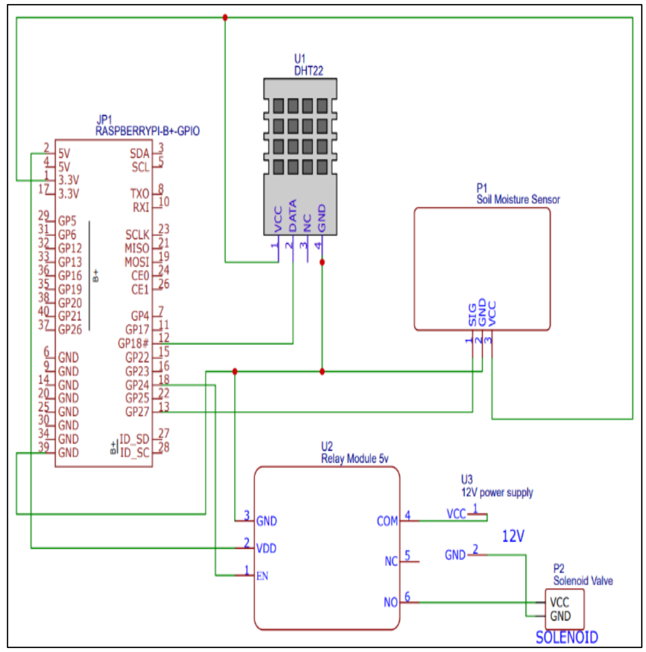

Fig. 2 Schematic of sensor and actuator connected to microcontroller

The Raspberry Pi 4B was chosen as the central microcontroller due to its processing power, connectivity options, and compatibility with Python programming. Wi-Fi was integrated for data transmission between sensors and the central control unit. Solenoid valves and sprinkler systems were implemented as actuators for controlling water flow, ensuring that the irrigation mechanisms could be remotely controlled and adjusted based on sensor data and predefined irrigation schedules.

Software development involved creating programs for real-time data acquisition from sensors using Python and implementing algorithms for processing sensor data, including data validation, filtering, and aggregation. Intelligent irrigation control algorithms were developed to use sensor data to determine optimal irrigation schedules. Machine learning techniques, such as decision trees and neural networks, were applied to predict irrigation needs based on historical data and real-time inputs.

A user-friendly mobile application was developed for farmers to monitor irrigation activities and system status, providing real-time data visualization, alerts, and remote-control capabilities. The flowchart for the app is shown in Figure 3, and the app's home screen is shown in Figure 4.

The system was then deployed in selected agricultural fields in El Cural, Arequipa, as shown in Figure 5, followed by initial tests to ensure the proper functioning of all components. Sensors and actuators were calibrated to ensure accurate data collection and irrigation control, and the irrigation control algorithms were fine-tuned based on initial field data and feedback from farmers.

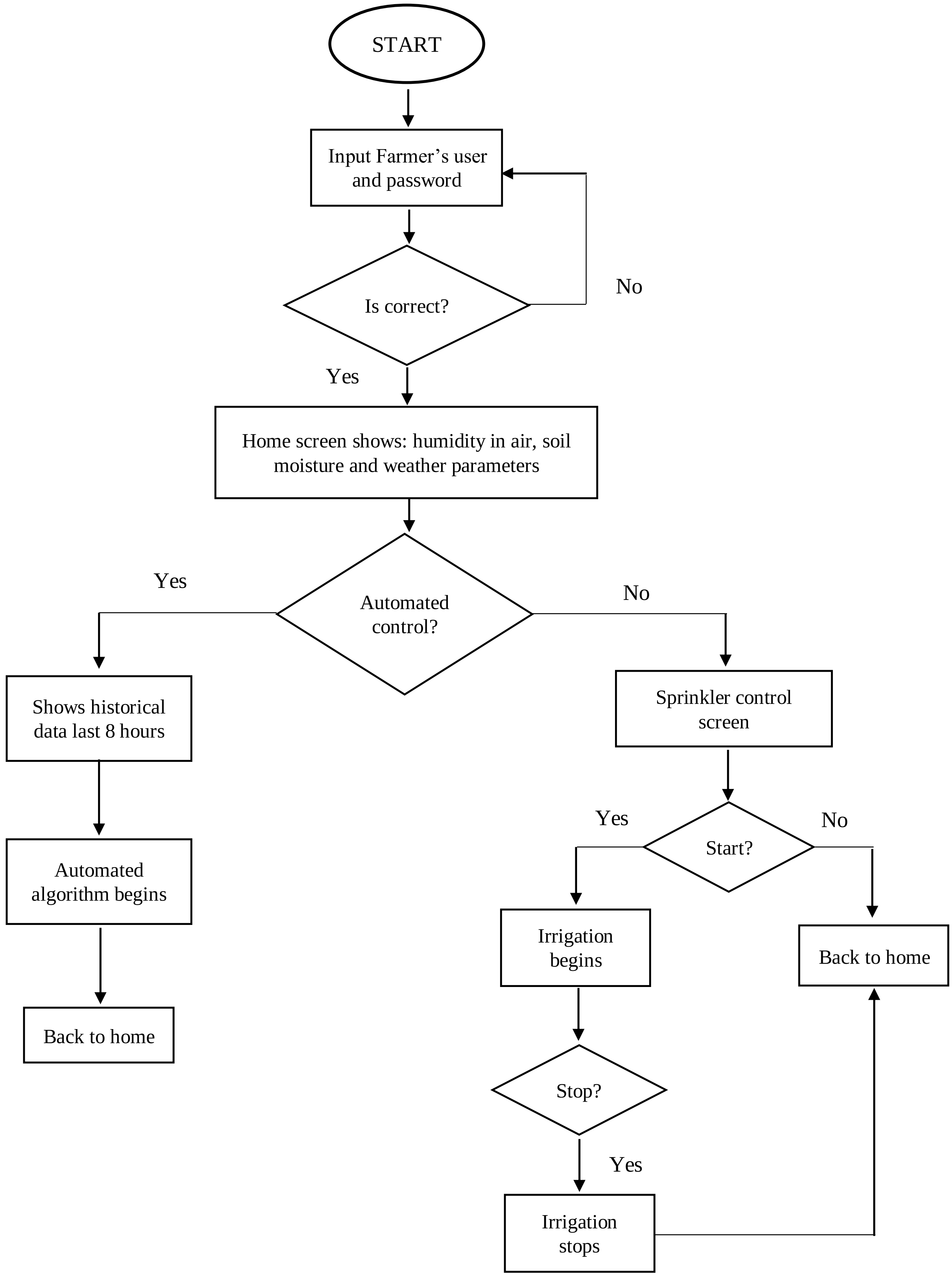

Fig. 3 Flowchart for the app performance

Performance metrics were defined to evaluate the system, including water usage efficiency, crop yield, and labor savings. Extensive field trials were conducted over multiple growing seasons to assess the system's performance, with data collected on soil moisture levels, water usage, crop health, and environmental conditions. The collected data was analyzed to evaluate the system's effectiveness in optimizing water use and improving crop yield. Feedback from local farmers was gathered to assess the system's usability, reliability, and overall impact on their agricultural practices.

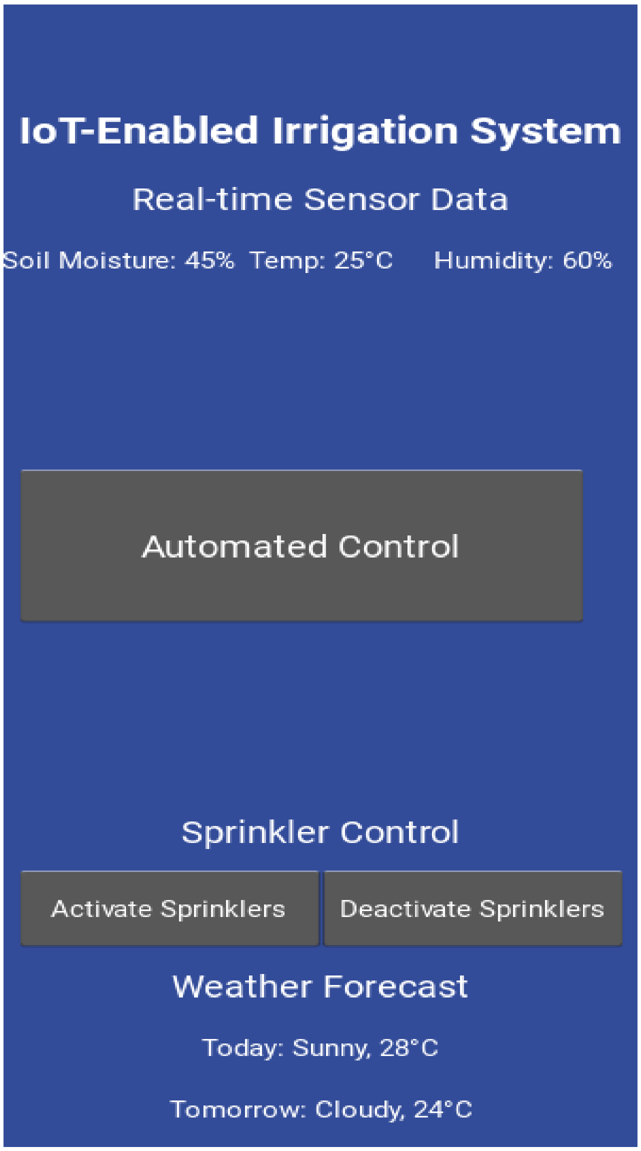

Fig. 4 App homescreen

Based on the evaluation results and farmer feedback, the system's hardware and software components were refined to improve performance and user satisfaction. The proposed methodology aimed to develop a cost-effective, efficient, and user-friendly IoT-enabled automated sprinkler irrigation system tailored to the agricultural needs of Arequipa, Peru. By leveraging advanced technologies and incorporating local farmer input, this system has the potential to significantly enhance water use efficiency, reduce labor costs, and promote sustainable agricultural practices in the region.

Fig. 5 The tests were made in farms from El Cural, Arequipa

4. Test and Results

The implementation of the IoT-enabled automated sprinkler irrigation system in Arequipa, Peru, demonstrated significant improvements in water management and agricultural productivity. The system's performance was evaluated based on sensor data, system responsiveness, and feedback from local farmers.

4.1. Sensor Data Collection and System Activation

Data from various sensors deployed across the agricultural fields were continuously monitored and transmitted to the central Raspberry Pi 4B microcontroller. The key sensors used in the system included:

- Soil Moisture Sensors (Capacitive and Resistive): These sensors measured the soil moisture levels at different depths, providing real-time data essential for determining irrigation needs.
- DHT22 Temperature and Humidity Sensors: These sensors monitor the ambient temperature and humidity, which are critical for understanding the environmental conditions affecting crop water requirements.
- Weather Stations: These stations collected data on precipitation, wind speed, and other weather parameters, aiding in the adjustment of irrigation schedules based on current weather conditions. The collected sensor data were processed by the Raspberry Pi using Python scripts. The system was programmed to activate or deactivate the solenoid valves, controlling the sprinklers based on predefined thresholds for soil moisture levels and environmental conditions. This automation ensured that water was applied only when necessary, optimizing water usage and improving crop health.

4.2. Data Transmission and User Accessibility

All sensor data were transmitted via Wi-Fi to a cloud-based storage system, providing farmers with real-time access. This cloud storage enabled farmers to review historical data on soil moisture, temperature, humidity, and weather conditions through a user-friendly web or mobile application. The application allowed for the following functionalities:

- Monitoring Historical Data: Farmers could access detailed logs of sensor readings over time, helping them make informed decisions about crop management
- Manual Control of Sprinklers: In addition to automated control, the application provided an option for manual activation of the sprinklers, allowing farmers to intervene based on their observations and experiences.

4.3. System Performance and Water Usage Efficiency

The system's effectiveness was evaluated by comparing water usage and crop yields before and after implementation. Approximate measurements of water used before and after the implementation of the system were taken from 5 farms of different sizes and crops.

There was a notable reduction in water consumption attributed to the precise and timely activation of sprinklers based on real-time soil moisture data. The system achieved an average water saving of 30% compared to traditional irrigation methods. The water saving for each farm is shown in Figure 6. The optimized irrigation schedules led to healthier crops and improved yields. On average, production increased by 12% over the previous crop, demonstrating the positive impact of the system on agricultural productivity. The increase by the farm is shown in Figure 7.

4.4. User Feedback and System Usability

To gather subjective feedback on the system's usability and overall satisfaction, Microsoft's Product Reaction Cards (MPRC) method was used among local farmers.

The farmers and some workers were asked to select words from a set of 118 predefined cards that best described their experience with the irrigation system. The feedback from the 43 people asked highlighted a generally positive reaction, as shown in Figure 8. Farmers appreciated the simplicity and intuitiveness of the web and mobile applications, making it easy to monitor and control the irrigation system.

The system was praised for its consistent efficiency and innovation, with minimal downtime or technical issues reported. Overall satisfaction was high, with farmers expressing a positive attitude towards the integration of IoT technology in their agricultural practices.

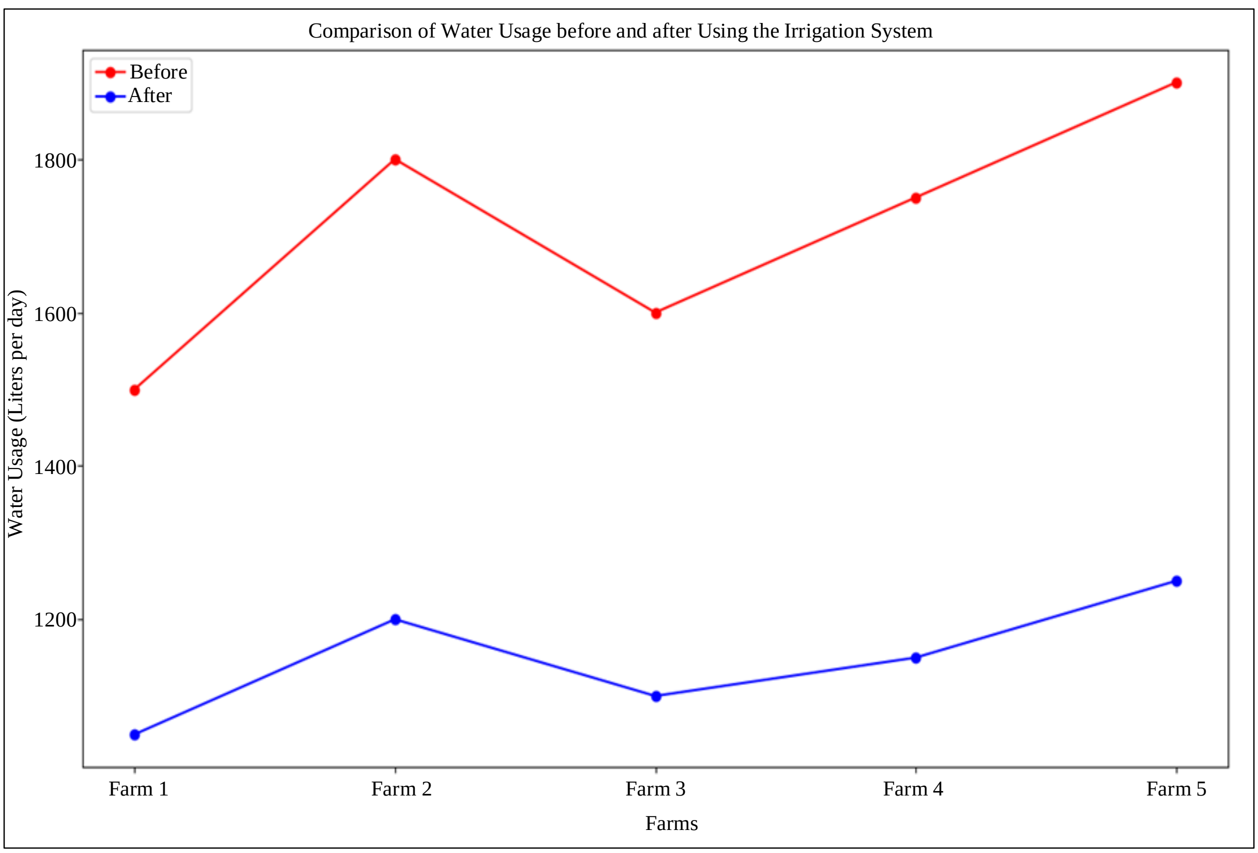

Fig. 6 Water used by each farm before and after using the system

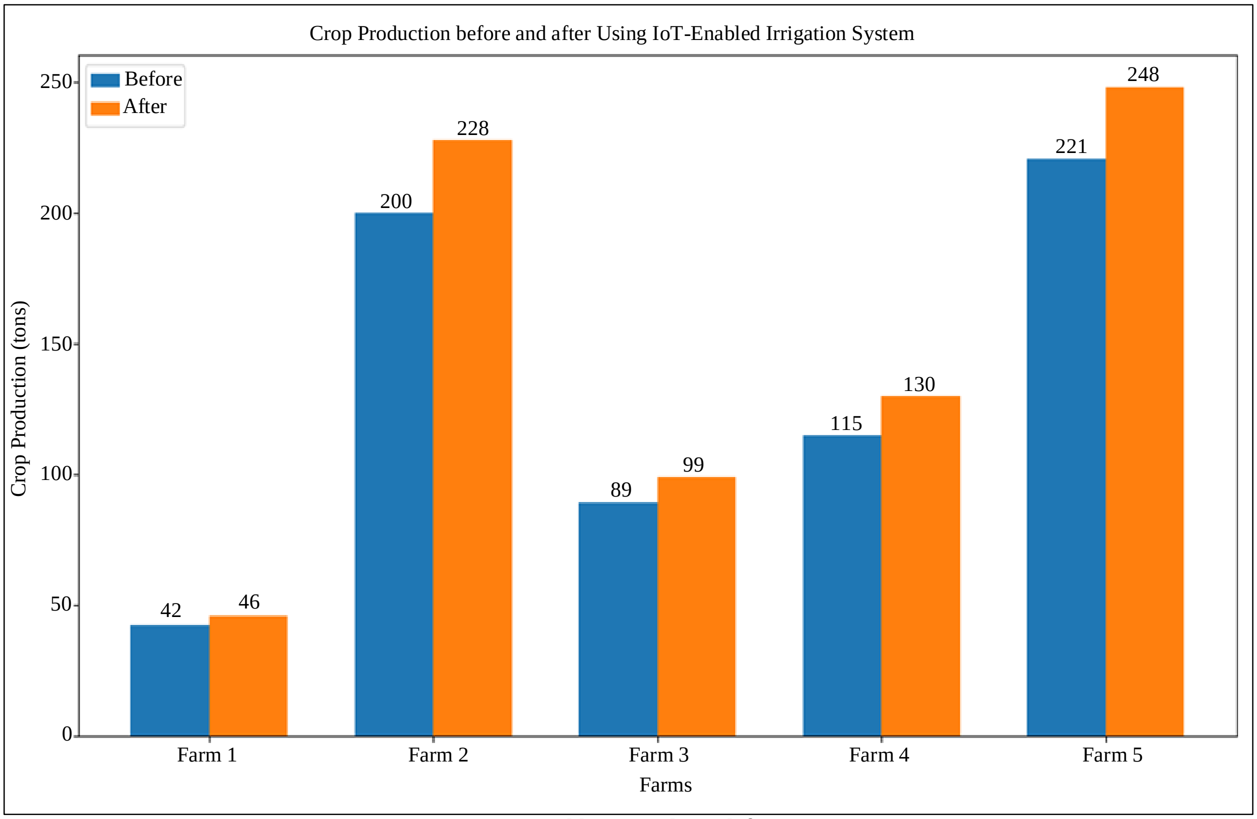

Fig. 7 Crop yield increase by each farm

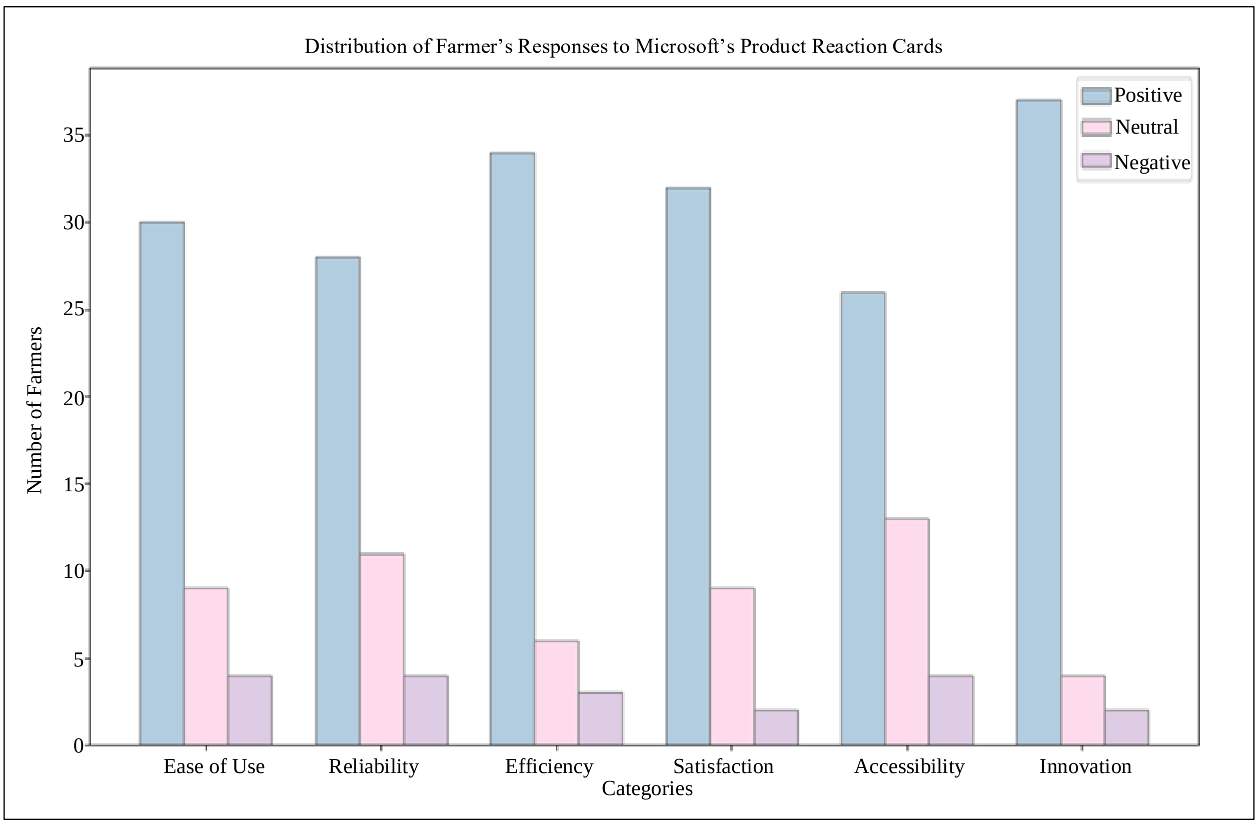

Fig. 8 Distribution of farmers' responses to MPRC

5. Conclusion

This study presents the development and implementation of an IoT-enabled automated sprinkler irrigation system designed to optimize water use in agricultural practices, specifically in El Cural, Arequipa, Peru. The system leverages real-time data from various sensors, including humidity, temperature, and soil moisture sensors, to make informed irrigation decisions and give data to the automated algorithm, thereby improving water efficiency and crop yields. The integration of IoT and machine learning technologies has shown great potential to transform traditional irrigation methods. By employing a low-cost, accessible and efficient solution, the system addresses critical issues of water wastage and labour-intensive irrigation practices. The ability to remotely monitor and control the irrigation process provides farmers with valuable information and flexibility, ultimately contributing to sustainable farming practices. The results of this study are consistent with previous research and highlight the benefits of IoT in agriculture. The system's real-time monitoring and automated control capabilities ensure accurate water distribution, reducing operating costs and environmental impact. Future work could focus on further integration of renewable energy sources and building up with low-cost materials. In conclusion, the IoT-enabled automated sprinkler irrigation system offers a viable and innovative solution for improving water management in agriculture, supporting the goals of sustainability and increased productivity in the agricultural sector.

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