SSRG International Journal of Electrical and Electronics Engineering
ISSN: 2348-8379/ https://doi.org/10.14445/23488379/IJEEE-V11I6P104

Volume 11 Issue 6, 31-40, June 2024

Original Article

Design and Development of an Integrated Monitoring and Automated Irrigation System with IoT Technologies for Sustainable Agriculture in Arequipa, Peru

Mario Abigail Cusi Huarancca[1], Luis Carlos León Huarache[2], Ramiro Cristobal Holguino[3], Raúl Ricardo Sulla Torres[4]

[1,2,3,4]*Universidad Nacional de San Agustin de Arequipa, Arequipa, Perú.*

[1]*Corresponding Author : mcusih@unsa.edu.pe*

Received: 02 April 2024 Revised: 04 May 2024 Accepted: 02 June 2024 Published: 29 June 2024

Abstract *- This paper presents the design, development and implementation of an integrated monitoring and automated irrigation system based on Internet of Things (IoT) technologies to optimize water use and improve agricultural productivity in the region of Arequipa, Peru. The system is composed of sensor nodes distributed in the field, a central control node, and a web-accessible user interface. Using soil sensors and actuators, the system adjusts irrigation based on real-time data on soil conditions. The pilot implementation showed a reduction in water consumption of up to 16% and an 18% increase in potato crop yields, demonstrating the feasibility and effectiveness of the system in real conditions. This approach promotes more sustainable and efficient agriculture, offering important lessons for the expansion of IoT technology in agricultural resource management.*

Keywords *- Automated irrigation, Internet of Things (IoT), Agriculture, Sensors, Technified irrigation.*

1. Introduction

Agriculture plays a vital role in Peru's economy and livelihoods, with potato cultivation being a significant part of agricultural activity. According to the Ministry of Agrarian Development and Irrigation (MIDAGRI) [1], potato production accounted for 15.1% of the gross value of agricultural production in 2022, generating approximately 6.0 million tons in an area of 340.9 thousand hectares, with an average yield of 17.6 tons per hectare in Peru.

However, the Peruvian agricultural sector faces critical challenges related to water management and irrigation efficiency. The National Water Authority (ANA) reports that 80% of available water in Peru is used for agriculture. However, it is estimated that about 70% of this resource is not distributed efficiently.

This problem is particularly acute in the Majes region, located in the department of Arequipa, Peru. Majes, known for its agricultural potential, faces significant obstacles that limit its productivity and sustainability. Inadequate irrigation structure, lack of modern technology, water scarcity and consequent low crop quality and production are factors that negatively affect farmers in the area. To address these specific challenges in Majes and improve the efficiency of the potato crop, an integrated monitoring and automated irrigation system based on Internet of Things (IoT) technologies is implemented. This innovative solution allows farmers in the region to monitor key variables such as soil moisture, temperature and pH in real time, reduce crop-specific water requirements, optimize the use of agricultural inputs, quickly detect and respond to problems, and improve decision making based on accurate and up-to-date data.

The system, designed specifically for Majes conditions, consists of an IoT sensor network, a data analysis platform, an automated irrigation system with solenoid valves, controllers with IoT integration, and a user interface. These components work together to provide a comprehensive solution to the irrigation and cultivation challenges in the region.

The implementation of this system in Majes not only increases water use efficiency but also contributes to significantly improving agricultural productivity and the quality of potato crops. In addition, it helps reduce operating costs, mitigate the effects of water scarcity, promote more sustainable agricultural practices, and empower local farmers with advanced technological tools.

This document is divided as follows: The related works are presented in Section 2, and the methodology is presented in Section 3. Section 4 describes the development of the system proposed, and the architecture system, hardware configuration and software configuration subdivide this section. Section 5 presents the test and results obtained. Finally, Section 7 presents the conclusions of the research.

2. Related Works

In recent years, the adoption of Internet of Things (IoT) technologies in agriculture has led to various smart irrigation systems designed to optimize the use of water resources and improve agricultural efficiency. One example of this is an IoT-based irrigation system that uses moisture sensors, NodeMCU, and a cloud platform. These sensors send data to the NodeMCU, which processes the information and triggers irrigation based on crop parameters. This system adapts dynamically using weather forecasts and real-time data, allowing farmers to control irrigation remotely through web or mobile applications, thus improving the efficiency and sustainability of water management [2].

Similarly, another IoT-backed smart approach optimizes conventional agriculture by collecting data on soil, water and environmental conditions. Sensors measure nutrients, soil conditions and water quality, providing additional security through motion detection and cameras. This data is analyzed locally and in the Google Cloud, enabling smart irrigation and accurate fertilization recommendations. This offers farmers increased efficiency, optimized yields, and enhanced security through real-time monitoring via a mobile app [3]. In addition, accurate information about soil conditions is essential for resource optimization in agriculture. Sensors identify nutrients and soil conditions, transmitting data to the cloud via technologies such as WiFi, LPWAN, LoRa and Bluetooth. The integration of weather data increases accuracy and reduces agricultural costs, driving automation without human contact through an embedded system that monitors soil and irrigation, replacing manual inspection with a mobile app [4].

In countries such as India, the minimum amount of water needed for cultivation has been investigated using Arduino technology and sensors that assess soil and weather conditions. This agricultural precision, together with cloud computing, maximizes water and fertilizer use efficiency, optimizing yields and assessing field weather conditions [5]. In the context of security in smart irrigation systems, the integration of lightweight cryptography techniques, such as the Expeditious Cipher (X-cipher) protocol, has been proposed. This approach uses the MQTT protocol to create secure channels, protecting sensor data and irrigation decisions from unauthorized alterations, as well as showing improvements in energy consumption and efficiency compared to AES and the PRESENT protocol [6].

A smart irrigation and monitoring system based on Mega 2560 and IoT has been implemented in India, where 85% of fresh water is used for agriculture. This system uses sensors and a microcontroller to send continuous data to the ThingSpeak cloud. When the soil moisture reaches the threshold, the system triggers irrigation and notifies the garden owner about sprinkler placement, optimizing water use through continuous data analysis [7]. In addition, another study proposes an IoT-based automated irrigation system for precision agriculture by integrating Precision Agriculture with cloud computing. This system allows farmers to adjust irrigation in real time through an intuitive interface, contributing to more abundant harvests and reducing water use [8].

Water pump monitoring using wireless sensors and a cloud server connected to the Blynk server has proven to be effective in remotely managing water pumps, optimizing irrigation and reducing dependence on schedules and electrical power [9]. At Siksha ‘O’ Anusandhan University (SOA), an innovative IoT-based system has been implemented to manage soil moisture. Using sensor nodes, wireless communication, and the cloud, the system enables real-time monitoring and automated control of irrigation, overcoming the limitations of manual methods. This system has improved water efficiency and is scalable to adapt to various crops [10].

In India, a smart irrigation system based on artificial intelligence and machine learning uses algorithms to predict soil moisture with 90% accuracy. This system, based on IoT sensors and the cloud, enables efficient water use, increasing yields and promoting agricultural sustainability [11]. Automation through IoT also addresses problems such as rural labor shortages. This study focuses on the creation of a smart irrigation system that enables decision making, remote monitoring, wireless operation, and voice control, improving efficiency in agriculture [12].

A comprehensive real-time prototype has been developed to address various agricultural issues. It uses Azure sensors and cloud services for irrigation control based on crop needs, weed and disease detection using imagery and machine learning, and crop identification and recommendation, enabling voice-based responses for farmers through a mobile app [13]. In Saudi Arabia, an advanced IoT-based agricultural automation system uses moisture sensors to control water pumps remotely. This approach optimizes irrigation and reduces dependence on schedules and electrical power, confirming its theoretical feasibility in a pilot test [14].

Although IoT faces security challenges, its implementation in agriculture has been shown to improve crop productivity and quality through efficient resource management and real-time monitoring [15]. A smart irrigation control system using IoT enables efficient monitoring of agricultural fields. Sensors measure parameters such as soil moisture and temperature, storing the data in the cloud. The pump is controlled manually or automatically by a mobile application, optimizing the use of water resources [16]. The adoption of scientific irrigation schedules is essential for efficient water use. An IoT-based precision irrigation system using a Wireless Sensor Network (WSN) has been shown to improve water use efficiency in irrigating crops such as hemp [17].

The integration of monitoring and control systems through a mobile application and cloud storage improves the continuous monitoring of agricultural fields. This system allows farmers to track in real time and adjust irrigation according to environmental conditions using a secure architecture with a webcam and sensors for agricultural monitoring [18]. An IoT-based prototype has been implemented to automatically control the water pump according to the soil moisture level, using an ESP32S microcontroller and sensors. Connected to the Arduino IoT cloud, this system allows global remote access and control, demonstrating its efficiency in the results section [19].

In India, a Raspberry Pi and IoT-based irrigation system has been developed using temperature, humidity, gas and LDR sensors to monitor environmental changes and estimate the water requirement in fields. The data are transmitted using the MQTT protocol, enabling the analysis of weather conditions and the implementation of precision agriculture with cloud computing [20]. A soil and irrigation monitoring system for agriculture in India has been proposed using the Google Firebase cloud server.

Sensors measure moisture, temperature, and nutrients, helping farmers make informed irrigation and crop decisions, with data accessible from any mobile device or computer [21]. The combination of IoT and Machine Learning (ML) in smart irrigation systems has proven to be highly effective. Using advanced algorithms such as Artificial Algebras (AAA) and Support Vector Least Squares Machines (LS-SVM), this IoTML-SIS system optimizes irrigation decisions with 97.5% accuracy, significantly improving agricultural efficiency [22]. These studies highlight the importance and potential of IoT in agriculture, demonstrating how the technology can transform traditional farming practices, increase efficiency and sustainability, and address challenges such as water scarcity and food security.

3. Methodology

To develop the integrated monitoring and automated irrigation system using IoT technologies, a structured approach involving several stages was followed (see Figure 1). Initially, extensive research was conducted to identify and select the most suitable components for the system, including soil sensors, irrigation actuators, microcontrollers, communication modules and central server.

Once the components were determined, the hardware was assembled, ensuring the proper connections between sensors, actuators, microcontroller and Raspberry Pi. Subsequently, the development of the necessary software for the system was carried out. This included programming the ESP32 microcontroller, configuring the MQTT server on the Raspberry Pi and creating a user interface for monitoring and controlling the system. Once this phase was completed, extensive testing was performed to verify the correct operation of the system under different conditions and scenarios. Aspects such as the accuracy of the sensors, the reliability of the wireless communication and the effectiveness of the actuator control were evaluated.

Finally, the system was piloted in a real agricultural environment in Majes, Arequipa. This involved working closely with local farmers to install the system in their fields and gather feedback on its performance and functionality. This approach ensured the feasibility and effectiveness of the system in a practical agricultural application context.

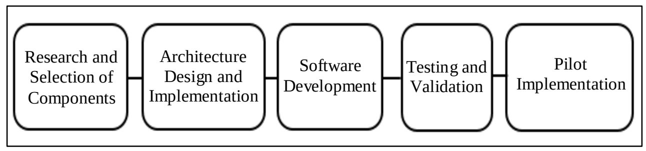


Fig. 1 Stages of integrated system development

4. Developed System

Farmers in the Majes region of Arequipa have traditionally been using sprinkler irrigation systems (see Figure 2), which have not produced good results and have led to a significant waste of available water. Therefore, it was decided to include a drip irrigation system to optimize water use (See Figure 3).

Fig. 2 Sprinkler irrigation system used normally

The integration of IoT technologies in agriculture, such as the automated monitoring and irrigation system developed for crops, has been shown to improve agricultural efficiency and sustainability.

This system, which uses drip irrigation in 4 main branches for the 4 sensor nodes, was designed specifically for potato cultivation, taking advantage of drip irrigation to strengthen the roots and ensure optimal product quality.

Fig. 3 Piping network for new drip irrigation system

Parameters such as temperature, humidity and pH were considered and programmed, adapted to the characteristics of the potato, such as its optimum temperature range of 15 to 25 degrees celsius, its preference for a humidity between 60 and 80%, and a pH of 5.5 to 6.5, data that are adjusted to its origin in the Andean Region and its different varieties and vegetative periods according to the region.

4.1. System Architecture

The developed system is based on an Internet of Things (IoT) architecture, which includes several hardware and software components, with the purpose of supervising and regulating crop irrigation in an automated way (See Figure 4).

It consists of three essential elements: the sensor nodes, arranged in a distributed manner in the field; the central control and monitoring node; and the user interface, which is web-based and facilitates the visualization and configuration of the system.

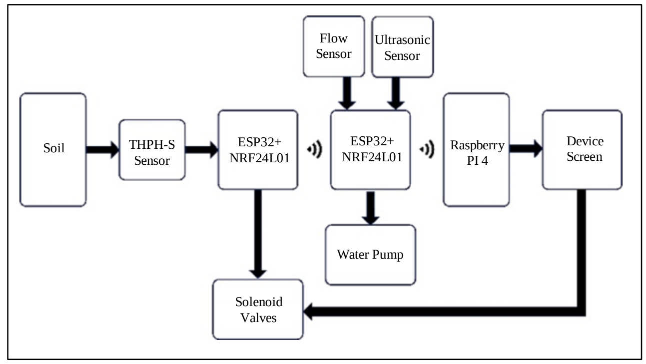


Fig. 4 Block diagram of a smart irrigation system using IoT

As for the sensor nodes, each one is equipped with an ESP32 microcontroller and an NRF24L01 transceiver module for wireless communication (See Figure 5.). These nodes are strategically distributed at different locations in the field and are responsible for collecting data from the soil temperature, moisture and pH sensors (THPH-S). Subsequently, these data are sent to the central control node via wireless communication.

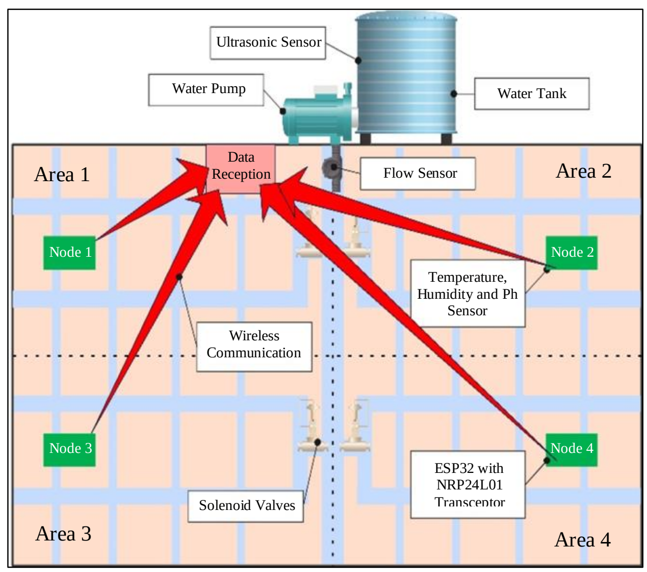


Fig. 5 Node distribution and wireless communications

The central control node also makes use of an ESP32 microcontroller to receive the data sent by the sensor nodes. In addition to this, it controls the irrigation solenoid valves and the water pump according to predefined thresholds and sensor readings. Also connected here are the HC-SR04 ultrasonic and flow sensors (See Figure 6.), which provide key information about the water level in the storage tank and the water flow through the irrigation system, respectively. Finally, the user interface is implemented using a Raspberry Pi as the MQTT server for communication between the central control node and the web-based interface. The Node-RED software is used for visualization and configuration of the system. Node-RED allows the creation of interactive data streams that provide an intuitive interface for monitoring soil conditions and controlling irrigation remotely. This distributed architecture provides a robust and scalable solution for automated irrigation monitoring and control, enabling farmers to manage their crop irrigation and improve agricultural productivity efficiently.

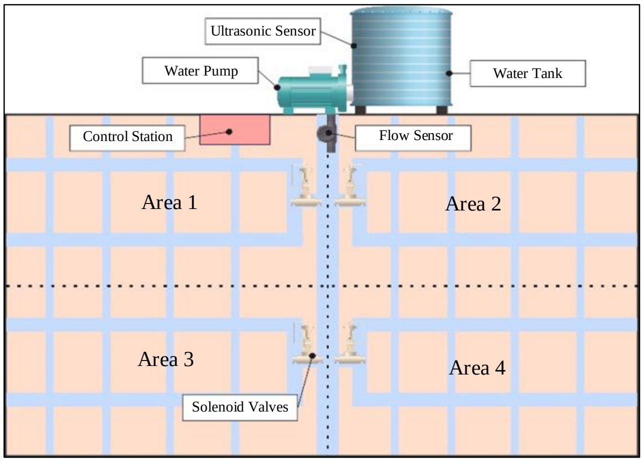


Fig. 6 Area distribution and central node

4.2. Hardware Configuration

The hardware configuration of the system comprises the selection and arrangement of the physical components that compose it. The hardware configuration used in the developed system is detailed below.

4.2.1. Sensor Nodes

They are equipped with ESP32 microcontrollers, which act as the brain of the system by enabling data acquisition and wireless communication with the central control node. To establish this communication, NRF24L01 transceiver modules are used, which ensure a stable and low power consumption wireless connection. Each sensor node is equipped with a THPH-S sensor, which integrates pH, temperature, and soil moisture measurement capabilities. However, to facilitate connectivity with the ESP32 microcontroller, an RS485 to TTL conversion module is required (See Figure 7). This configuration allows for accurate data acquisition of soil conditions, which is essential for efficient irrigation management.

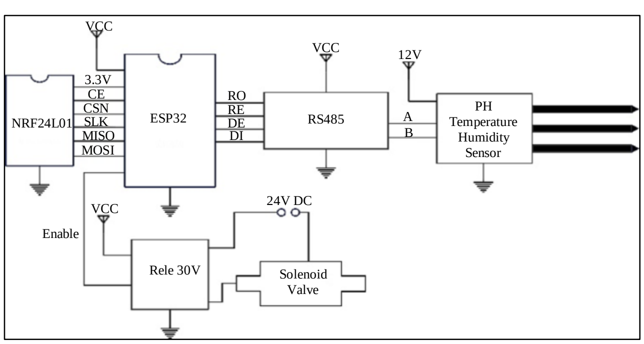


Fig. 7 Soil sensor and transceiver connections on distributed nodes

4.2.2. Central Control Node

It is composed of an ESP32 microcontroller, which is responsible for managing the reception of data from the sensor nodes and controlling the irrigation solenoid valves and the water pump. In addition, this central node incorporates ultrasonic and flow sensors (see Figure 8), which monitor the water level in the storage tank and the water flow through the irrigation system, respectively.

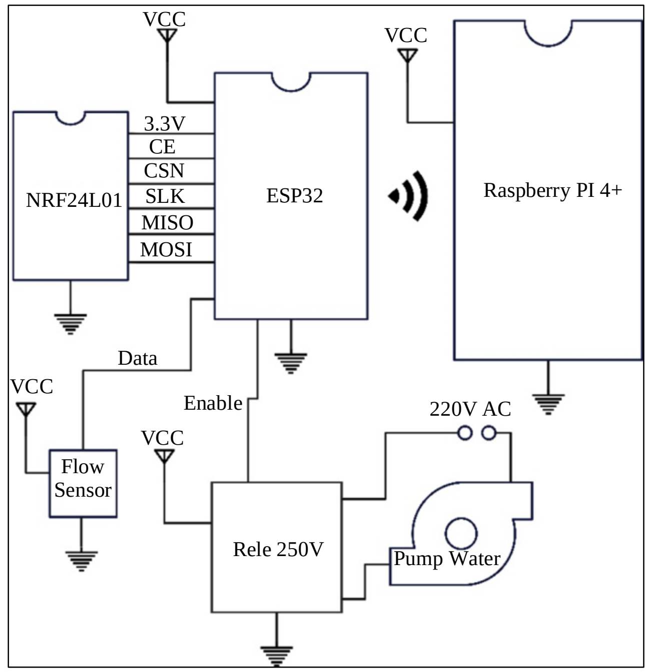


Fig. 8 Connection of data reception and irrigation control on the central node and Raspberry Pi 4

4.2.3. User Interface

It is based on a Raspberry Pi, which acts as a server for the web interface. Through the Node-RED software, an intuitive visual interface is provided to interact with the monitoring and irrigation system. In addition, InfluxDB is used as a database to store and manage the data collected by the system, which facilitates detailed analysis and effective visualization of the data. This hardware configuration ensures reliable and efficient operation of the automated irrigation and monitoring system, with careful selection of components to ensure harmonious integration and optimal performance in the field.

4.3. Software Configuration

The implementation of the automated irrigation and monitoring system requires a precise configuration of the software to ensure its effective operation. An MQTT protocol is used, in which a Raspberry Pi 4 is the broker that connects to the 4 ESP32 sensor nodes and the ESP32 central node (See Figure 9). First, the ESP32 microcontroller firmware is programmed using the Thonny IDE integrated development environment. Custom code is developed that facilitates data acquisition from the sensors, wireless communication with the central control node using the MQTT protocol, and control of the irrigation solenoid valves and water pump. Control algorithms are implemented that use the sensor data to activate or deactivate the irrigation devices as needed.

The central control node, which is also an ESP32, uses custom firmware developed specifically for this purpose. This firmware is programmed on the ESP32 microcontroller and is responsible for managing communication with the sensor nodes through the MQTT broker, receiving and processing sensor data, and controlling the irrigation solenoid valves and water pump based on the data received. In addition, control logic is implemented to ensure efficient water use and optimize crop irrigation.

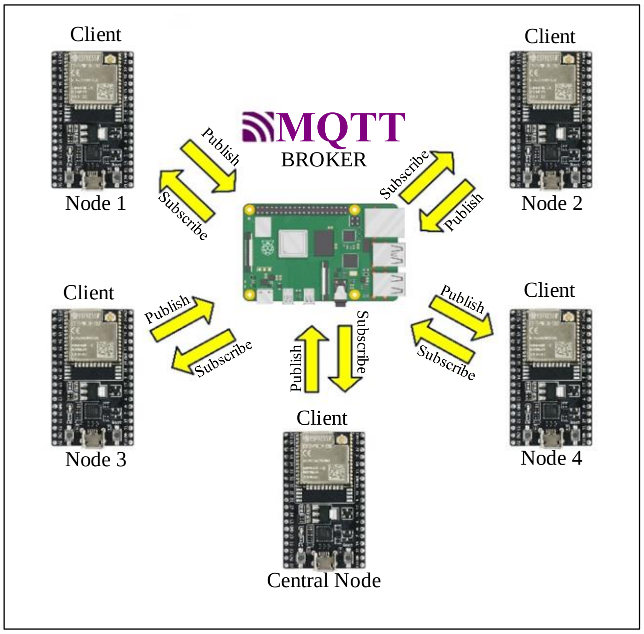


Fig. 9 MQTT network with Raspberry Pi 4 and ESP32

For the user interface, the Node-RED framework is used to create an intuitive visual interface that allows the user to monitor system status, visualize sensor data in real time, and adjust system settings as needed. A responsive user interface is implemented that adapts to different devices and screen sizes for an optimal user experience (See Figure 10).

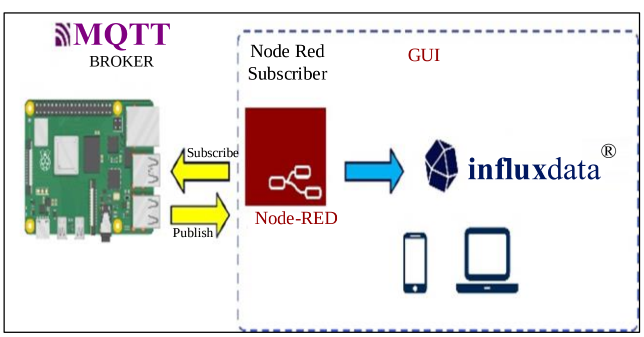


Fig. 10 MQTT communication with node-RED and influx DB for user interface

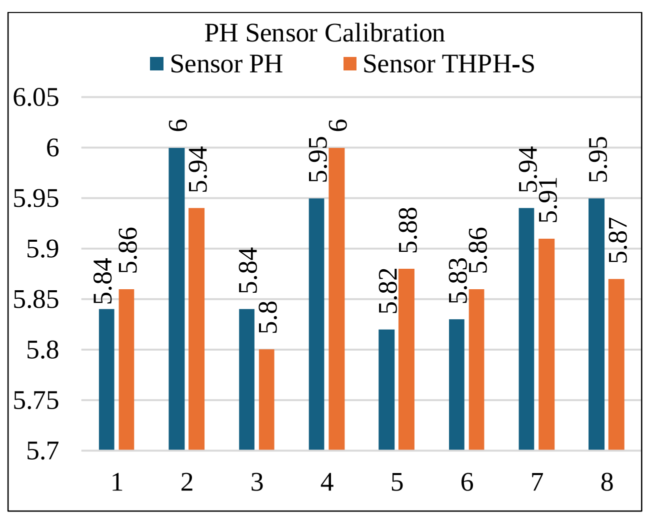
Finally, InfluxDB is used as the database to store and manage the data collected by the system. InfluxDB provides a robust and scalable platform for storing time series data, which facilitates the analysis and visualization of historical data. InfluxDB is configured to store sensor data at regular intervals and is integrated with the user interface to provide real-time graphs and visualizations of the data (See Figure 11). The software configuration is carefully designed to ensure efficient and reliable operation of the automated irrigation and monitoring system, providing the user with an intuitive and user-friendly experience for managing their crops.

Fig. 11 InfluxDB dashboard

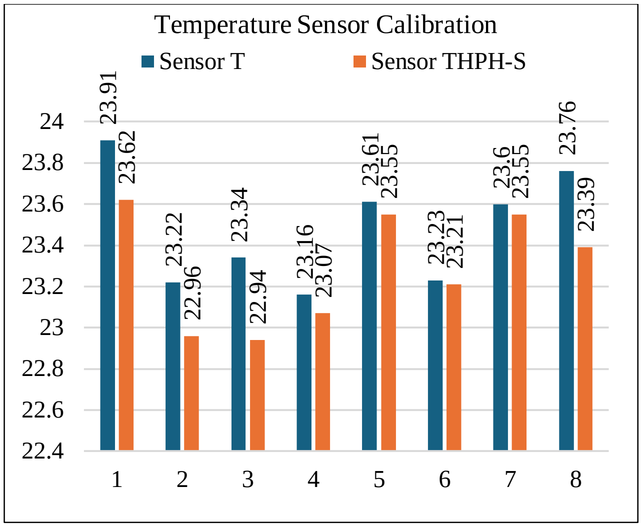
5. Tests and Results

To evaluate the effectiveness, performance and feasibility of the automated irrigation and monitoring system, a pilot implementation was carried out in a real field environment in the Arequipa region of Peru. Extensive testing was conducted over a full growing season, allowing for the collection of empirical data on the performance of the system and its impact on agricultural management.

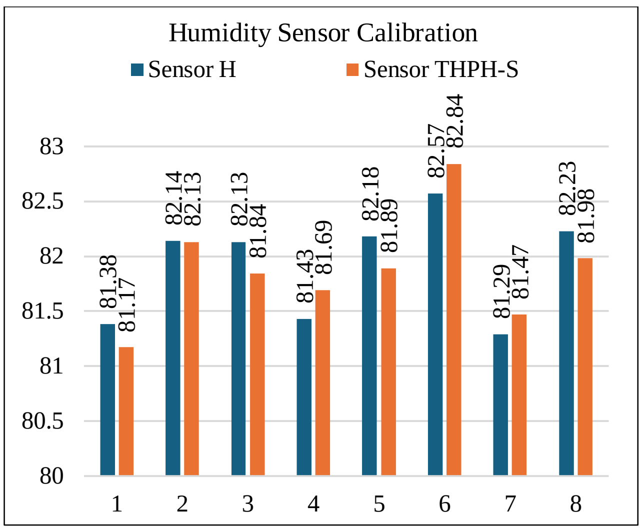
The accuracy of the THPH-S sensors was evaluated by comparing their readings with manual measurements made by experts. The results showed high accuracy, with deviations of less than 2% for soil moisture, 0.5°C for temperature and 0.2 pH units compared to reference values (See Figure 12).



(a) pH values



(b) Temperature values



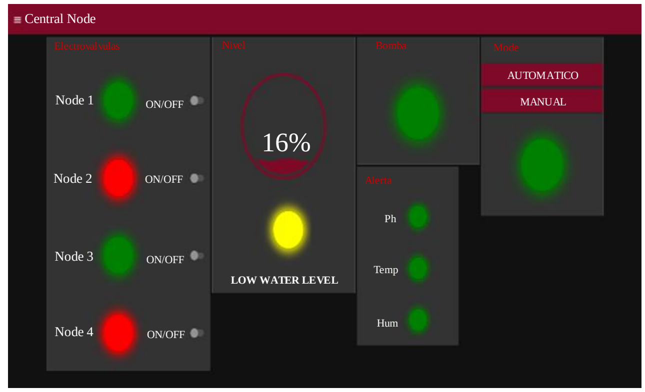
(c) Humidity values

Fig. 12 Comparison of values taken with high-precision sensors and the THPH-S

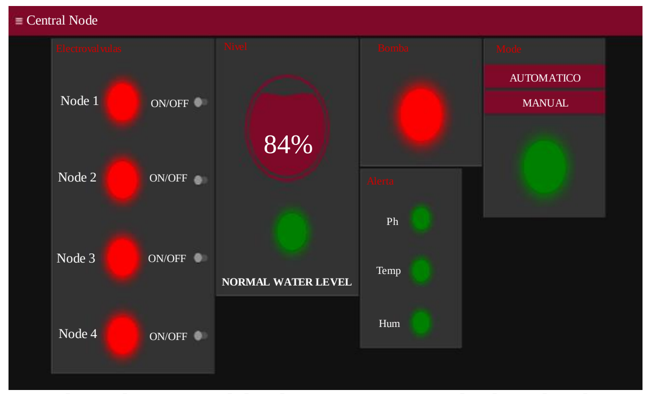
In the process of validation of the automated irrigation system, exhaustive tests were carried out on the dashboard of the central node to verify the correct operation of the critical components. The status of the solenoid valves of each node, the level of the water tank through its corresponding indicator, the activation of the water pump, as well as the reading of values within normal ranges for the pH, humidity and temperature parameters were monitored.

Additionally, the capacity to activate the manual operation mode was verified.

On the other hand, several tests were carried out to ensure the adequate performance of the control devices, such as the solenoid valves and the water pump, under different operating conditions (see Figure 13). The results obtained showed a reliability higher than 98% in the precise control of irrigation.



(a) Low water tank level, pump active and node 1 and 3 valves open



(b) High water tank level, pump inactive and valves closed

(c) Manual mode activated, node 1 and 2 valves activated, and pump deactivated

Fig. 13 Central node dashboard testing and parameter verification

The reliability and stability of data transmission over the NRF24L01 wireless network between the sensor nodes and the central node were evaluated. A communication success rate of 99.7% was obtained, demonstrating the robustness of the wireless connection.

Usability tests were conducted with a group of local farmers, who evaluated the ease of use and effectiveness of the web interface. The System Usability Scale (SUS) was used, obtaining an average score of 96.5, indicating excellent usability by industry standards (see Figure 14).

Compared to traditional irrigation methods, the automated system demonstrated water savings of up to 16.12%, thanks to precise irrigation application based on sensor data (See Figure 15). In addition, an 18% increase in potato crop yield was observed, attributable to optimized irrigation cycles (See Figure 16). These results support the effectiveness and feasibility of the IoT-based automated irrigation and monitoring system. Its implementation in the Arequipa region has the potential to contribute significantly to the sustainability of agricultural practices by optimizing water use and increasing crop productivity.

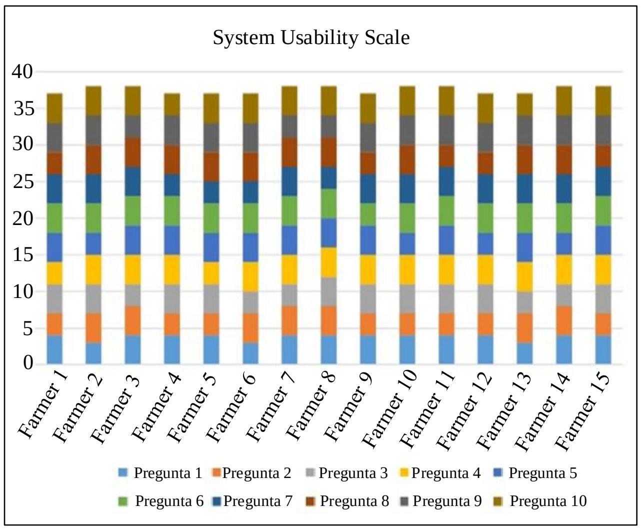


Fig. 14 SUS results applied to agricultors

In addition, farmers expressed high satisfaction with the user interface, highlighting its ease of use and its ability to provide valuable information on crop status and irrigation needs. Areas for improvement, such as optimizing the control logic and integrating new features, were identified and will be addressed in future iterations of the system.

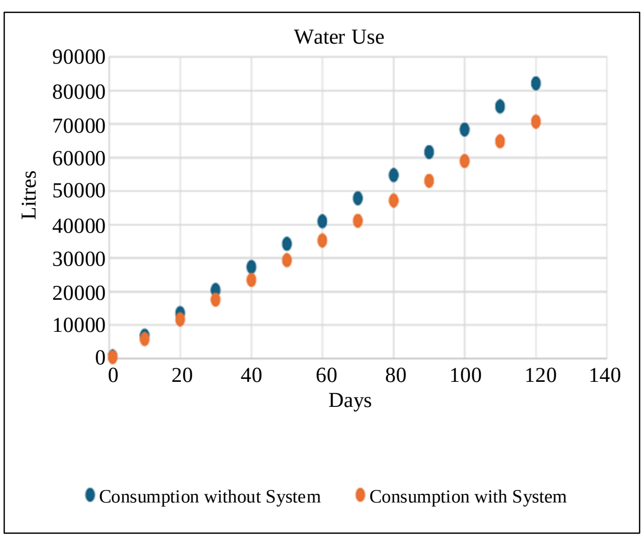


Fig. 15 Water use with the proposed system

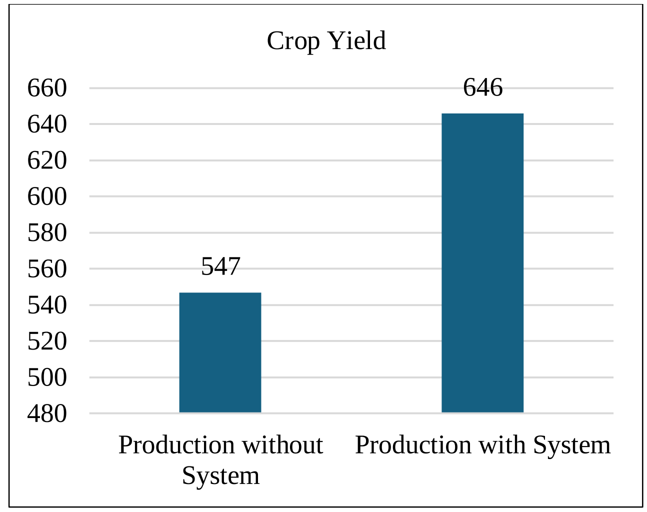


Fig. 16 Increased production with the proposed system

6. Discussion

The results obtained in the pilot implementation of the automated irrigation system in Arequipa demonstrate that the use of IoT technologies in agriculture can have a significant impact on water use efficiency and crop yields. The system enabled a 16.12% reduction in water consumption, which is a remarkable advance considering that 80% of available water in Peru is used for agriculture, and about 70% of it is not distributed efficiently.

Furthermore, the 18% increase in potato crop yields is a clear indicator that real-time data-driven irrigation not only conserves resources but also improves agricultural productivity. These findings are consistent with previous studies that have demonstrated similar benefits in other regions and with other types of crops. Importantly, the adoption of this technology also offers advantages in terms of informed and accurate decision-making.

Farmers, having real-time data on soil moisture, temperature and pH, can adjust their irrigation practices optimally, mitigating the negative effects of climatic and economic challenges. However, it is crucial to consider some challenges associated with the implementation of IoT systems in agriculture.

Data security and privacy are aspects that require continuous attention to avoid vulnerabilities that could compromise the system. Also, training and technical support to farmers are critical to ensure a successful and sustained adoption of these technologies.

7. Conclusion

This study has demonstrated the significant potential of automated irrigation systems based on IoT technologies to transform agricultural resource management in arid regions such as Arequipa. The implementation of an integrated monitoring and irrigation system has led to significant improvements in water use efficiency and increased agricultural productivity. The results obtained show a 16.12% reduction in water consumption and an 18% increase in potato crop yields, underscoring the ability of this technology to optimize the use of water resources and provide valuable information for decision-making based on real-time data.

In addition, the adoption of this technology empowers farmers with accurate and timely information on soil and weather conditions, allowing them to adjust their irrigation practices optimally. However, successful implementation of these systems requires attention to data security, privacy, and technical training of users.

In conclusion, IoT-based automated irrigation systems offer a sustainable and efficient solution for water management and improved agricultural productivity in arid areas. This approach can be replicated and adapted to other regions with similar conditions, contributing to the resilience and sustainability of agriculture in the face of climate change challenges.

Acknowledgments

The authors express their sincere gratitude to the Universidad Nacional de San Agustín de Arequipa for their invaluable support and collaboration throughout the research process.

References

[1] Ministry of Agrarian Development and Irrigation, Observatory of Sowing and Production Prospects 2023, 2024. [Online]. Available: https://www.gob.pe/institucion/midagri/informes-publicaciones/4344772-observatorio-de-siembras-y-perspectivas-de-produccion-2023

[2] Sreelatha Reddy V., Harivardhagini S., and Sreelakshmi G., "IoT and Cloud Based Sustainable Smart Irrigation System," *E3S Web of Conferences*, vol. 472, 2024. [CrossRef] [Google Scholar] [Publisher Link]

[3] Ujjaval Patel, Rohit Patel, and Priyank Kadecha, *An IoT-Aided Smart Agritech System for Crop Yield Optimization*, Precision Agriculture for Sustainability, 1st ed., pp. 433-452, 2024. [Google Scholar] [Publisher Link]

[4] Tran Thi Hong Ngoc, Phan Truong Khanh, and Sabyasachi Pramanik., *Smart Agriculture Using a Soil Monitoring System*, Handbook of Research on AI-Equipped IoT Applications in High-Tech Agriculture, pp. 200-220, 2023. [CrossRef] [Google Scholar] [Publisher Link]

[5] Manjunathan Alagarsamy et al., "Automation Irrigation System Using Arduino for Smart Crop Field Productivity," *International Journal of Reconfigurable and Embedded Systems*, vol. 12, no. 1, pp. 70-77, 2023. [CrossRef] [Google Scholar] [Publisher Link]

[6] Cherine Fathy, and Hassan M. Ali, "A Secure IoT-Based Irrigation System for Precision Agriculture Using the Expeditious Cipher," *Sensors*, vol. 23, no. 4, pp. 1-16, 2023. [CrossRef] [Google Scholar] [Publisher Link]

[7] Ipseeta Nanda, Monika Singh, and Lizina Khatua, "Automated Irrigation System Using IoT Cloud Computing," *International Journal of Intelligent Systems and Applications in Engineering*, vol. 11, no. 2s, pp. 360-365, 2023. [Google Scholar] [Publisher Link]

[8] Ajay Kumar, Raj Gaurang Tiwari, and Naresh Kumar Trivedi, "Smart Farming: Design and Implementation of an IoT-Based Automated Irrigation System for Precision Agriculture," *2023 3rd International Conference on Innovative Sustainable Computational Technologies (CISCT)*, Dehradun, India, pp. 1-6, 2023. [CrossRef] [Google Scholar] [Publisher Link]

[9] Shivam Amoli et al., "Internet of Things Enabled System for Water Pump Monitoring," *2023 4th International Conference on Smart Electronics and Communication (ICOSEC)*, Trichy, India, pp. 388-391, 2023. [CrossRef] [Google Scholar] [Publisher Link]

[10] Suprava Ranjan Laha et al., "An IOT-Based Soil Moisture Management System for Precision Agriculture: Real-Time Monitoring and Automated Irrigation Control," *2023 4th International Conference on Smart Electronics and Communication (ICOSEC)*, Trichy, India, pp. 451-455, 2023. [CrossRef] [Google Scholar] [Publisher Link]

[11] Gunjan Bobade et al., "Design of Smart Irrigation System Based on MLA," *2023 IEEE World Conference on Applied Intelligence and Computing (AIC)*, Sonbhadra, India, pp. 174-179, 2023. [CrossRef] [Google Scholar] [Publisher Link]

[12] Moustafam Kurdi, "Smart Irrigation System Using LoRaWAN," *2023 International Conference on Information Technology: Cybersecurity Challenges for Sustainable Cities (ICIT)*, Amman, Jordan, pp. 108-113, 2023. [CrossRef] [Google Scholar] [Publisher Link]

[13] Shyam Peraka et al., "FPGA Based Smart and Sustainable Agriculture," *2023 36th International Conference on VLSI Design and 2023 22nd International Conference on Embedded Systems (VLSID)*, Hyderabad, India, pp. 274-278, 2023. [CrossRef] [Google Scholar] [Publisher Link]

[14] Shabana Habib et al., "Design and Implementation: An IoT-Framework-Based Automated Wastewater Irrigation System," *Electronics*, vol. 12, no. 1, pp. 1-12, 2023. [CrossRef] [Google Scholar] [Publisher Link]

[15] A. Kumar, and R. Jha, "IoT in Smart Farming: A Boon to Farmers," *Internet of Everything: Smart Sensing Technologies*, pp. 185-206, 2022.

[16] Ramachandran Veerachamy et al., "Autonomous Application Controls on Smart Irrigation," *Sensors, Computers and Electrical Engineering*, vol. 100, 2022. [CrossRef] [Google Scholar] [Publisher Link]

[17] Zisis Tsiropoulos et al., "Sustainable Irrigation Using Internet of Things," *TAE 2022 - Proceeding of the 8th International Conference on Trends in Agricultural Engineering*, pp. 394-401, 2022. [Google Scholar] [Publisher Link]

[18] Lalit Kumar, and Pradeep Kumar, "Webcam Based Secure Surveillance System for the Smart Agriculture Using Raspberry Pi," *2022 International Conference on Smart Generation Computing, Communication and Networking (SMART GENCON)*, Bangalore, India, pp. 1-6, 2022. [CrossRef] [Google Scholar] [Publisher Link]

[19] Viswanatha V. et al., "Implementation of IoT in Agriculture: A Scientific Approach for Smart Irrigation," *2022 IEEE 2nd Mysore Sub Section International Conference (MysuruCon)*, Mysuru, India, pp. 1-6, 2022. [CrossRef] [Google Scholar] [Publisher Link]

[20] G. Saranyadevi et al., "Smart Irrigation for Enhanced Agriculture Production Using IoT," *Computational Intelligence in Machine Learning*, vol. 834, pp. 289-299, 2022. [CrossRef] [Google Scholar] [Publisher Link]

[21] K. Gayathri, and S. Thangavelu, "Monitoring the Soil Parameters Using IoT for Smart Agriculture," *Intelligent Data Communication Technologies and Internet of Things*, vol. 101, pp. 743-757, 2022. [CrossRef] [Google Scholar] [Publisher Link]

[22] Khalil Ibrahim Mohammad Abuzanouneh et al., "Design of Machine Learning Based Smart Irrigation System for Precision Agriculture," *Computers, Materials and Continua*, vol. 72, no. 1, pp. 109-124, 2022. [CrossRef] [Google Scholar] [Publisher Link]