Smart irrigation system with internet of things for rose cultivation in a basic greenhouse in Canchis, Cusco, 2025

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ABSTRACT

A large percentage of the world's freshwater is allocated to agriculture, which presents a significant challenge for the future in light of a growing global population and climate change. In this context, it is essential to implement technologies that enable more efficient water resource management. Consequently, a smart irrigation system with internet of things (IoT) was developed for rose cultivation in a basic greenhouse located in Canchis, in the Cusco region, in 2025. This project integrated sensors for data acquisition, ESP32 modules for control, and solenoid valves as actuators. Additionally, the ThingSpeak platform was used for monitoring. The implementation of the system in the basic greenhouse demonstrated reliable communication between the different nodes and the virtual platform, as well as full automation through the solenoid valve's response to a defined threshold. Finally, it showed an average water consumption savings per irrigation of up to 46.26% compared to the previous system.

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1. INTRODUCTION

In Peru, agriculture plays a fundamental role in the national economy, but it is also the sector that consumes the largest amount of freshwater. According to Ministry of Agrarian Development and Irrigation [1] it was estimated that in 2023, over 80% of the country's water usage was allocated to agriculture, primarily for crop irrigation. Therefore, there is an urgent need to transition toward agricultural practices that incorporate technological advances in order to preserve the available natural resources [2], [3]. One of the most commonly used irrigation systems in basic greenhouses is drip irrigation; however, this system does not monitor soil moisture or irrigation time [4]. These factors are essential for crop growth and development, as over-irrigation can lead to plant diseases. In rose cultivation, the flower's lifespan and quality largely depend on proper water supply. If this resource is interrupted, wilting of buds, leaves, and petals occurs rapidly [5]. Thus, optimizing the irrigation system for rose cultivation is critical to ensure efficient water use.

In recent years, various technological innovations have been implemented to improve agricultural processes and address sector-specific needs [6]. One of these innovations is the internet of things (IoT), which has proven to be a key tool in agriculture. For instance, a study demonstrated that a system based on moisture, temperature, and sunlight sensors—managed through cloud platforms and controlled via Arduino—helped apply only the necessary amount of water, reducing waste and improving efficiency [7]. Another study implemented precision agriculture in a greenhouse by using descriptive and statistical methods to control environmental conditions and automate previously manual agricultural processes [8]. In Peru, a research project based on IoT technologies developed and deployed an integrated monitoring system using sensor nodes (SN) distributed across the field, with a user interface accessible via the web. The pilot implementation showed a water usage reduction of up to 16%, along with an 18% increase in potato crop yield [9]. Meanwhile, a study in Malaysia introduced an IoT-based fertigation (irrigation and fertilization) control system. This approach integrated a NodeMCU ESP32 microcontroller, and through electrical conductivity and pH sensors, the system accurately recorded nutrient concentration and acidity levels, displaying the data on an IoT platform for real-time monitoring [10]. Another Malaysian study developed and implemented an automated irrigation system incorporating multisensor capabilities—specifically for measuring temperature and soil moisture—using an Arduino MEGA 2560 microcontroller together with a mobile monitoring application. The system operated via an algorithm that adapted irrigation based on the detected soil type, allowing for more precise water resource management [11]. Similarly, in Thailand, IoT was used to support agricultural operations in greenhouses. This research presented an irrigation control system implementation that monitored soil moisture and temperature levels [12].

An IoT-based smart SN integrating soil moisture and pH sensors was implemented in Sabu *et al*. [13], enabling efficient water management. The collected information was transmitted to a cloud platform, allowing farmers to monitor field conditions in real time from any remote location. Similarly, in Florea *et al.* [14], a flexible, scalable, and user-friendly integrated IoT system was designed and implemented to automatically control sprinkler irrigation in a conifer nursery. The solution combined sensors, solenoid valves, Raspberry Pi microcontrollers, fuzzy logic, a web interface, and cloud services, successfully managing water resources under variable weather conditions.

In low-resource environments such as basic greenhouses, practical solutions have been deployed that combine sensors and mobile platforms to manage crops like strawberries, achieving notable savings in water, fertilizers, and pesticides without the need for complex technology [15]. Likewise, the use of wireless sensor networks and fuzzy logic has enabled the development of zoned irrigation systems that automatically adjust based on soil and environmental conditions. One such system reported a 26.41% improvement in water savings [16]. At a more advanced level, a study on drought stress detection in vegetable crops monitored acoustic emissions from plants and was applied to tomato cultivation, resulting in more precise irrigation models [17]. Campos *et al.* [18] proposed a comprehensive system that not only monitors and predicts soil moisture but also filters outliers and synchronizes data from various sources. This enables more accurate decision-making, even in fields without direct soil moisture sensors. The results showed significant water savings. Finally, the integration of technologies such as IoT, artificial intelligence, 5G networks, and decision support systems (SDSS) offers a robust ecosystem for smart agriculture, although developing countries like Peru continue to face barriers in technology adoption, limited infrastructure, and weak institutional support [19]. In this scenario, it is essential to develop context-adapted solutions for the Peruvian highlands.

In the high Andean rural areas, traditional irrigation systems rely on manual control, leading to inefficient water use and variability in crop quality. Although several automatic irrigation systems based on technologies such as Arduino and Raspberry Pi have been developed, many of them still present limitations related to cost, system complexity, and dependence on constant Internet connectivity. In this context, the present study proposes an intelligent irrigation system based on the IoT using ESP32 microcontrollers and ESP-NOW communication, which enables data transmission between nodes without the need for a router. The system, integrated with the ThingSpeak platform, aims to improve water efficiency in a basic greenhouse located in the Canchis region of Cusco, Peru.

The main objectives of this research were to automate irrigation according to soil moisture levels, monitor environmental variables in real time, and evaluate water savings achieved through the proposed design. The results demonstrate the feasibility of a low-cost and replicable model for precision agriculture in resource-limited environments. Therefore, the aim of this research was to implement a smart irrigation system using IoT for rose cultivation in a basic greenhouse located in Canchis, Cusco. The project incorporated temperature and humidity sensors to capture environmental data, as well as solenoid valves for improved water control. Each SN was equipped with an ESP32 controller that communicated with a central module via the ESP-NOW protocol, and used Wi-Fi to transmit data to the ThingSpeak platform.

2. METHOD

2.1. System construction

This research followed a quantitative approach, as it worked with numerical values and collected study units through the devices installed within the environment of the basic greenhouse. Furthermore, an experimental method was applied, given that the variables were controlled and the results were measured accordingly [20]. The overall development of the system was carried out through a series of defined stages. Initially, the general system architecture was designed. In this phase, the complete operation of the project was conceptualized, including the positioning of all devices in the field, taking into account the layout of the area and the rose cultivation plots. Subsequently, two specific SN were designed to monitor four rose cultivation sections. In this stage, the type of sensors to be used in each node was also determined, along with the controller responsible for transmitting the data to the central node (CN). In the final stage, called server communication, data transmission to the cloud was established using the ThingSpeak platform. This allowed the farmer to remotely monitor soil moisture and ambient temperature conditions in the cultivation area. Figure 1 illustrates the stages of the project.

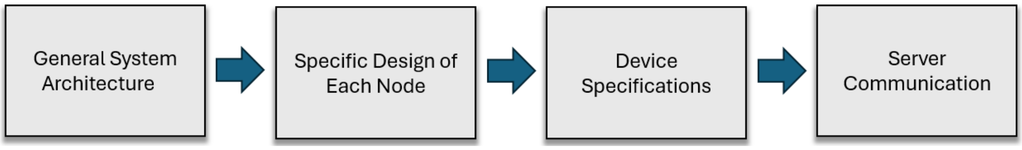


Figure 1. Stages of system development

2.1.1. General system architecture

The objective of this project was to implement an irrigation system based on IoT technology. Therefore, to define the general architecture, the first step involved selecting the area within the basic greenhouse where the two SNs and the CN would be installed. In addition, the sensor coverage was evaluated in order to strategically position the devices within the cultivation zone. Currently, the basic greenhouse contains eight crop rows in total. However, the system was implemented only on four rows—representing half of the cultivation area. Subsequently, the manual valves were replaced with solenoid valves to enable automatic soil moisture control. Figure 2 shows the layout of the entire system as deployed in the basic greenhouse field.

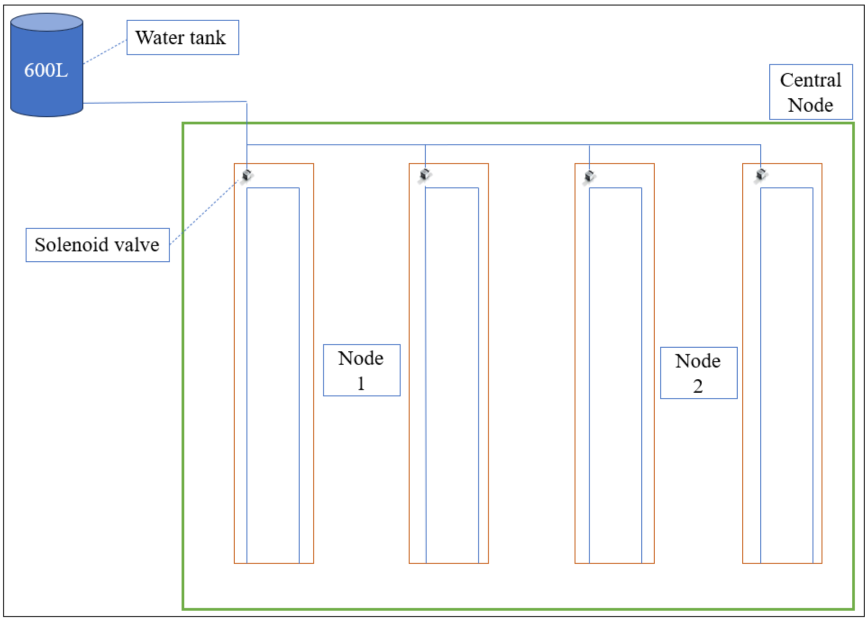


Figure 2. Architecture of the entire basic greenhouse system

2.1.2. Specific design of each node

The implementation of dedicated SN and a CN was considered essential, as the communication protocol used between them was ESP-NOW. The CN is composed of an ESP32 DEVKIT V1, an integrated 4-channel relay module, and four 24V DC solenoid valves, see Figure 3. On the other hand, each SN includes an ESP32 DEVKIT V1 module, a DHT22 temperature and humidity sensor, and a capacitive soil moisture sensor V1.2, see Figure 4.

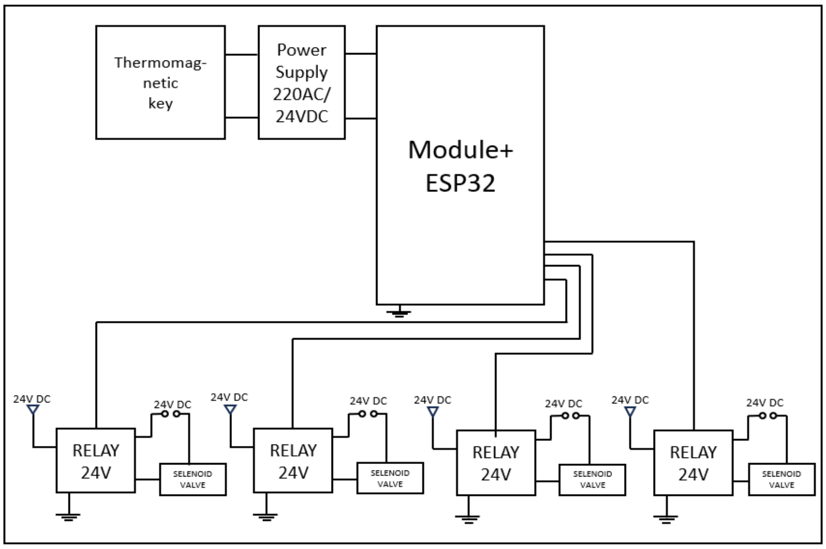


Figure 3. Central node

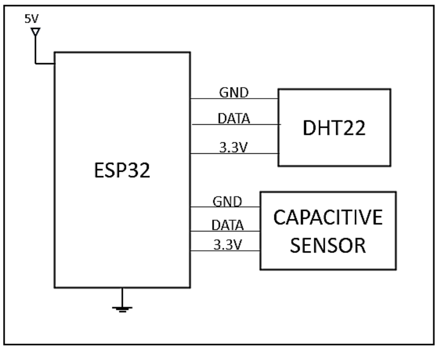


Figure 4. Specific node (SN)

2.1.3. Device specifications

The main devices used in this project are described below. The ESP32 DEVKIT V1 is a highly efficient microcontroller designed for rapid development of IoT applications. It can be programmed via a micro USB connection and includes onboard voltage regulators and status LEDs. It can be powered either through its USB port or an external 5 V or 3.3 V power supply. In this project, it serves as the main processor in each node [21]. The temperature and humidity sensor used is the DHT22, which measures both ambient temperature and relative humidity. This device integrates a capacitive humidity sensor and a thermistor to measure air temperature. The data is transmitted digitally through its output pin [22]. The system also includes a capacitive soil moisture sensor V1.2, which measures the capacitance between two electrodes inserted into the soil. This capacitance varies with the moisture level: when the soil is moist, the capacitance is low, and when dry, the capacitance increases significantly [23]. These two sensors provide the input data to the central module. Finally, the solenoid valve is activated when a confirmation signal is received, and it is controlled by a relay connected to the central module [24]. This setup allows for precise control of water flow within the basic greenhouse.

2.1.4. Server communication

For remote control and monitoring, the ThingSpeak server was used. ThingSpeak is an open-source application and development environment designed to facilitate interaction with electronic prototypes [25]. Among its key features are sensor data visualization and data storage capabilities [26]. In this project, the IoT architecture implemented in the basic greenhouse communicates with the server using the Wi-Fi protocol. Figure 5 shows how the system network is connected, illustrating the linkage between the SNs, the CN, and the ThingSpeak platform.

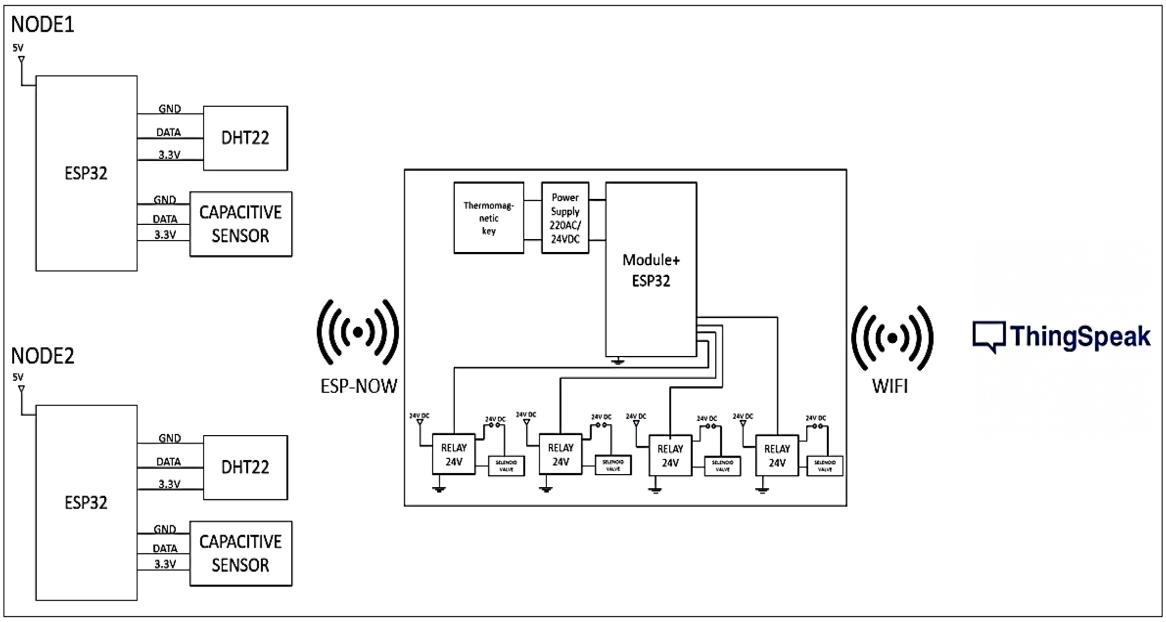


Figure 5. Communication of the proposed system with the ThinkSpeak platform

2.2. Flow diagram

Figure 6 presents the flowchart of the irrigation system's control algorithm, which sequentially describes the decision-making process based on the values of relative humidity and soil moisture for activating or deactivating the solenoid valves.

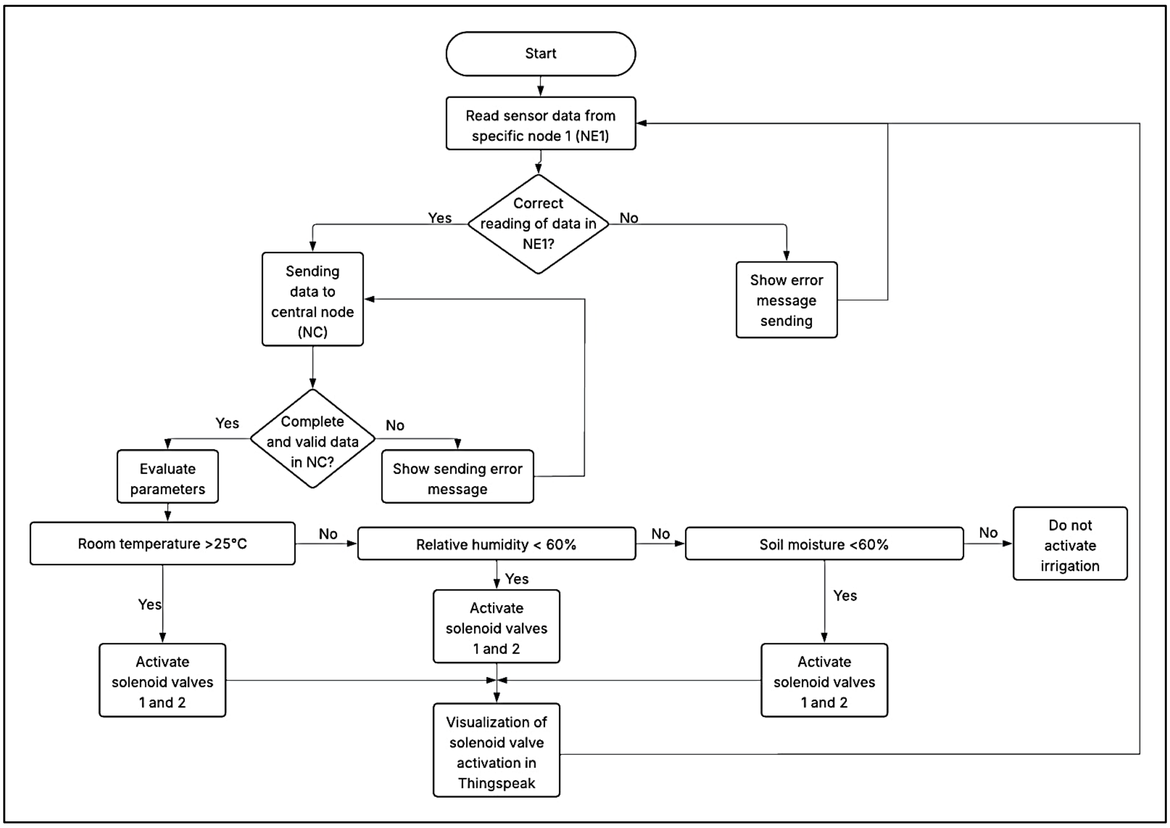


Figure 6. Flowchart of the irrigation control algorithm

2.3. Testing stages

First, to verify the communication performance between the CN and the SN, a laptop was used to record the transmitted data from both devices. In this test, the soil moisture readings obtained from the SN were compared with those received by the CN to ensure reliable data transmission. Second, a test was conducted to evaluate the operation of the solenoid valve. To generate a noticeable variation in soil humidity, the capacitive sensor was first placed in dry soil and then watered to simulate irrigation. The soil moisture threshold was established to detect the activation of the solenoid coil, confirming the correct on/off control of the irrigation system. Third, data acquisition from the ThingSpeak cloud platform was validated. The humidity values recorded by the CN were compared with those displayed on the ThingSpeak dashboard to ensure accurate data synchronization and transmission integrity. Finally, the system's water consumption efficiency was evaluated. A 600-liter Nicoll tank was used as the main reservoir for the greenhouse. However, since the experimental setup covered only half of the greenhouse area (four cultivation sections), the analysis considered 50% of the tank's total capacity. The water consumption during irrigation using the proposed automated system was compared against the previous manual irrigation method, which used the full tank capacity. A metallic rod with centimeter markings was placed inside the tank to measure the remaining water level after each irrigation cycle, allowing precise quantification of the saved water volume.

Temperature data were also monitored; however, since the recorded values remained within normal limits, this parameter was not prioritized. Instead, the soil moisture data, obtained using a capacitive soil moisture sensor V1.2, was the main control variable due to its direct interaction with the soil. Both the DHT22 and capacitive soil moisture sensors were experimentally calibrated using reference instruments. A critical humidity threshold of 60% was determined as the irrigation trigger point, based on agronomic literature specifying the optimal moisture range for rose cultivation. The system was programmed using the espressif IoT development framework (ESP-IDF) environment, implementing periodic tasks under the FreeRTOS scheduler for data acquisition and transmission. Each sensor reading was obtained by averaging three consecutive samples, discarding outliers beyond ±5% of the expected range. The adopted architecture employed ESP-NOW for communication between nodes and WiFi TCP/IP for the connection between the CN and the ThingSpeak server, ensuring reliable operation without dependence on external network infrastructure.

3. RESULTS AND DISCUSSION

The system was implemented under real field conditions in the Cusco region of Peru, as shown in Figure 7. Figure 7(a) illustrates the CN installed on the outer structure of the greenhouse, which houses the microcontroller and electronic modules responsible for managing sensor data and actuator commands. Inside the greenhouse, Figure 7(b) shows the specific sensor nodes connected to solenoid valves that control irrigation lines for each crop row. During two weeks of cultivation, detailed evaluations were conducted, allowing for the collection of empirical data on the system's performance and its impact on agricultural management.

(a) (b)

Figure 7. Implementation inside and outside the greenhouse; (a) the CN and (b) the SNs with solenoid valves

3.1. System configuration overview

Figure 8 illustrates the hardware implementation of the developed system, which includes both the CN and the SNs. The ESP32 microcontroller functions as the central control unit and is powered by a 220 VAC to 24 VDC power supply, which provides the necessary voltage for operating the components on the CN board. Figure 8(a) shows the CN, which integrates the ESP32 microcontroller with a relay module and a power supply unit. The relays, consisting of a coil and a normally open (NO) contact, act as electromagnetic switches that open or close the circuit. In this system, these relays are responsible for activating the solenoid valves installed at the beginning of each irrigation hose along the rose cultivation rows. Meanwhile, Figure 8(b) presents the SN, which includes the ESP32 microcontroller, a DHT sensor for temperature and humidity measurement, and a capacitive soil moisture sensor. These components enable real-time monitoring of environmental and soil parameters. Communication between the CN and SNs was established using the ESP-NOW protocol, ensuring efficient wireless data transmission.

(a) (b)

Figure 8. Own development of; (a) CN and (b) SNs

The microcontroller was responsible for managing interactions with the nodes distributed across the field. The ESP32 programming for both the CN and the SNs was carried out using the visual studio code text editor with the ESP-IDF framework developed by Espressif, the manufacturer of the ESP32. This ensured proper communication and data transmission between nodes. This configuration allows the system to collect information from the temperature and humidity sensors and transmit it to the CN, which in turn sends the data to the ThingSpeak platform. As a result, real-time monitoring of soil moisture and ambient temperature is possible through a web interface or mobile application. Thanks to the microcontroller's ability to integrate with various sensors, the system achieves coordinated data acquisition and stable overall performance. With proper hardware connections and accurate microcontroller programming, the IoT-based automated irrigation system can deliver precise monitoring and control.

3.2. Functionality testing between central node and sensor node

Tests were conducted between the CN and one of the SN in order to evaluate the accuracy and stability of soil moisture readings, as well as the correct transmission of data. In Figure 9, the blue curve represents the moisture data from the SN, which remained around 30%, indicating a condition that required irrigation. Around the 450-second mark, a sharp increase in soil moisture is observed, reaching approximately 80%.

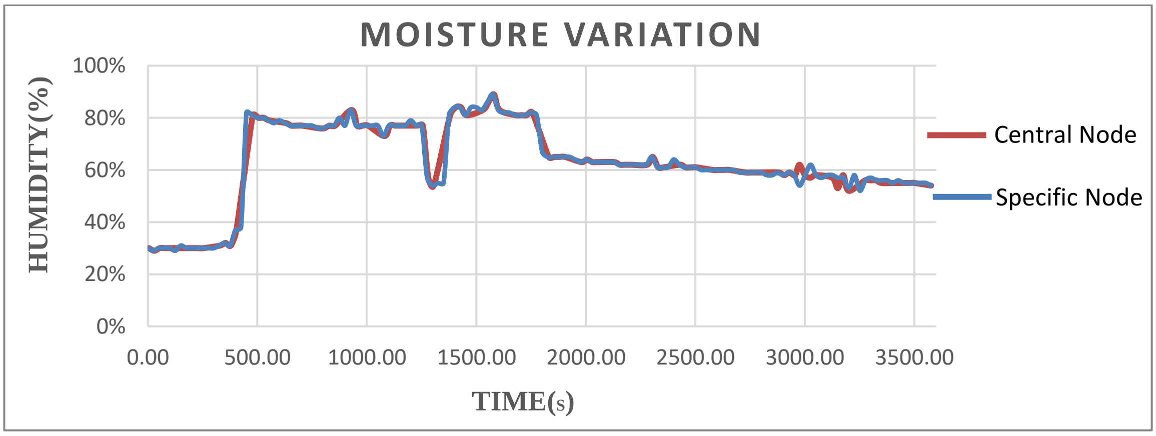


Figure 9. Variation in soil moisture, recorded by the central and SNs during the connection test

Likewise, the red curve shows a pattern very similar to that of the SN, confirming that data transmission between nodes was successful and without significant losses. Therefore, both graphs demonstrate consistency between the information recorded by the SN and the data processed and stored in the CN, which validates the effectiveness of the communication design implemented.

3.3. Functionality testing for solenoid valve activation

To determine the average response delay in the solenoid valve's first state change, Figure 10 was analyzed. The graph below represents the variation in soil moisture (0 to 100%) and the state of the solenoid valve (1=active, 0=inactive) over time.

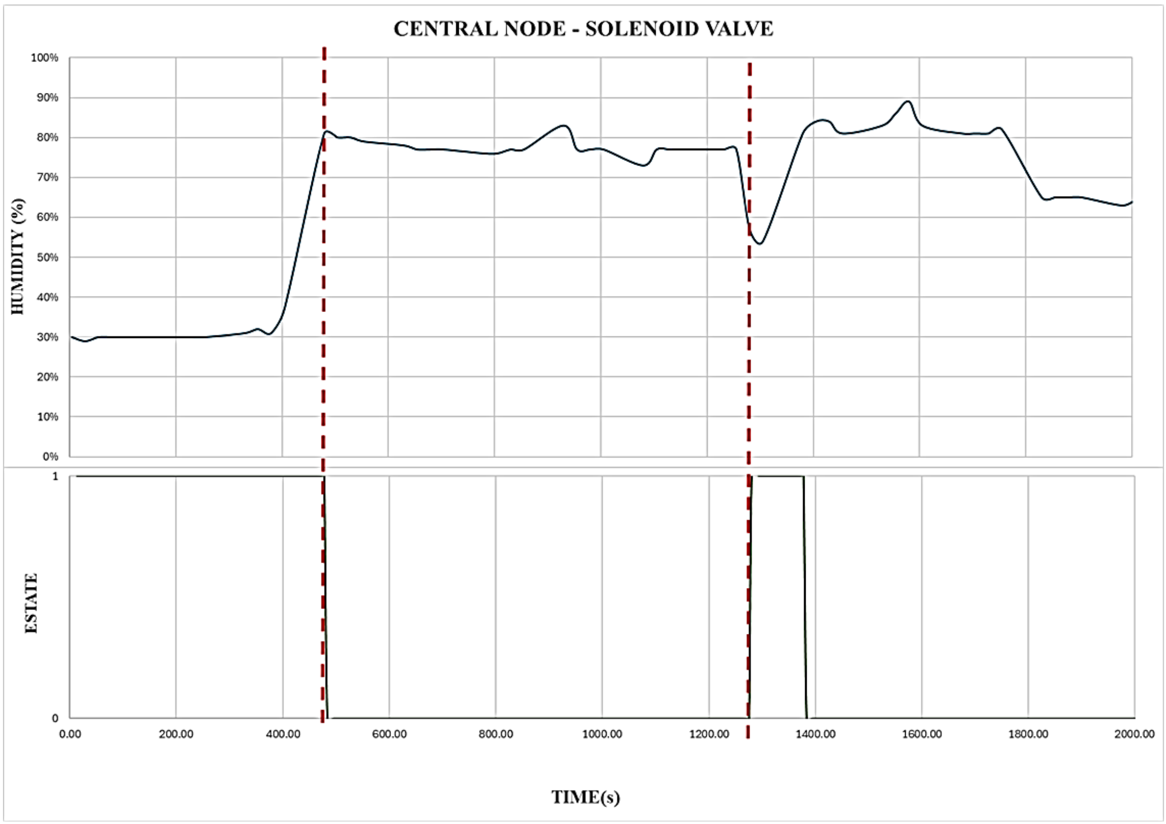


Figure 10. Activation of the solenoid valve due to the 60% humidity threshold as a function of time

From the figure shown, during the first change from 1 to 0, soil moisture exceeds 60% at approximately 479 seconds. The valve state then changes at around 484 seconds. Therefore, the delay in the first state change (system reaction time) is 5 seconds. For the subsequent variation from 0 to 1, soil moisture drops below 60% at around 1280 seconds, and the valve state changes at approximately 1281 seconds. These delays are acceptable in agricultural irrigation systems, as they do not compromise crop health and demonstrate the efficient performance of the automated system.

3.4. Prueba de plataforma web

In Figure 11, the red curve represents the variation in soil moisture data over time as displayed on the ThingSpeak platform, while the blue curve corresponds to the CN's data. Both graphs show consistent behavior, indicating that the data from the CN is being correctly transmitted to the web platform.

To determine the delay between the two curves, the CN and ThingSpeak, we analyzed the point at which the sharp increase in soil moisture begins, which indicates the activation of the irrigation system. The blue curve, representing the CN, shows that the peak rise in moisture occurs at 480 seconds, while the ThingSpeak curve shows a similar behavior around 540 seconds. This reveals a difference of 60 seconds. This delay is normal and can be attributed to data transmission and processing times in the cloud (ThingSpeak). Additionally, the CN transmits data from the other SN as well, which results in slight delays compared to direct local readings. Moreover, Figure 12 shows the data recorded in the basic greenhouse can be viewed remotely through both the website (Figure 12(a)) and the mobile application (Figure 12(b)).

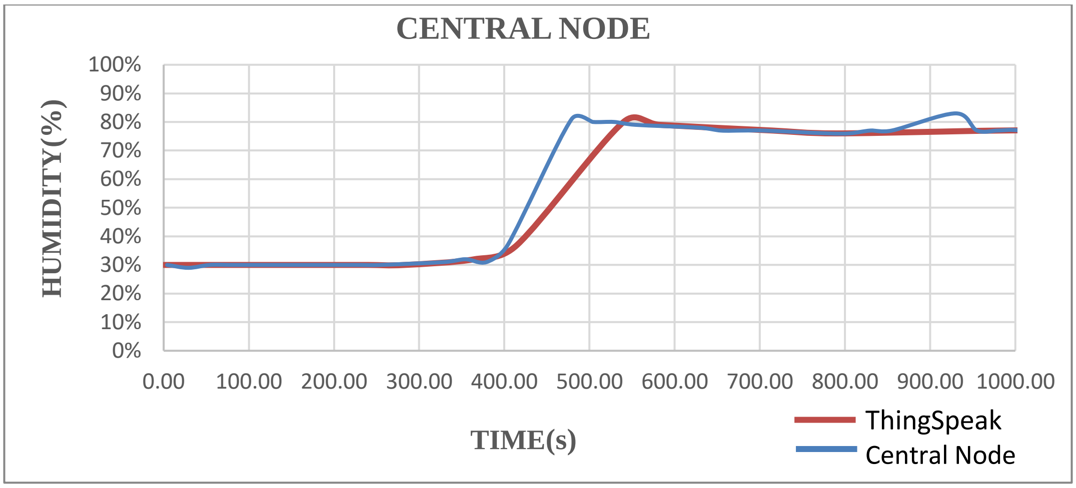
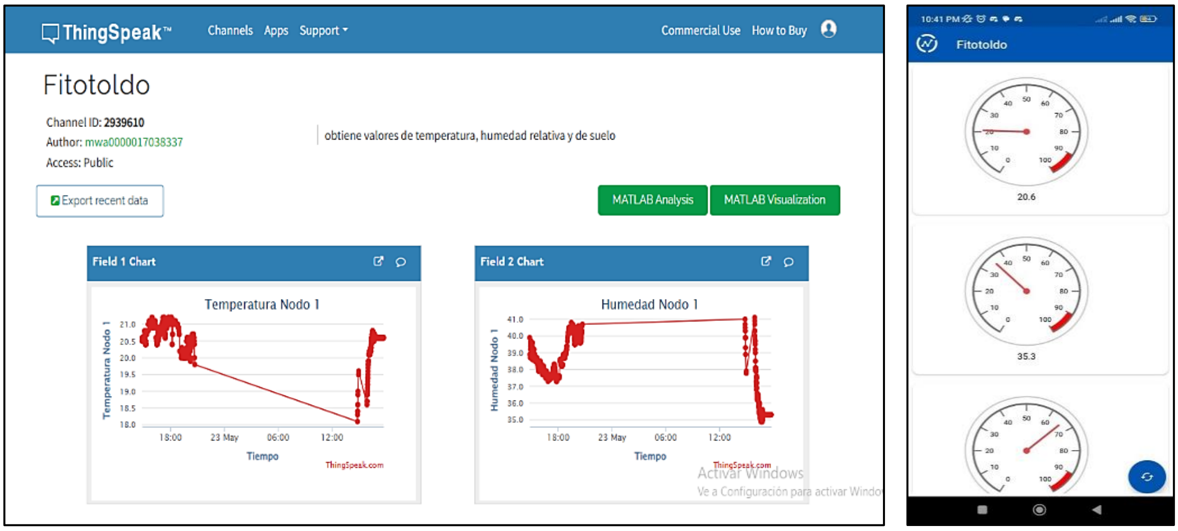


Figure 11. Variation in soil moisture recorded by the ThingSpeak platform and the CN



(a) (b)

Figure 12. ThingSpeak environments; (a) web platform and (b) mobile application

3.5. Water consumption testing

As part of the validation of the automated irrigation system, two independent tests were carried out using a 600-liter Nicoll-brand water tank for each trial. In the first test, when the soil moisture reached the threshold of 60%, the solenoid valves were deactivated, resulting in a water saving of 177.57 liters (59.19%). For the second irrigation test, the tank was refilled, and a saving of 116.32 liters (38.77%) was observed. In the final test, the water saved per irrigation cycle was 122.46 liters (40.82%). These results confirm the effectiveness of the system in reducing water consumption, see Figure 13.

In this study, the results indicate that the IoT-based irrigation system implemented in the basic greenhouse achieved an average water savings of 46.26% per irrigation cycle. According to the literature cited in Huarancca *et al.* [9], a pilot implementation reported a water consumption reduction of up to 16%. Moreover, their system used a Raspberry Pi for communication between the microcontroller and the web platform. In contrast, our system relies solely on the ESP32, making it more cost-effective. Additionally, in Benyezza *et al.* [16], a water saving of 26.41% was achieved; however, their setup required additional components for communication between modules and for server integration. Therefore, this study demonstrates that the proposed system represents a significant step toward the implementation of low-cost IoT technologies. Its benefits in water conservation make it well-suited for future agricultural applications.

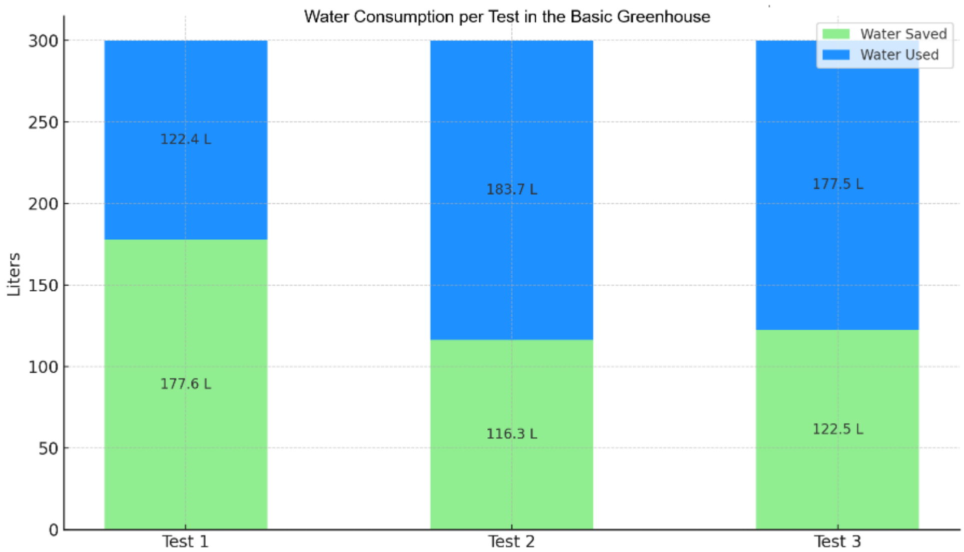


Figure 13. Water used and saved during automated irrigation tests

4. CONCLUSION

The intelligent IoT-based irrigation system developed in this research proved effective in optimizing water consumption and automating irrigation in a basic greenhouse. The average water savings of 46.26% validate the efficiency of the control implemented through ESP32 microcontrollers and ESP-NOW communication, demonstrating that low-cost solutions can be highly functional for small-scale agriculture. The application of IoT technologies in high-Andean regions promotes more sustainable water resource management and supports agricultural modernization in rural contexts. As future work, the integration of solar energy, weather prediction, and machine learning models for predictive irrigation is proposed to enhance system autonomy and scalability.

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