

A low-cost smart irrigation system proposal for small farmers

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ABSTRACT

Objective: To propose a low-cost smart irrigation system that can be implemented by any small farmer to improve water management.

Design/methodology/approach: A smart irrigation system was designed so that different nodes collect temperature and humidity data from the soil and send it wirelessly via ESP-Now protocol to a receiver node, which manages data and then sends it to another receiver node via LoRa communication protocol. Finally, this latter node sends data to a google-sheet and acts as a webservier via Wi-Fi, so that users can access to the data via Wi-Fi, locally or worldwide.

Results: The system was tested measuring and sending data to the server every 10 seconds to prove its reliability. The system proposed consisted of three nodes installed on a two-hectare plantation area. ESP-NOW nodes were able to send data without any losses at a maximum distance of 73.21 m. LoRa node was able to send data over 389.45 m distance.

Limitations on study/implications: The system was implemented over a simulated area, not on a real plantation. Also, estimations of total energy consumption were made for each node, but experimental results are still in progress.

Findings/conclusions: The system proposed was able to collect and to send the whole data without losses successfully. The system architecture is flexible; more ESP-NOW nodes can be added if they are required. Also, if the distance between farmer's home and plantation area is greater than the distance achieved by the LoRa node, more LoRa nodes can be added to reach the server node.

Keywords: Internet of things, LoRa nodes, ESPNOW protocol, irrigation system.

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INTRODUCTION

The Internet of Things (IoT) has emerged as an indispensable technology in the transformation of the agricultural sector, as it facilitates the collection and analysis of real-time information on key crop variables such as soil temperature and humidity, the monitoring of critical conditions in greenhouses, and even livestock management and irrigation system



performance. These smart applications seek not only to increase productivity, but also to reduce costs and promote more efficient resource management. To this end, it is crucial to have communication systems that combine wide coverage, low energy consumption, and reduced costs, characteristics that are often limited in conventional technologies such as cellular or Wi-Fi networks in rural areas (Codeluppi, Cilfone, Davoli, & Ferrari, 2020).

Given this scenario, low-power wide-area networks (LPWAN) are a viable alternative. Among these, LoRa technology and its LoRaWAN protocol have gained particular relevance due to their ability to transmit data over distances of up to 20 km in rural areas, with such low energy consumption that devices can operate for years on standard batteries (Feltrin, Centenaro, Zanella, Vangelista, Zorzi, & Verdone, 2018).

These qualities have driven its growing application in smart agriculture projects and consolidated it as one of the most researched technologies in this field.

Performance studies indicate that LoRaWAN offers high levels of reliability and scalability. For example, in urban environments, it has been observed that, with the incorporation of multiple gateways, it is possible to achieve packet delivery rates of over 95% even when more than a thousand nodes are connected (Magrin, Centenaro, & Vangelista, 2017). Likewise, it has been shown that, in densely populated networks, the use of unconfirmed messages is more efficient than confirmed ones, while the addition of gateways significantly increases network coverage and reliability (Reynders, Wang, & Pollin, 2018; Van den Abeele, Haxhibeqiri, Moerman, & Hoebeke, 2017).

In agriculture, various practical experiences reinforce these findings. Codeluppi *et al.* (2020) proposed the LoRaFARM platform, tested in vineyards and greenhouses, where successful data transmission was verified in both indoor and outdoor spaces. Complementarily, Feltrin *et al.* (2018) demonstrated through simulations that architectures with multiple gateways allow for the coverage of large rural areas, improving service capacity and information delivery rates.

However, there are still limitations that require attention. Network performance depends directly on the number of nodes, the frequency of data transmission, and the distance between devices and the gateway. In densely populated networks with short transmission intervals, the probability of interference and packet loss increase considerably. To address this problem, mathematical models have been proposed that can predict the success rate of packet delivery based on these variables, allowing for the selection of more appropriate configurations in the design phase (Magrin *et al.*, 2017; Reynders *et al.*, 2018; Van den Abeele *et al.*, 2017).

Among the available wireless communication technologies, LoRa and its LoRaWAN network protocol have established themselves as fundamental tools in smart agriculture due to their long range, low energy consumption, and low implementation cost (Enock *et al.*, 2025). According to Pagano, Croce, Tinnirello, and Vitale (2023), LoRaWAN stands out for its ability to connect nodes distributed over long distances (up to 10-15 km in rural areas) without the need for cellular infrastructure, making it a viable alternative for agricultural areas with limited connectivity. Its hierarchical architecture, based on gateways and network servers, allows data to be collected from humidity, temperature, and water level sensors, enabling remote irrigation control with minimal human intervention.

However, although LoRa technology offers significant advantages in coverage and energy efficiency, it presents challenges in latency and transmission capacity, especially when frequent communication between local nodes within a small crop area is required. Faced with this scenario, Aldhaheeri *et al.* (2024) propose combining LoRaWAN with other local communication protocols—such as ESP-NOW—to create hybrid networks that balance energy consumption, transmission speed, and system autonomy.

ESP-NOW enables direct communication between microcontrollers (ESP32/ESP8266) without intermediaries, with response times in the order of milliseconds and minimal energy consumption, making it ideal for synchronization and communication between nearby nodes within the same irrigation sector.

In accordance with this approach, Zhang *et al.* (2025) developed a smart irrigation system based on LoRa and Edge Computing, demonstrating that the integration of local processing with long-range transmission significantly reduces latency in making decisions and improves real-time irrigation efficiency. This decentralized hybrid approach allows critical actions, such as opening or closing valves, to be executed locally using embedded algorithms, while aggregated information is transmitted to central servers for historical and trend analysis.

A review of previous research has revealed a clear trend towards the design of low-cost smart irrigation systems, where modularity, energy efficiency, and independence from commercial infrastructure are priority requirements. The combination of LoRaWAN (for long-range communication and data transmission to servers) with ESP-NOW (for fast local communication between nodes and actuators) offers scalable, economical, and robust architecture capable of operating in rural areas with connectivity limitations. In addition, this structure enables the implementation of affordable prototypes for educational institutions, small farming communities, and applied research projects, promoting technology transfer and the adoption of Agriculture 4.0 at the local level.

The development of a low-cost smart irrigation system prototype based on LoRaWAN and ESP-NOW is therefore justified as a significant technological contribution to the field of smart farming, as it simultaneously addresses water efficiency, reduced operating costs, energy autonomy, and sustainability in rural environments in the absence of conventional network infrastructure.

MATERIALS AND METHODS

The study was carried out at Engineering Faculty, Universidad Veracruzana, as the simulated plantation area because it has a wide expanse of land. It is in km 1.0 of highway Sumidero – Dos Ríos Campus, Ixtaczoquitlán, Veracruz, Mexico.

Experimental design

There were created three wireless nodes to measure soil's temperature and humidity within an approximated area of two hectares. The system can be extended to measure more soil parameters and to measure broader areas of plantation, but as already stated, this system is intended to meet the needs of small farmers.

Two of the three nodes measure soil temperature and humidity, process the data, and send it wirelessly via ESPNOW communication protocol to the third node. This latter node also measures soil temperature and humidity, processes its own data, and sorts it with the received data from the other two nodes. The third node also is connected to a LoRa module which is used to send the whole data via LoRa communication protocol to a fourth node which has been located at the farmer's home. The fourth node also takes the role of a webserver which can be accessed by mobile devices connected to the local network or from anywhere in the world from an external network. This node also sends the data to a google sheet so that users can access to the historical data asynchronously whenever is required. The irrigation system may be programmed to be activated automatically if the humidity level is below a minimum established level. The level value can be configured depending on the type of crops. Users can also activate the irrigation system manually using the webserver (Figure 1).

Experimental devices

It has been stated that three nodes are installed at the plantation field area; a fourth node is installed at the farmer's home. The following paragraphs describe how each of the nodes used in the proposed irrigation system is composed.

First and second node devices

These two nodes are equally constructed. They consist of an ESP32-C3 super mini microcontroller, a DS18B20 temperature sensor, and an FC-28 soil humidity sensor (Figure 2). Communication via ESP-NOW is set as a "one slave", "multiple masters". These nodes work as "masters".

Third node device

The third node device, like the first and second, consists of an ESP32-C3 super mini microcontroller, a DS18B20 temperature sensor, and an FC-28 soil humidity sensor. But it also uses an E220-900T22D LoRa module (Figure 3). This node works as a "slave" in the ESP-NOW communication.

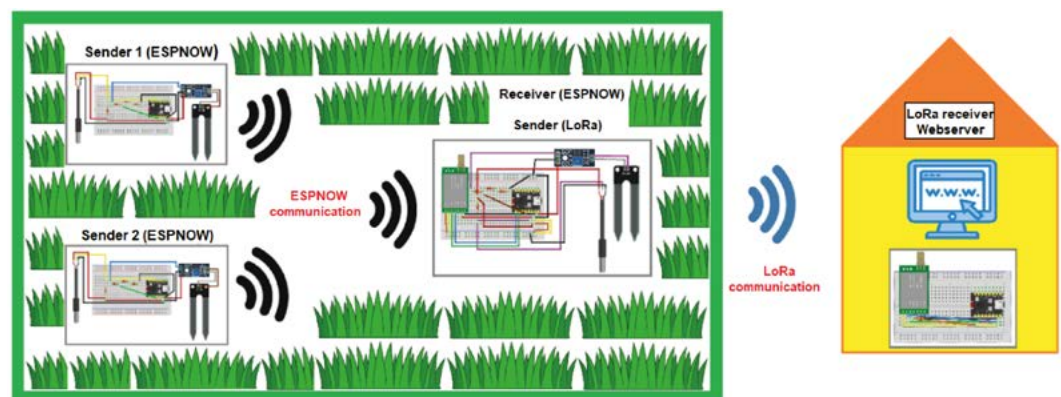


Figure 1. Proposed IoT irrigation system.

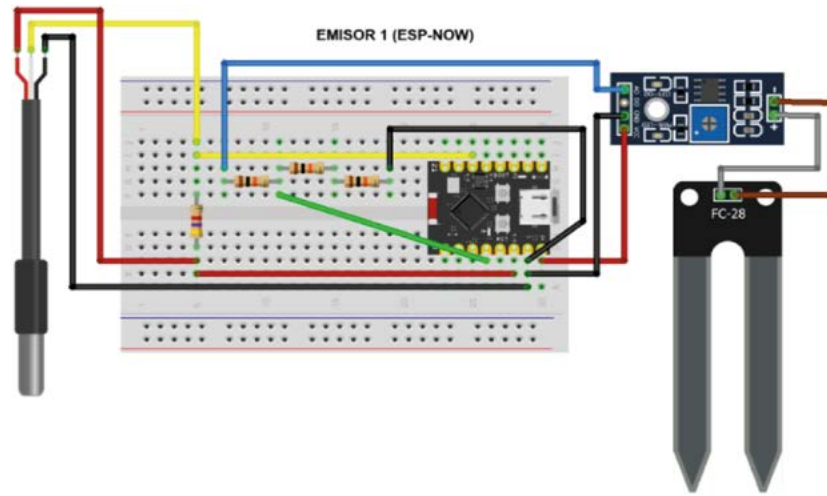


Figure 2. First and second nodes schematic diagram.

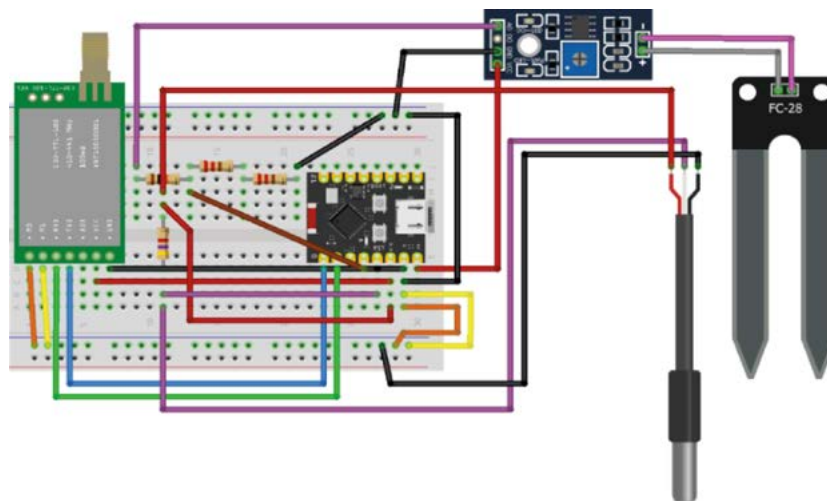


Figure 3. Third node schematic diagram.

Fourth node device

The fourth node device consists of only an ESP32-C3 super mini microcontroller and an E220-900T22D LoRa module (Figure 3, without temperature and humidity sensors).

LoRa modules can communicate with ESP32-C3 super mini microcontrollers via UART protocol. The E220-900T22D LoRa module must be configured before it can be used. Serial port was set to 9,600 bps, transmission band was set to 915.125 Mhz, air rate transmission was set to 2,400 bps, and maximum packet size of 200 bytes (Figure 4).

The LoRa spreading factor for this module is non-conventional, compared with LoRa spreading factors at 125 kHz bandwidth. Its bitrate is 2,400 bps, falling between SF8 and SF9, as stated on (Qingjie, G., Fengu, Y. and Jianming, W., 2021) with 3,125 bps (88.58 ms time on air 10 bytes packet) and 1,758 bps bitrate (144.38 ms timer on air 10 bytes packet).

The total number of electronic devices required to deploy the proposed system is summarized in Table 1.

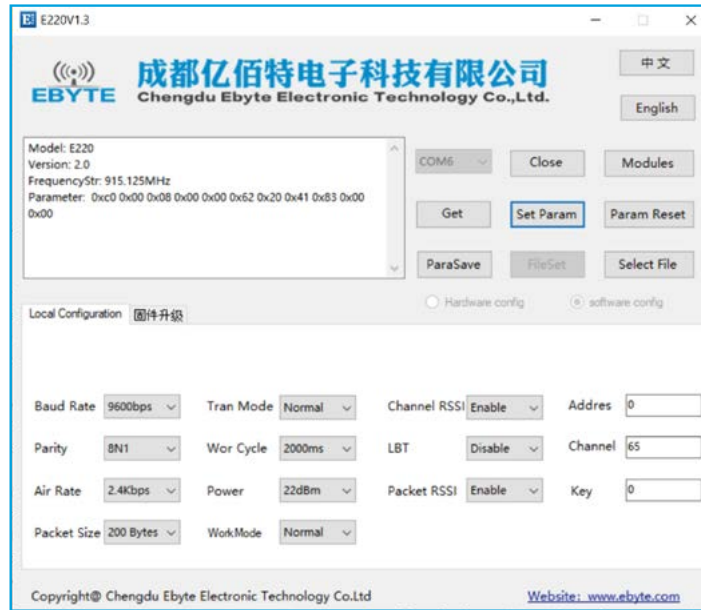


Figure 4. LoRa module configuration.

RESULTS AND DISCUSSION

It is confirmed that the research was conducted in compliance with applicable institutional standards and no conflicts of interest were identified at any stage of the study. The smart irrigation system was programmed to collect and send data every ten seconds, because the goal was to stress the system and evaluate its reliability. It also turns on automatically a relay to activate a water pump to water the crops when humidity sensors indicate low water levels and turn it off when moisture content is back to a set value.

Communication range

The focus of the experiment was to determine the maximum communication distance between nodes. Firstly, nodes that use the ESP-NOW Protocol could reach a maximum transmission distance of 73.21 m. Tests were run over different weather conditions, such as sunny, cloudy, and rainy days. The 73.21 m distance is a secure communication distance, where no data loss existed (Figure 5).

Table 1. Electronic components.

Electronic component	Quantity	Unit Price (\$USD)
E220-900T22D LoRa module	2	5.09
ESP32-C3 Super mini microcontroller	4	1.64
FC-28 humidity sensor	3	2.02
DS18B20 temperature sensor	3	2.51
915 MHz antenna	2	2.71
Li-Po battery 500 mAh, 3.7 V	4	1.41
130×80×70 mm waterproof box	4	7.24
Total		70.35

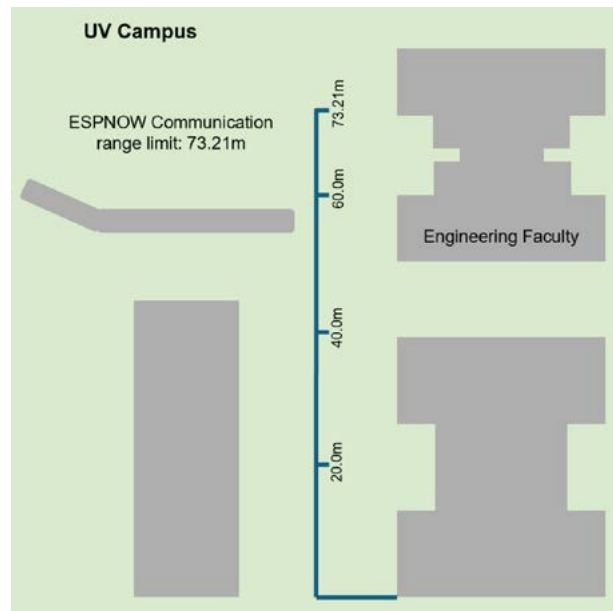


Figure 5. Maximum distance reached by nodes connected through the ESP-NOW protocol.

This achieved distance is more than enough to meet the requirements for a two-hectare plantation. Nevertheless, it is important to note that there are ESP32-C3 super mini microcontroller models that can handle external antennas, so that larger distances can be achieved. The ESP-NOW protocol supports a maximum of 20 pairing devices, making it easy to extend the irrigation system to cover a broader area of plantation.

In other hand, it also was tested the maximum communication distance reached by the E220-900T22D LoRa modules, again, without any data loss. These LoRa modules achieved a maximum communication distance of 389.45 m, including obstacles like trees and an 8 m high building (Figure 6). This result has shown that a larger distance may be obtained in a plantation without any obstacles.

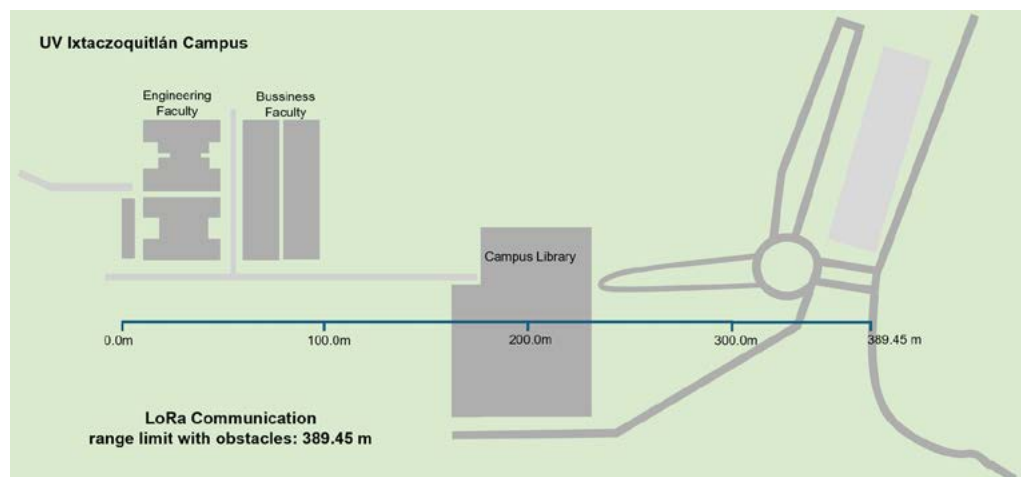


Figure 6. Maximum distance reached by nodes connected through LoRa Protocol.

As has been already stated, tests have been conducted under sunny, cloudy and rainy conditions. Nodes that communicate over the ESP-NOW protocol were deployed at a separation distance of 70 m, while nodes that communicate over the LoRa protocol were deployed at a separation distance of 385 m. Every data packet which is sent via LoRa protocol contains 36 bytes. Tests were conducted by sending data packets every 10 seconds within 1 hour, resulting in a total of 360 data packets (12,960 bytes). The results are summarized in Table 2. As can be seen, every packet was successfully received, there was not any missing data.

In comparison, Yik-Tian, T. and Kah-Yoong Chan, 2024) conducted tests with different LoRa modules, working at frequencies of 433 MHz, 866 MHz, and 915 MHz. The separation distances were 25 m, 50 m, and 100 m. Five nodes were tested, sending 1 packet every 5 minutes within 1 hour. The total data packets sent by every node were 12. The two nodes separated at 50 m missed at least 1 packet, and the node separated at 100 m missed 3 packets. These results suggest that the E220-900T22D LoRa module has better performance than those utilized in the research mentioned.

Database

The fourth node of the irrigation system manages the data received, sorts it and sends it to a google-sheet which is used as a database, where users can retrieve the historical data whenever they required it (Figure 7).

Table 2. Data transmission packets over different weather conditions within 1 hour.

Weather	Sent packets (bytes)	Received packets (bytes)
Sunny	360 (12,960)	360 (12,960)
Cloudy	360 (12,960)	360 (12,960)
Rainy	360 (12,960)	360 (12,960)

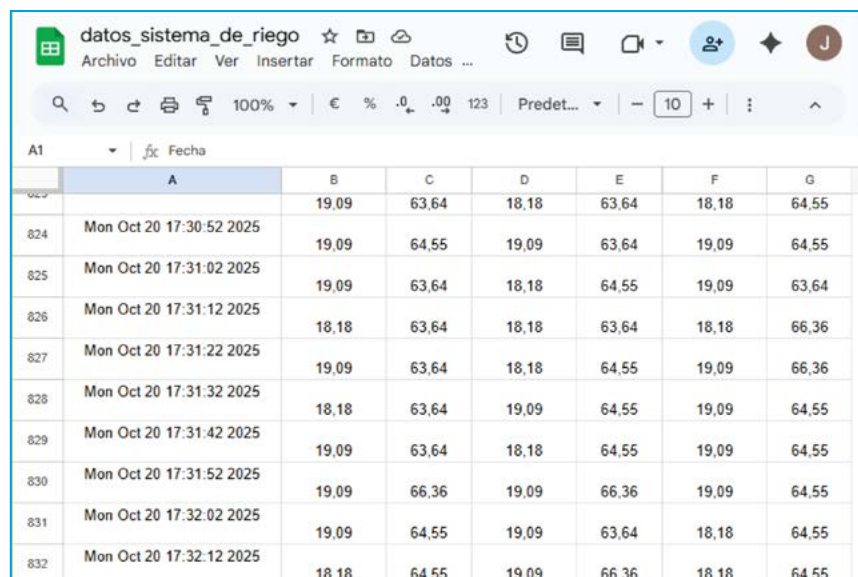


Figure 7. Example of data reads saved in a google-sheet.

Application layer

In IoT the application layer is where users interact with things. In this research, it was decided to create a webserver where users can access data and control the irrigation system. WebSockets enable full-duplex, real-time communication between clients and servers and it was the protocol implemented in this research. Users can access the IoT irrigation system by using any mobile device connected to the local network or from anywhere in the world if a port of the network has been forwarded. The data can be viewed on an interactive webpage (Figure 8).

Energy consumption

ESP-NOW technology itself offers lower power consumption than traditional Wi-Fi because it avoids the overloads of a full network connection. Nodes are programmed for using deep-sleep mode and a synchronized approach to send data in predefined intervals, so most of the time nodes are in sleep mode, reducing significantly energy consumption. The average current consumption is about 100 mA when transmitting via ESP-NOW protocol. LoRa technology is also low power consumption, the E220-900T22D has an average current consumption of 110 mA. In this research LiPo batteries of 500 mAh were used to power the nodes. Now, considering a situation where data must be sent every 30 minutes, estimation of power consumption of the system is as follows. Nodes 1 and 2 only send data, having an estimated long life of 10 months before replacing or recharging batteries. Node 3 receives data via ESP-NOW and sends data via LoRa protocol. It has an estimated long life of 4.5 months. Last, node 4 is suggested to be powered by a fixed source because it receives data via LoRa protocol, manages data, sends it to a google-sheet and serves the webpage to clients.

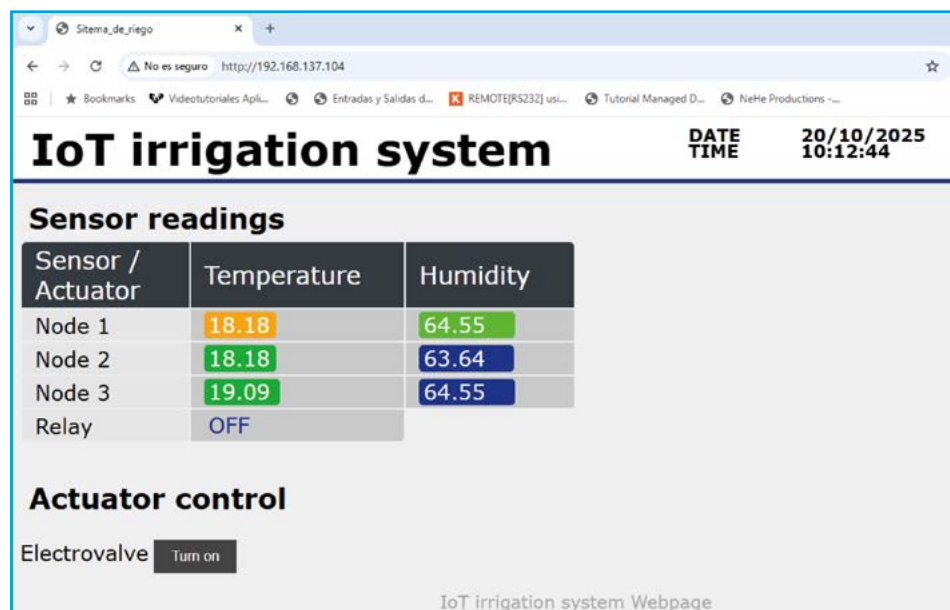


Figure 8. Interactive webpage to access and control the irrigation system.

LoRa/LoRaWAN is designed for sporadic transmissions and very low power consumption in radio mode, enabling battery life of several years (depending on the sampling profile and battery size). Studies include models and measurements that show a clear advantage over cellular links in low-rate scenarios. (Mekki *et al.*, 2018). LoRaWAN establishes three classes of devices (A, B, and C) according to the type of application, and each one has a different energy consumption pattern associated with its operating mode. The operation mode of the E220-900T22D LoRa module was configured to work as a class-A end-device, allowing the lowest power consumption. An agricultural irrigation system is not a system that requires real time acquisition data, so low latency is not a concern. For systems where latency is not crucial due to the frequency of monitoring soil variables such as moisture and temperature, low energy consumption is sufficient (Mekki *et al.*, 2018) (Liopa-Tsakalidi *et al.*, 2024.)

The choice of Class A LoRaWAN devices in agricultural telemetry systems is mainly justified by the need to optimize the energy consumption of the nodes deployed in the field. In this mode of operation, the nodes remain in a low-power state most of the time and only activate reception windows immediately after an uplink transmission, which minimizes the transceiver's active time and significantly extends battery life (Križanović *et al.*, 2023). Since downlink communication in irrigation systems is used sporadically or on a scheduled basis, for example, for threshold adjustments or sending irrigation commands, Class A mode offers an ideal balance between autonomy and functionality. Recent studies have confirmed that this architecture can sustain stable, low-power transmissions over large crop areas, reaching distances of more than 5 km with packet delivery rates (PDR) greater than 95%, even under variable propagation conditions (Liopa-Tsakalidi *et al.*, 2024; Ting & Chan, 2024).

Furthermore, specialized literature supports that Class A nodes are the most suitable when the sampling frequency of agricultural variables —such as soil moisture or water flow— does not require continuous communication, but rather periodic readings every few minutes or hours (Jabbar *et al.*, 2024; Benameur *et al.*, 2024). Under these conditions, the use of nodes with predominantly unidirectional links reduces energy consumption by 30% to 50% compared to more active modes such as Class B or C, without compromising the functionality of the control system (Križanović *et al.*, 2023). This energy efficiency translates into greater sustainability of the irrigation system, less field maintenance, and reduced operating costs, consolidating the suitability of Class A mode for smart irrigation systems with battery-or solar-powered nodes in extensive agricultural environments (Liopa-Tsakalidi *et al.*, 2024; Benameur *et al.*, 2024).

The results of the comparative analysis indicate that, for periodic sensing applications of variables such as soil moisture, ambient temperature, or battery monitoring in large agricultural plots, LoRa/LoRaWAN technology is the most efficient alternative in terms of cost and energy consumption, in addition to offering the possibility of implementing private networks without relying on telecommunications operators. This feature makes it particularly suitable for low-maintenance, long-term deployments in rural environments (Soy, 2023; Aldhaheri *et al.*, 2024; Rajab *et al.*, 2023).

On the other hand, when applications require low latency, guaranteed quality of service (QoS), or the transmission of large volumes of data, the integration of LPWAN technologies with cellular networks is recommended, such as in the LoRa+5G or NB-IoT hybrid models, which, according to recent studies, reduce operating costs and increase network reliability (Mohamed Rafi *et al.*, 2025).

Finally, for extremely remote geographical areas without terrestrial communications infrastructure, LPWAN solutions combined with satellite links (NTN/LEO) are identified as an emerging trend, allowing coverage to be extended and continuous connectivity to be guaranteed in dispersed agricultural scenarios, according to advances reported between 2024 and 2025 (Ledesma, Lamo & Fraire, 2024; Lee *et al.*, 2025).

The following link is provided to the repository where the configuration codes for the proposed system have been made available in order to ensure the transparency and repeatability of the research: A low-cost smart irrigation system proposal for small farmers.

CONCLUSIONS

The irrigation system was proved under different weather conditions, and data always was completely collected. The combination of ESP-NOW and LoRa protocols let the IoT irrigation system proposed to be really a low-cost one, because a commercial LoRa gateway is not required and users only must provide internet on their homes; there is no need to provide Wi-Fi, NB-IoT, LTE, 4G or 5G technologies on the plantation area, which involves a monthly or annual cost.

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