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LoRa-based IoT platform for remote soil parameter monitoring

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Abstract
The objective of this work was to develop an innovative LoRa-based platform that provides a low-cost and customizable solution for real-time monitoring of soil parameters. The system architecture was based on four levels: environmental (rural), sensors and actuators, communication network, and application, with the code made available for operation. The collected data were transmitted to data collection points using LoRa technology. The application level allowed for data storage, analysis, and visualization, enabling end-users to remotely monitor and control environmental measurement operations. With LoRa technology range tests, results indicated the capability to cover a maximum area between 95 and 120 hectares in the studied areas. Additionally, the collected data were sent to ThingSpeak.com and a mobile application called Thingsview. This demonstrated the efficiency and viability of LoRa technology for industrial communication sensor and IoT applications in rural environments, offering automation, increased efficiency, and savings in human resources for environmental monitoring tasks.

Keywords: LoRa technology; rural environmental monitoring; sensors and actuators.

Plataforma IoT basada en LoRa para monitoreo remoto de parámetros del suelo

Resumen
El objetivo de este trabajo fue desarrollar una innovadora plataforma basada en LoRa que proporciona una solución económica y personalizable para la monitorización en tiempo real de parámetros del suelo. La arquitectura del sistema se basó en cuatro niveles: ambiental (rural), sensores y actuadores, red de comunicación y aplicación, con el código disponible para su funcionamiento. Los datos recopilados se transmitieron a puntos de recopilación de datos mediante la tecnología LoRa. El nivel de aplicación permitió el almacenamiento, análisis y visualización de datos, lo que permitió a los usuarios finales supervisar y controlar de forma remota las operaciones de medición ambiental. Con pruebas de alcance de tecnología LoRa, los resultados indicaron la capacidad de cubrir un área máxima de entre 95 y 120 hectáreas en las áreas estudiadas. Además, los datos recopilados se enviaron a ThingSpeak.com y a una aplicación móvil llamada Thingsview. Esto demostró la eficiencia y viabilidad de la tecnología LoRa para aplicaciones de sensores de comunicación industrial e IoT en entornos rurales, ofreciendo automatización, mayor eficiencia y ahorros en recursos humanos para tareas de monitorización ambiental.

Palabras clave: tecnología LoRa; monitorización ambiental rural; sensores y actuadores.

1 Introduction

The communication between humans and machines through the Internet of Things (IoT) has been routinely used in various applications. Machine-to-machine and machine-to-human interaction using sensors has potential applications in various sectors [1-3].

When agriculture is associated with the application of the

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Internet of Things (IoT), it enables an approach aimed at optimizing the use of human and environmental resources with the goal of improving the efficiency and sustainability of agricultural activities [4]. In this context, Long-Range (LoRa) wireless communication technology has been used to develop monitoring networks in agricultural applications due to its data transmission capabilities over long distances with low power consumption [5].

Recent studies have demonstrated the use of LoRa technology for soil moisture monitoring as a highlight in Precision Agriculture. [6] proposed an IoT and LoRaWAN-based system for crop monitoring and irrigation control, emphasizing the efficiency of this technology in transmitting collected data. [7] also highlighted the use of LoRaWAN to implement intelligent irrigation systems in agriculture, contributing to water and energy savings.

Another relevant application is real-time crop monitoring. [5] developed a LoRa-based wireless sensor network for soil moisture monitoring in a coffee plantation, highlighting the reliability and low energy consumption of this technology. [8] also proposed an IoT and LoRaWAN-based system for soil moisture monitoring, emphasizing LoRa's long-distance coverage capability.

LoRa technology has also been applied to real-time weather monitoring to support decision-making in agriculture [9,10]. As highlighted by [11], the use of LoRa devices for transmitting agricultural data has shown promising results, enabling the acquisition of accurate information for crop management.

The use of LoRa in Precision Agriculture applications has proven to be a viable and promising solution for real-time monitoring of agricultural variables, enabling more informed decision-making, efficient resource management, and reduced operational costs [2,3,12].

To date, there are no known works that utilize sensors with RS-485 serial communication standards, Modbus serial communication protocol, real-time access, and simplified data visualization and processing capabilities for users. Thus, the objective of this work was to develop an innovative LoRa-based platform that provides a low-cost and customizable solution for real-time soil parameter monitoring.

2 Methodology

The development consisted of building a prototype using the Design Science Research methodology [13] for LoRa technology [14], with the potential for use in different environments. Subsequently, an IoT solution was implemented on the prototype using the Thingspeak platform. The following will demonstrate the steps for carrying out this work.

2.1 Proposed architecture

The development of the architecture was based on the one proposed by [2,15], consisting of four levels: Environmental (rural), Sensors and actuators, Communication network, and Application, as shown in Fig. 1.

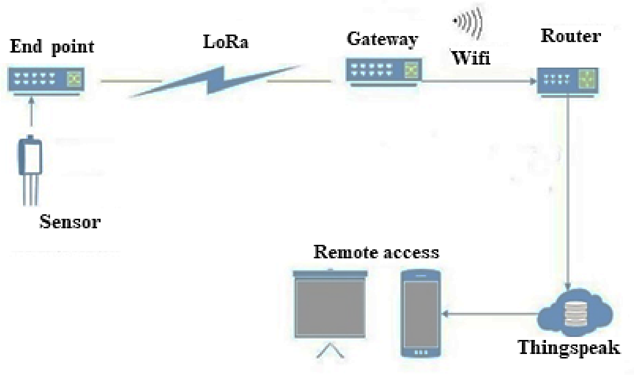


Figure 1. The proposed architecture.
Source: Adapted from Faria and Cavazzoti, 2019 and from Rudiger, 2021.

The characterization of the levels considered for execution starts with the rural environmental level, which includes various soil monitoring parameters, enabling data transmission with minimal human intervention. Subsequently, the sensor and actuator level can be observed. This level consists of different sensor nodes and soil parameter measurement devices that are installed to collect data on temperature, soil moisture, and electrical conductivity. The collected data is then transmitted to data collection points or gateways through wired or wireless communication.

Continuing with data acquisition, the communication network level enables data transmission from the environmental level to the application level using different long-range communication technologies such as LoRa. LoRa is used to exchange data with the assistance of a gateway located in an area with internet access in the rural environment.

Finally, the last level is the application level, where all the data received from the sensor nodes and devices through the communication network level allows for data storage, analysis, and visualization. This level enables end-users to remotely monitor and control environmental measurement operations. Thus, the application layer facilitates management, including planning and decision-making.

2.2 Transmitter-receiver set characterization

The operation of the prototype begins with the Arduino Pro Mini sending requests via Modbus RTU to the THC-S sensor through the RS-485 module. The sensor responds to the request by sending the collected data of soil moisture, temperature, and conductivity to the Arduino Pro Mini. The choice not to adopt the Heltec module to directly receive data from the sensor is due to the specific nature of the soil moisture sensor. This sensor requires a 5V power supply to operate correctly and, consequently, operates at a voltage of 5V. On the other hand, the Heltec module operates at 3.3V. Due to this voltage difference, the Heltec module is unable to directly read the data obtained from the sensor through the RS-485 module, making it necessary to use the Arduino Pro Mini as an intermediary to ensure accurate and reliable reading of the sensor data.

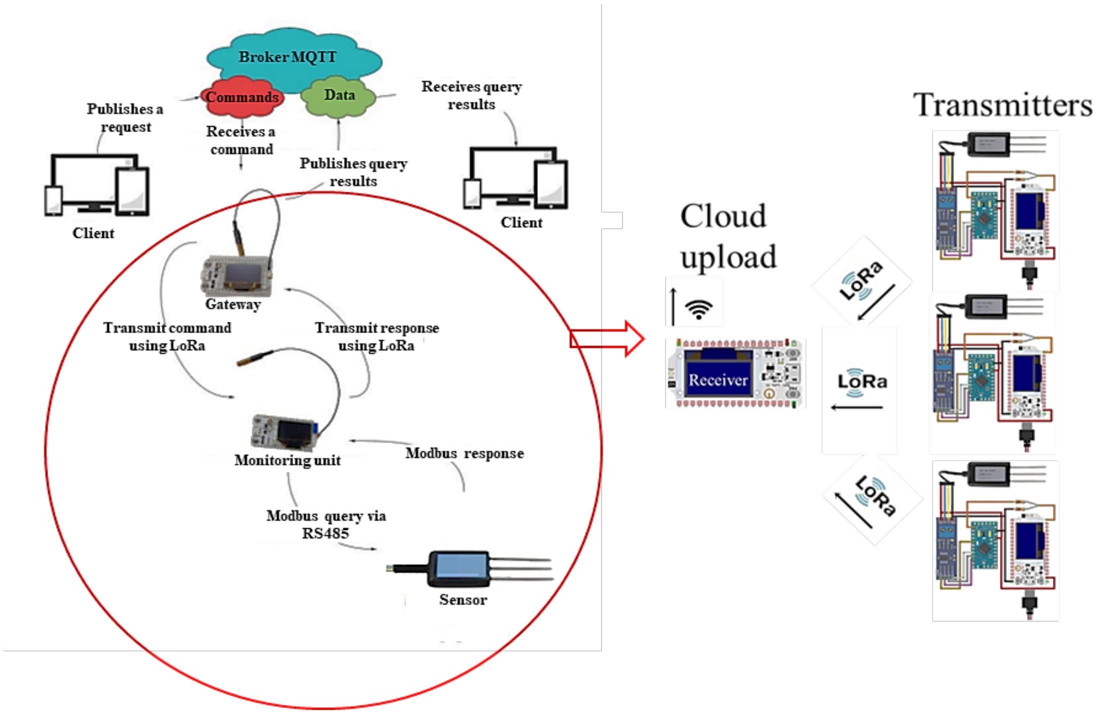


Figure 2. Transmitter-Receiver system details.
Source: Adapted from Rudiger, 2021.

To enable this serial communication, it is necessary to implement the use of the SoftwareSerial.h library in the code, where a new virtual serial port is created using two digital pins as TX (Transmitter) and RX (Receiver). After reading the data received by the Arduino Uno, it interprets it and converts the soil moisture, temperature, and conductivity values into real values.

After the Arduino Uno receives the data read from the sensor, it is necessary to send this collected information to another location. For this purpose, the Heltec Esp32 LoRa microcontroller is used, which has long-range communication capabilities. Communication between the Arduino and the LoRa was done via hardware serial port (UART), where this data will be sent via TX-RX.

Since the voltage levels of the Arduino Pro Mini and the Heltec Esp32 LoRa are different, they are not directly compatible for communication. The Arduino operates at 5 volts, while the Heltec operates at 3.3 volts, which could potentially damage the Heltec Esp32 LoRa due to the reception of a higher voltage.

To ensure that this serial communication is done safely, the use of a voltage divider is necessary to reduce the Arduino's voltage to a level compatible with the LoRa. This divider consists of two resistors connected in series, and the voltage at the midpoint between the two resistors is given by:

$$Vout = Vin \times \frac{R2}{R1 + R2} \qquad (1)$$

To achieve a voltage of 3.3V, where Vin = 5V, and using resistors R1=5k ohms and R2=10k ohms, you would arrive at:

$$Vout = 5V \times \frac{10k}{10k + 5k} \rightarrow Vout = 3.33V \qquad (2)$$

With all the data to obtain the necessary voltage, the transfer of information stored by the Arduino will be transmitted through the Pro Mini's TX pin, passed through the voltage divider, reducing it from 5V to 3.3V, and then received by the RX, pin 16, of the Heltec. Fig. 3 illustrates the serial communication between the Arduino and the Esp32 LoRa Transmitter with the voltage divider.

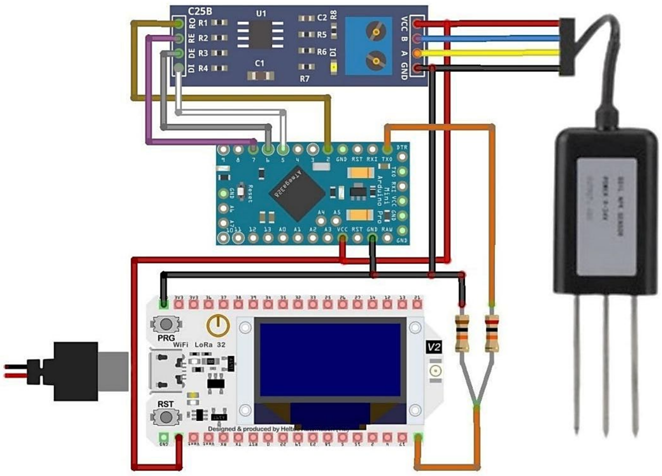


Figure 3. Serial Communication between arduino and Heltec Esp32 LoRa with voltage divider
Source: Author's Own.

The receiver is characterized by a LoRa unit, which functions as the gateway. Its configuration was designed to receive data from three different LoRa transmitters. Due to the nature of the transmitter-receiver communication, which processes one transmitter at a time, there was a need for a time-sharing strategy to ensure the integrity of the received data.

This strategy involved allocating specific periods where the gateway focuses on receiving data from one transmitter at a time. This was done to avoid conflicts and packet losses during transmission. Each transmitter was synchronized to send its data at predetermined times, ensuring that the gateway could capture all the information in an organized manner.

Additionally, the transmitters send an identification along with the packet, allowing the receiver to verify if the received messages are addressed to it. When destined, the gateway publishes its content to the data topic via the MQTT protocol. Thus, concluding the transmission of captured data to an IoT service, ThingSpeak.com, and to a mobile application, Thingsview.

2.1 Characterization of the Sensor (CWT-SOIL-THC-S)

According to the objective, the CWT-SOIL-THC-S sensor was used, designed to monitor soil conditions in agricultural, environmental, and crop monitoring applications. It is capable of measuring soil moisture, temperature, and soil electrical conductivity with high precision and reliability. However, the system has the capability to receive data from various sensors with Modbus communication via RS485. In other words, through the RS-485 module, it can establish an efficient serial connection between the Arduino and the sensors.

The CWT-SOIL-THC-S sensor has a measurement range of relative soil moisture from 0% to 100%, a temperature ranges from -40°C to 80°C, and a conductivity measurement range from 0 to 200,000 µS/cm.

The sensor can collect data on soil moisture, temperature, and electrical conductivity, enabling the transfer to a control system, which can be used to monitor real-time soil conditions and make informed decisions regarding irrigation and plant nutrition, similar to [10].

With its IP68 rating, the CWT-SOIL-THC-S sensor is protected against dust and liquids, indicating that the sensor is robust enough to withstand light impacts and vibrations, making it ideal for field applications.

Table 1.
Characteristics of the Sensor (CWT-SOIL-THC-S)

Parameters	Characteristics
Temperature	Measuring range: -40°C - 80°C Accuracy: 5%°C (25°C) Long-term stability: ≤0.1% °C/y Response time: ≤15s
Soil moisture	Measuring range: 0-100%RH Accuracy: 2% within 0-50%, 3% within 50-100% Long-term stability: ≤1%RH/y Response time: ≤ 4s
Conductivity (EC)	Measuring range: 0-200000us/cm Accuracy: 0-10000 us/cm range is ±3%; 10000-20000 us/cm range is ±5% Long-term stability: ≤ 1%uS/cm Response time: ≤ 1s

Source: ComWinTop - Soil parameters measuring (https://shre.ink/rQR1)

With high precision, long-term stability, and a fast response time, the CWT-SOIL-THC-S sensor is a reliable and efficient solution for measuring soil moisture, temperature, and conductivity in various applications, from agriculture to environmental and scientific studies.

2.2 Simplified signal range

To validate the use of the developed system in locations where environmental data acquisition sites lack adequate infrastructure, such as for the installation and use of WiFi networks, Ethernet, or cellular networks, a range test was conducted. The purpose was to assess the distances at which the equipment could be installed.

The system operates at a frequency of 915 MHz. The signal evaluation metric for received messages was simplified, adopting only the RSSI (Received Signal Strength Indicator). RSSI is a metric of the relative signal quality that represents its power in dBm.

To evaluate the operational range of the system, the monitoring unit was connected to a power bank to provide the necessary power for its operation. The gateway was positioned in a location with elevation similar to the monitored area and with access to the internet via a WiFi network.

RSSI measurements were taken at three different spatially distributed points within each area. The locations for measurements were selected, including the Laboratory of Studies in Hydraulic and Hydrology of the Department of Agronomic Engineering at the campus of the Federal Institute of Bahia, in Bom Jesus da Lapa, and the Laboratory of Agricultural Instrumentation of the Postgraduate Program in Agricultural Engineering at the campus of the Federal University of Recôncavo da Bahia, in Cruz das Almas. The communication quality between the devices, operating distances, signal strength, and data storage system were determined.

The distances between the two points were calculated considering the flat distance between the points. According to the configuration described in the previous paragraph, the monitoring unit was positioned at one end of the indicated paths, while the gateway was positioned at the opposite end. RSSI of the signal received by the monitoring unit was evaluated throughout the distance between the transmitters and the receiver but was characterized only when the points reached their respective area boundaries.

3 Results and discussion

To validate the implementation of the system developed for its purpose, which is to monitor equipment in a rural environment, the following tests were conducted in temporarily deployed networks in the different climatology mesoregions of Bahia, Brazil.

The first test aimed to validate the functionality of the system as a whole, ensuring that it is possible to remotely acquire data from devices using ModBus communication via RS485 with the use of the LoRa protocol to transmit the data to a gateway.

The second test aimed to assess the range of communication via the LoRa protocol of the developed devices, as well as the effects of obstacles on the range.

Finally, the third test aimed to evaluate the availability of data through the MQTT protocol via WiFi to Thingspeak.

3.1 Prototype validation

To validate the integrated operation of the system as a whole, a test was set up as described in the previous methodology (see Fig. 2). The aim of this test is to demonstrate the system's capability to acquire and remotely transmit data. The system was entirely developed in the Arduino IDE and consists of three physical units, including the Arduino Uno for receiving data from the sensor and forwarding it to the LoRa transmitter, and to complete the LoRa receiver.

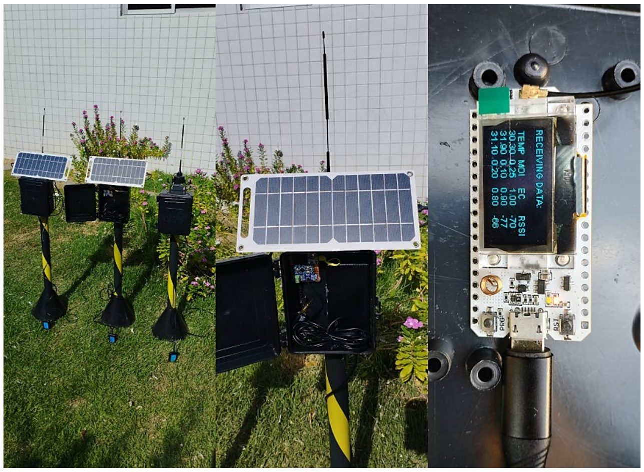
Before proceeding with the range and data transmission quality evaluation for the experimental fields, the entire system was already operational, receiving sensor data by the Arduino, which was then received by the LoRa transmitter and transmitted to the LoRa, as can be observed Fig. 4 below.

The system validation included testing the prototype under real "laboratory" conditions to verify if it meets the requirements and operates as expected. The following is a presentation of the operational and range test.

3.2 Field operation and range test

With the choice of the data collection and transmission scheme through the sensor, endpoint, gateway, and data storage location, the transmitters were moved away from the receiver and positioned at the boundaries of the properties at different points within the IF Baiano Campus Bom Jesus da Lapa area (Fig. 5A) and repeated at the UFRB Campus Cruz das Almas area (Fig. 5B). This was done to cover as much of the total area as possible, associating remote data acquisition. The geographical coordinates of each transmitter were recorded for distance reference purposes.

To collect data, the transmitters were programmed to send data from a probe-type sensor that collects soil moisture, temperature, and electrical conductivity variables at regular intervals. The messages contained a unique identifier for each transmitter, and the receiver was configured to record the received data, including the transmitter identifier and signal strength.



```
RECEIVING DATA:
TEMP MOI  EC   RSSI
30.30 0.25 1.00 -70
31.90 0.10 0.90 -77
31.10 0.20 0.80 -86
```

Figure 4. Prototype in operation.
Source: Author's Own

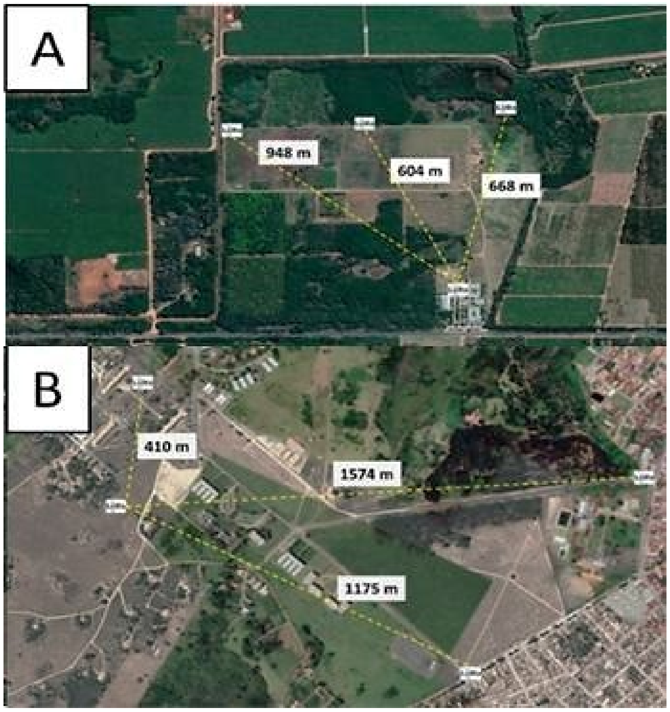


Figure 5. (A) Experimental area in Bom Jesus da Lapa, Bahia; (B) Experimental area in Cruz das Almas, Bahia.
Source: Adapted from Google Earth.

The receiver was positioned in a location with internet access. The central positioning of the receiver aimed to achieve better signal coverage throughout the area of interest. This, in conjunction with the potential location of an office on a rural property, aimed to minimize excessive personnel expenses for manual data collection.

Data was collected every 15 seconds with the goal of obtaining representative data from different locations within the campuses of different cities. After data collection, an analysis was conducted to determine the range achieved by the transmitter signal. The range was defined as the distance from the receiver at which data was successfully received, without data loss.

To determine the range, different scenarios were considered, including the presence of obstacles (trees, buildings) and atmospheric conditions (rain, fog). Signal strength data received by the receiver was also evaluated to assess signal intensity at different points in the field area.

The results allowed for demonstrating the quality of transmission, which did not study the maximum distance but achieved positive results ranging from 410 to 1514 meters with the reception of collected data. This differs from [12], who, through field tests in the rural sector between the municipalities of Sibaté and Granada in Colombia, established LoRa technology performance and its communication protocol within a radius of no more than 500 meters, under adverse terrain conditions.

The Received Signal Strength Indicator (RSSI) indicator was also obtained (Tab. 2), representing the signal strength received by the device in dBm. This is a measure of signal intensity and can be used to determine the device's proximity to the gateway or the number of obstacles along the path [2].

Table 2.
Distance and signal quality

Location	Transmitter	Distance (m)	RSSI (dBm)
Bom Jesus da Lapa - BA	LoRa 1	604	-123
	LoRa 2	948	-127
	LoRa 3	668	-115
Cruz das Almas-BA	LoRa 1	410	-91
	LoRa 2	1574	-123
	LoRa 3	1175	-132

Source: Author's Own.

The test was conducted using the antennas that came with the Heltec LoRa board. These antennas were connected to each Heltec LoRa board to improve signal transmission and reception capability.

The threshold of the boards is -139 dBm. So it is likely that greater distances could be achieved. [16] obtained better RSSI values when compared to those in the table above, which was associated with positioning based on field tests in rural and open environments. This differs from the environments in the present study, which had vegetation and structures in the line of sight. Values closer to 0 dBm are generally considered better when the device is close to the gateway [17].

3.3 *Web monitoring*

The system's operation test was conducted, involving the reading of sets of soil moisture sensors, data modulation to LoRa radio frequency by the endpoints, signal demodulation by the gateway, and data transmission to a web server with remote access in the cloud via ThingSpeak (Fig. 6).

After receiving the data, it was stored in channels, which are organizational units within ThingSpeak. Each channel was dedicated to a specific type of data and could contain multiple time series of information. The first channel was used to receive temperature data from sensor 1, the second channel for soil moisture from sensor 1, the third channel for electrical conductivity from sensor 1, and so on for sensor 3. The only exception was the electrical conductivity of sensor 3, as the free version of ThingSpeak only allows the simultaneous storage of 10 channels.

An ease of working with ThingSpeak leads to considerations similar to those of [18], who reported that IoT is becoming ubiquitous and universal, reaching all potential clients. The ThingSpeak IoT web service is unquestionably a fascinating web-based technology that has the potential to shape engineers' expectations.

With such a tool, data was stored as time series, which means it was organized by capture date and time. This facilitates trend analysis over time and the generation of dynamic graphs, as can be seen in the construction of auxiliary graphs with a 4-day period, as an illustrative example Fig. 7.

In general, considerations about the efficiency of LoRa technology in covering a large field area and its applicability in IoT applications can be made. Through the range test experiment with Heltec LoRa boards, it was observed that LoRa technology was capable of covering approximate areas of 90 to 120 hectares, although it did not achieve the maximum range values. The results demonstrated the efficiency and reliability of LoRa technology in long-range communications, making it a viable solution for IoT applications, especially in agriculture.

Channel Stats
Created: about a month ago
Last entry: less than a minute ago
Entries: 49296

Figure 6. Graphical and data visualization in web monitoring.
Source: Thingspeak.com.

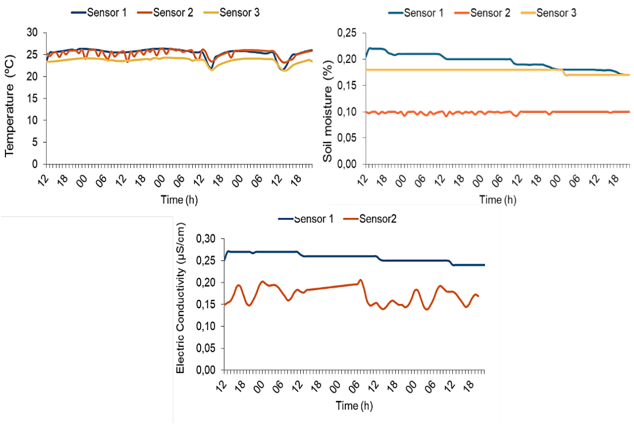


Figure 7. Graphs created with the stored database.
Source: Author's Own

The results are similar to those found by [19] suggesting that the IoT-based system developed using LoRaWAN technology can potentially be used for soil water monitoring applications and improve the sustainability of vegetable production systems, increasing marketable yield and saving irrigation water. However, there is an advancement in data transmission range, where the range presented by the respective authors does not exceed an application distance of 50 meters.

Noteworthy in all the presented results is the ability to replace manual labor with automation. Technology in rural environments has been a widely pursued goal in various industries and sectors over the decades. A significant result of this manuscript is the potential for increased efficiency, reduced human errors, and the release of human resources for more strategic and creative tasks, as also observed by [9].

4 Conclusions

In this case, it is achieved through embedded devices that collect soil parameter data and make it available to system users. This work presented applications of IoT and LoRa technologies, which are of great interest for their support of various applications in medium and large-scale agricultural farms.

The goal of implementing a soil variable monitoring system for agricultural fields has been achieved. Real-time data monitoring was conducted, and data was transferred to the ThingSpeak platform every 15 seconds. Various stages and corrections occurred before it was fully implemented because, in addition to being a new technology, the entire project needed to function perfectly, from the calibrated sensors providing accurate moisture readings to the endpoint devices sending data to the gateway and, finally, to the data cloud.

After numerous analyses, readings, attempts, and corrections, a definitive source code was developed, which proved to be efficient for the proposed application, thus achieving communication with the chosen cloud service.

It is necessary to bring rural areas closer to accessible and practical technological advancements. As evidenced in the state of the art, research in this field has been limited. Consequently, rural areas have not been able to fully leverage low-cost wireless network technologies.

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