Low-Cost LoRa-Based IoT System for Automated Irrigation and Remote Monitoring in Family Horticulture

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Abstract. *This project developed a low-cost embedded system for automated irrigation and remote monitoring, based on IoT (Internet of Things) with LoRa communication, applied to family horticulture in Alagoas. The system enables remote monitoring of ambient and soil humidity and temperature without requiring Wi-Fi, making it ideal for rural areas. Collected data is sent to the cloud for analysis and control. An application was developed to facilitate farmers' usage. The automation of irrigation reduces water waste and enhances agricultural productivity. Furthermore, the solution offers an excellent cost-benefit ratio, surpassing traditional market-available systems.*

1. Introduction

The city of Arapiraca is the most important in the interior of the state, with a population of over 231,000 inhabitants [IBGE 2019]. In terms of vegetable production, the municipality is the largest producer in the state of Alagoas [NEPSEPLAG 2016], which directly impacts the local economy. However, most of the vegetables are produced by farmers who use conventional systems, with the use of pesticides and irrigation systems that have deficiencies in controlling water consumption for crops. In addition, the current scenario of climate change highlights the importance of the judicious use of natural resources in agriculture. Among these resources, water stands out as one of the main determining factors of agricultural success and, consequently, of food production [Sousa et al. 2024].

In recent years, there has been a significant increase in interest in developing soil moisture monitoring systems, resulting in numerous studies in the area. Some studies focus on monitoring nutrients and moisture, while others explore the integration of this monitoring with irrigation automation [Silva et al. 2024]. In this context, the need to introduce alternatives to the conventional production system drives the implementation of technological innovations that promote sustainability and agroecological cultivation, improving the quality of life of farmers and production efficiency, while optimizing the use of available water resources.

Therefore, precision irrigation is a technique used to increase the efficiency of water use in agricultural systems, where knowledge of the variables in the planting environment (humidity and temperature) makes it possible to reduce waste of inputs, which can be achieved through continuous monitoring with the application of sensors.In view of this, this project proposes the development of a low-cost automated irrigation system with remote and real-time monitoring of parameters such as soil moisture, ambient temperature and air humidity, aiming to optimize water consumption, reduce costs and promote sustainability in the municipality of Arapiraca.

According to data from the Municipal Department of Rural Development of the Arapiraca, the region known as the Green Belt houses about 600 vegetable producers, with an average area of 1.089 hectares of land (10.890 m²) per producer. In this region, it is possible to find gardens filled with various types of vegetables, with lettuce, cilantro, and green onions being the most notable, harvested and sold daily. Among the most cultivated vegetables, cilantro represents 40% of the total cultivated area, with a yield of 8,000 kg/ha, followed by lettuce, which represents 35% of the total, with a yield ranging from 56,600 to 76,800 kg/ha, and green onions, which represent 15% of the total, with a yield ranging from 28,800 to 36,600 kg/ha [SEBRAE 2023].

The literature review indicated that optimal cultivation parameters vary with climate, season, vegetable type, soil, and ambient temperature, requiring the automated irrigation system to account for all these factors [Silva 2018]. Another noteworthy point is that the majority of vegetables are adversely affected by excessive heat and rainfall, thriving best under moderate temperatures, typically ranging from 18°C to 22°C. While certain vegetables exhibit a preference for higher temperatures, others require cooler conditions to achieve optimal growth [Amaro et al. 2007]. Thus, there is a need to monitor temperature, a critical factor for plant development. It is recommended to perform more frequent irrigation with lower volumes during the early stages of the crop cycle, and less frequent irrigation with larger volumes towards the middle and end of the cycle. Sandy soils require more frequent irrigation with smaller volumes of water, while clayey soils need less frequent irrigation but with larger volumes per application. According to Amaro, on hotter, sunnier days, more frequent irrigation should be applied, emphasizing the need to monitor humidity. For each type of crop, a detailed study is essential, as the optimal levels of humidity and temperature differ for each plant [Altoé 2012].

2. Methodology

The project activities began with exploratory research aimed at defining the vegetables to be implemented in the system. During this initial phase, a literature review was conducted, complemented by consultations with local producers to gather information relevant to the research context. Following this process, the team decided to focus on lettuce, chives, and cilantro cultivation, initiating the process of identifying the necessary parameters for each crop, as well as selecting the required hardware for their monitoring. This stage included assembling initial circuits to test the sensors (Fig. 1).

After researching the available sensors on the market, the team selected the analog resistive soil moisture sensor GC-58, which was later replaced by the capacitive soil moisture sensor V2.0 (explained in more detail later). Additionally, the DHT11

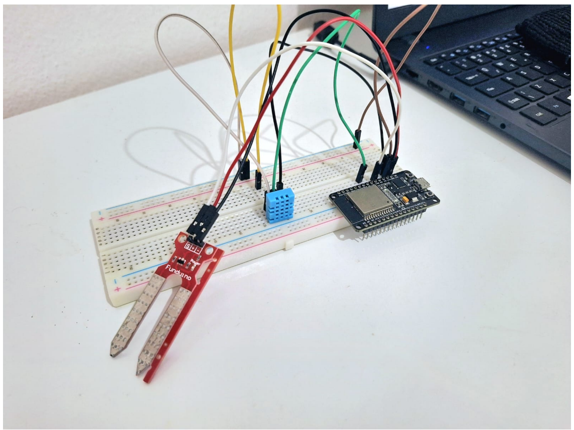


Figure 1. Assembly of the first circuits with soil and environmental humidity sensors.

sensor was chosen for monitoring environmental humidity and temperature. For resource management, the ESP32 microcontroller was selected due to its low cost, robustness, high performance, and efficient energy consumption during operation—an important consideration given the project's application in open fields. Furthermore, the ESP32 integrates Bluetooth and Wi-Fi communication modules [ESPRESSIF 2024], simplifying the project's development while enhancing efficiency and facilitating connection to the database.

To meet the needs of small-scale rural producers, it was essential to implement an independent Wi-Fi connection directly in the planting area. LoRa (Long Range) technology emerged as a viable solution, providing secure data transmission, low energy consumption, and long signal range, distinguishing itself from Wi-Fi and Bluetooth by not requiring high bandwidth or power [CONSULTIMER 2024]. This technology is capable of operating over distances on the order of kilometers, reaching up to 15 km in open fields, which makes it especially suitable for remote agricultural applications.

To utilize LoRa communication and leverage the advantages of the ESP32 microcontroller, the LILYGO T-Beam V1.1 module was implemented. This module integrates the ESP32 with an antenna for the desired technology (Fig. 2).

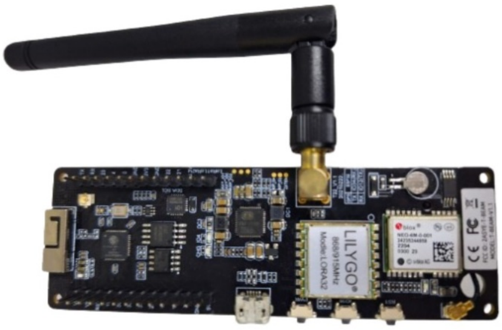


Figure 2. LILYGO module based on ESP32 and LoRa.

The project required two module units: one in the planting area (LoRa1) and another at the farmer's residence (LoRa2). LoRa1 was responsible for collecting data from installed sensors, controlling irrigation based on defined parameters, and transmitting this information. LoRa2 acted as the communication bridge between the sensor system and the cloud database, receiving data via LoRa and forwarding it to the backend using the HTTP protocol (HyperText Transfer Protocol) as shown in the system architecture diagram (Fig. 3).

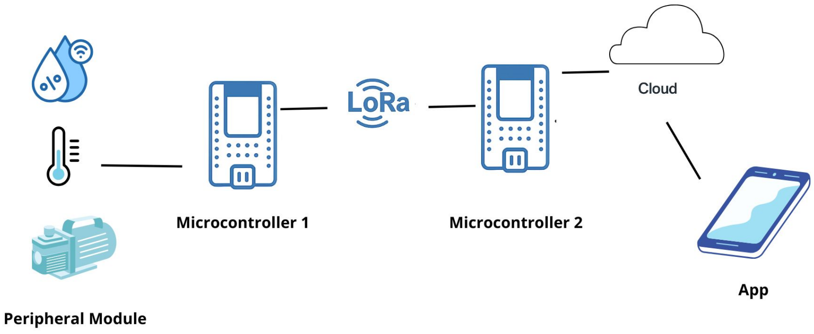


Figure 3. System Architecture Diagram

A similar study, which uses a comparable framework, indicated that the proposed solution employs long-range wireless communication through LoRa technology, ensuring the efficient transmission of the collected data. Additionally, the use of cloud storage and analytics technologies enables optimized processing of the information [Cunha et al. 2024], reinforcing the efficiency of the structure used to ensure the reliability and availability of the data in the system. After conducting platform tests, communication between the two boards was established, providing a better understanding of their functionality and the data transmission process.

The implementation utilized the LoRa.h library to initialize and configure the LoRa module and handle data transmission and reception, along with the SPI.h library for synchronous serial communication between the microcontroller and connected peripherals. During the development of the electrical schematics, improvements were identified, such as replacing the resistive soil moisture sensor with the capacitive V2.0 sensor to prevent oxidation issues and ensure compatibility with the ESP32, which operates at a logic voltage of 3.3V. Modifications were made to the printed circuit board (PCB) design to optimize module utilization. These changes included adjustments to the number of DS18B20 temperature sensors used for measuring soil temperature. Later, this sensor was planned as an optional addition to the project (Fig. 4).

Another aspect addressed during the project development was the programming of sensors and the definition of the operational workflow. At this stage, tests were conducted to optimize data generation and collection. It was determined that the LoRa 1 module would read data and send it to LoRa 2 at specific times of the day. Additionally, it was

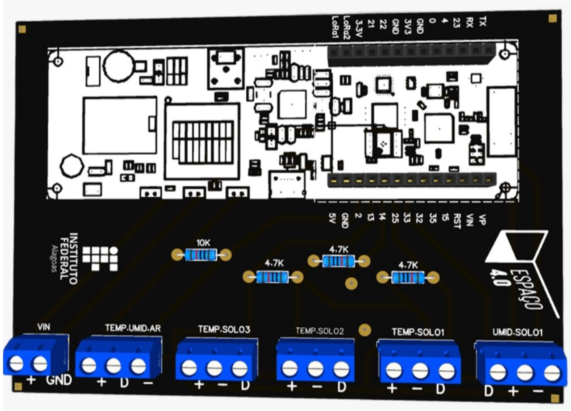
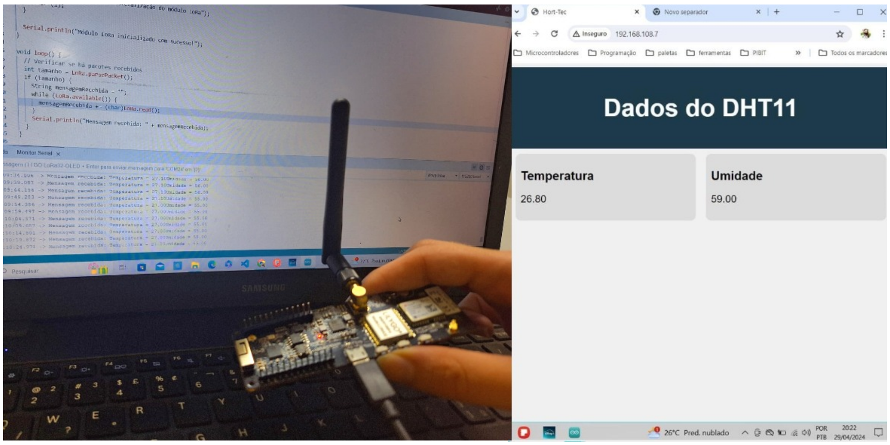


Figure 4. Prototype printed circuit board design.

planned that, at another set time, LoRa 1 would receive updated ideal parameters, enabling the farmer to modify them as needed. The decision to transmit data only at specific times was facilitated by the use of the time.h library and was based on the latency exhibited by most monitored variables regarding their variation. This approach reduced information traffic by having LoRa 1 send only a single string containing the required data. Upon reception by LoRa 2, the data was processed and assigned to their respective variables.

However, as no system is free from potential failures, it was noted that soil moisture should be monitored more frequently to prevent issues with the pump activation process. If the parameter remains unchanged despite pump activation, an alert is sent to indicate possible errors, such as relay inefficiency or communication failure. After defining the system's functionality, initial tests were conducted to integrate the two communication flows. Initially, the DHT11 sensor was used to collect humidity and temperature data. LoRa 1 transmitted these readings via LoRa to the second microcontroller, which received the data and forwarded it to a web server, allowing for testing of both communication protocols (Fig. 5).



Dados do DHT11

Temperatura
26.80

Umidade
59.00

Figure 5. Communication test and data visualization on a web server.

The development of the irrigation management application began with defining essential features for farmers and prototyping interfaces with Figma. The choice of

Dart and the Flutter framework was based on their agility and high performance. At the same time, a cloud-based database was created, accessed via a REST API, with MySQL and Node.js selected for high performance and scalability. Communication between the application and the microcontroller was structured using HTTP methods (GET, POST, PUT, DELETE). DigitalOcean was chosen for hosting due to its scalability and cost-effectiveness.

After building the API, its integration with the mobile application was initiated, defining the resources and routes. User interface flows were designed for intuitive navigation, with error messages to enhance user experience. Communication between the microcontroller and the cloud database was established using HTTP protocol and JSON, with support from the HTTPClient.h and Wifi.h libraries. The protective casing for the modules was created using 3D modeling and printing. For PCB production, EasyEDA software was used, and the thermal manufacturing method was adopted, transferring laser print ink to a phenolic plate with a copper layer, ensuring high precision and low cost.

3. Results and Discussion

This study developed a low-cost embedded system for automated irrigation and remote monitoring, designed to support family horticulture in Alagoas. The system employs the LoRa protocol to enable communication in areas without Wi-Fi access, allowing data collection from sensors that monitor environmental parameters such as temperature and humidity. The irrigation system is controlled based on real-time data, with one LoRa unit monitoring and managing irrigation, while the second unit handles data transmission to the server. The system features low latency, using simple string transmissions that avoid data overload. It is powered either by a 5V power supply or a rechargeable lithium battery, offering flexibility for deployment in the field. The prototype (Fig. 6) demonstrates the integration of LoRa modules for data collection and irrigation control.

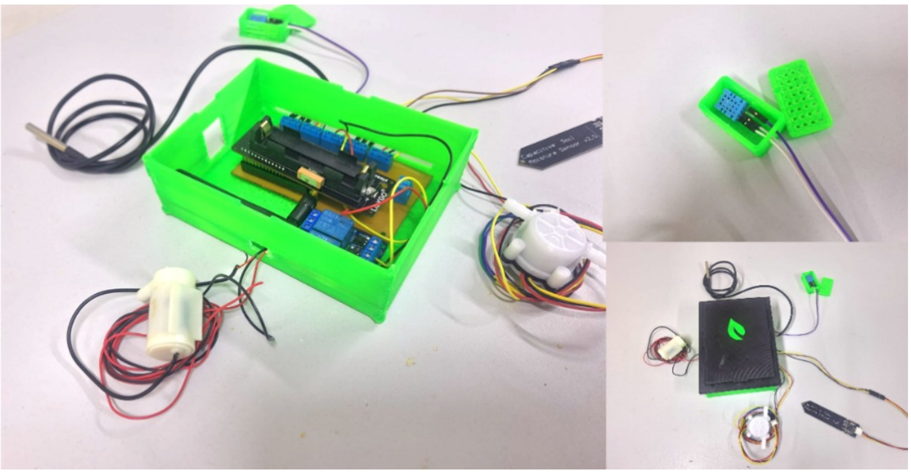
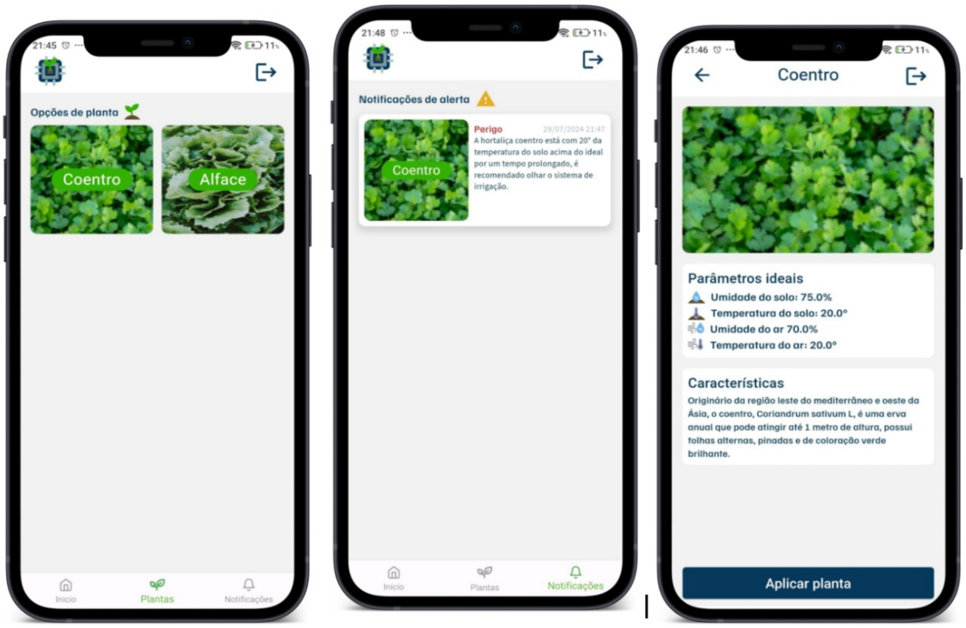


Figure 6. Final system hardware.

The system's functionality is complemented by a mobile application developed to provide farmers with an intuitive interface for managing their crops and the irrigation system (Fig. 7). Upon registering and logging in, users are directed to the main dashboard, where they can view all monitored plants. Notifications are accessible through a dedicated icon and display environmental alerts—such as excessive temperature or humidity—sent in real time from the embedded system. These are categorized as warnings or danger alerts depending on severity. Farmers can also explore a list of crops available for monitoring, each with its own ideal temperature and humidity parameters. When a crop is selected, the app shows detailed information and offers an “Apply Plant” button. Upon confirming prior installation of the embedded system, the plant is linked to the farmer’s account and assigned a unique ID that is also stored in the microcontroller, enabling automatic monitoring.

From that point, soil and air temperature and humidity readings are collected daily, with visualizations available as current averages and monthly graphs. Farmers can modify irrigation thresholds by selecting the monitored crop and using the edit option. This complete workflow ensures user-friendly, flexible, and responsive irrigation management tailored to each crop’s requirements. Despite the intuitive interface and system automation, it is important to consider potential barriers to adoption by farmers. Factors such as digital literacy, limited internet access in rural areas, and the need for initial technical support to install the embedded system may affect the effective use of the proposed solution.



A hortaliça coentro está com 20° da temperatura do solo acima do ideal por um tempo prolongado, é recomendado olhar o sistema de irrigação.

Parâmetros ideais

Umidade do solo: 75.0%
Temperatura do solo: 20.0°
Umidade do ar 70.0%
Temperatura do ar: 20.0°

Características

Originário da região leste do mediterrâneo e oeste da Ásia, o coentro, Coriandrum sativum L, é uma erva anual que pode atingir até 1 metro de altura, possui folhas alternas, pinadas e de coloração verde brilhante.

Figure 7. App screens for managing the irrigation system by the farmer.

The system’s integration of both hardware and software enables the automated collection of environmental data, real-time irrigation control, and user-friendly monitoring through the mobile app. Parameters such as soil moisture and temperature, as well as air temperature and humidity, are recorded daily and displayed in the app as current averages or monthly graphs. The app allows users to fine-tune irrigation settings for each plant, ensuring that the system adapts to specific environmental conditions and enhances crop productivity. The results from the prototype demonstrate the potential for this system to provide accessible, efficient, and cost-effective irrigation management for small-scale farmers.

The project costs were divided between hardware and software. Hardware expenses are mainly related to the LoRa module and environmental sensors, with average prices ranging from US$4 to US$10. The app development incurred no additional costs; however, hosting the REST API in the cloud required a subscription to the DigitalOcean platform, with plans starting at US$6 per month. Alternatives such as Google Cloud, Azure, and AWS were also considered, but due to usage limitations on free plans, they were not adopted. Additionally, purchasing a domain may incur extra costs.

In comparison, commercial systems that offer IoT-based environmental monitoring and data visualization tools can reach prices of up to US$600 per unit, depending on the range of features provided, integration capabilities, and support services. While such solutions may offer advantages like scalability or brand reliability, the system developed in this project represents a significantly more affordable alternative, particularly suited for small-scale farmers.

4. Conclusion

The implementation of automated family horticulture using the ESP32 microcontroller and LoRa technology has proven to be a promising solution for making food cultivation more practical, accessible, and sustainable. The system enables remote monitoring and control of critical environmental variables such as temperature and humidity, fostering optimal conditions for food production.

This study demonstrates how the integration of Internet of Things (IoT) and cloud computing technologies can significantly contribute to the modernization of small-scale agriculture and the promotion of food security. However, a notable limitation was the inability to conduct field tests, which prevented practical validation of the system in real cultivation environments.

Future work should focus on deploying the system in real-world scenarios to assess its robustness, energy autonomy, communication stability, and direct impact on productivity. Furthermore, the use of climate-based data for automated decision-making and increased installation flexibility are promising areas of development. It can be concluded that the system holds great potential for application, particularly in rural communities seeking low-cost and high-efficiency technological alternatives.

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