Development of a LoRa Wireless Sensor Network to Estimate Agricultural Risk

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***Abstract*—Sensors are quite important for agricultural risk monitoring, and the customization of a LoRa wireless network and its use in rural applications is still a challenge. This paper presents a data collector system based on a Wi-Fi and Lora platform. The arrangement includes an ESP32, which is a single 2.4 GHz Wi-Fi and Bluetooth combo chip designed to operate with ultra-low-power and based on the 40 nm technologies. Therefore, the module allows using both protocols for Wi-Fi and LoRa wireless networks. One of the main characteristics, which was leveraged in this study, is its applicability for long-range communication in rural areas with low power consumption. During operation, the proposed receiver node is connected to the internet, thereby enabling data storage on servers, such as ThingSpeak, which is an Internet-of-Things analytics platform service. The results in a controlled-environment test showed that the connection between the station and receiver was fully functional at a distance of 500 meters. Besides, once this advanced data collector, currently under development, is finished, interconnection of several stations will be possible, even if they are remotely located with respect to the receiver node.**

***Index Terms*—Agricultural Sensors; LPWAN; LoRa; Wireless Sensor Network**

I. INTRODUCTION

Agribusiness is an important pillar of the Brazilian economy encompassing several areas. Automation has recently gained prominence in an area called precision and decision-making agriculture. In this scenario, the use of intelligent Global Positioning System (GPS) guided machines to plant, cultivate, and harvest accurately is growing in the most advanced areas of the country, achieving greater savings in inputs, productivity increase, and sustainability. Thus, it has become a driving force and an integrator within and outside the production chain.

In addition to the new technologies embedded in agricultural machinery, the development of low-cost agrometeorological stations and their connection by building a wireless network of sensors has proved to be useful in the field. This is because, based on the data generated by such equipment, computational techniques and statistics can be applied to extract useful information for the farmers.

In this context, the development of computational tools to support decisions based on these data is important to reduce risks and, consequently, losses in agricultural areas. Preliminary discussions about such subject have been presented in the regional meeting of Computer Brazilian Society [1]

Technologies to integrate microelectronics, collect and compute data, and evaluate field conditions based on agrometeorological data have been developed since the advent of microprocessors and advances in digital electronics [2]. More recently, however, the Internet-of-Things (IoT) has been playing a key role in Agriculture 4.0. Several types of sensors can be used for continuously measuring a great amount of data, assisted by wireless networks and cloud computing to create evaluation models for field conditions while providing greater safety for farmers [3].

An important application for sensors in agriculture is directly measuring soil characteristics through parameters such as pH, nutrient content, temperature, and moisture, among other variables of interest.

The results of soil evaluation are important for obtaining a more precise scenario of the planting area and, therefore, higher performance and quality. Advanced technology systems are thus necessary for high-performance yields [4].

Based on this scenario, Figure 1 shows an adaptation of the structure to agricultural risk models proposed by Cruvinel and collaborators [5]. In such context, the developed method exploits smart sensors to measure Soil Quality (SQ) indicators.

SQ is one of the factors that influence agricultural risk given that it can influence the productivity indexes of crops [6]–[9].

In such a context, different protocols for data communication have been observed in the literature. One example is the LoRaWAN protocol, which can enable implementation for long-range networks, avoiding the use of conventional cellular networks, whose coverage in Brazil in rural areas is still not ideal.

As part of a broader project in which the development of agricultural-risk analysis tools based on data from different sources is being developed, this study presents a new approach of both climatical and soil data collector system based on a wireless network, which is intended to be one of those data-sources for support decision making in agricultural risk [10]–[12].

The remainder of the paper is organized as follows: Section II presents the materials and methods; Section III presents the results and discussions; finally, conclusion and future studies are presented in Section IV.

 ISBN: 978-1-61208-875-4

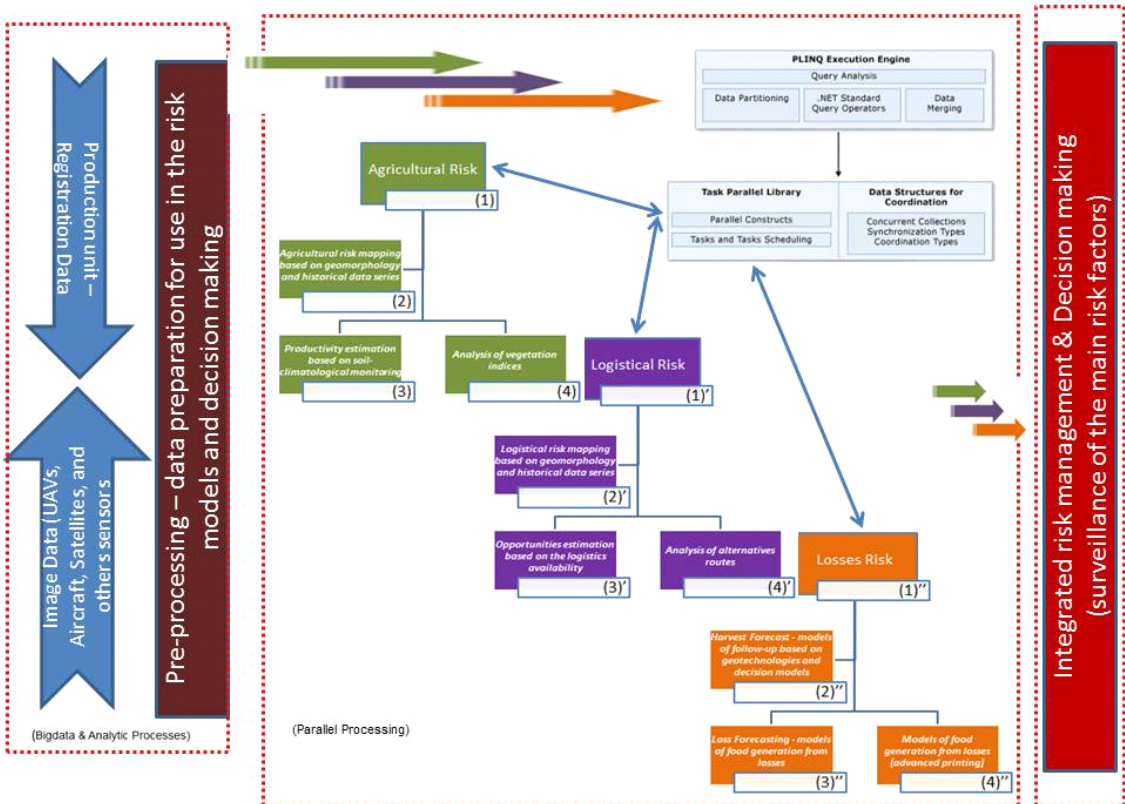


Figure 1. A framework related to the use of geo-technologies and embedded support decision systems for agricultural risk management.

II. Materials and methods

A hardware device based on Arduino Mega 2560 was used to build the first version of the data collector equipment, connecting sensors to a Heltec Wi-Fi Lora 32 [13], which contains an ESP32 micro-controller, a Bluetooth low-energy transmitter, a Wi-Fi transmitter, and a LoRa transmitter, in a single board. Both boards exchange information through their serial ports. Data were also received using a Heltec Wi-Fi LoRa 32 module. The equipment receives, organizes, and transmits data to a remote server using a dedicated Wi-Fi network. In the first sensor validation stage, data from stations were stored in ThingSpeak, an IoT platform that enables real-time aggregation, visualization, and analysis of data flows in the cloud. Air temperature, humidity, wind speed and rainfall were initially monitored. Data were also inserted into a Mosquitto, NodeRed, and Postgres-based platform, which will be integrated in a high-performance architecture using Apache-Spark to treat and process data through a risk calculation algorithm [14].

Figure 2 presents the basic architecture developed for soil quality risk analysis, in which it is possible to observe not only the model components but also the LoRa structure and protocol used for wireless agricultural data communication.

Figure 3 presents the developed concept: a station containing microprocessors, a DS DHT22 sensor, a bascule pluviometer [15], and an anemometer. Another Wi-Fi LoRa module was positioned 500 meters away playing the role of a gateway, receiving data from the station and transmitting them to ThingSpeak through a dedicated Wi-Fi network.

The following sections describe the experimental organization of the equipment, the hardware used for the collector system, a brief notion about LoRa networks, and the organization of the station firmware.

A. Area and agricultural experiment

The collector system prototype was installed inside a reserved area of the National Precision Agriculture Reference Laboratory (Lanapre) from the Embrapa Agricultural Instrumentation Center, São Carlos, Brazil, aiming to build a database to validate risk calculation models. The agricultural area was about 80 by 50 meters, having corn (*Zea mays.*) planted throughout its extension. The area was divided into 4 plots measuring 20 meters by 50 meters each. Their soil will receive different amounts of nitrogen; the soil and plants will be measured over time. As presented in Figure 4(a), the first plot did not receive nitrogen at all (0%), the second received 50% of the amount recommended in the literature, the third received 100% of the recommended amount, and the fourth received 200% of that amount. Soil samples were extracted in three growth stages along the crop cycle from three depths: 0-20, 20-40, and 40-60 centimeters.

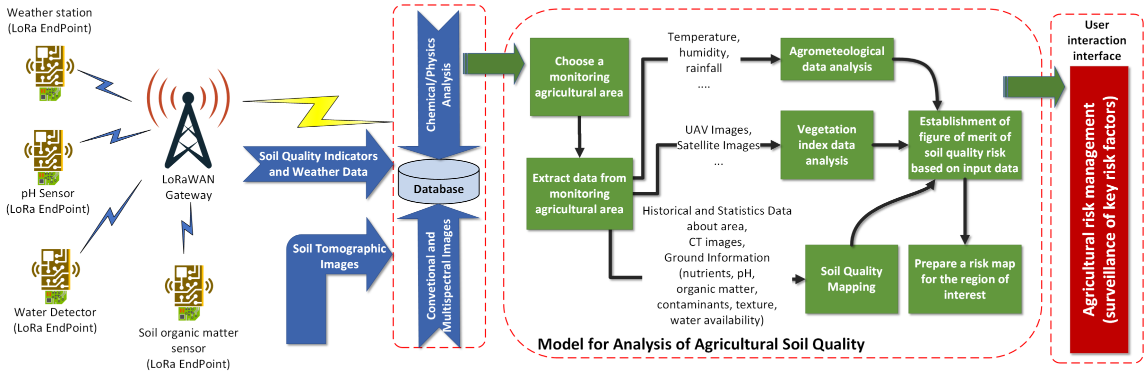


Figure 2. Soil quality risk management based on wireless communication and embedded systems for decision support.

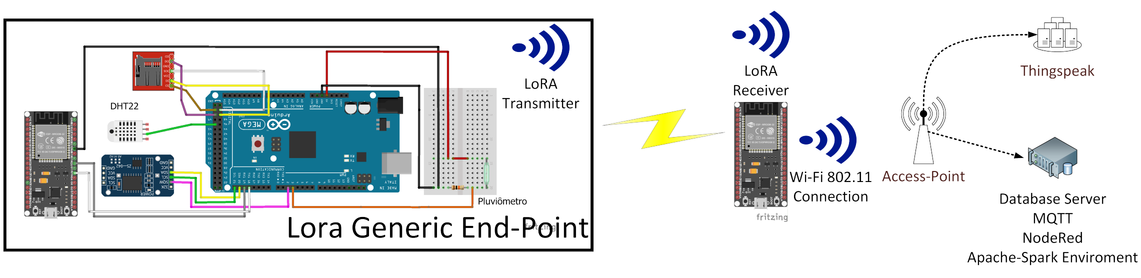


Figure 3. Prototype of data collector device based on Arduino Mega and Heltec automation using LoRa to transmit agrometeorological data in the field.

The collector system has obtained climate data over a prescribed experimental period from temperature, humidity, wind speed, and rainfall sensors to build more accurate agricultural risk models. The objective was to integrate those pieces of information into an agricultural-risk analysis model. Figure 4(b) shows the experimental area with corn planted according to the experiment plan. In addition to various climate variables from the planting stage, aerial images were extracted from drones equipped with multi-spectral cameras. The resulting images also composed the dataset used in the high-performance processing platform.

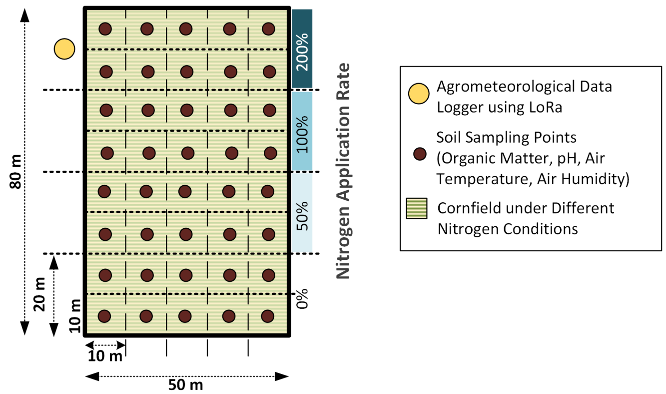
B. LoRa and LoRaWAN

LoRa (long-range) is a patented modulation technology for wireless communications acquired by Semtech Corporation in 2012 [16] [17].

LoRa is a wireless solution for networks below 1 GHz. It uses frequencies that demand no licensing, e.g., 433, 868, and 915 MHz. This type of networks is used to connect devices in low-consumption long-range applications because it can reach 15 km in open field [18].

A remarkable advantage of LoRa is the high sensitivity of its sensor and the great capacity of its communication link, allowing long-range transmissions. Typical SNR levels for spreading factors 10 and 12 when using LoRa modulation are -20 dB and -15 dB, obtaining receiver sensitivities of -134 dBm and -129 dBm, respectively. These values are barely comparable to the typical sensitivity of Wi-Fi or Bluetooth receivers, which is often in the range from -40 dBm to -80 dBm. The main properties of LoRa modulation are 1) its scalable bandwidth and frequency, enabling easy change from narrowband to wideband hopping, 2) resistance to Doppler shift, 3) relatively high immunity to fading or multi-path, especially in dense scenarios, and 4) robustness to interference.

The LoRa specification just provides the physical layer for radio communication. Besides, the LoRaWAN is the most popular protocol for wide area networks and it is, fundamentally, a network protocol designed with a special focus on battery-powered devices, as they are the most commonly used devices with LoRA. Therefore, energy consumption must be kept as low as possible. The network topology of LoRaWAN is a star network, in which several end-devices transmit to a given gateway. In fact, devices broadcast their transmissions, which might be received by several gateways. Then, backend servers, which all gateways are connected to, make an automatic decision on which gateway manages the received packets. Uplink transmissions are considered predominant in LoRaWAN, and therefore have preference over downlink connections. The protocol addresses this aspect by defining three different classes of connected end-devices with an incremental number of features: (1) Class-A devices, with the basic set of features that all devices must implement; (2) Class-B devices, with scheduled listening windows; and (3) Class-C devices, for bi-directional communication at any time [19]–[22]. To meet the different requirements of a wide range of IoT applications, the LoRaWAN communication protocol offers three class types for sending and receiving packets, as shown in Figure 5.



(a)

(b)

Figure 4. Experimental area: (a) Design of the plots using an agricultural data collector system; (b) Corn crop (*Zea mays.*) according to the plan.

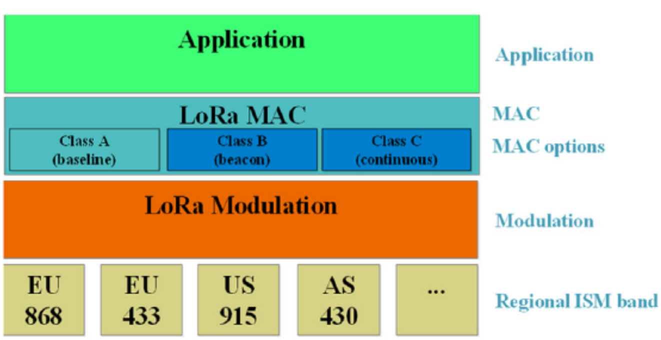


Figure 5. LoRaWAN Classes [23].

C. Heltec Wi-Fi Lora 32 Module

The Heltec Wi-Fi LoRa 32 module presented in Figure 6 stands out for its ESP32 processor from Espressif [24] with a 32-bit Reduced Instruction Set Computer (RISC) architecture, and its dual-processing ultra-low-power core. The SX1276/SX1278 LoRa chip [25] is also attached to the module, enabling connections using this type of network. In addition to LoRa, the module includes Wi-Fi and Bluetooth connections through their respective antennas. An IPEX interface is available to connect an external antenna for LoRa.

An SH1.25-2 battery interface in the lower portion of the module with an integrated lithium battery management system allows controlling charging and discharging, protecting against overload, and switching between USB and battery sources. The module also has a 0.96 inch, 128 x 64, organic light-emitting diode (OLED) display on the top for programming and operating.

The manufacturer provides libraries for programming in the native Arduino environment, Platformio, and Visual Code.

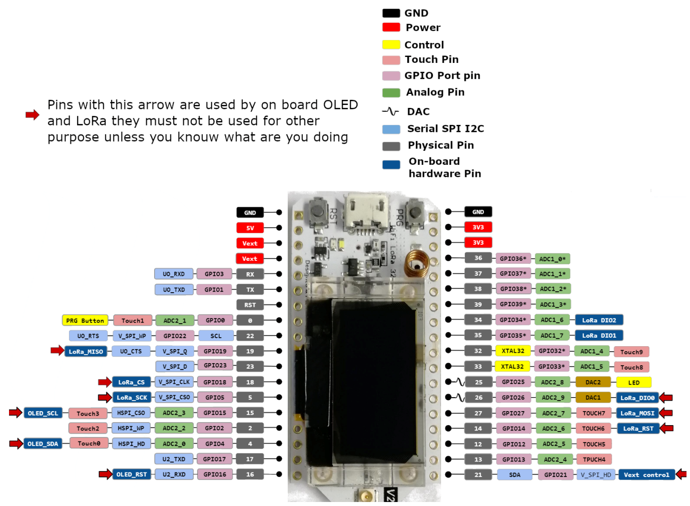


Figure 6. Heltec Wi-Fi 32 LoRa module pinout.

D. Structure of the collector station firmware

All sensors, the Real Time Clock DS3231, and non-volatile memory modules were connected to Arduino Mega 2560, while the Heltec Wi-Fi LoRa 32 module managed communication tasks. Therefore, all the data collection was programmed into Arduino's firmware. At first, the firmware used the interrupt ports to facilitate processing. The pluviometer interrupts when a new pulse is detected, which occurs when its inner recipient reaches a 0.25-mm rain volume, and moves the weighbridge, generating a 5-V signal in port 47 of the Arduino, which interrupts its activity to record a flag and an increment in the number of pulses. The DS3231 was programmed to fire once a minute in the same firmware, and all the events of information data collection from the DHT22, anemometer, and rainfall were coordinated by this signal, which also determined when the information had to be packed and sent through the serial port to the LoRa-WiFi module. The same data were recorded into the memory card to increase safety.

The Heltec module received data through the serial port and communicated with the receiving module, sending the packages from Arduino. The Wi-Fi and Bluetooth networks remained switched off in this module for consumption purposes. Figure 7 presents the algorithm structure and the parallel execution of each module.

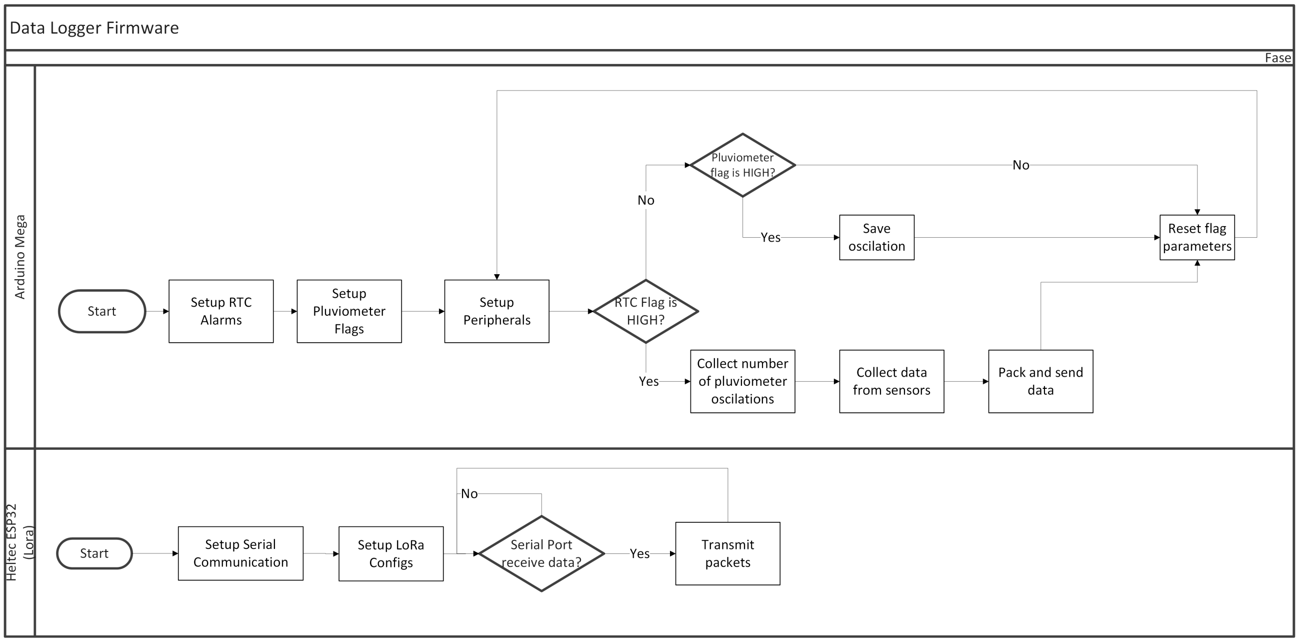


Figure 7. Data collection flowchart.

The receiving module was programmed to receive data permanently, unpack the received information, check the type of data, and transmit it to the correct ThingSpeak channel. Subsequently, it transmitted the necessary confirmation to the information sender station.

III. RESULTS AND DISCUSSION

The corn crop (*Zea mays.*) is divided into two major phases: vegetative and reproductive. Each vegetative stage is defined according to the last fully expanded leaf or out of the cartridge. The reproductive phases begin with mating and go on to physiological maturation, stage where the grains have a black layer at the insertion between the grain and the cob.

The growing stage of the maze crop, for the validation of this development, was defined into a period of time comprised between 60 and 65 days. Therefore, the complete monitoring time of climate and soil variables have took from 1440 hours to 1560 hours, since the night period also requires follow-up.

Thus, for the evaluation of the Lora wireless sensor network in a rural environment, wireless networks based on ZigBee (IEEE 802.15.4-based) and Wi-Fi (IEEE 802.11-based) were also tested for comparison purposes. Table I presents comparative information for these wireless network modalities.

In this context, the total energy consumption in kWh and the range distance in meters have been evaluated, as well as other parameters of interest. Therefore, for the maize cultivation monitoring time of 1560 hours a consumption of 0.16 kWh was observed for the platform based on LoRa, while using ZigBee and Wi-Fi a consumption of 0.40 kWh and 1.95 kWh respectively were observed, i.e., based on the use of a +5Vdc power supply for each of the technologies in order to calculate the amount of energy consumed during the same period of monitoring.

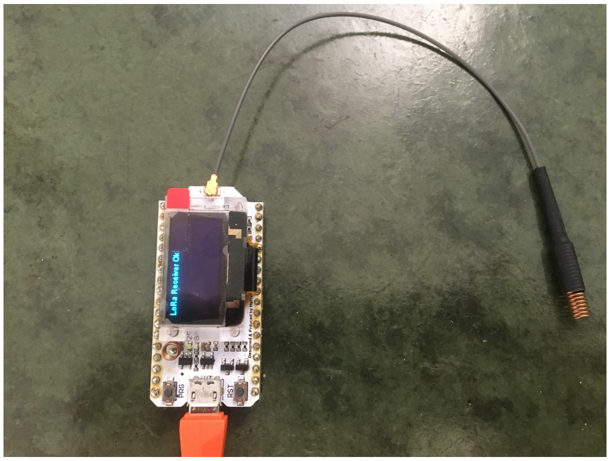
On the other hand, the range provided by the use of LoRa technology was observed to be 150 times superior to ZigBee and 60 times superior to Wi-Fi use.

The prototype was assembled using a breadboard (Figure 8) to validate the hardware and firmware in the laboratory before building the circuit boards and boxes for field application. During the tests, the collecting and receiving modules were placed 500 meters apart with a wall between them. There was no information loss in this distance according to the data from the memory card and the receiving log file. Eventually, some transmission and ThingSpeak failures occurred. Code improvements to allow resending and checking the Wi-Fi network were proposed to reduce failures.

Figure 9 shows a section of code configuring the use of a LoRa module in the Heltec Wi-Fi LoRa 32 board, specifically in the data receiving module. This configuration allows data exchange using both LoRa and Wi-Fi networks.

Table I
MAIN CHARACTERISTICS OF THE TECHNOLOGIES ZIGBEE, WI-FI , AND LORA [26]–[28]

Indicator	**Wireless Network's Technologies**		
	ZigBee	**Wi-Fi**	**LoRa**
Range Average	up to 100m	up to 250m	up to 15 km
Power Consumption	52 mA	251mA	20 mA
Baund Rate	up to 250 Kbps	3 Mbps up to 866 Mbps	up to 50 Kbps
Robustness	High	Medium	High
Network topology	mesh	start, mesh	star-of-stars, mesh



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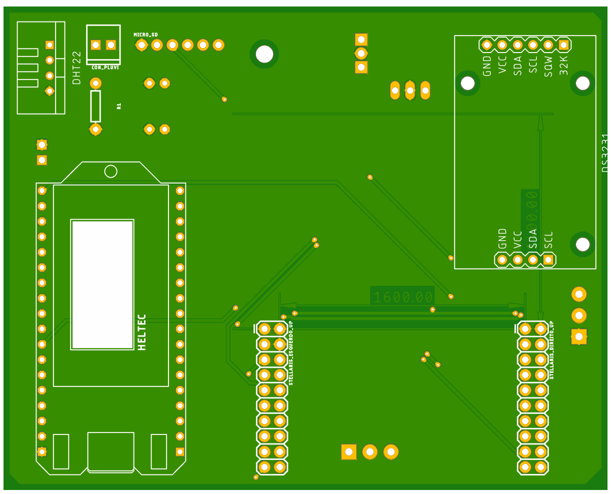


(b)

Figure 8. Prototypes for collecting and transmitting data through a LoRa network: (a) Network data receiver module; (b) Collector device board installed in the field.

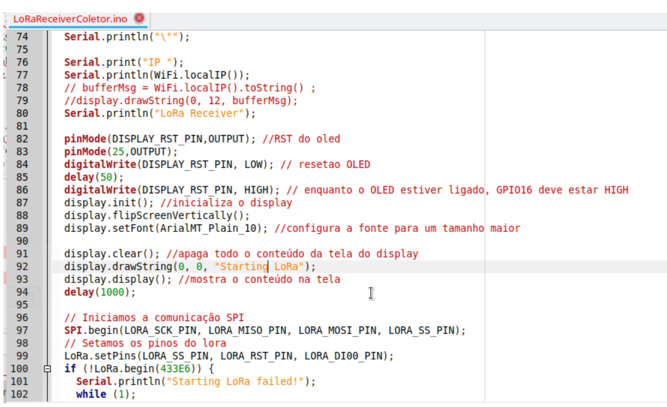
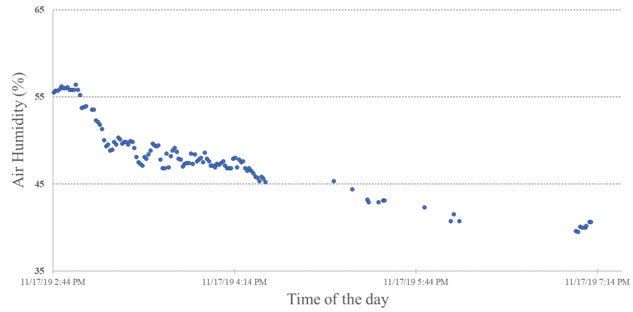
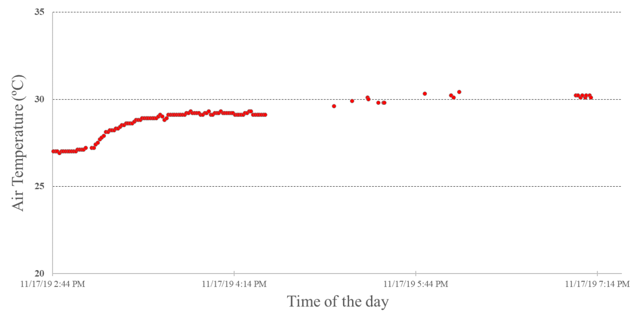


Figure 9. A section of the data receiving code.

Furthermore, experimental tests have allowed recording data into ThingSpeak, which can be analyzed using its tools. The charts in Figure 10 present an example for a period of 12 hours of data temporal series from both air humidity and air temperature in the agricultural area. Some data correctly transmitted using the LoRa network were not retransmitted to ThingSpeak.



(a)



(b)

Figure 10. An example for a period of 12 hours of data temporal series from both air humidity (a), and air temperature (b) in the agricultural area. Such data are part of the variables set data vector for the evaluation of the soil quality analysis, which also uses the wind speed, rainfall, pH and the % of organic matter measurements from each plot.

During operation, it was observed that some data was not properly retransmitted. After verification, it was found the occurrence of interruption in the use of the Wi-Fi module due to the momentary unavailability of the Internet in the rural area. Once that such an occurrence has been verified, the algorithm has become reorganized for automatic reconnection to the network, i.e., when any events of this nature occur again. Also, energy saving concepts have been used based on deep-sleep, controlled by the ESP32 microcontroller present in the Heltec module, i.e., configuring the Real Time Clock (RTC) DS3231 to signal the moments when the microcontroller should actually work. The current consumption for the microcontroller's circuit when in deep-sleep are in the order of 20μA [29].

The contributions of this work involve the use of a long-range and low power consumption of agricultural data transmission that is very promising and suitable for application in the rural environment, mainly for agricultural management based on precision agriculture, which is an approach to farm management that uses information from sensors to ensure that crops and soil receive exactly what they need for optimum health and productivity.

Besides, based on such a concept it is possible to take into a better manner the risks that occurs in agricultural production, and their mitigation. However, to achieve this goal, so fundamental for production, it is necessary to monitor the behavior of soil, climate and plant variables, their values and ranges, as well as the dynamics for decision making in real time.

In this study, the risk modeling has referred to the risk on soil quality, one of the essential parts that make up the total agricultural risk.

Likewise, to establish the soil quality risk behavior, it is necessary to know the variability of air temperature and humidity, organic matter content, pH and availability of nutrients in the soil, among others. However, a merit function that can integrate either a set of variables or information about their behavior at instants of time has to be considered.

One way found to integrate the variables is the use of their occurrence probabilities obtained from the time series of the collected data, which are treated as random variables. In addition, using a risk model it is possible to meet prevention and containment strategies, so that as many scenarios as possible help the promotion of expected result in terms of number of tons/hectares.

IV. Conclusions

In this present study it has been shown the use of LoRa wireless network for agricultural application, i.e., related to risk analysis. Results have shown that the whole implementations worked satisfactorily not only at the laboratory but also during the validation occurred in a corn's agricultural field. In such a context it has been observed that there are needs for some firmware corrections and additional agricultural experiments in order to increase system reliability to the users. Therefore, the use of a LoRa network has been proved to be suitable for agricultural application, with special interest for soil quality risk analysis.

In addition, another important aspect to be observed in these conclusions is that the development of a wireless sensor network based on Lora made it possible to transmit long range and operating agricultural data at low power consumption, which is promising for decision support in the rural environment.

Likewise, the development of the wireless network based on Lora minimized the limitations regarding the availability of energy sources and the difficulty of accessing the internet in rural areas, which required seeking customization for real-time operation considering variables of climate and soil which can bring impacts to soil quality during agricultural planting.

Future works will take into account the implementation of pH and organic-matter embedded smart sensors, as well as algorithms structured using Apache-Spark to operate the model for agricultural soil quality risk analysis.

Acknowledgment

This study was financially supported by the São Paulo Research Foundation (FAPESP), process no. 17/19350-2, through an agreement involving IBM Brazil and the Brazilian Agricultural Research Corporation (Embrapa). The authors are also grateful for the institutional support by the Federal University of Mato Grosso (UFMT).

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 ISBN: 978-1-61208-875-4