LoRaWAN Infrastructure Design and Implementation for Soil Moisture Monitoring: A Real-World Practical Case

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Abstract. The application of Internet of Things technology in the agricultural sector has allowed to achieve a significant improvement in the process of growing and harvesting products. This has been possible since it allows obtaining a more exact control of the information in real time, thus allowing better decision-making in crop management and thereby improving their quality. Faced with this situation, this paper proposes the design and implementation of a soil moisture monitoring system for a strawberry crop using LoRaWAN technology to allow the farmer to improve the production of their crops, while maintaining low technological implementation costs. The system allows the visualization of the data in real time through a web application, which are obtained from the sensors installed in the ground and which are transmitted through the LoRaWAN network. Once the system was developed using different trending technological tools, its functionality could be verified with satisfactory results. The functionality of the application obtained an acceptance of 94% and an usability a score of 86.87, indicating that the system meets the expectations of the users. Additionally, in the coverage tests, it was possible to verify the long communication range of the installed LoRaWAN devices.

Keywords: LoRaWAN, Smart Farming, IoT, Soil Moisture Monitoring.

1 Introduction

Year after year, the Internet of Things (IoT) technology is used more frequently in different areas such as health, transportation, communication, among others [1]. However, its use is still not very common in some areas in developing countries, such is the case with the agriculture and farming [2], especially with the small and medium size producers. The lack of knowledge and low budgets are the main reasons why they do not apply technology in their activities. This situation causes the progress of small and

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DOI: 10.1007/978-3-031-63783-4_11

medium size producers to be delayed compared to the large producers who use technology more frequently creating an important gap in production levels.

According to the Food and Agriculture Organization (FAO) of the United Nations, by 2050, the world should produce 70% more food than in previous years [3]. In order to promote the development of this sector and take it to another level, it is essential to use the latest technologies, looking for solutions for improving the level of production but avoiding high costs [4].

In the case of developed countries, technologies such as the Internet of Things (IoT) are used frequently in agriculture. This has allowed them to achieve important production improvement. Among the used technologies in this area, one of the most important one is the LPWAN networks. This type of technology allows farmers to access accurate information in real time, achieving better decision-making in crop management in order to improve its quality [5].

On the other hand, efficient production of agricultural crops is affected by different physical variables such as temperature, humidity, soil pH, among others; and depending on the good control of these variables, you can have a successful harvest, as well as have product losses [4].

In the specific case of strawberry cultivation, soil moisture represents one of the main factors influencing its production. Most of the process from planting, growing and maturing of the strawberries depends on this variable. If this variable is not adequately controlled, it can generate ineffective production and can even generate diseases in the plants [6].

With this background, in order to contribute to the sector of agricultural production, this work proposes a smart solution (design and implementation) for a strawberry crop based on LoRaWAN technology. The proposed solution has been implemented in a real farm located in Ecuador in order to verify its functionality.

The proposed solution is composed of a sensor infrastructure that accumulates soil moisture monitoring data, a LoRaWAN network which allows transmitting the gathered data to the server, and an web application which allows farmers to visualize the real time data in order to make decisions in their crops. Through the proposed system it is intended to obtain a more efficient cultivation process, while having a low-cost investment. This solution allows not only to improve soil moisture control but also helps to manage natural resources more efficiently, i.e. water [7].

This paper is organized as follows. Section 2 describes the state of the art of the usage of LoRaWAN technology in agriculture solutions. Then, in section 3, the methodology used for the development of the proposed solution is explained. Later, Section 4 describes the details of the development process. Then, in section 5, tests executed to the developed system are described. Finally, section 6 concludes the present work.

2 State of the Art

In the present work, an analysis of several previous works has been carried out with the aim of knowing in depth how strawberry crops work and better understanding the problem farmers have. Additionally, the intention of analyzing previous works is to

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understand the used technologies and, at the same time, to understand their limitations with the objective of overcoming such restrictions in the present work.

One of the analyzed works presents a greenhouse prototype using LoRa technology with various sensors [6]. This work presents a technical solution, listing the different types of LPWAN technologies, as well as a more detailed explanation of the elaboration of the used sensors used. Although this work is quite interesting, it has certain limitations: e.g., a field test has not been carried out on an real crop; on the other hand, the authors do not analyze what are the problems that farmers present in their daily basis activities [8].

Another analyzed work is the evaluation of LPWAN technologies to guide the approach of long-range communication solutions for the agricultural sector of Ecuador [9]. This work is quite similar to the previous one. It also focuses only on the technical part, leaving aside an important part that is to know the problems that farmers live with their crops on a daily basis. Additionally, this work has not been implemented in a real crop to test its overall performance in real environments.

In the work called "Design of a low-cost LoRa network for monitoring the agricultural sector", the authors design a technological solution and make a study of its cost. However, the work does not carry out the implementation of the proposed solution in a real crop which could generate a deeper social contribution [10].

Additionally, a scientific article entitled "IoT agriculture system based on LoRaWAN", a work carried out in Greece in a grape field, presents an IoT model in an agricultural system using the LoRaWAN protocol in the data transmission between the sensors and the TTN network [11]. In this paper, the authors highlight the advantages of implementing LoRaWAN in different fields such as agriculture and food production.

On the other hand, the article “Internet of Things and LoRaWAN - Enabled Future Smart Farming” indicates the different use cases of IoT applications in the agricultural field [12]. This work mentions that LoRaWAN shows great potential to be applied in the agricultural and industrial sector. This paper also presents an analysis of a possible limitation of LoRaWAN i.e., the effect of packet collision that would occur in the case that the number of devices connected to the network increases significantly. However, there are already several investigations that seek to solve this future limitation, but it is important to keep this in mind when working with this technology.

As we can see, several previous works have been carried out on the application of IoT technologies in the agricultural sector. However, most of them focus on the development of a design or prototype and not in the implementation of the solution in a real case. We believe that it is important to carry out a real implementation, since new requirements from real users usually appear from such stage.

In this situation, in this work, in addition to carrying out an optimal design of a monitoring solution for a strawberry crop using LoRaWan technology, it is intended to carry out an implementation in a real crop applying the real requirements of farmers. We hope that the knowledge generated in this work can provide an important contribution to the development of this sector, especially in developing countries such as Ecuador.

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3 Methodology

For the design and implementation of the LoRaWAN network and the software solution, Scrum development methodology have been used. Scrum is a framework that reduces the complexity of application development in order to satisfy customer requirements. It has been decided to use this methodology due to its flexibility managing changes and functionality on delivering functional systems in the short term [13].

In the first phase, an identification of the needs of the strawberries farmers was carried out. A field visit was done to learn in detail the current crop management process and the physical variables that is required to be controlled.

Based on the farmers' needs, phase 2 was executed, where the LoRaWAN network was designed taking into account the dimensions of the land and the crop. For this work, we have decided to use the soil moisture as the variable to be measured, since it is one of the most important variables in the strawberry production.

In a third phase, the necessary equipment for the implementation of the LoRaWAN network in strawberry cultivation was chosen, following the design of the previous phase.

In the fourth phase, the web application was developed which will serve as a graphical user interface so that the user can view the data obtained from the implemented LoRaWAN network and the established humidity levels, which will allow farmers to know the appropriate time for watering the crop.

4 Proposed Solution

4.1 Analysis and Design of the LoRaWAN Network

Description of the case study. For the actual implementation of the solution, a strawberry crop located in the parish of Tababela belonging to the Metropolitan District of Quito, capital city of Ecuador, was selected. This sector is characterized by having a large influx of farmers who are dedicated to the cultivation of various products such as corn, beans, strawberries, peas, among others.

The strawberry crop belongs to a farmer who has worked all his life planting different products such as corn, beans, and peas. In particular, he has dedicated his whole life to the cultivation of strawberries as the main source of income for his family. As a case study, it was taken a crop that covers approximately 6,900 m^2 with a total of 134 beds and 60,000 strawberry plants. Table 1 shows a summary of the characteristics of the case study.

Description of the problem. There are several factors that influence the cultivation of strawberries and, on which, depend the good quality of the fruit. One of the most important is the soil moisture making the watering process one of the main activities that the farmer must carry out to obtain good strawberry productivity.

One of the diseases that is produced by high humidity is the gray rot or better known as botrytis. This disease appears as spots on the fruits. And these spots cause buyers of

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strawberries not to accept them. This disease also infects other strawberries making the problem an important issue for farmers. Therefore, discarding of strawberries is required to prevent its spread, which causes great losses in crops [14].

Table 1. Characteristics of the case study.

Characteristic	Value
Land area	Approximately 6900m^2
Type of crop	Strawberries
Plant type	Monterrey
Number of plants	60000
Number of beds	134
Soil type	Sandy

There are also several diseases or pests that are generated by the lack of humidity, such as the red spider or mites, which are caused by the lack of irrigation in the soil. This plague affects the leaves initially and later the growth of the plant. To counteract the problem, fungicides are usually applied, which generates an increase in expenses for the farmer [14].

Another effect caused by the poor humidity control, as mentioned by farmers, is the size of the fruits. To obtain good-sized fruits, an adequate irrigation of water is required in the plants. If this does not happen, smaller fruits are obtained generating low incomes for farmers.

For the solution of the aforementioned problems, it is necessary to have adequate humidity control. It is for this reason that the present work seeks to deliver an automatic irrigation control solution based on the IoT technology at low cost solution, so that the farmer can implement it without major inconveniences.

LoRaWAN Network Design. Based on the ground conditions described above and the carried-out literature review, it was decided to use 2 sensors for the LoRaWAN network, one for each irrigation module. The sensors were placed at the depth of the plant roots i.e., 16 cm below the drip tape. In Fig. 1, a diagram of the LoRaWAN network design in strawberry cultivation is presented.
The network consists of two sensors that are located in strategic places in the strawberry crop. These sensors are connected wirelessly to the LoRaWAN network generated by the LPS8 Gateway, which is connected to a The Things Network (TTN) server. On the other hand, the web applications takes the data stored in the TTN server by using the MQTT protocol.

Equipment for the implementation of the LoRaWAN network. For the LoRaWAN network, the Dragino brand equipment was chosen because it is open source in both hardware and software, it has a low cost, and because it has extensive documentation.

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LoRaWAN Gateway. The selected gateway was the LPS8 Indoor LoRaWAN Gateway. LPS8 is an open source gateway that allows you to create a Wireless LoRa network, which allows data to be sent over extremely long distances [15].

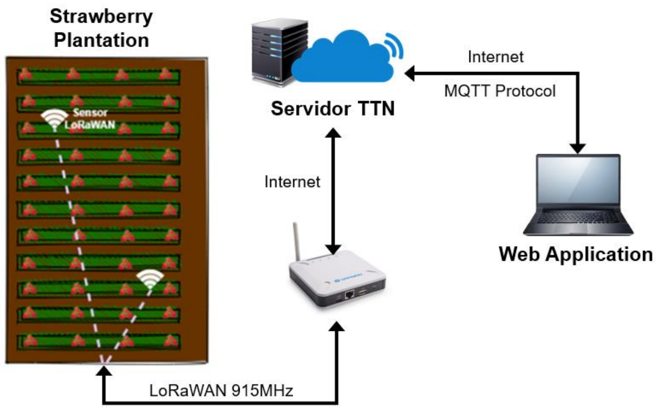

Fig. 1. LoRaWAN Network Design

Soil moisture sensor. The selected soil moisture sensor was the LSE01 LoRaWAN Soil Moisture & EC Sensor from the Dragino brand (see Fig. 2). LSE01 is a LoRaWAN sensor that measures soil humidity, temperature and conductivity. This sensor uses the Frequency Domain Reflectometry (FDR) method, which measures the dielectric constant of the soil. The device is calibrated for mineral soils that include sandy and clayey soil types [14]. The LSE01 sensor is configured by default as LoRaWAN OTAA Class A, so it has the authentication keys to the server [16].

Fig. 2. LSE01 Soil Moisture Sensor

4.2 Implementation of the LoRaWAN Network

Configuration of the LPS8 gateway. The LPS8 gateway is configured by default as a WiFi Access Point. To configure the device, it must be connected through a computer

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either via Wi-Fi or Ethernet port. In this case, it was connected via WiFi to carry out the configuration. Once in the configuration, the registration to the TTN server was done. For this, the creation of an account in TTN was carried out. Once the gateway was configured to connect to the TTN server, the configuration portal showed the LoRaWAN network connection figure (see Fig. 3).

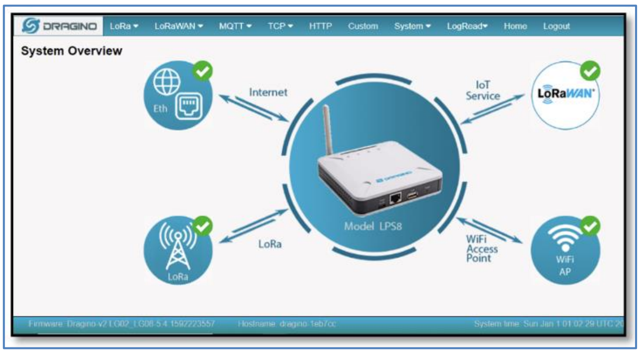

Fig. 3. LPS8 device configuration page after TTN connection.

Configuration of LSE01 sensors. These devices, as well as the gateway must be registered in the TTN server with their respective keys. After the devices are registered, the sensor must be powered on to join the LoRaWAN network automatically by OTAA authentication method. In Fig. 4, you can see the messages sent and received between the server and the sensor at the time of the device joining process.

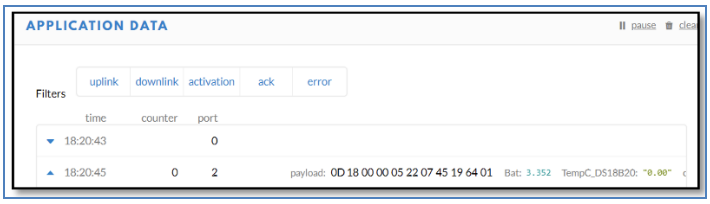

Fig. 4. Messages exchanged between the LSE01 sensor and the server in the process of joining the network.

4.3 Development of the Web Application

Application architecture. The web application has been developed in three components. The first component is the application interface with which the user will be able to interact; this component was implemented using HTML, JavaScript and CSS, and the Semantic UI framework was used for the design of the interfaces. The second component is the back-end server in which the Node JS and Express JS frameworks were used. This component allow the connection of the application with the TTN server to send and receive data. Finally, the third component is Firebase, which fulfills the functions of storing the authentication credentials and system data [17] [18].

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The system was deployed by using Heroku. This service offers the necessary infrastructure to implement and manage modern web applications based on the use of containers, allowing user access from anywhere in the world [19]. In Fig. 5, the design of the web application architecture is presented.

In sprint 1 of the development stage, the tasks to be implemented i.e., the user registration functionality, were determined. As a result of this sprint, the functional modules shown on Fig. 6 and 7 were obtained.

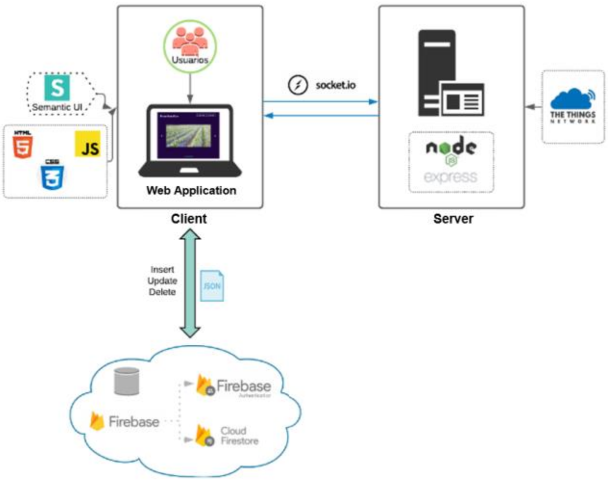

Fig. 5. Web Application Architecture

Fig. 6. Account creation screen.

Fig. 7. Login screen

In sprint 1, the application was deployed through a local server using the Node JS and Express JS frameworks. For sprint 2, the crop information management functionality were developed. Through this functionality, the farmer can visualize the soil moisture

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values of the crop and receive notification of irrigation in the crop. As a result of this sprint, the following screens were obtained (see Fig. 8).

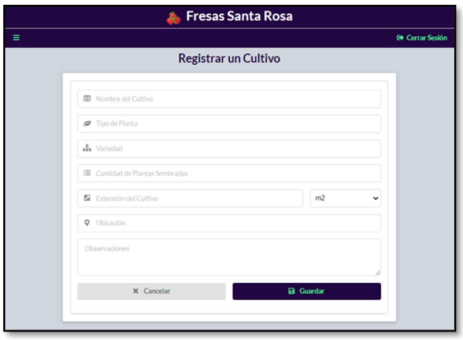

Fig. 8. Crop Record Screen

In order to obtain the data from the sensors, the MQTT connection protocol used by the TTN server was used. For the web application development, one of the client libraries of TTN was used i.e. library for Node JS [18]. The data from the server is sent to the client of the web application via the socket.io library and is displayed on the main screen of the application as shown in Fig. 9.

For the implementation of the irrigation notification requirement in the crop, the optimal levels of soil moisture were established. There are two methods used to measure soil moisture: gravimetric and volumetric [20]. The method used by Dragino sensors is the volumetric one i.e. Volumetric Water Content (VWC). Table 2 shows the soil moisture levels according to [21] [22]. In the event that there are low humidity levels, a message will be displayed at the top of each sensor and the value box in red, as shown in Fig. 9.

Fig. 9. Notification of irrigation in the crop.

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Table 2. Characteristics of the case study.

Soil Moisture Levels	Value
Low	Lower than 10%
Optimal	Between 10 and 18%
High	Higher than 18%

5 Tests

To verify the proper functioning of the developed system, different types of tests were carried out, which are presented below.

5.1 Functionality Tests

In this part, the functionality tests of the application were carried out with people related to the agricultural business and external people. Eight test cases were carried out for the most relevant functionalities of the application.

After having carried out the test cases, a survey was carried out on the 8 people who executed the system tests to verify that the expected results have been met. These people ranged in age from 18 to 50 years.

In most of the survey questions, satisfactory results were obtained. Fig. 13 shows the global results obtained in the functionality tests. As can be seen in the figure, 94% of the users were satisfied with the functionality of the developed system.

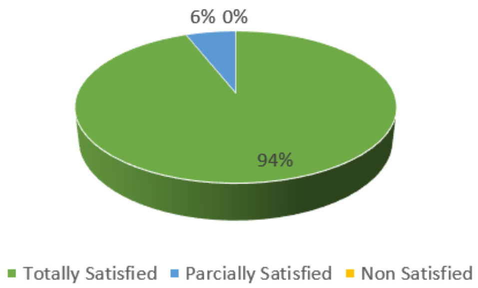

Fig. 10. Result of the Functionality Tests.

5.2 Usability Tests

Usability tests indicate the ease of use of the application from the user's point of view. To carry out these tests, the System Usability Scale (SUS) tool was used, which consists of a 10-question questionnaire with 5 response options with a scale from 1 to 5, where 1 corresponds to totally agree and 5 corresponds to totally disagree [23]. These questions were answered after running each test case. The questions evaluated in this test were the following:

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- Do you think you will use the application frequently?
- Do you find this app unnecessarily complex?
- Do you think the app is easy to use?
- Do you think you would need technical support to use the application?
- Do you think that the different functions of the application are well integrated?
- Do you think there are any inconsistencies in the application?
- Do you think most people would learn to use the application quickly?
- Did you find the app too complicated to use?
- Did you feel very safe using the application?
- Did you need to learn several things before you could use the application?

After executing the test, it could be noticed that the question with the lowest score were the number 4 (Do you think you would need technical support to use the application?). The reason of this situation was because of a misunderstanding i.e., most of the testers requested an explanation before running the test cases and they thought it was a technical support. On the other hand, one of the highest scoring questions was the number 2 (Do you find this app unnecessarily complex?). This is because the main objective of the application is to show the data obtained from the sensors to the users in a simple and direct way. Table 3 shows the score obtained by each user according to the SUS scale.

Table 3. Scores obtained according to the SUS scale by each user.

Surveyed Use	SUS Score (over 100)
User 1	82.5
User 2	100
User 3	87.5
User 4	75
User 5	90
User 6	92.5
User 7	87.5
User 8	80
Average	86.87

5.3 Sensor and LoRaWAN NetworkTest

To test the sensors and LoRaWAN network designed in this work, a coverage test was also carried out. For this purpose, the sensors were placed in the strawberry field that was located at approximately 750 meters from the gateway. The gateway was placed inside a house to be connected to the Internet through an Ethernet cable.

The sensors were installed horizontally at the height of the roots of the strawberry plants, approximately 16 cm deep, as shown in Fig. 11.

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After installing the sensors, the data collection in the application was verified. Fig. 12 shows the real values obtained from the sensors already installed in the strawberry crop.

Through the coverage tests, it was possible to verify one of the main characteristics of the LoRaWAN protocol, which is to achieve communication over long distances.

Fig. 11. Sensor installed on the ground horizontally.

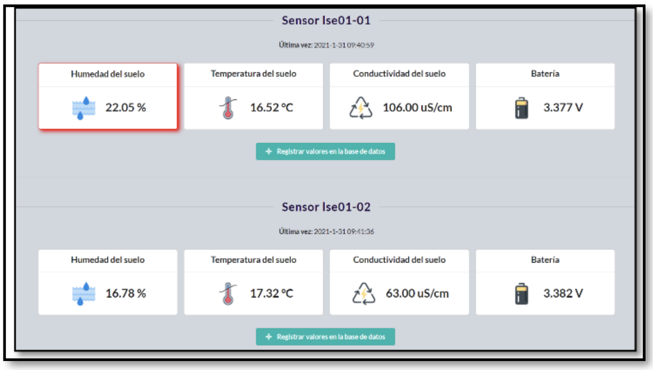

Fig. 12. Reception of Sensors' Data.

6 Conclusions

In the present work, a soil moisture monitoring system was designed and developed using LoRaWAN technology with the aim of improving the production of a strawberry crop.

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The in-depth knowledge of the entire strawberry cultivation process from sowing to harvest facilitated obtaining the requirements, as well as a better understanding of the farmers' needs which facilitated the optimal implementation of the project.

Additionally, with the implementation of this project, real values of soil moisture in strawberry cultivation were obtained thanks to the installed sensors. This allowed to improve the cultivation process optimizing time and water resources. It was also possible to avoid some diseases that were caused by excess or insufficient irrigation in the soil.

After having implemented the system, the functionality, usability and coverage tests allowed to know the fulfillment of the objectives set at the beginning of the project. In the tests carried out, a satisfactory result was obtained in terms of the acceptance of the system. In the functionality tests, an acceptance result of 94% was obtained, which means that it was possible to perform most of the functions of the application without problems. In addition, it can be mentioned that the people who tested the application did not need any technical knowledge to achieve the expected results thanks to the friendly user interfaces and the easy flow of the application. On the other hand, usability tests resulted in a score of 86.87 on the SUS scale. This indicates that the application is highly usable and clear based on the user experience. Finally, the coverage tests allowed to know the reach of the LoRaWAN networks. It was found that a single Gateway could cover the entire plantation. This represents a considerable benefit since the sensors can be located in any part of the terrain even kilometers away from the gateway without losing the connection. As a further work, we will try to implement other smart farming solutions using the LoRaWAN technology.

Acknowledgments. The authors would like to thank to Corporación Ecuatoriana para el Desarrollo de la Investigación y Academia - CEDIA for the financial support given to this work through its Fondo Divulga.

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