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Intelligent Mobil App Design of IoT System Based on Wireless Sensor Networks for monitoring and improvement of production in fruit crops

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Abstract

This article shows the details of the design and implementation of a wireless sensor network (WSN) system, through the use of an Arduino prototyping platform and Lora communication modules, to collect soil humidity, temperature, and PH data in a fruit crop. Data is captured and stored to generate a time series of data to improve decision-making when variation in the essential nutrient application was required. The case study was a parcel in the village of Piedra Larga, in the municipality of Ciénega - Boyacá, where the WSN was deployed that collects the data and allow a visual representation to compare with reference levels and determine the nutrient level requirements. An irrigation monitoring system is implemented by applying artificial intelligence to assist the farmer with two key tasks: *i*) the activation of the drip irrigation system seeking the efficient use of water, and *ii*) improving fruit production by controlling the percentage of nutrients. The mobile application shows real-time data monitoring of environmental and soil variables, for the analysis of results and the concentrations of the nutrient mixture together with the drip control to be applied to the crop. An optimal estimation of the required nutrient concentrations was estimated from a neural network to simplify and improve the efficiency of the farmer's agricultural activities, such as saving water consumption by 40% and improving fruit production by up to a 30%

Keywords: IoT, LoraWan, Relative Humidity, Temperature, Soil PH, SNR, RSSI, Node, Gateway, Precision Agriculture.

Diseño de aplicación Móvil Inteligente de sistema IoT basado en Redes Inalámbricas del Sensores para el monitoreo y mejora la producción en cultivos de fruta

Resumen:

En este artículo se muestran los detalles del diseño e implementación de un sistema de red inalámbrica de sensores (WSN), mediante el uso de una plataforma de prototipos Arduino y módulos de comunicación Lora, para recolectar datos de humedad, temperatura y PH del suelo en un cultivo frutal. Se captura y almacena los datos para generar una serie temporal de datos que permita mejorar la toma de decisiones cuando se requerían variación en la aplicación nutrientes esenciales. El caso de estudio fue una parcela en la Vereda de Piedra Larga, en el municipio de Ciénega - Boyacá, donde se desplegó la WSN que recolecta los datos y permite una representación visual para comparar con niveles de referencia y determinar los requerimientos a nivel de nutrintes. Se implementa un sistema de monitoreo de riego aplicando inteligencia artificial para asistir al agricultor con dos tareas clave: *i*) la activación del sistema de riego por goteo buscando el uso eficiente del agua, y ii) mejorar la producción de frutos controlando el porcentaje de nutrientes. La aplicación móvil muestra datos en tiempo real monitoreo de variables ambientales y del suelo, para el análisis de resultados y las concentraciones de mezcla de nutrientes junto al control por goteo a aplicar al cultivo. Se realizó una estimación óptima de las concentraciones requeridas de nutrientes a partir de una red neuronal para simplificar y mejorar la eficiencia en las actividades agrícolas del agricultor como ahorro en el consumo de agua en un 40% y mejora de la producción de frutas hasta en un 30%.

Palabras clave: IoT, LoraWan, Humedad relativa, Temperatura, PH del suelo, SNR, RSSI, Nodo, Puerta de enlace, Agricultura de precisión.

1. Introduction

One of the most important factors for the development of Colombia lies in the agricultural sector since it is one of the primary lines of the economy of the South American countries. The impact of the post-pandemic in all socioeconomic aspects has brought the opportunity to improve the agricultural process being precision agriculture a key technology for maximizing production and making efficient use of water. Currently, in the rural sector, the farmers perform manual monitoring of crops, which introduces increasing in water and fertilizer waste and additional work for the people. On the other hand, the vast majority of the rural population has little economic income from agricultural activities, hindering the economic development of agriculture. Additionally, there is low access to telecommunications infrastructure and information on technological development in agriculture in rural areas of the country (Howland et al., 2016), and that limitation reduces the development of the competitiveness of agriculture in the sector. For this reason, in recent years, with the evolution of wireless networks and the development of the IoT, it has been possible to approach different areas of industrial development, among these areas is identified ***precision agriculture***, looking to help farmers in their daily tasks and seeking to increase their productivity by optimizing processes in the cultivation (Nóbrega et al., 2019). However, this application domain is surrounded by restrictions, either associated with technologies or with the specificities of the farm users. From the above, the collection of *soil humidity, temperature, and PH data* is proposed as determining factors in the analysis of the state of the soil through sensors controlled by an Arduino system, interconnected by LoRa technology belonging to the LPWAN technology. As an advantage, this choice optimizes the range of communication, the battery life of the devices, and the costs considering a lower frequency of data transmission; thus this kind of solution makes it an ideal standard for the IoT (Hernández, 2020). Given the above, in this article the use of the internet of things is proposed with precision agriculture to implement a monitoring system for the irrigation system (on a farm in the town of Ciénega, Boyacá, Colombia), through a low-cost sensor network to allow the efficient use of the amount of water and fertilizers used in the soil of fruit crops, besides it facilitates the control of extreme situations in the crop, be it dryness, diseases, pests, etc.

This paper addresses the development of the project in the *Related Works* with a review of different projects that contribute to this proposal presented in *Section II*; then, a collection of relevant information is made for the understanding of the tools and systems implemented in *Section III monitoring system architecture*. Then, a description of the design in the node block model, Mockups, and implementation of hardware and software for measuring the soil humidity, temperature, and PH with the Arduino system and for the communications using the LoRa platform, Additionally, in *Section IV Design and implementation*, a neural network is realized for data analysis to enable decision making on concentration for the nutrients of the crops, and a mobile application is developed for data levels visualization. After that, the *Section V discussion of results,* allows us to analyze the collected data and compare them with those identified in the related works. Finally, the last section *Conclusions*, present the results and analysis for the case of use, presenting a demonstration in precision agriculture, the potential of the implementation, and the opportunities in face of future work.

2. Related works

In carrying out this project, a review of the state of the art was made on the topics of the Internet of Things (IoT), sensor networks, and LoRaWan technology, and finally, on Artificial Intelligence and Neural Networks (Misra et al., 2022; Javaid et al., 2022), that is the choice for implement a cognitive system. In Khanna & Kaur (2019)one of the most familiar name scaling new heights and creating a benchmark is Internet of Things (IoT, the authors makes a compilation of the evolution of the internet towards the internet of things as part of the industrial revolution 4.0, as shown in Figure 1. As can be seen, the system evolves from pre-internet recognized as human-to-human communication, then the access to information to the *www*

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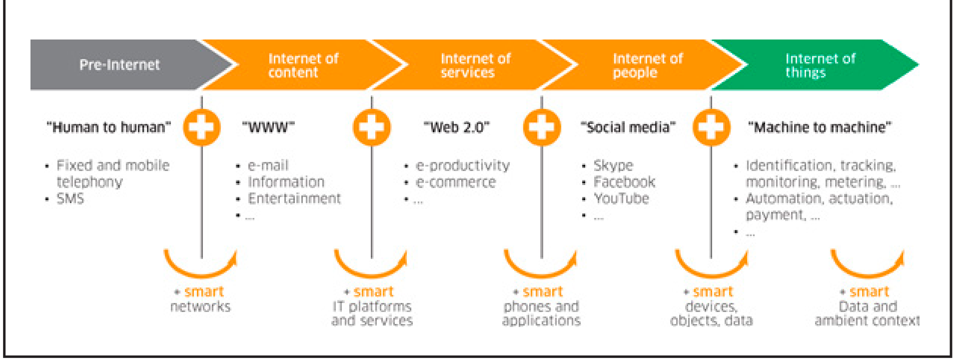
(internet of contents), after that, the internet of services looking for improvement in particular the commerce and productivity, then, the internet of people, where the connectivity was focused on social media and relations, and finally, the Internet of Things, where the connections are machine-to-machine, for logistics, metering, automation, payment, etc.

Figure 1 *Evolution of the Internet (Khanna & Kaur, 2019; Kumar, 2017)one of the most familiar name scaling new heights and creating a benchmark is Internet of Things (IoT*



It is noteworthy that the study by Khanna, et al. (2019), highlights the applications of the IoT, in some of these scenarios: Smart Mobility, Smart Grid, Smart Homes and Buildings, Smart Public Safety and Environment Monitoring, Medical and Health Care, Industrial Processing, and Agriculture y Breeding, within others. The paper shows the potential of the IoT technology evolution, for this paper, the topic is centered on precision agriculture and also contextualizes the different technologies used for the development and implementation of the sensor network, as shown in *Table 1*.

In Hernández (2020) the author focus on the analysis of the different technologies developed on LPWAN technology, showing their advantages and disadvantages. It also highlights that due to the maturity and the rise of IoT, and the increase in the number of connected devices, LPWAN appeared as a solution for interconnection with low energy consumption at a higher range. On the other part, the work of Coello & Silva (2020), looks for monitoring variables that impact the area of work (for the case, the water), the design of the nodes was discussed including the connection of the temperature sensor DS18b20, Total Dissolved Solids (TDS) sensor SEN0244, and a PH sensor, the data is collected in a non-relational database in FireStore. The implementation was tested in two scenarios, a 10,000-liter tank of raw water extracted from the subsoil (*unsuitable for human consumption*) and another tank with the same capacity but with processed water (raw water that has passed through filters and reverses osmosis) that allows for humans better quality and drinking water.

***Table 1** Frequencies and ranges covered by different technologies used in IoT for communication (Khanna & Kaur, 2019)one of the most familiar name scaling new heights and creating a benchmark is Internet of Things (IoT*

Technology	Standard	Year of discovery	Downlink/ Up Link	Range (in meters)	Operating frequency (in MHz)
RFID	Wireless	1973	100 kbps	2	0.125 – 5876
IEE802.15.4	6loWPAN	2003	250kbps	30	826 & 915
Z-Wave	Wireless	2013	100 kbit/s	30	868.42 & 908.42
LTE	3GPP, LTE, and 4G	1991	100Mbps	35	400 – 1900
Lora	Wireless	2012	0.3 37.5 (kb/s)	3000-5000	169,433 & 868 (Europe) & 915 (North America)
NFC	ISO 18092	2004	106,212 or 424 Kbits	<0.2	13.56
UBW	IEEE 802.15.3	2002	11 – 55 Mbps	10-30	2400
M2M	Open to all communication protocols	1973	50-150 Mbps	5-20	1-20
6loWPAN	Wireless	2006	250 Kbps	30	915

The work in Escobar Iza et al. (2021), seeks to implement an Artificial Intelligence (AI) system for monitoring and analysis of the soil of a greenhouse. It collects information on the PH of the

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soil, and thus, the system can determine the soil temperature and moisture for evaluating the presence of plant diseases. For this, the authors propose the development of a mobile application that supplies the optimal values of the variables of the soil. With these data, the system implements a neural network by using the digital back-propagation algorithm to define the desired values according to the stable measurements taken previously. In Baldoncini (2015), a study on the cultivation of grains (soybean, corn, sunflower, sorghum, wheat, barley, and peanuts) in Argentina, evaluated how the components of fertilizers determine the state of the PH of the soil, evaluating 3 different types of fertilizers: nitrogenous fertilizer (Urea and Urea Ammonium Nitrate (UAN)), phosphate fertilizers (SPS (Simple Superphosphate), SPT(Triple Superphosphate)), and monoammonium phosphate (MAP). The author evaluated the interaction of the chemical components of each type of fertilizer and its soil response in a greenhouse with a Haplustolentic Oncativo series soil type. In a conclusion, the control of the PH of the soil is determined by the nitrogen composition of the fertilizers producing hydrolysis in the soil. In addition, the Urea increased the alkalinity of the soil and the UAN produced an increase in the acidity of the soil, phosphate fertilizers increase the acidity of the soil and the MAP fertilizer did not produce any variation in the pH values, the results of the analysis of the fertilizers were given to the buffer effect present in the soil. On the other hand in Gutiérrez Espíritu & Armas Valencia (2018), the authors proposed the design of a controller based on neural networks for drip irrigation in the Huacho district, North of Lima, Peru. This system proposes the acquisition of humidity data from three crops at different depths (in steel rods of 60 cm, 40 cm and 20 cm). The data acquisition uses traditional humidity sensors controlled with a 74HC4051 multiplexer and a DS137 clock. The system implements a microcontroller based neural network with three neurons at the input and one output using the Levenberg-Marquardt algorithm as a training method, implementing two tests with different numbers of neurons at hte hidden layer. As conclusions, according to the characteristics of the roots, it was found that, *i*) the longer the root length of the crop it requires more moisture to keep the plant in optimal conditions; *ii*) the evo-transpiration of the plant was estimated to find the optimal irrigation time for the crop; *iii*) the use of more neurons in the hidden layer has a linear trend behaviour, decreasing the error; and, *iv*) the use of the predictive results of the neural networks using as input the data collected from the humidity of each one of the plants allowed to reduce the water consumption in the analyzed crop. Another work in Vázquez Rueda et al. (2018), shows the performance of a neural network image analysis for a greenhouse growing six basil plants (using a Microsoft LifeCam HD-6000 camera), the system includes a ventilation system, and infrared sensors to measure air temperature, greenhouse temperature, and humidity of each plant. The MXL90614 infrared temperature sensor is factory calibrated to provide temperatures in the ranges of -40 to 125°C for ambient temperature and -70 to 380°C for planting temperature. For the processing algorithm, the system detects yellow color in the leaves as a chlorophyll deficit indicator of lack of water or possible plant disease indicating a poor irrigation of the plants. With the data provided by the sensors, the system implements a neural network with the Widrow-Hoff learning rule using Matlab software. This method allows an appropriate control of the water supply.

3. Methodology.

A deductive analysis is used taking general concepts of the operation of drip irrigation, open-source software and hardware, servers, and mobile applications that control the actuators to translate to an irrigation system case of the crop in the land tower of Piedra Larga in Ciénega – Boyacá town. A descriptive method is also used since the results obtained from the humidity of the soil and the water necessary for the crop will be transcribed, thus giving a series of data that describes the situation of the humidity necessary for the improvement of the crop. The explanatory method will be used since the data obtained will be considered to perform an appropriate operation of the irrigation with available hardware that can be controlled by using a mobile device, the whole system complies with the objectives outlined in this project.

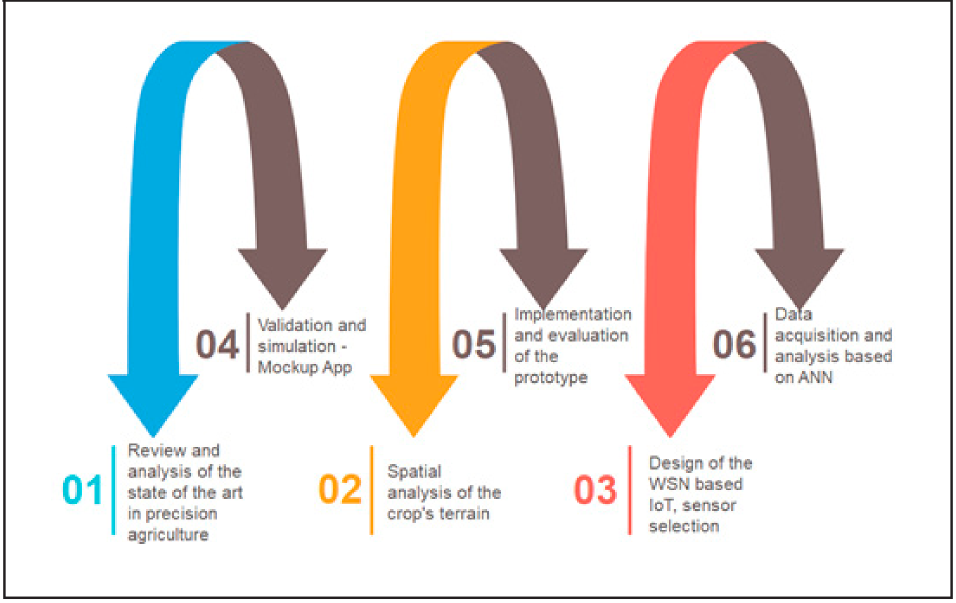
For the design of this project, it is necessary to divide it into steps, starting with the collection and analysis of data to analyze and organize the implementation of the application to control the irrigation system as function of the measured levels of the PH, humidity and nutrients of the crop (Ayyasamy et al., 2020).

The methodological steps to follow are:

- The review of information on the state of the art, on the issues of sensor network implementation under LoRaWan protocol, and other technologies.
- Spatial analysis of the location where the project will be developed, characteristics of the land, description of the crops in the sector, and climatic and meteorological factors related to the actual state of the soil on the farm.
- Description of components used and design of the sensor network with wireless technology, design of requirements for mobile application.
- Validation of the design proposal through the use of simulation software and mockup design of the application used.
- Implementation of a designed prototype, and data collection for the evaluation of the system's operation.
- Collection of monitoring data implemented in the project and mathematical and predictive analysis through a neural network developed in Matlab.

In Figure 2 the steps to follow are shown according to the items listed above.

***Figure 2** Methodology applied in the project*



4. System monitoring architecture

In this section, we address fundamental concepts for the planning, design, and implementation of irrigation system monitoring.

Drip irrigation system

It is a system that is characterized by the use of water at a slow rate and is located directly on the root of the plant "*Water is supplied slowly and evenly at low pressure through plastic hoses installed in or near the root zone of the plants*" (Welch & Shock, 2013). The use of this system is suitable for the application since it allows for the reduction of unnecessary water drains, wetting only the foot of the plant and thus creating a humid bulb that changes according to the characteristics of the soil, the amount of water, and the irrigation time (Eric & Asesor, 2009).

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Sensors Networks

They are a set of sensors connected, which are a type of transducer that is responsible for converting an analog input signal, generally physical phenomena (temperature, pressure, humidity, etc.), into an electrical signal at the output that can be voltage or current. Some examples of sensors are pressure, strain, strain gauges, humidity, and pH sensors (Cruz, 2009). A network of humidity sensors is inserted underground to obtain information about the moisture it contains and uses an output signal which is digital by integrating a small microcontroller to process the signal (García, 2015).

IoT and Cloud Computing

IoT and Cloud Computing technologies are used to collect data from different objects in different geographical locations, for which the implementation of a sensor network (WSN) and servers in the cloud is necessary. i) WSN Perception Layer – Wireless Sensor Network: It deals with data collection with the use of radio frequency detection devices (RFID), these data are stored and managed on the local server. ii) Transport Layer: This layer collects the data stored on the local server and uses technologies such as Wi-Fi, CDMA, and 3G to transport the data to the cloud. iii) Processing Layer: Cloud Computing technology is used for virtual storage (Kiran R. Badua, 2015), and iv) User Layer: corresponds to the supervision and management actions by the user.

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2015), and iv) User Layer: corresponds to the supervision and management actions by the user.

The implementation of Cloud Computing allows the following benefits: Improvement in the efficient use of inputs such as soil, water, fertilizers, pesticides, reduced cost, livestock monitoring, applications in indoor agriculture – greenhouses and stables, pisciculture, forestry, storage monitoring – water tanks, fuel tanks, unlimited on-demand resource allocation, maintenance and upgrades performed in the back end, easy rapid development, including collaboration with other cloud systems (Kiran R. Badua, 2015).

LoRaWAN

LPWAN networks, short for Low Power Wide Area Networks, are wireless networks that transmit small amounts of data over long distances. These wireless networks have a lower energy consumption requirement than other technologies and networks, such as those used in telephony that also cover large areas (Hernández, 2020), and of course, the application is different, mainly focused on metering at low bit rates. Currently, different LPWAN technologies can be found on the market that meets the requirements of the IoT industry needs, such as being able to connect the large number of devices that are appearing:

- Long Battery Life: Low signaling allows increasing the battery life for years.
- Low cost: the protocols and the lightweight LPWAN networks reduce complexity in hardware design and also reduce costs.
- Broad Coverage: The operational range of LPWAN varies from a few kilometers in urban areas to more than 10 km in rural settings. It also enables effective data communication in indoor and underground locations (Carrion Sarmiento, 2018).

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LoRaWAN devices implement several functionalities for different applications, these functionalities vary according to the Class where the device has been configured within the protocol.

- Class A End Devices: These devices establish two-way communications.
- Class B end devices: allow link communication downstream of the end device by adding receive windows.
- Class C end devices: End devices listen continuously as long as they are not transmitting (Carrion Sarmiento, 2018).

Spreading Factor

One of the most important parameters for the implementation of the physical network is the Spreading Factor (SF), that is, the relation between the bandwidth of the signal and the symbol rate. By keeping the bandwidth constant, it is possible to improve the receiver's sensitivity by increasing the airtime (transmission duration of a packet). More precisely, each increase in SF by one unit, in LoRa from the minimum value of 7 to the maximum value of 12, corresponds to a doubling of airtime and a decrease in receiver sensitivity of approximately 3 dB (Moya Quimbita, 2018).

5. Design And Implementation

System designed for farm monitoring. For the monitoring of the irrigation system, the geometry and topography of the farm to be analyzed were taken into account, according to the indications and recommendations of the farmer, the sensors were located according to Figure 3.

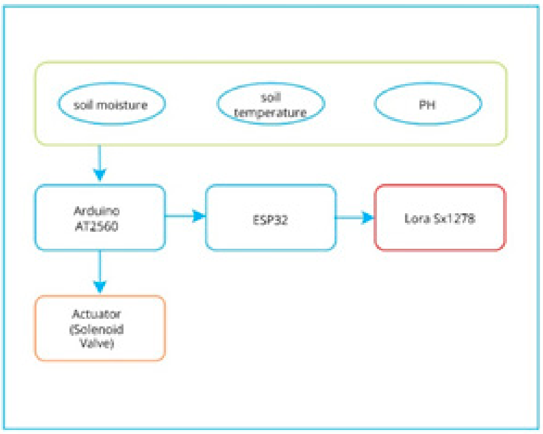
***Figure 3** Map of the terrain and location of the sensors (Own Source)*

Sensor Network Design

The proposed network system is composed of a Gateway node and 4 nodes, each node is composed of a sensor FS2000-SHT10 (Humidity and Temperature Sensor) and EC201 (PH Sensor), the nodes are interconnected through the Lora Sx1278 module.

The Gateway node is connected to a server implemented on a Raspberry Pi 3B, and the configuration of the sensor nodes is shown.

Figure 4 *Node model with its parts (Own Source)*



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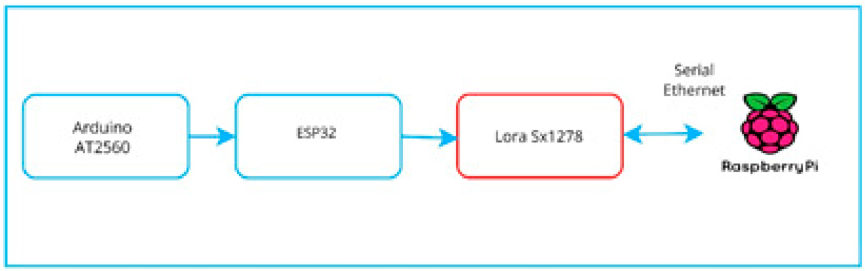
At the same time, the configuration of the Gateway node is shown in Figure 5.

Figure 5 *Gateway node model (Own Source)*



Mobile App Design

For the design of the Mobile application, the requirements of gathering and the implementation were developed by using the SCRUM methodology (Khudadad et al., 2014). To facilitate the visualization of the requirements the proposal applies the case diagrams to obtain a better experience for the users.

Figure 6 *Use case diagram (Own Source)*

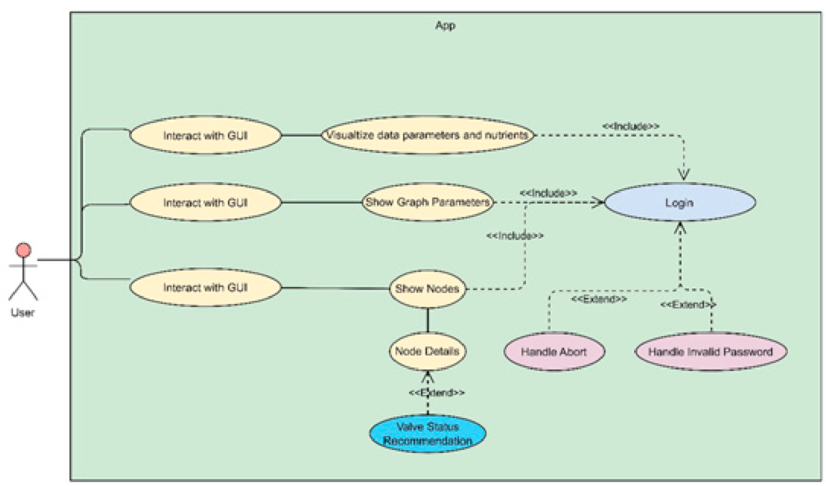
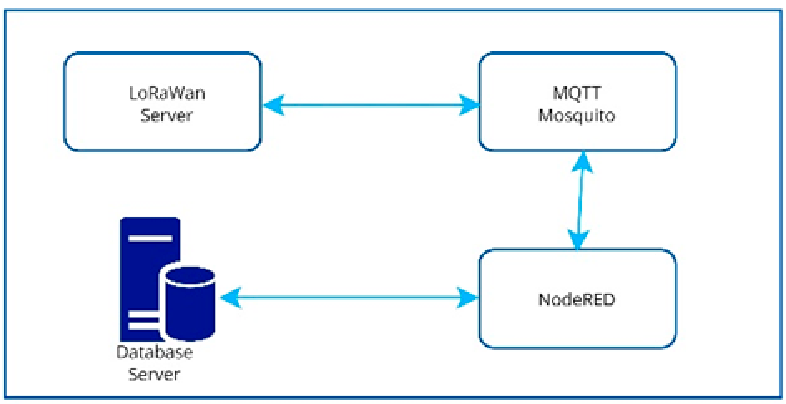


Figure 6 shows the different uses cases necessary for the design of the application, one of the necessary requirements is the implementation of login with credentials to provide access with security. The design of the application indicates the requirements allowing the user to access each node through a history of the data collected from the variables acquired such as soil moisture, temperature, and soil PH, also the app enable the visualization of the monitored data graphically, and also, the system receives the recommendation delivered by the neural network results according the expected settings.

Server Design

A serial connection with the Gateway node is implemented in the server and the reception of the data is managed by the MQTT protocol and using NodeRed, as shown in Figure 7 .

Figure 7 *Server Model (Own Source)*



On the server side, the design uses the entity relationship diagram shown in Figure 8 , the SQLite database collects the information indexed by the NodeRed platform.

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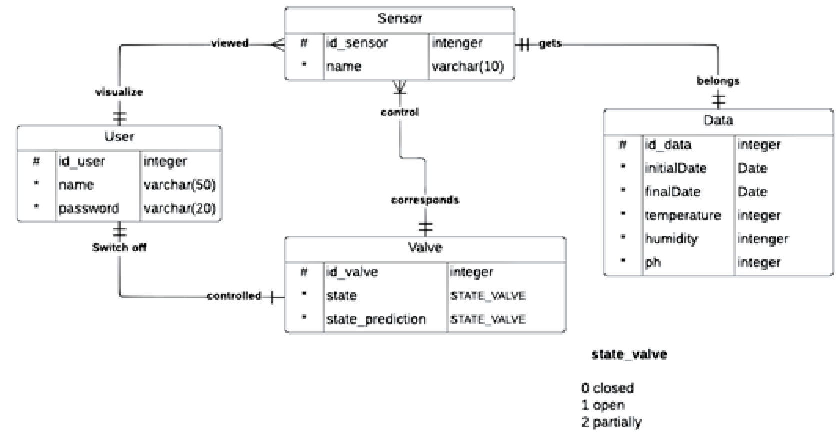

Figure 8 *Entity-Relationship Model Database (Own Source)*

Sensor Network Implementation

The implementation of the WSN nodes in the field can be seen as shown in Figure 9.

Figure 9 *Crop present in the plot object of the project (Own Source)*

When carrying out the implementation, the analysis of the signal transmission was carried out, which yielded the results shown in Figure 10. Besides, Figure 11 and Figure 12 how the received strength signal intensity (RSSI) and the packet drop rate, respectively.

***Figure 10** Distance SNR relationship for each sensor node (Own Source)*

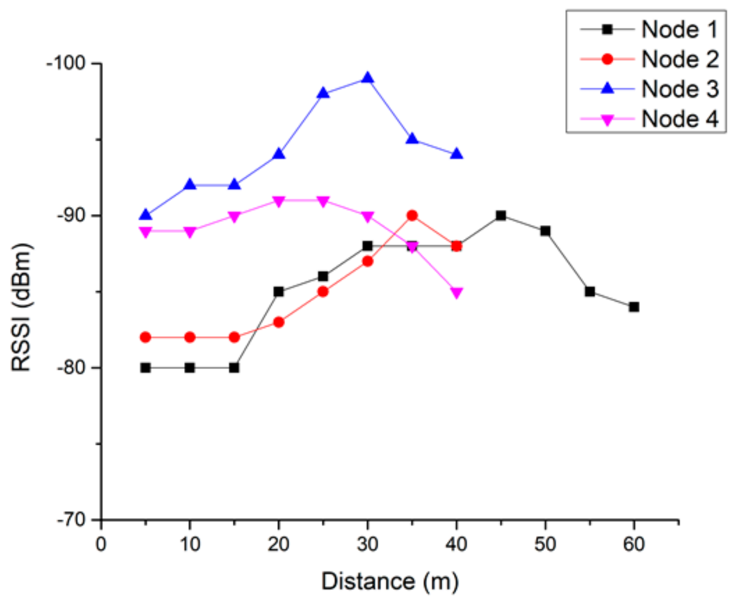

Figure 10 shows the distance vs. SNR relationship, according to the topology of the terrain. The losses under the path of node 1 decrease, evidencing that during its evaluation from the Gateway node there is a small obstruction (undulation in the terrain) that increases the loss, but it can reach up to 40 meters in range.

Additionally, the strength of the signal received by each sensor concerning the Gateway was measured, and the values were plotted in Figure 11. The node 3, has the highest RSSI for the range between 5 and 35 m, due to interference between the construction (farmer's home) and the localization of the crop.

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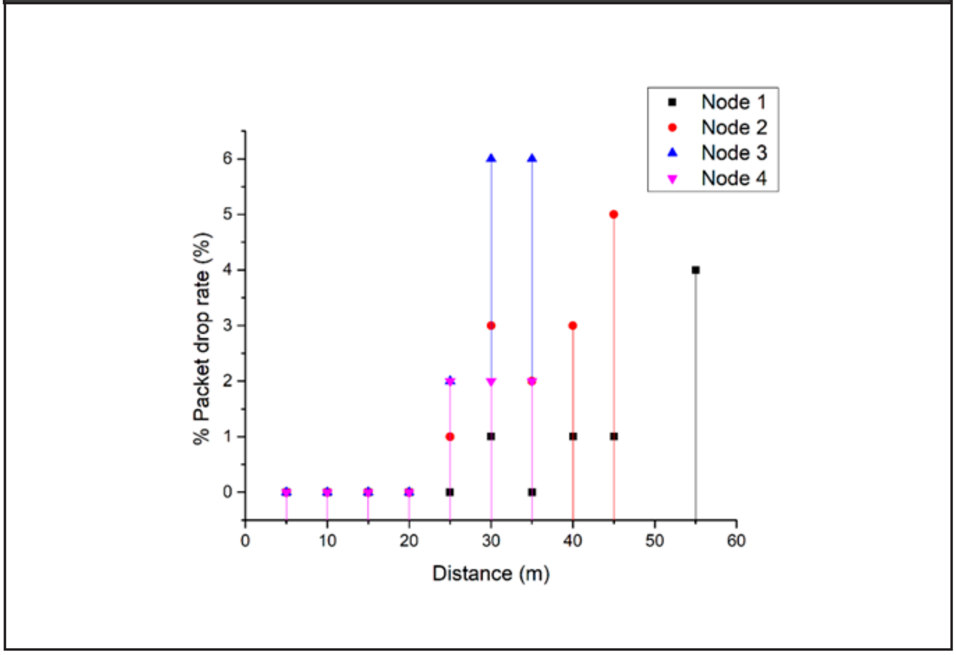
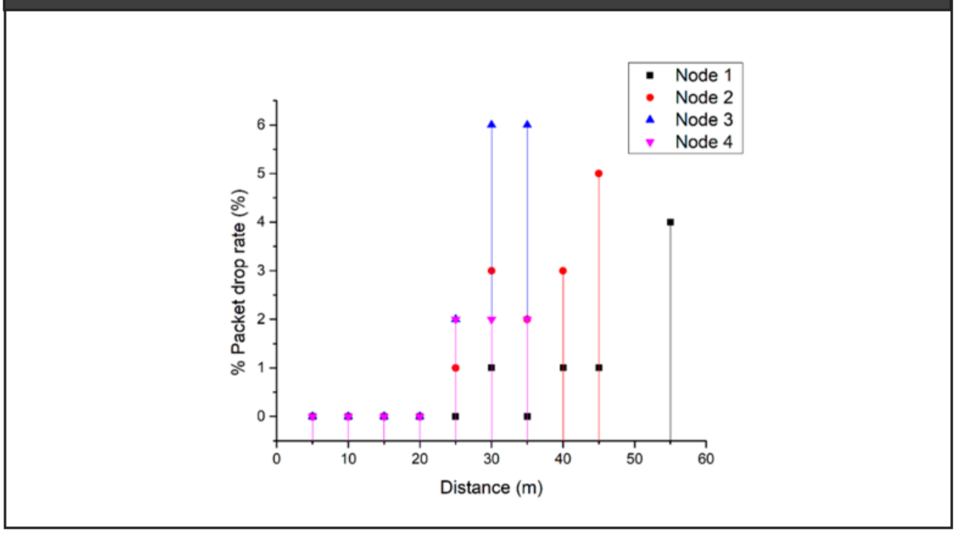
Figure 11 *Signal Intensity Received by each node (Own Source)*



The greatest power is evident in the path of node 3 since it is the closest to the Gateway, presenting loss only due to the obstruction of the building.

Additionally, the number of packets lost in the data transmission along the path from the Gateway to each of the node locations was taken, these data are shown in Figure 12.

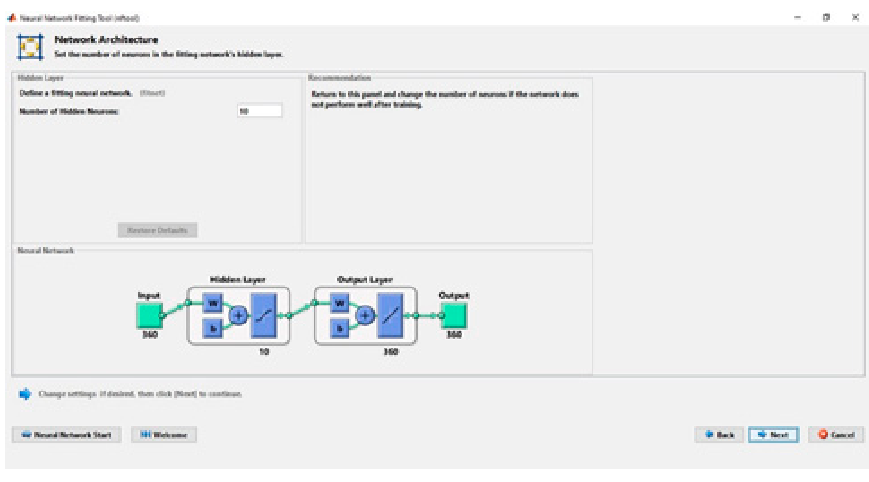
Figure 12 *Packet Drop rate of each node (Own Source)*



Neural Network Implementation

For the neural network implementation, the retro programming algorithm was used with the Levenberg-Marquardt learning method (Vázquez Rueda et al., 2018; Tlatelpa-Becerro et al., 2020), which is characterized by presenting a better performance of approaching a nonlinear behavior. The tool used is the Matlab® package with the "Neural Net Fitting" APP, entering the values of the input variables (Relative Humidity, Temperature, and Soil PH), the variables entered correspond to a database of 5400 values corresponding to 36 days, corresponding to the period from march 20 to april 18 of 2022. For the training and learning of the neural network, 360 samples (10 samples per day) collected from the database are used, these samples correspond to the most representative values of the variables (soil moisture, soil temperature and PH) of the crop. Figure 13 shows the configuration of the neural network, 20 hidden neurons were configured to achieve error reduction.

***Figure 13** Neural Network Configuration (Own Source)*



Next, with the learning stage of the neural network, it is possible to obtain the performance by epoch for the data approximation as shown in Figure 14 .

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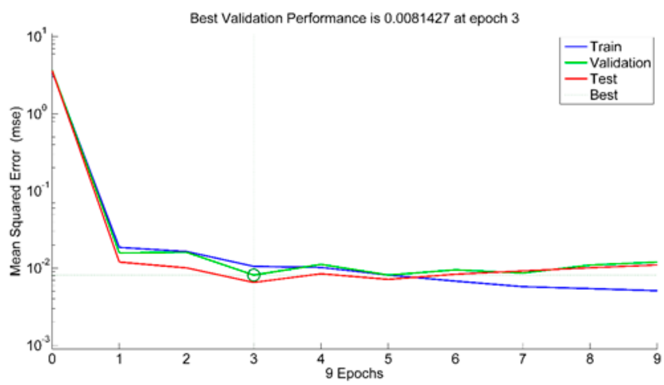
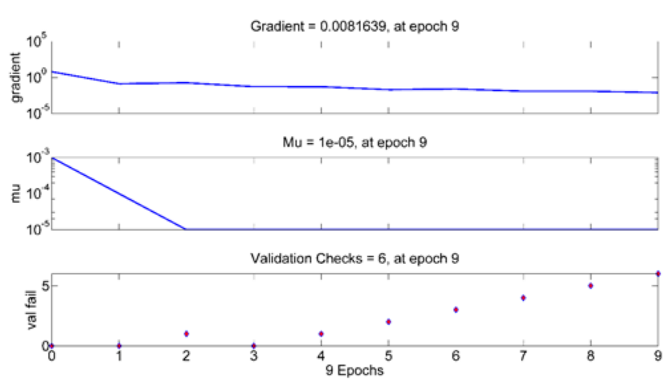
Figure 14 *Graphs of Analysis of the performance of the neural network and behavior of the activation functions (Own Source)*



The Matlab software compiles the training statistics shown in Figure 15. These statistics are: *i*) the backpropagation gradient to determine the minimum of the function estimated by the neural network; *ii*) the MU value to control the update weights of the neurons in the backward propagation of the training; *iii*) the validation failures that diagnose the overtraining of the neural network.

In the training process of the neural network, the Matlab software makes successive approximations called Epochs, which correspond to complete cycles of analysis of the data entered for training (in this case 360 samples), the revision of epochs is finished when Matlab detects the least squared error value shown in Figure 14 and when they start to increase the validation failures shown in Figure 15.

Figure 15 *Statistics of the neural network training performed in Matlab (Own Source)*



After the learning stage, the Matlab software allows us to export a Script to develop and test the neural network. This code includes a matrix called NET that characterizes the behavior of the variables to perform data prediction. The NET matrix code was adjusted to evaluate the optimization of the prediction data given by the neural network by entering the values of the variables (humidity, temperature and PH) described in *Table 2*.

Table 2 shows the results of a test with values taken in the field to evaluate the data prediction of the state of the valve (fully open, partially open, closed).

Table 2 *Results of Neural Network Optimization Values (Own Source)*

Relative humidity	Dry temperature	PH	Desired valve condition results			Results obtained for the state of the valve		
			Fully open	Partially open	Closed	Fully open	Partially open	Closed
96	12	5,8	1	0	0	1.9357	1.7997	-0.6353
94	11,2	5,8	0	0	1	-0.2377	-0.2265	0.8878
57	18,4	6	1	0	0	2.3348	2.2144	-1.7908

The values obtained from the Matlab are generated by a heuristic process in the designed neural network, the approximation of the results is carried out by taking the highest value of the results obtained with a value of 1 and the 2 remaining data obtained with a value of 0.

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Mobile Application Implementation

A mobile application was developed using the following tools:

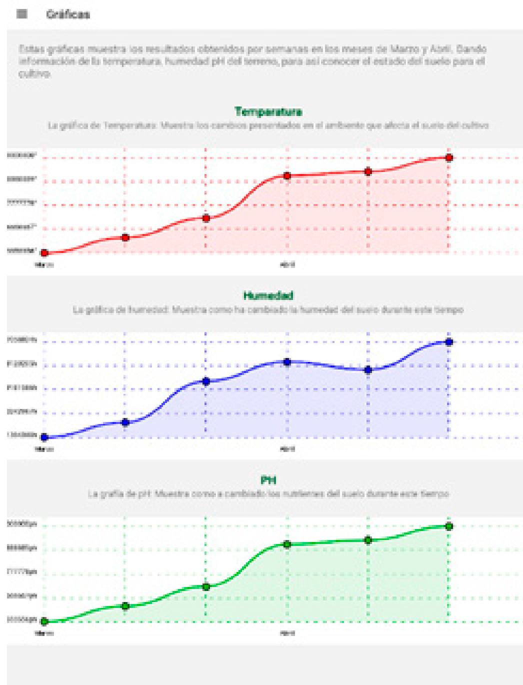
- For SQlite Database.
- For Backend Node Js.
- For Front End React Native.

This application was implemented on a Tablet, owned by the farmer, which allows access to view the data collected within the server, classified according to each node displayed with the variables of humidity, temperature and PH. In the application the main page, includes the map of the area with the geographical location of the sensors. Figure 16, presents the screen where the data collection configuration for node 4 takes place. As can be seen, it allows the farmer to receive the information collected by the sensors in each node as a table to facilitate the visualization in a graphical form.

Figure 16 *Screen with node information within the application (Own Source)*

Figure 17 shows the graphs of the values captured and processed by the sensor network, the implementation of this screen was made so that the user has an expanded perspective on the terrain conditions and allows support for the decision to activate the security system irrigation.

***Figure 17** Screen with graphs on the variables own to monitor (Own Source)*



6. Discussion of results

The results obtained from the implementation of the monitoring system allows to conclude the following observations:

i) The LoRa technology is one of the most effective technologies for the development of Precision Agriculture - IoT, it enables new perspectives for the development of control systems for monitoring and applications in the agriculture area.

ii) It is possible to affirm that the use of LoRa systems are one of the best tech options for the implementation of sensor networks that consume low energy at low cost, although some losses were generated in the system due to the use of a single Gateway, the terrain topology, and environmental conditions, it performs adequately at outdoor scenarios.

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iii) The effect of signal losses is intrinsically connected to the environment where it works, and in this case it can be clearly that there are fewer losses due to deployment in a rural area.

iv) The use of Artificial intelligence is one of the most appropriate options to optimize agricultural production systems. It is noteworthy that it requires the use of computational resources to operate faster and more effectively since a neural network is a multiple-processing heuristic system.

The monitoring system implemented by the landowner of Piedralaga in the municipality of Ciénega shows, a system to perform data collection where the following characteristics of the land were determined:

i) The soil corresponding to the plot is partially humid and its values oscillate between 70% and 90%, the soil temperature is between 3.0ºC and 23.6ºC, and, the PH of the soil is partially acid with values that are between 5.8 and 6.3, these values correspond to the nominal characteristics of the land for the cultivation of fruit trees, these values tend to change according to the variation of the climate and the state of the crop analyzed (newly planted, under the supervision of the farmer or in harvest), this monitoring shows the farmer when the soil of the crop exceeds the mentioned limits, affecting the fruit tree; these data is also recollected by authiors of the (Escobar Iza et al., 2021).

ii) The monitoring and implementation of the neural network advises the farmer to determine when to activate the valve for the application of water and fertilizer in the soil of the crop. The use of the neural network makes the irrigation system maintain the normal values of the soil avoiding the saturation of water and nutrients that wither the crop and the propagation of diseases among the fruit trees, as mencioned in the works Vázquez Rueda et al. (2018) and Baldoncini (2015). The prediction of the neural network makes the grower see improvements in production and reduces the damage caused by crop diseases by 70% compared to manual supervision. It also reduces the use of labor by 60% since the owner manages with the information collected the supply of the necessary fertilizer that the plant requires.

iii) With the monitoring of the crop, the PH levels are determined, to apply fertilizers and maintain the normal values explained above (pH = 6 in average), obtaining an adequate growth and a good evo-transpiration of the crop and improving the production of fruits, recommended by Baldoncini (2015).

iv) The implementation of the mobile application makes it easier for the farmer to obtain information and make decisions to maintain the crop in optimal conditions and obtain a good production, this method was applied and validated by the authors in Escobar Iza et al. (2021).

v) As a final observation an as feedback of the farmer, during 4 months of using the IoT based WSN the water consumption decreased near to a 40% and the fruit production increased to 30%. This is a key point that stimulate the implementation for improving the system by including other soil parameters as Potassium, Phosphorus and Nitrogen.

7. Conclusions

In this work, a review of the different technological platforms for the implementation of IoT in rural productive sectors was carried out, regarding the power of the signal, the scope of data transmission, and the cost associated with the implementation for farmers. In literature review, the selection of LPWAN technologies was chosen, specifically, Lora, since said technology allows a good range (greater than 100 meters) and good power (RSSI averaged at -85 dB at the open air) for implementations in areas rural, taking into account that the Municipality of Ciénega - Boyacá is an area with medium-high relative humidity and the land where the project was carried out is on a slope of considerable height. For the design and implementation of the sensor network, the sensor choice in the market show that there is low availability of non-industrial soil PH sensors, the system used an EC201 sensor for detection of PH in liquids, hindering the constant measurement of the sensor since constant revision and cleaning is necessary.

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In the design of the Artificial neural network for the prediction of the data from acquired information, the different configurations were developed by using the backpropagation learning method, being one of the most robust techniques according to the state of the art. However, when it is implemented, it is recommended to change the activation functions since the data entered is better adapted using the nonlinear function regression method compared to the sigmoid function. Besides, the artificial intelligence system provides adequate predictive values, being a heuristic system it performs reconfigurations for each measurement, not always generating acceptable expected results.

Farmers generally have low-end mobile devices, this leads to limiting the technological implementation of the project. In addition, mobile connectivity coverage and the provision of internet service in rural areas is limited introducing eventual unavailability of the service that can be handled by using a power supply. Also, some rural regions experiment periodic electrical failures that affects and limits the amount of time in monitoring the system. As a future work, some additional soil sensors to measure Potassium, Phosphorus and Nitrogen, will we included in each module to improve the soil characterization for the irrigation control stage.

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