PROTOTYPE OF AGRICOL MONITORING AND CONTROL BASED IN IoT

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Abstract— There are currently many challenges for agriculture due to problems such as soil acidification, lack of technification of agro-industrial processes, waste of land and the use of manual and old systems for crop management, which cause a reduction in crop yields and economic losses. This paper presents the design and implementation of a prototype monitoring and control system incorporating Internet of Things (IoT) approaches, to obtain atmospheric variables and control parameters present in the nutrient solution supplied to the crop, which are essential for plant growth and development. This prototype presents to the farmers the information about the monitoring variables, helping them to make more efficient decisions on their crops and thus incorporate better agricultural practices, which will allow long-term benefits in terms of yield and profits.

***Index Terms*— IoT, agriculture, monitoring, control, climatic variables.**

I. INTRODUCTION

One of the current challenges is to promote solutions that are aligned with the objectives of sustainable development, since these broadly encompass economic, social and environmental issues [1], therefore, technology plays a fundamental role in the search for and development of innovative solutions that make human welfare possible. On the other hand, one of the main problems of agricultural production processes is soil acidity [2], which is caused by erosion, acid residual effects of fertilizers [3]. Particularly in Colombia, this is reflected in the DANE figures from the last national agricultural census [4], which show that of the 43 million hectares occupied by Colombian agriculture, only 0.3% belong to agricultural infrastructure and 19.7% belong to transitory and permanent crops, which means that the remaining 80% are of little use, therefore, the country's potential for agricultural production is not exploited and the integration of technologies in this sector is scarce. In addition, the lack of governmental attention has caused problems such as: inefficient use of natural and sanitary resources, waste of land, indebtedness, and economic insolvency on the part of farmers [5][6]. To satisfy current and future food demand, it is necessary to expand crop areas and improve crop yields by incorporating new technologies to technify processes through precision agriculture and strengthen the conservation of natural resources such as water [7]. On the other hand, the expansion of land for crops alters ecosystems and with it the services they provide, thus, there is a growing migration from traditional crops to hydroponic crops to mitigate this problem [8].

Under the second aspect, the constant evolution of technology has allowed its inclusion in different fields thanks to integrated solutions of low cost, low energy consumption, size, ease of implementation and scalability, which when integrated with IoT approaches allow forming a network infrastructure to process information from the physical and virtual world and react to certain situations, composed of information resources, objects, people and systems[9], which at the agricultural level allows improving the efficiency of farms, increasing profitability and optimizing the management of resources [10].

Focusing on the municipality of Guasca as a case study, a research study revealed the lack of information storage systems, the use of old and manual tools to obtain atmospheric conditions, which is inaccurate, resulting in waste of resources, lengthening of agro-industrial processes, decrease in the harvest or otherwise cause sectoral or complete losses in semi-hydroponic strawberry crops [11][12]. Therefore, the design and implementation of a monitoring and control prototype based on these needs is proposed.

The document structure is organized as follows. Section II illustrates the context of the proposed device, Section III describes the proposal from the case study, focusing on its components from the IoT approach, Sections IV and V focus on the prototype implementation and test scenarios. Finally, section VI describes the conclusions and section VII lists the acknowledgements.

II. BACKGROUND

Given the problems mentioned above, there is a worldwide boom for this type of technological developments that are aligned with the Sustainable Development Goals (SDGs) proposed by the United Nations. Likewise, there is an alignment with 2 of the mega trends to keep the SDGs on track [13]. A great example is Europe, where drone-based systems and telemetry are widely used in conjunction with web applications, with features such as: constant and historical information on fertilizers to use them properly and effectively, IoT and precision agriculture to collect data [14]. In Asia, there are more advanced and efficient systems for the needs [15], which integrate hardware and software to establish an IoT scheme that allows farmers to monitor the health of their crops and obtain specific recommendations according to the crop for the application of the dosage of fertilizers or crop protection products. On the other hand, Africa, one of the less developed continents that does not have equally effective or technologically advanced systems with the previous ones, given its climatic, territorial, and natural resource conditions, makes it necessary to implement techniques and systems that generate more efficiency and crop yields, thus some applications provide farmers with weather data through text messages, ways to increase productivity and protect their crops in critical times [16]. Finally, the United States has sophisticated tools, which provide information such as prices of products produced by farmers, comments, weather, and news, that allow to take decisions that maximize crop yields by collecting, storing and visualizing data to promote sustainable agriculture [17][18].

In Latin America, there are also several solutions that address productivity and sustainability. First, in Mexico, the use of hardware and software allows farmers to obtain real-time information on crops in order to make more accurate decisions such as saving water or energy, automate processes such as irrigation from these information captures, and market their products [19]. Then there is Argentina, where some of the solutions implemented are based on obtaining better yields by reducing water consumption, which is a complete monitoring and control system through an application that automatically manages subway irrigation on farmers' land, which requires taking soil samples to adjust the model and interaction with meteorological data which are variable, and the data entered by the user on the production objectives to be achieved [20]. Finally, in Chile, which is one of the pioneers in the implementation of IoT solutions in small and medium scale agriculture, the integration of hardware and software using computer vision and artificial intelligence techniques under an IoT scheme allows obtaining soil, climate, and plant data, alerting farmers about frost and providing irrigation recommendations through a virtual advisory model [21].

In the Colombian context, several solutions have been developed, some of them consist of applications focused on farms can access to a status of quality productive enterprises, guiding them on good agricultural practices to obtain a certification, in addition, this software provides producers with statistics, technical assistance and recommendations for activities [22]. Some of them have a "smart field notebook", where the farmer records all the tasks he has performed on his crop and thanks to the use of technologies such as Big data and Machine learning, the application provides the farmer with reports on costs, future production, potential pests and diseases, worker assistance, products available in the warehouse and finances [23]. In addition to various projects aimed at providing solutions to the problems mentioned above, there are also companies such as Microlink, which offer IoT solutions for physicochemical monitoring and automation oriented to Precision Agriculture [24], based on the same requirements of the current agriculture, using tools that automate irrigation on demand, artificial intelligence, and image recognition.

III. PROPOSAL

A. Description

Given the particularities of the case study identified from an interview with the producer community, in terms of limitations, costs and profits generated by strawberry crops, a prototype is presented that integrates an intermediate degree of technification for the benefit of producers in this work and that is aligned with the SDGs. Based on an analysis of the factors that affect the crops, it is determined that the most relevant variables are temperature, relative humidity, and substrate humidity, in addition to pH and electrical conductivity, which measure and guarantee the availability of nutrients present in the irrigated nutrient solution in the crops. Therefore, the proposal is made for a prototype comprising a wireless network of sensors and actuators to collect data such as relative humidity, temperature and humidity of the substrate, data that will be transmitted through a wireless network to reach the Gateway, which through software will initiate a processing sequence, in which it will determine whether or not to irrigate the crop, in case of be required, it must be turning on the necessary actuators to balance the parameters present in the nutrient solution and activate a water pump to irrigate the crop. Finally, the monitoring and control data will be stored in the cloud and presented to the farmer through a web application. *Figure 1* presents the general scenario of the prototype system described.

B. Prototype architecture

In order to comply with the prototype proposal, six subsystems are being developed:

1) Monitoring subsystem*:* As can be seen in *Figure 2*, it is composed at the hardware level of the wireless nodes of the network and the sensors responsible for collecting data on temperature, relative humidity, substrate humidity, pH and electrical conductivity transmitting them to the main node of the network.

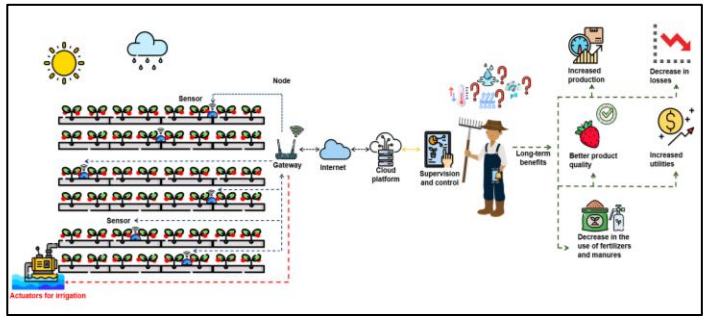


Fig. 1. Proposal design

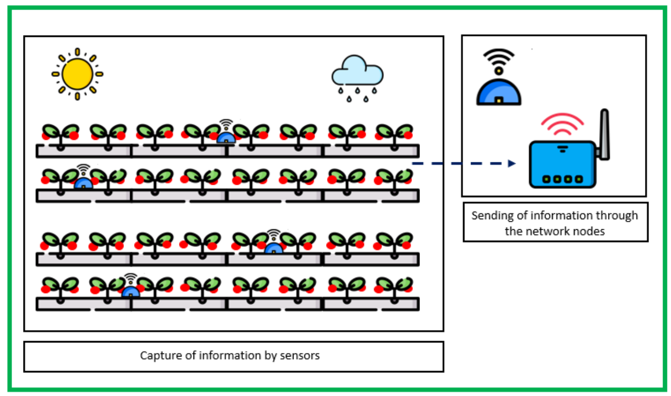


Fig. 2. Monitoring subsystem.

2) Storing and processing subsystem: As can be seen in *Figure 3*, it receives the data generated by the monitoring subsystem as input and the software compares the data obtained with respect to the allowed ranges and sends them to the database server in the cloud for storage.

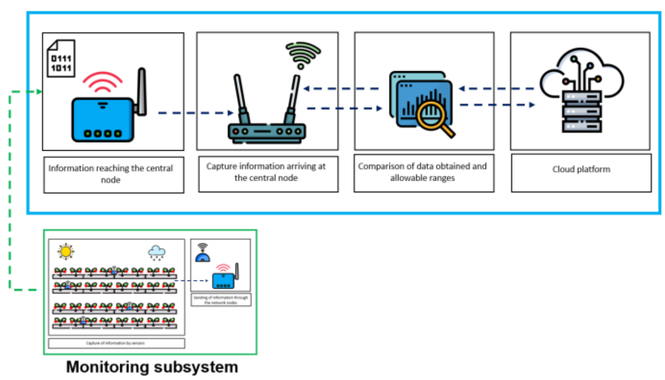


Fig. 3. Storing and processing subsystem.

3) Notification subsystem: It starts with the output of the flow generated by the storage and processing subsystem as shown in Figure 4, the processing identifies whether the nodes are connected to the network and the captured data are optimal, otherwise a notification or alert will be sent to the end user to act.

4) Control subsystem: The start of this subsystem is given by the flow generated by the storage and processing subsystem, which determines whether it is necessary to turn on the actuators, either to balance the parameters of the nutrient solution or to irrigate the crop. This can be seen in *Figure 5*, in which there is a bidirectional relationship between the two subsystems for turning on the actuators and recording them in the database.

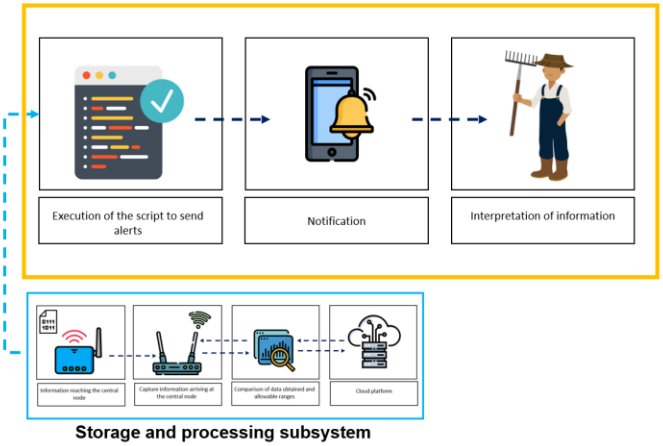


Fig. 4. Notification subsystem.

5) Network management subsystem: This subsystem allows to manage and monitor the implemented network devices, the flow generated is sent to the storage and processing subsystem, and if anomalies are identified, it is sent to the notification subsystem so that the end user can take action. This subsystem can be seen in *Figure 6*.

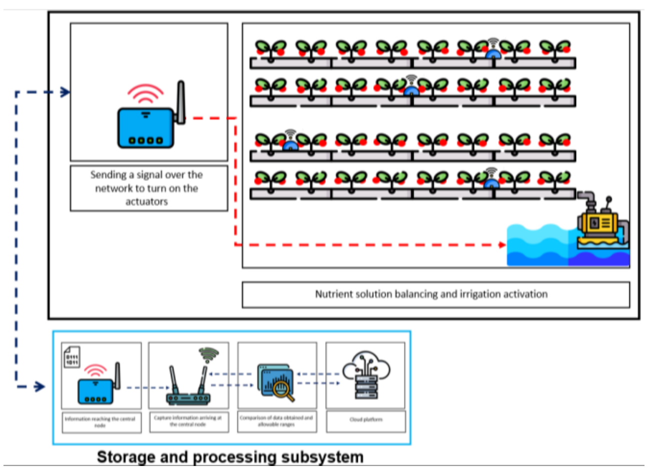


Fig. 5. Control subsystem.

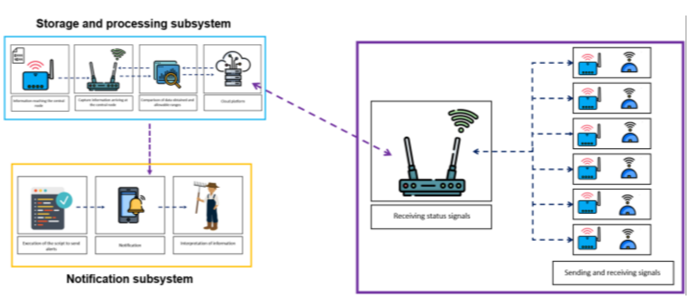


Fig. 6. Network management subsystem.

6) Virtualization subsystem: It connects with the storage and processing subsystem, since the web application connects to the database server in the cloud in order to display in a friendly way the stored data, so that the user can easily interpret them. It also allows interaction with other subsystems to reset devices and change control ranges of the nutrient solution.

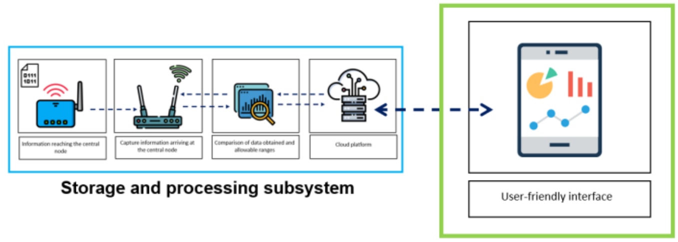


Fig. 7. Virtualization subsystem.

IV. IMPLEMENTATION

In congruence with the design of the prototype, the subsystems that compose it and the needs of the case study, the most optimal hardware and software technologies are chosen for its development and deployment in the simulated environment.

A. Hardware

As a fundamental part of the process, a comparison is made between different hardware elements and technologies available in the market, in order to determine the most appropriate ones according to the needs.

First of all, an analysis of the wireless communication standards is carried out, since this is one of the main requirements in the case study due to the fact that the environment where the problem is developed is rural and the wide territories of implementation and access to wired technologies present greater difficulty, therefore the most appropriate communication standard is Zigbee, since it is the one with the lowest energy consumption, a factor of high importance for rural environments; The transmission speed is in an intermediate range with respect to others; it supports a large number of nodes, a relevant factor since sensors and actuators are required at different points of the crop, and the standard chosen is DigiMesh, which is the module manufacturer's own, since it allows configuring the routers in sleep mode and not only the end devices as is the case of the Zigbee standard, and its characteristics are adequate to guarantee the transmission of information in the failure of any network node [25].

Regarding the hardware modules that incorporate this standard, the Digi Xbee Zigbee 3.0 modules are chosen because they are the most accessible on the market, have better documentation than others, are easy to implement, have lower associated costs, allow the programming, and use of sensors without the need for additional microcontrollers from MicroPython and the operating frequency band is the 2.4 GHz allowed in Colombia.

For the selection of sensors that allow satisfying the monitoring subsystem, factors such as: associated costs, references found in the market, compatibility, and integration with the modules and the MicroPython language, and the types of interfaces required for their reading are taken into account. Therefore, the ones presented in *Table I* are selected, where some of their characteristics and associated costs are discussed.

In accordance with the control subsystem, the variables of greatest incidence in the nutrient solution and the measures to be taken to keep them in the optimal ranges, the actuators proposed in *Table II* are needed. The choice of these elements is conditioned by qualities such as cost, market references and ease integration with the Xbee modules for their implementation, in addition to specific characteristics such as the flow rate of the water pump for irrigation in the crop and the pressure of the electro valves to supply the reservoir with four specific solutions, two corresponding to hydroponics liquids that allow balancing the pH, and two for balancing the electrical conductivity that are water in its purest state and a solution with macro and micronutrients.

TABLE I
SENSORS ELECTION

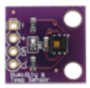
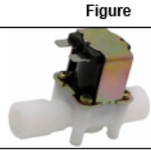
Sensor	Figure	Reference	Price (COP)	Features
Temperature and relative humidity		HDC1080	18.000	-Digital sensor -Good measurement at low power -Low cost Relative humidity accuracy ± 2% - Temperature accuracy ± 0.2ºC -Temperature accuracy ± 0,2ºC -I2C communication -Temperature range -40ºC to 125ºC -Power supply voltage 2.7V to 5V -Stability at high humidity
Soil moisture		HD 38	30.000	- Analog sensor -Size: 38 * 15 * 7 mm -Voltage: DC 3.3-12V -Current: <20mA; <30mA -Interface: + - DO AO -Operating temperature: -25 - 85 Celsius
Electrical conductivity		TDS Meter V1.0	81.000	- Analog sensor 0 ~ 2.3V -Supply voltage of 3.3 ~ 5.5V -Submersible for long periods of time - TDS measurement range: 0 ~ 1000ppm -TDS measurement accuracy: ± 10% F.S. (25°C)
pH		SEN0161	104.500	- Power supply: 5.00V - Measuring range: 0-14 pH -Measuring temperature: 0-80°C -Accuracy: ± 0.1pH (25°C) -Response time: = 5s -pH probe with BNC connector

TABLE II
ACTUATORS CHOICE

Actuator	Figure	Price (COP)	Features
Solenoid valve		30.000	-Thread: 1/2 NPT -Material: ABS plastic -Voltage: 12VDC -Pressure: 0.02-1 MPa -Power: 4.8W
Air pump		29.500	-Operating voltage: 110 v. -Maximum output: 2 liters per minute. -Pressure: 0.012Mpa -Power: 2.9W
Water pump for irrigation		47.000	-Operating voltage of 12 V 4.2 W -Maximum height 3 meters -Flow rate 240 L/h -Submersible

Finally, the choice of the Single Board Computer is made, its determination is given by the difference between a microcontroller or microprocessor, which roughly lies in that the microcontroller is designed to meet specific tasks and requires a degree of control imposed by the user, unlike microprocessors that allow running large and generic applications that may require greater resources [26]. The Raspberry Pi series stands out from others, due to the wide range of features it presents, thus, the most feasible choice in terms of cost and features to support the processes is the Raspberry Pi 4, due to the price-quality ratio, processing characteristics, storage, operating systems supported and connectivity, which are optimal to support the tasks corresponding to the Gateway of the prototype.

B. Software

To determine the choice of the type of application to be developed, a comparative table made by IBM is used to compare native applications, hybrid applications and web applications, whereby the web application is established as the most appropriate for the development of the project, since it is easier to develop, can be accessed from multiple platforms through a URL and also presents portability and flexibility in its respective updates [27].

Through comparisons between the different existing programming languages for web applications, JavaScript was determined as the language with the greatest advantages for the development of the project, since it has particular characteristics such as: it carries out all the processing on the client's computer reducing the amount of resources needed on the server, it has a good performance if the number of users is high and at the same time the infrastructure costs would be reduced. Under the same model, the choice of the programming framework for JavaScript was carried out, where it was concluded that the React.js framework is the most appropriate, since its objective is to develop applications that work entirely on the client side, reducing the consumption of resources on the server side [28], which can satisfy the visualization subsystem.

Regarding cloud storage requirements for the IoT approach, the most popular cloud service providers such as Google, Amazon, Microsoft, and Alibaba Cloud are analyzed. Amazon was chosen due to cost factors and the broad ecosystem of components it offers, since it offers 85 free services that never expire, as well as give access to the full range of products and services, availability, and security for one year.

In order to comply with the storage and processing subsystem, the database engine is defined based on a comparison between characteristics, advantages, and disadvantages. Therefore, SQLite is selected first, since it is light, does not require additional configurations, performs operations quickly and needs few resources for its operation, chosen for redundancy issues in case the Gateway loses connectivity. Secondly, MariaDB is chosen for use in the cloud, since it has better performance than MySQL, has full compatibility with the SQL language, offers an efficient optimizer for queries, is free to use, its high availability, in addition to its ease of handling independent tables. The two engines will use the relational model shown in *Figure 8*.

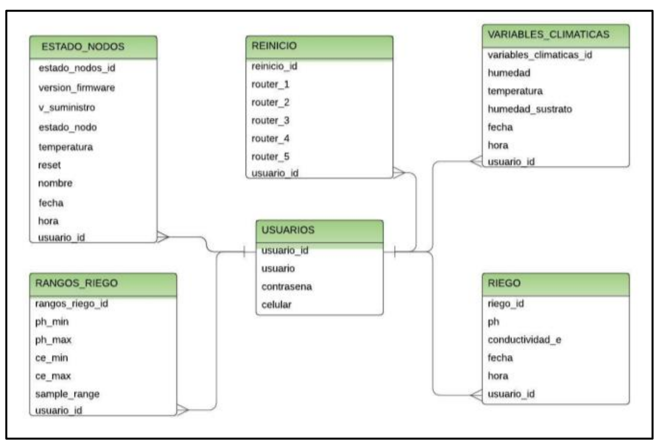


Fig. 8. Relationship entity model.

1). Visualization subsystem structure: The web application is composed of 4 sections: 1. Login, so that the user can access the information. 2. Monitoring, it presents the records of atmospheric variables and their graphs, irrigation records and text boxes to modify the monitoring ranges of pH and electrical conductivity. 3. Network status, shows the records of each node, allows sending restarts and updating the telephone number that will receive the notifications. 4. History, in which the user can access records filtered by date.

2). Cloud architecture: As shown in *Figure 9*, in this architecture, the database is located in the Amazon RDS (Relational Database Service), which can only be accessed from the sensor network gateway and from the Amazon Lambda service. The application is hosted in the Amazon Elastic Beanstalk service, which works in conjunction with the Amazon CodePipeLine service to access the source code that is hosted in the GitHub online repository. On the other hand, the API Gateway service was also used, which works in conjunction with the AWS Lambda service, in order to access the database from the web application in a secure way. Finally, the last service used in the cloud architecture is the Amazon SNS (Amazon Simple Notification Service), which is consumed from the Gateway of the sensor network through unique security credentials and allows sending text messages to customers notifying them of important events occurring in the crop.

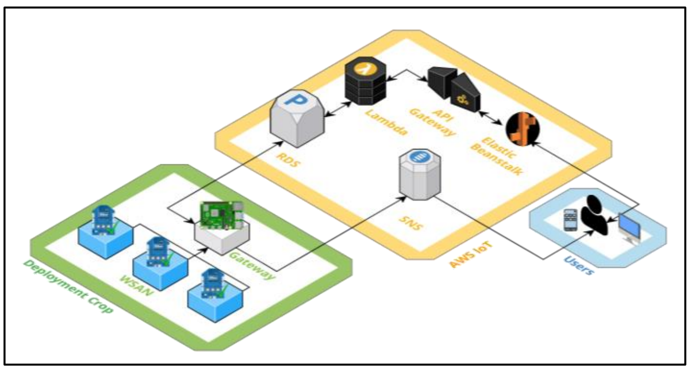


Fig. 9. Cloud architecture.

C. Simulated environment deploy.

After the choice of technologies and respective configuration of each of the nodes of the wireless network, the prototype is implemented in a simulated environment that presents in amplitude qualities of a real environment of semi-hydroponic strawberry crops. This can be seen in *Figure 10*.

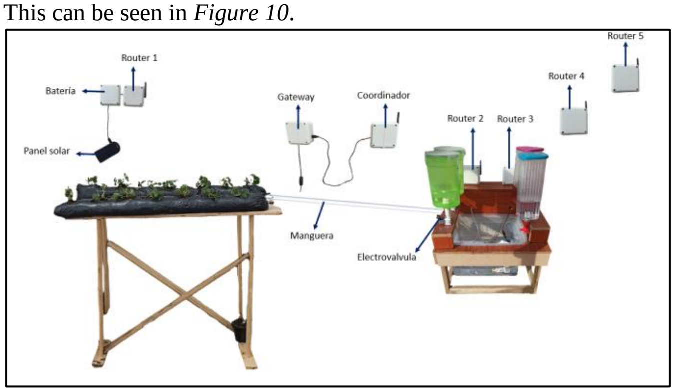


Fig. 10. Prototype deploy.

As can be seen in Figure 11, the container in which the drops of each solution fall correspond to the control subsystem, since it contains the electrical conductivity sensor, the pH sensor, the hoses coming out of the air pump and the water pump connected to the hose that supplies the nutrient solution to the crop.

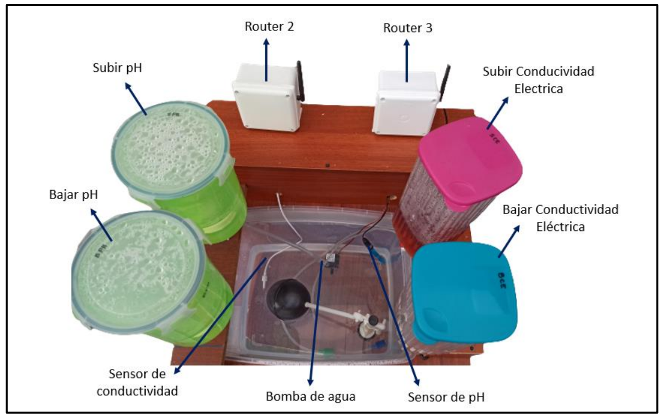


Fig. 11. Nutrient solution reservoir.

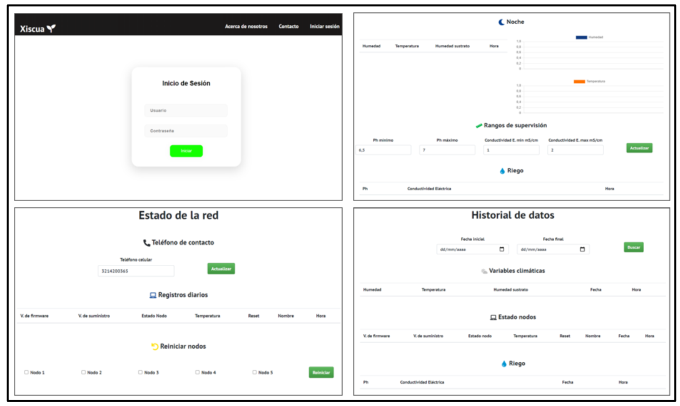


Fig. 12. Application web sections.

D. Develop of the application web.

After making the schemas corresponding to the database and the architecture in the cloud, the database is implemented in the Amazon RDS service, with which it was necessary to make use of the Amazon API Gateway service, which allows to easily create, publish, maintain, monitor and protect the APIs, resulting in a front door for applications to access the information or business logic that is hosted in the backend services[29], together with the AWS Lambda service to execute code without provisioning or managing servers [29]. In the latter service, a Python script was used, which securely and privately contains the database credentials and is responsible for performing queries or modifications in the sentences, depending on the URL from which the request was made.

For its development, the corresponding dependencies are installed using node.js [30] and the development of styles was streamlined using Bootstrap, which is the most popular open-source toolkit in the world [31]. Using the AWS API Gateway service, rest services are consumed, and the chart.js library for the corresponding charts [32]. Finally, the application was hosted in the Amazon Elastic Beanstalk service, which requires the use of the Amazon CodePipeline service, which allows deploying and testing the code every time a change is made to it [29]. As a result, the screens shown in Figure 12 are obtained.

V. TEST SCENARIO

The tests are performed in the simulated environment comprising 3 phases, the first corresponds to the transmission and reception time of the information in the network nodes, the second to tests of the request to the database server in the cloud and finally tests of the power on of the network actuators.

A. Test of data recopilation.

At this stage, a script is used to test the request from the Gateway to the different nodes to request the information corresponding to the sensors for: atmospheric and substrate variables, pH and electrical conductivity. The corresponding graph is shown in *Figure 13*. It can be seen that the first one has a longer delay, which is due to the fact that it reads 3 sensors and then sends the information through the network. The second one has to take 30 samples every 30 ms, so it is on a par with the electrical conductivity sensor, which takes 30 samples every 40 ms and its conversion from analog to digital is more complex.

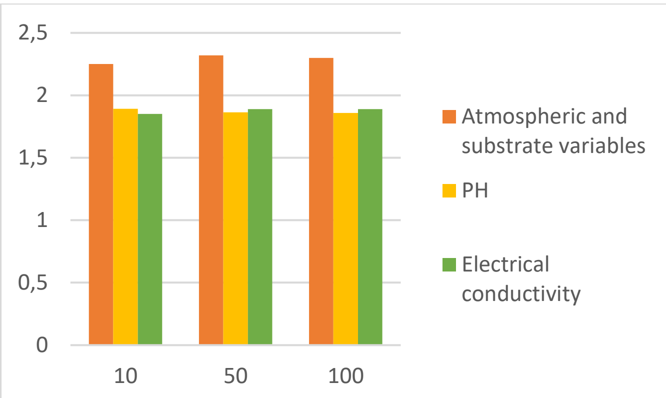


Fig. 13. Tx y Rx data of the sensors (s).

B. Test of requests

After collecting and storing the data from each of the network nodes, several tests are performed for the get requests corresponding to *Figure 14*, insert in *Figure 15* and update in *Figure 16*, database requests, simulating clients using the Apache JMeter tool [33]. With this test it is observed that the number of requests is proportional to the time, in addition, the more fields to enter, request or update the table contains, the longer the response time.

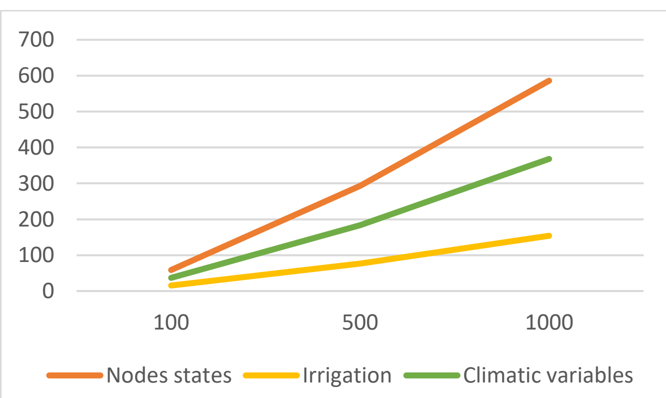


Fig. 14. GET - Response Time (s)

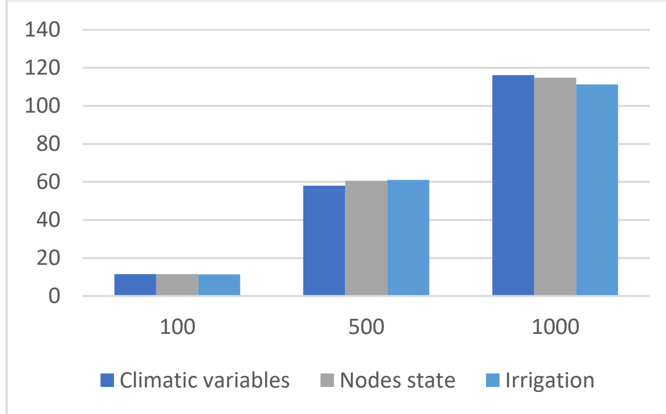


Fig. 15. INSERT - Response Time (s).

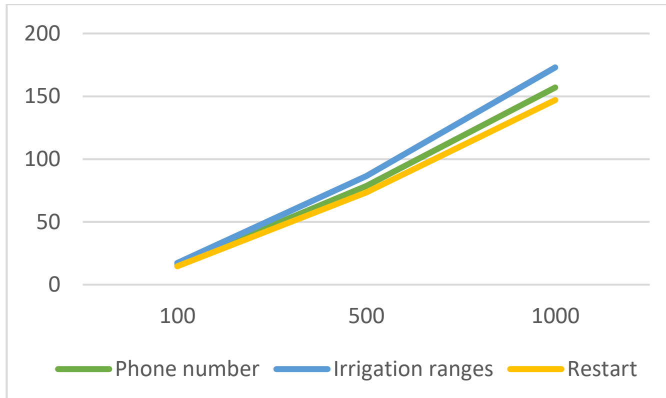


Fig. 16. UPDATE - Response Time (s)

C. Actuators test

At this stage, the delay time is taken when turning on the relays corresponding to the actuators of solenoid valves to control the pH and electrical conductivity parameters, air pump and water pump. The corresponding graph is shown in *Figure 17*, where stability in the activation delay times is observed.

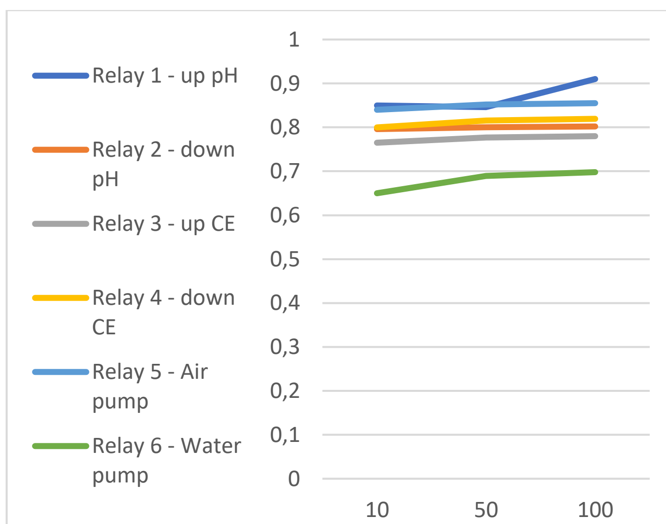


Fig. 17. Relay activation time (s).

D. Outdoor test range

In this stage the range distance of the line view of the modules Xbee is compared respect the transmission and reception delay from the gateway and the coordinator node of the network to the router 1. The results of the test can be appreciated in the *Figure 18.*

E. Battery duration test

In this test the coordinator node is used and the router 1 which is connected to a 5000-mA battery, the relative humidity sensor, temperature and two soil humidity sensors. This node will remain on and without use the sleep mode, to determinate the duration of the battery in days. The results can be appreciated in the *Figure 19*.

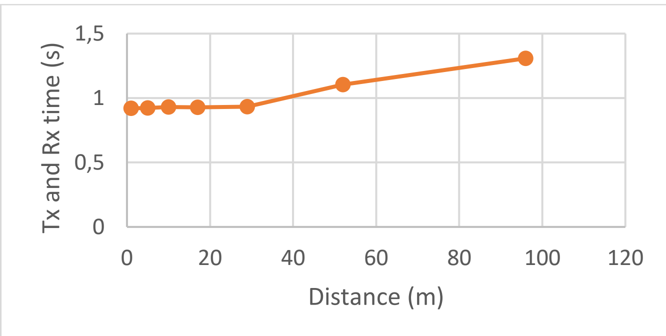


Fig. 18. Line of view test Xbee.

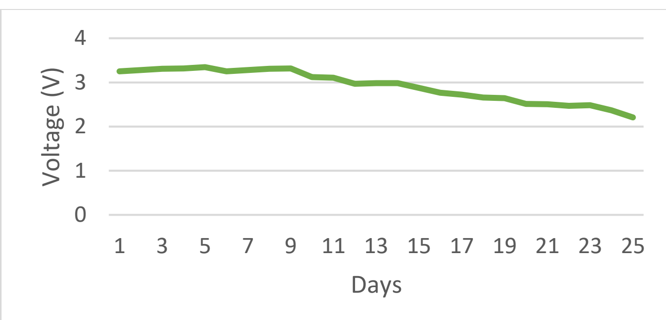


Fig. 19. Battery duration.

VI. CONCLUSIONS

- The control of water is a factor of great importance as it is a non-renewable resource vital for all forms of life, therefore, a responsible consumption must be made which can be managed more efficiently using technologies applying IoT approaches, since particularly in agriculture, in traditional crops this resource is filtered through the soil and is not used to its full potential.
- Based on the research and analysis carried out, it is possible to say that Colombia has ample potential to increase its economy through the migration of traditional crops to the technification of agro-industrial processes, policies in favor of producers and developments focused on this area.
- The Zigbee communication standard represents an efficient alternative for rural environments and for the current boom in the reduction of energy consumption. However, there are few modules on the market that integrate this standard, as well as the amount of documentation and low cost.
- The use of cloud computing currently represents great economic and technological benefits, as it is on-demand, you only pay for what you consume, avoids initial infrastructure costs, its availability is among the highest, avoids maintenance costs, is easy to implement and has a wide range of services.
- The tests performed on each of the subsystems make it possible to evaluate the performance of the prototype in small proportions, therefore, its overall performance depends on the success of the individual tests.
- A prototype monitoring system was developed that is capable of measuring variables such as relative humidity, temperature and substrate humidity, which serve as a reference to automatically perform tasks such as balancing the nutrient solution based on parameters such as pH and electrical conductivity for irrigation or sending notifications to the user by SMS.
- A system was developed to back up information in an SQLite database in case the Gateway does not have internet access to send the data to the Maria DB database deployed in AWS.
- As future work, better energy consumption schemes can be analyzed and generated to make the IoT approach more plausible in industrial level deployments.
- It is presented as an open problem, the deployment of the prototype at industrial level to evaluate its behavior and efficiency.
- For environments of greater automation, management, and control, it is recommended to incorporate new technologies such as artificial intelligence to find weather and irrigation patterns, in order to optimize the Gateway management processes and data collection, as well as the presentation of reports to the farmer or field diaries to record all the actions performed on the crop.

VII. ACKNOWLEDGMENT

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VIII. REFERENCES

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