Neural network for crop rotation and soil analysis in a Greenhouse

Red Neuronal para la rotación de cultivos y análisis de suelo en un Invernadero

RAFAEL-PÉREZ, Eva†*, MONTERO-CORTÉS, Yeimi Yanet, RUIZ-RAMÍREZ, Alan Eduardo and MORALES-HERNÁNDEZ, Maricela

Tecnológico Nacional de México/ Instituto Tecnológico de Oaxaca, Departamento de Sistemas y Computación. Avenida Ing. Víctor Bravo Ahuja No. 125 Esquina Calzada Tecnológico, Oaxaca, Oax., México. C.P. 68030

ID 1st Author: *Eva, Rafael-Pérez* / **ORC ID:** 0000-0003-2793-1254, **CVU CONACYT ID:** 905268

ID 1st Co-author: *Yeimi Yanet, Montero-Cortés /* **ORC ID**: -0000-0001-5510-7241 **CVU CONACYT ID:** 1148726

ID 2nd Co-author: *Alan Eduardo, Ruiz-Ramírez* / **ORC ID:** -0000-0001-9269-5951 **CVU CONACYT ID**: 1148734

ID 3rd Co-author: *Maricela, Morales-Hernández* / **ORC ID:** 0000-0002-3521-2041, **CVU CONACYT ID:** 731036

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Abstract

Currently, Artificial intelligence (AI) is a very important area, the way in which it has revolutionized has allowed it to be an essential part of technological evolution in different sectors of society such as agriculture, it is a fundamental activity in the development of our country, and one of the developing areas is implementation of greenhouse crop. This article describes the use of artificial intelligence for a greenhouse through an Artificial Neural Network (ANN) of the multilayer perceptron type using the BackPropagation algorithm. The main aim is obtain the most optimal type of crop to be sown by means of the crop rotation, which, supported by a data acquisition device through sensors, obtains the values of temperature and humidity of the environment and soil pH, with those data the ANN makes the soil analysis. Through the interfaces of the data analysis module and the measurement module, the data collection process, the calculation and the results produced by the artificial neural network are shown. For this project, the Prototype model was used using the Java programming language.

Artificial Neural Network, Crop rotation, Soil analysis

Resumen

La inteligencia artificial (IA) es un área importante en la actualidad, la manera en cómo ha revolucionado le ha permitido ser parte esencial de la evolución tecnológica en varios sectores de la sociedad como es la agricultura, actividad fundamental en el desarrollo de nuestro país que se ve implementada en la producción de cultivos bajo invernadero. El presente artículo describe el uso de la inteligencia artificial para un invernadero a través de una Red Neuronal Artificial (RNA) de tipo perceptrón multicapa utilizando el algoritmo de BackPropagation, con el objetivo de obtener el tipo de cultivo más óptimo a sembrar por medio de la rotación de cultivos, que apoyados de un dispositivo de adquisición de datos a través de sensores se obtuvieron los valores de temperatura y humedad del ambiente y pH del suelo para realizar el análisis del suelo. Mediante las interfaces del módulo de análisis de datos y del módulo de mediciones se muestra el proceso de obtención de datos, el cálculo y los resultados que arroja la red neuronal artificial. Para este proyecto se utilizó el modelo en Prototipos utilizando el lenguaje de programación Java.

Red Neuronal Artificial, Rotación de cultivos, Análisis de suelo

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* Correspondence to Author (e-mail: evarafaelperez@gmail.com)
† Researcher contributing first author.

Introduction

The incorporation of artificial intelligence has transformed the form and way of life in human beings, the way of production in agriculture has changed, currently agriculture considers various methods of production, efficient and high performance as protected agriculture, which is defined as a specialized agricultural system in which a certain control of the climatic environment is carried out, altering its conditions: soil, temperature, solar radiation, wind, humidity and atmospheric composition (Castellanos-Ramos, 2004). According to data from the Mexican Association of Protected Horticulture (AMHPAC), there are a total of 25,814 active protected agriculture facilities.

The project called Neural Network for Crop Rotation and Soil Analysis in a Greenhouse was developed with the objective of supporting the farmer in making a decision on the optimal type of crop to plant in the greenhouse. It is called optimal crop to the results that are thrown after having performed the soil analysis, taken measurements of temperature, humidity and pH of the soil through the data acquisition module, having selected the type of previous family that was planted based on the technique of crop rotation technique and the application and analysis of the neural network, i.e., once the process is done, the results generated are: The most optimal type of crop to be planted, the optimal humidity values and the ranges in which they should be, the optimal temperature for the type of crop to be planted and the ranges in which it should be and the corresponding family.

The production of crops under greenhouse is one of the most modern techniques currently used in agricultural production that is implemented through a greenhouse that provides an appropriate environment, both in the soil and in the air for the cultivation of plant species, which is supported by techniques to improve crop production.

In this case it was supported by the technique of crop rotation, which is an agricultural practice to increase the productivity of the land and optimize the use of resources by alternating different types of crops in the same soil, its use helps to reduce soil "fatigue" (Seminis, 2016).

Since through the neural network and soil analysis through the values of humidity and temperature of the environment, as well as soil pH, the type of the optimal crop to plant is determined, thus avoiding the risk of loss of production and unnecessary expenses for the farmer. The basic principle of rotations is that crops follow one another according to the characteristics between the preceding crop and the following one, waiting some time to replant a certain crop in the same plot. When designing a rotation, crops with different characteristics should be combined, always taking into account the effect that each crop produces on fertilization and soil structure.

This project was based on the technique of 4 groups of 8 families, starting with the Solanaceae family, then the Leguminosae family, then the Compositae family and finally the Umbelliferae family. For soil analysis, a data acquisition module was used, which consists of taking samples from the real world (analog system) to generate data that can be manipulated by a computer, it is composed of the breadboard, sensors, arduino and electrode.

It is worth mentioning that for the purposes of this work, only the data acquisition module will be explained in general terms, since it is a fundamental part to obtain the values for the measurement, perform the calculations and the results generated by the neural network. The detailed operation and design will be presented for the purposes of another future work.

Likewise, the expert system on which the neural network for crop rotation and soil analysis in its version 2.0 is based, for the purposes of this article will be explained only the functionality of the modules that were added such as: Soil Analysis and Measurements to explain the functionality of the neural network and the values generated by the data acquisition module.

Therefore, this article contains the problem statement, the data acquisition module including the materials and the circuit design; a section on the artificial neural network that covers the part of the operation, the design, the data of the Network and the BackPropagation Algorithm that was used for the neural network programming, another part of the work is the description of the phases for the learning and the presentation of the neural network.

A section of the crop rotation, the development methodology using the model in prototypes and the description of the stages, then the results of the soil analysis module, the functionality of the neural network and the data acquisition module, the acknowledgements and finally the conclusions and bibliographical references.

Problem Statement

The production of crops under greenhouse is one of the most modern techniques currently used in agricultural production, one of the main problems of any greenhouse is when the monoculture system is practiced, as it has certain disadvantages, the soil suffers a wear of nutrients because the same plant is planted in the same place which depletes the nutrients it needs, for example the lack of nitrogen in the soil prevents the growth of plants, The tendency towards erosion and drought, also with the production of a single crop there is a greater likelihood of soil impoverishment, since the same nutrients are abused, and greater exposure to pests and diseases, this creates a risk for the farmer because he bases his production on a single crop endangering his entire crop and therefore economic losses occur, or also that the product often has no quality.

Data acquisition module

For the correct operation of the neural network for soil analysis in the crop rotation in a greenhouse, it is necessary to rely on a data acquisition module; data obtained will be used for the training phase of the neural network, in addition to predicting whether the soil and environmental data are favorable for the harvest of plants of a specific family.

Materials

For the design of the data acquisition module, the following materials were used

– Dht11 (temperature and humidity sensor)
– Arduino Uno
– Protoboard
– Ph-4502C (pH sensor)
– Electrode

Circuit diagram

Figure 1 shows the design of the circuit diagram that was used to obtain data through the dht11 sensor which is used to obtain temperature and humidity from the environment in addition to the Ph-4502C sensor for pH values.

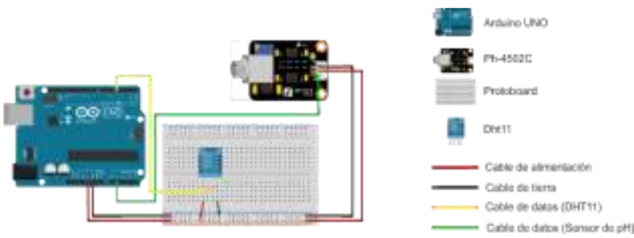

Figure 1 Circuit diagram
Source: Own Elaboration

Artificial Neural Network

Artificial Intelligence is an area with greater growth in recent years, for Iberdrola, (2019) AI is able to analyze data in large quantities, identify patterns and trends and, therefore, formulate predictions automatically, quickly and accurately, one of its areas are artificial neural networks.

Biological neuron, it was Santiago Ramón y Cajal (1888) who discovered the cellular structure (neuron) of the nervous system. He defended the theory that neurons interconnected with each other in parallel, consisting of a cell body (soma) of between 10 and 80 mm, from which a dense tree of branches (dendrites) and a tubular fiber (axon) of between 100 mm and one meter.

On the other hand, Anderson (1995) defines the artificial neural network as a computational model inspired by biological neural networks, which can be considered as an information processing system with a distributed structure of parallel processing, formed by processing elements that are the artificial neurons, which are interconnected by a large number of connections called synapses.

These connections are used to store information that is available for use. An artificial neuron is intended to mimic the most important characteristics of biological neurons. Figure 2 shows the comparison between the biological neuron and the artificial neuron.

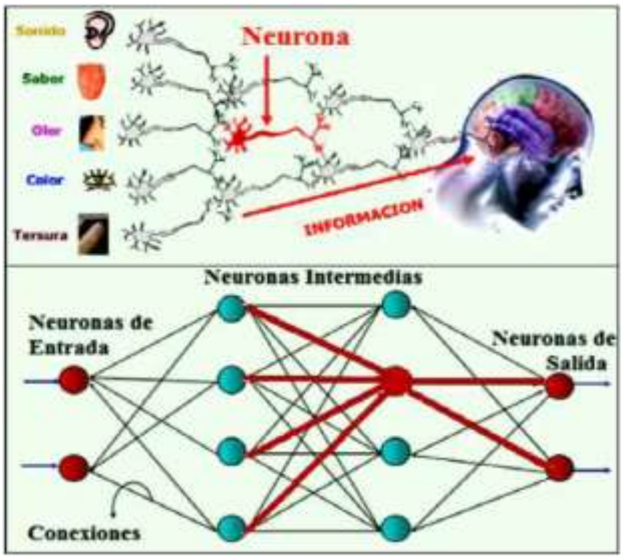

Figure 2 Comparison between biological and artificial neuron
Source: Hilera, J. and Martínez, V. 1995

Functioning of a Neural Network

A neural network is a set of artificial neurons divided into layers. Each neuron of a layer will be connected with all the neurons of the next layer by means of arcs with weights. The weights of these arcs will be modified during the learning phase of the neural network to achieve the desired results in the output of the network.

The layers of the network will be divided into three types: the input layer, the hidden layer(s) and the output layer. The input layer will be the first layer of the network and the data will be fed into the network through it. In this layer there will be as many neurons as the number of inputs required by the network. The hidden layer can be a single layer or there can be several hidden layers, depending on the problem and the design of the network. This layer will be in charge of carrying out the intermediate step or steps between the input layer and the output layer. (Valencia Reyes, Yañez Márquez, and Sánchez Chávez, 2006).

The output layer will be in charge of taking the results obtained to the outside. The number of neurons in this layer will be defined by the problem being solved.

Neural Network Design

The type of neural network used is a multilayer perceptron. Figure 3 shows the structure of the neural network on which the neural network design was based.

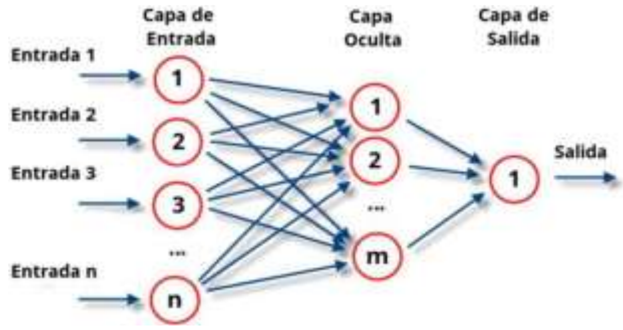

Figure 3 Neural network structure
Source: IBM Knowledge Center

Neural Network Data

The data that were used for the network are:

- An input layer of 5 neurons.
- Two hidden layers of 19 and 20 neurons respectively.
- An output layer with 51 neurons
- BackPropagation Algorithm

In 1986, Rumelhart, Hinton and Williams, formalized an algorithm for a neural network to learn the association that exists between input patterns and corresponding classes, using several levels of neurons.

Steps to apply the backpropagation algorithm

1. Initialize the weights of the network with random small values.
2. Present an input pattern and specify the desired output to be generated by the network.
3. Calculate the actual output of the network. To do this, the inputs to the network are presented and the output of each layer is calculated until the output layer is reached, this will be the output of the network.
4. Calculate the error terms for all neurons.
5. Update the weights: for this we use a recursive algorithm, starting with the output neurons and working backwards until reaching the input layer, adjusting the weights.
6. The process is repeated until the error term is acceptably small for each of the learned patterns.

The Java programming language was used to develop the neural network.

Neural network processing phases

A. Learning Phase

In this phase a network is initially generic and through a series of examples the weights of the arcs will be adapted in such a way that it produces the desired outputs.

Testing and learning of the neural network. A pattern recognition dataset (Iris) obtained from https://archive.ics.uci.edu/ml/datasets/iris was used for this process.

The dataset contains 50 samples of each of three species of Iris (Iris setosa, Iris virginica and Iris versicolor).

Neural network test values

– 4 input neurons
– 8 neurons in the hidden layer
– 3 neurons in the output layer
– Learning factor of 0.05
– Maximum allowed root mean square error 0.005

Figure 4 shows the result of the error percentage of the iris data set, once the neural network is trained, the data in the graph shows that the y variable does not vary as the x variable increases, which means that the maximum allowed mean square error percentage of 0.005 of the epoch variable is maintained. The Epoch variable: It is a complete iteration of the BackPropagation algorithm, this includes the data input, the forward propagation through all the layers of the neural network, the calculation of the error and the adjustment of the neuron weights for all the data of the training set.

Figure 4 Percent error of the iris data set
Source: Own Elaboration

Implementation of the Neural Network with the crop data set.

Data set

The dataset is composed of 8 data, which are:

1. Crop name
2. Crop family
3. Minimum humidity
4. Maximum humidity
5. Minimum temperature
6. Maximum temperature
7. Minimum PH
8. Maximum PH

Training

The values that were used for training the neural network are:

– An input layer of 5 neurons.
– Two hidden layers of 19 and 20 neurons respectively.
– An output layer with 51 neurons
– Learning factor 0.001
– Maximum allowed root mean square error 0.005

Figure 5 shows the result of the error percentage of the crop data set once the neural network is trained, the data of the graph shows that the variable y does not vary when increasing the variable x, which means that the maximum allowed mean square error percentage of 0.005 of the epoch variable is maintained. As already mentioned that the Epoch variable is a complete iteration of the BackPropagation algorithm, this includes data input, forward propagation through all the layers of the neural network, error calculation and adjustment of neuron weights for all the data in the training set.

Figure 5 Percentage error of crop set
Source: Own Elaboration

B. Presentation Phase:

In this phase the neural network is already trained and can be used to solve a given problem.This phase describes the operation of the Data Analysis and Measurement modules that were designed and coded using the Java programming language and that were added to the expert system version 2.0 for its operation, using the prototype model. It is important to emphasize that for the purposes of this work only the two modules will be described, as the functionality of the entire expert system version 2.0 will be the subject of future work.

Crop rotation

The practice of planting different crops sequentially on the same piece of land to improve soil health, optimize nutrients, avoid pests, diseases and weeds. Figure 6 shows the 4-group 8-family crop rotation model that was used for the neural network tests.

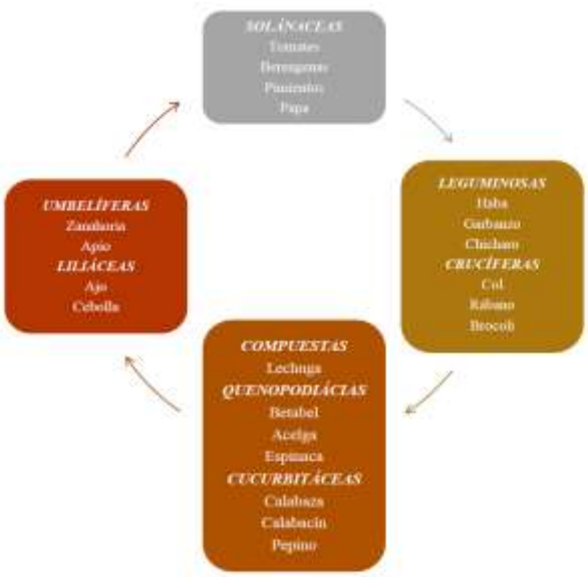

Figure 6 Crop rotation, 4 groups 8 crop families and rotations
Source: (Pellicer, 2015) https://blog.mundoikos.com/familias-de-cultivos-y-rotaciones/

Crop rotation description

The rotation cycle starts with the first crop of Solanaceae, a demanding family as it requires a large amount of nutrients, especially nitrogen(N). For this, if the soil is not rich in organic matter, it is advisable to add it, fertilizing it before sowing; once we have finished with the solanaceae, it is suggested to plant leguminous or cruciferous plants.

Both families are considered as improvers, mainly due to their characteristics in relation to the soil. Leguminous plants maintain a symbiosis in the soil with microorganisms of the Rhizobium genus, which fix atmospheric nitrogen and incorporate it into the soil, while crucifers are plants that improve soil structure due to their tap roots and also reincorporate sulfur (S) into the soil.

The next to be sown are the crops of medium demand, such as composites, quenopodiaceae or cucurbits.

Finally, there are the umbellifers and liliaceae, both of which are not very demanding at the nutritional level and leave the soil ready to be fertilized again and start the rotation cycle. (Pellicer, 2015).

Development Methodology

For the operation of the two modules the Prototyping model was used, this model aims at the direct participation of the customer in the construction of the required software, helps to improve the understanding of what is to be developed when the requirements are not clear and serves as a mechanism to identify and define the requirements of the software, also the prototype evolves through an iterative process, (Pressman, 2010, p. 37).

Figure 7 shows the stages: communication, rapid plan, rapid modeling and design, prototype construction, deployment, delivery and feedback.

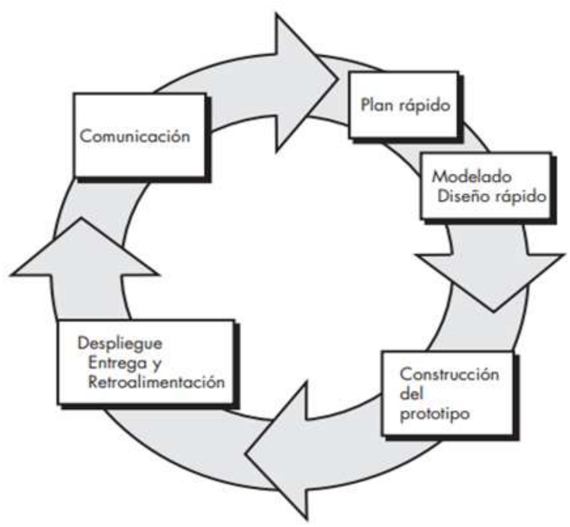

Figure 7 Model stages in prototypes
Source. (Pressman, 2010, p. 37)

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Development of the stages

First iteration:

A. Communication stage, in this first stage interviews were conducted with the farmer to find out what were the real needs and problems presented, for example: identify manual processes, irrigation system, manual preparation of manure, fertilization, planting periods, harvesting, cutting, weather conditions in terms of humidity and temperature, type of crops planted, number of harvests, information that served to define the requirements, the definition of both general and specific objectives of the software, as well as users to interact with the system.

For the functionality of the modules, 3 types of users were identified with different roles and privileges to access the system:

– The Administrator user, who has full access to each of the modules, is in charge of adding data to the user system, new crops and new irrigation, soil analysis, measurements.

– The user Farmer, adds the data of sowings, harvests, process log, crops, history of sowings, harvests, crop rotation, soil analysis and measurements.

– The guest user can only view information about crops, plantings, harvests, crop rotation, soil analysis and measurements.

B. The Quick Plan stage is carried out when the project results of the previous stage are accepted, then an abbreviated representation of the requirements is developed. For this project, the Use Case technique was used to model the requirements of the data acquisition module, an example of a Use Case for obtaining sensor data is shown in Figure 8.

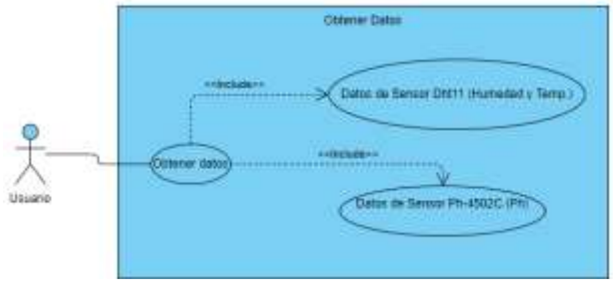

Figure 8 Sensor data collection use case
Source: Source: Own Elaboration

C. In the rapid design modeling stage, different models were designed that serve as the basis for the correct operation of the system, such as sequence diagrams, the entity-relationship model, the circuit diagram design and the graphical user interfaces. As an example, a sequence diagram to execute the data acquisition program is shown. See figure 9.

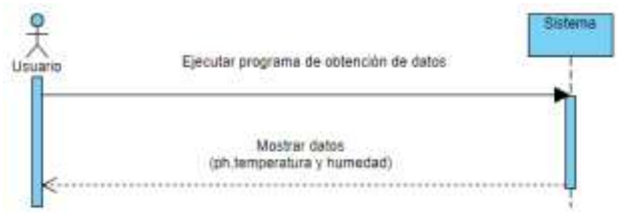

Figure 9 Sensor data collection use case
Source: Own Elaboration

D. In the rapid design modeling stage, different models were designed that serve as the basis for the correct operation of the system, such as sequence diagrams, the entity-relationship model, the circuit diagram design and the graphical user interfaces. As an example, a sequence diagram to execute the data acquisition program is shown. See figure 9.

Figure 10 Access to the system
Source: Own Elaboration

E. In this stage of construction of a prototype, the circuit was built, only shown in Figure 11, since the description of the functionality will be a topic to be discussed in the future as mentioned above.

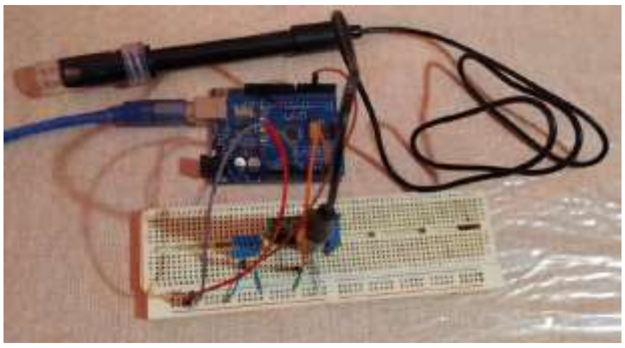

Figure 11 Circuits
Source: Own Elaboration

F. The last stage of deployment, delivery and feedback, the data acquisition module was tested with the variables of temperature, humidity of the environment and pH of the soil.

```
Prueba DHT11
Humedad: 18.00%  Temperatura: 25.00°C
```

Figure 12 Results of humidity and temperature of the environment
Source: Own Elaboration

Second Iteration module: Soil analysis

A. Communication stage, in which the requirements of the soil analysis module were analyzed, the integration of the neural network in the expert system, as well as the specification of the process to obtain the data taking into account the crop rotation technique.

B. In the Quick Plan stage, a representation of the requirements was made by means of use cases to model the requirements of the soil analysis module.

C. In the Rapid Design Modeling stage, sequence diagrams were designed, two databases were created, both local and remote databases using the MySQL database management system. The remote database serves as a backup for the local database, if there is any problem with it, it can be recovered through the backup, also the remote database is updated every time there is an internet connection adding the newest data. The graphical user interfaces were also designed.

D. Prototype construction stage, in this stage the Soil Analysis and Measurements modules were developed, and Java programming language was used for their coding. In relation to the operation of the Soil Analysis module, it is linked to the Data Acquisition module by means of the Take Measurements button to obtain temperature, humidity and pH measurements.

The last stage of Deployment, delivery and feedback of the system, the design, phases, training and functionality of the neural network was tested.

Results

The results of the modules: Data Acquisition, Soil Analysis, Measurements and the implementation of the Neural Network are described below.

– Access to the system, to enter the system a user name and password are required. See Figure 13.

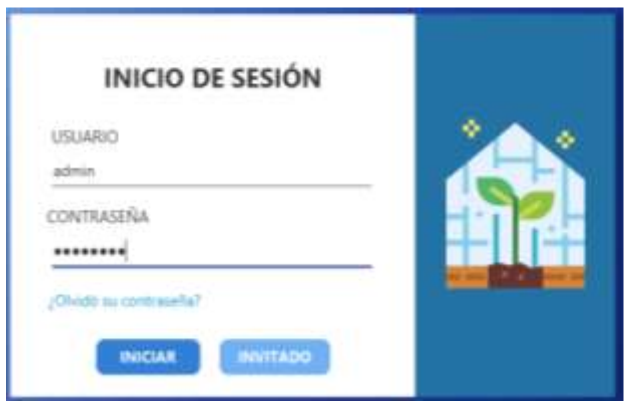

Figure 13 System access screen
Source: Own Elaboration

a) Results of the data acquisition module

To perform the tests correctly, the following steps need to be followed:

1. Make a solution with two portions of water and one portion of soil in a container.
2. Shake said solution and let it stand for at least 15 minutes.
3. Clean the electrode nozzle with a dry and soft cloth to remove any existing solution as it may contaminate the sample made.

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4. After the 15 minutes of waiting, insert the electrode nozzle into the solution.
5. Run the data acquisition program.

Once the system is accessed, select the Soil Analysis module option, see Figure 14.

Figure 14 Soil analysis module
Source: Own Elaboration

When selecting the option, the system first validates that there is a connection with the data acquisition device, once validated, click on the Take measurements button to obtain the data, which internally takes 10 global measurements of temperature, humidity and pH and displays an average of the data obtained. See figure 15.

Figure 15 Take measurements button
Source: Own Elaboration

When clicking on the *Take measurements* button, the following message is displayed to the user, see figure 16.

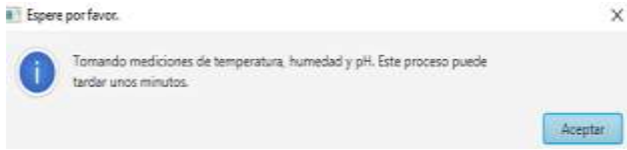

Figure 16 Temperature, humidity and pH measurement message
Source: Own Elaboration

Figure 17 shows the values obtained from the data acquisition module:

– PH: This text field shows the PH of the soil obtained by the data acquisition device.
– Humidity: This field shows the humidity of the environment obtained by the data acquisition device.
– Temperature: This field displays the temperature of the environment obtained by the data acquisition device.

Figure 17 Values obtained
Source: Own Elaboration

b) Results of the implementation of the Neural network

When obtaining the data, it is necessary to select the previous family type that was previously seeded, when clicking on it, the 8 families are shown, for this example the Solanaceae family is chosen as shown in Figure 18.

Figure 18 Selecting the family type above
Source: Own Elaboration

Figure 19 shows the functionality of the neural network when clicking on the *CALCULATE* button, the neural network begins to perform the analysis and shows as a result the option of the most optimal type of crop to be planted.

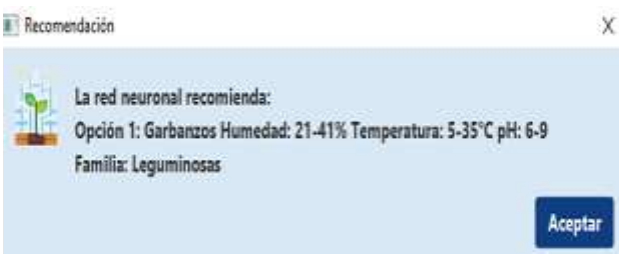

Figure 19 Result of the neural network functionality
Source: Own Elaboration

The results are:

– The most optimal type of crop to plant is Chickpea.

– Optimum moisture values should be in the range of 20 to 41%.

– The optimum temperature for the type of crop to be planted should be between 5 to 35 °C.

– The corresponding family is the legume family.

c) Results of the *Data Acquisition* module using the Measurements module

When clicking on the Measurements option, the system sends a message where the current measurements of temperature and humidity of the environment are being taken, see figure 20.

Figure 20 Measurement module
Source: Own Elaboration

The measurements show in real time the temperature and humidity values, see figure 21.

Figure 21 Measurements Module option
Source: Own Elaboration

Acknowledgments

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Conclusions

The neural network for crop rotation and soil analysis in a greenhouse was developed with the purpose of providing alternatives on the type of crop to be planted through crop rotation.

With the decision of the type of crop to be planted in the greenhouse, the risk of production loss can be reduced.

The solution to the problem posed is crop rotation, an alternative technique for the types of plants that are grown in the same place with the intention of not developing diseases that affect a specific family of crops and prevent the soil from being exhausted.

With the analysis of the optimal crop to be planted, the risk of loss of production would be considerably reduced, resulting in greater economic gains for the farmer.

The farmer is thus assured that his crop will obtain the best production according to the experience and knowledge of the neural network, in addition to optimizing the use of the soil and reducing the incidence of pests and diseases by interrupting their life cycles.

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