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Preparación de Artículos revista VISIÓN ELECTRÓNICA: algo más que un estado sólido
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Fecha de recepción: 08 de enero de 2020
Fecha de aceptación: 27 de enero de 2020

A case-study vision

Automated greenhouse, instrumentation and fuzzy logic

Invernadero automatizado, instrumentación y lógica difusa

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Cite this article as: S. A. Vaca-Vargas, “Automated greenhouse, instrumentation and fuzzy logic”, *Visión electrónica, algo más que un estado sólido*, vol. 14, no. 1, pp. xx, january-june 2020. doi: xxx

Abstract: Crops are vulnerable to climatic conditions; therefore, their quality may vary according to environmental behavior. Under optimal conditions the crop can have a good productive development and an increase in the yield per unit area, reducing the risks caused by climatic changes, pests and diseases. With the electronic application in greenhouses it is possible to make efficient use of the resources since these can be controlled according to each stage of the development of the crop. Being in an isolated environment, in other words, independent of the external environment, it is possible to carry out production at any time of the year, thanks to the microclimates. The following paper shows the development of an automated greenhouse using electronic instrumentation to control its irrigation, lighting, humidification and ventilation systems using fuzzy logic.

Keywords: Control, crop, fuzzy logic, greenhouse, instrumentation, microclimate.

Resumen: Los cultivos son susceptibles a condiciones climáticas, por ende, la calidad de los mismos puede variar según el comportamiento ambiental. Bajo condiciones óptimas el cultivo

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puede tener un buen desarrollo productivo y un aumento en el rendimiento por unidad de superficie, reduciendo los riesgos causados por cambios climatológicos, plagas y enfermedades. Con la aplicación de electrónica en invernaderos es posible hacer uso eficiente de los recursos ya que se pueden controlar según cada etapa fenológica del cultivo. Al estar en un ambiente aislado, es decir independiente del medio exterior, es posible realizar producción en cualquier época del año, lo anterior gracias a los microclimas. El siguiente articulo muestra el desarrollo de un invernadero automatizado haciendo uso de instrumentación electrónica para controlar mediante lógica difusa sus sistemas de riego, luz, humidificación y ventilación.

Palabras clave: Control, cultivo, lógica difusa, invernadero, instrumentación, microclimas.

1. Introduction

At present, crops depend on very fluctuating climatic variables, therefore their quality can vary, increasing costs and being inefficient. In order to solve this problem, it is necessary to use automated systems to adequately control different variables inside the greenhouse [1,5]. Automation in greenhouses is developed to maintain solar radiation energy, protect the product and produce suitable environments for plants.

The humidity and temperature are variables used to control the heating and cooling of the greenhouse, it can be passive control with zenithal openings, types of enclosure and construction materials or active with nebulizers, fans and heaters [5,6].

To give light to the plant, light devices, incandescent lamps, fluorescent lamps, LEDs, electroluminescent, etc. are implemented.

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Ventilation affects CO2 levels, so the ventilation system can let it escape, or it can be compensated for. Airflow is important to maintain uniformity in temperature, humidity and CO2. Measuring all these variables is not enough, for this reason it is necessary to use controllers considering many interrelated variables. Classical control methods are used such as P, PI and PID; predictive and adaptive control methods; fuzzy control, neural networks and genetic algorithms.

1.1. Greenhouse solution

The team developed a scale prototype of a Venlo greenhouse Figure 1 that with the application of fuzzy logic manages to control and monitor some of the systems influencing crop production, such as light and irrigation, in addition to being a prototype of low energy consumption, affordable to all types of users and efficient. This paper gives an overview of the development of this prototype, its phases, implementation and failures in general, as well as possible improvements.

Figure 1. Automated greenhouse.

Source: own

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These systems are based on the use of a central computer with a set of connected sensors, collecting the variations of the different parameters with respect to initially programmed values. These systems, in turn, can be connected to the fertigation and climate regulation sub-systems. The sensors or automatisms are distributed in different sub-systems, being able to work each one of autonomous form. In the central controller the information captured by the sensors is collected, the actions are coordinated, and the orders are sent to the different sub-systems. At industrial level there is a great significance in the handling of automation but there is technology for the home and high performance for the user who wants their own crops and plant management.

2. Theoretical framework

Currently the implementation of fuzzy logic in the world is everywhere, for this reason countries such as Colombia must continue with the idea of renewal and monitoring of these technologies, in the following project is developed a greenhouse, which will make the sense of a low aromatic plant, which facilitates the user to know the status of the plant and its needs.

There are currently numerous automation systems on the market to control the climatic parameters of greenhouses: automation of the vents opening, radiometers indicating the luminosity degree inside the greenhouse, installation of heating equipment, and so on. The most relevant parameters in the control that intervene in a greenhouse are the relations with the climate, irrigation, control of CO2, and humidity, among others.

2.1. Structure types

There are different structures where the characteristics are unique for each type of greenhouse, such as the passive type (that is, with low energy consumption for heating or maintenance), without high technological level but well thought out to take advantage of the natural resources of the Mediterranean coast, such as light and climate.

- **Autochthonous greenhouses:**

Built with the experience in the use of the local materials of the installers of each zone. For the design of these greenhouses the constructive tradition of a determined zone has predominated over the scientific-technical rationality.

Wood is the most widespread structural element, and polyethylene film with different optical and mechanical properties is the covering material per excellence. [1]

Some of the disadvantages of this type of structure are that the light transmission is low, especially in structures with low slope roofs. Ventilation is inefficient due to the reduced window surface area and the type of windows (rolled plastic) is usually ineffective. In addition, in cold periods often have excess moisture by dripping condensation and sometimes by entry of rain. [1]

- **Industrial greenhouses:**

In this group is included a great variety of structures generally of galvanized steel, although the one that predominates more is the one of attached ships multitunnel arched structure Figure 2. The roof cover is made of plastic film while the fronts and sides can be of semi-rigid plastic sheet, based on polycarbonate. [1]

Some of the disadvantages of this type of greenhouses is that condensation accumulates at the top of the arc where it is difficult to remove. It reduces light transmission; as a consequence, it drips on the crop. Some designs can improve on this problem but have not managed to eliminate it completely, another problem is the ventilation that is insufficient when there are insect screens in the windows. [1]

Figure 2. Industrial greenhouse.

Source: own.

- **Glass-covered greenhouses:**

This type of structure is typical in cold countries; the most characteristic model is the Dutch Venlo. These are usually built in large areas to reduce installation costs and save energy. From a technical point of view this greenhouse structure is excellent, with the only objection that ventilation should be adapted in colder areas as opposed to those with discontinuous roof windows and no lateral ventilation Figure 3.

Figure 3. Glass-covered greenhouse.

Source: own.

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In warmer areas the roof window is recommended to continue along the length of the greenhouse. It is also recommended to combine zenithal and lateral ventilation, particularly in light wind conditions.

2.2. Irrigation systems

- **Drip Irrigation:**

It consists of a network of interconnected pipes which have small holes and are located at the foot of the plants Figure 4. The water circulates through the network and through the small holes the water falls according to the programmed speed, opening or closing the valves of the holes. This system is controlled by means of a small programmer that manages the duration and the moment of the irrigation.

Figure 4. Drip irrigation.

Source: own.

On the holes it is possible to adapt different types of sprinklers, either single or multiple drippers, also with the possibility of adapting hoses to extend using stakes.

- **Sprinkler Irrigation:**

These are systems composed of pipes and sprinklers, which function as a kind of localized rain Figure 5. These have control elements, such as regulating valves, which serve to limit the flow

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to the sprinklers and regulate the irrigation pressure. It is important to highlight the types of sprinklers: stationary sprinklers and mobile sprinklers (movable branches). There is also talk of micro sprinklers, in which the water is projected onto the ground in the form of thin rain.

Figure 5. Sprinkler irrigation.

Source: own.

2.3. Climate control

The development of crops, in their different stages of growth, is conditioned by factors, including environmental or climatic: such as temperature, relative humidity, light and CO2, among others. For plants to be able to carry out their functions it is necessary to combine these factors within minimum and maximum limits. Without these, the plants cease their metabolism, which can lead to death [3].

Environmental control is based on properly managing all those systems installed in the greenhouse: heating system, ventilation and fertilization supply Figure 6., to maintain adequate levels of radiation, temperature, relative humidity and CO2 level, and thus achieve the best response of the crop and therefore, improvements in yield, product quality and crop quality.

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Figure 6. Climate control.

Source: own.

- **Sensors and actuators:**

There are different ways of acquiring the variables inside a greenhouse, depending on the physical principle it handle and therefore its resolution, are of different costs. In the case of temperature there are thermocouples, thermocameras, and humidity sensors where it is recommended to handle a range of 10-90\% humidity.

With the measured variables, control techniques are applied to manipulate the actuators (taking into account the air temperature, plant transpiration and evaporation of water from the soil), these can be electric heaters (to raise temperatures in local areas), and fans or motors in the fans (to cool, as in the case of solar radiation) Figure 7.

These are chosen according to size, shape, efficiency, intensity, color and temperature and are controlled by LDR sensors, which can measure the lumens that affect their surface, returning resistive values that can be used to control the instruments mentioned above Figure 7.

Figure 7. Temperature and light actuators.

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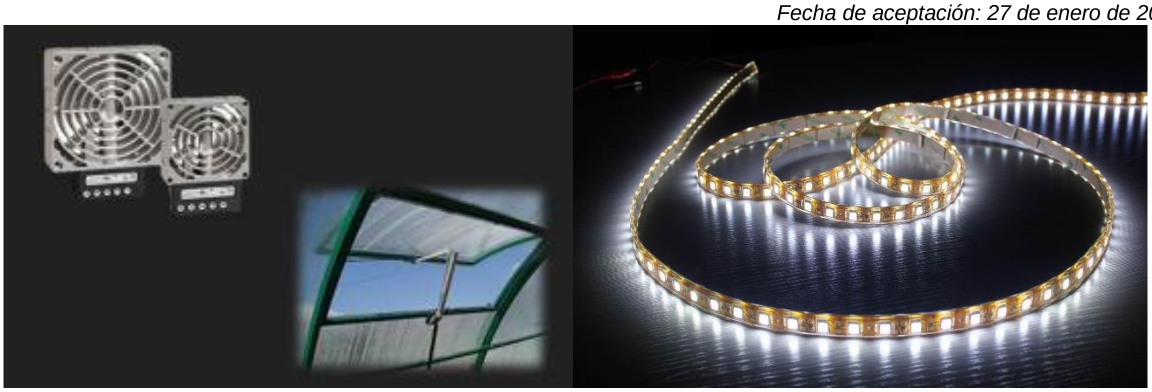

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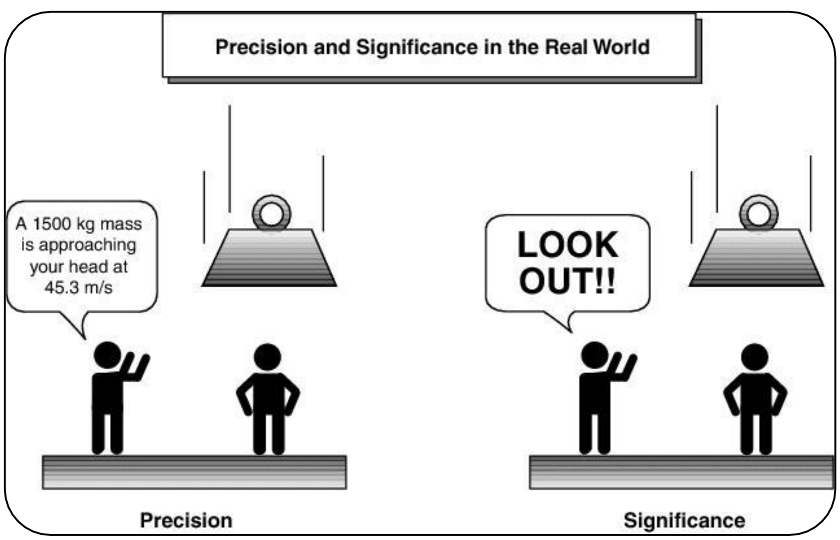
2.4. Fuzzy logic

The idea resides that the elements on which human thought is built are not numbers but linguistic labels. Our knowledge is grouped in terms without well-defined boundaries as opposed to a specific number. These linguistic tags can generate much more useful information for our benefit, an example can be seen on Figure 8.

Figure 8. First Fuzzy logic example.



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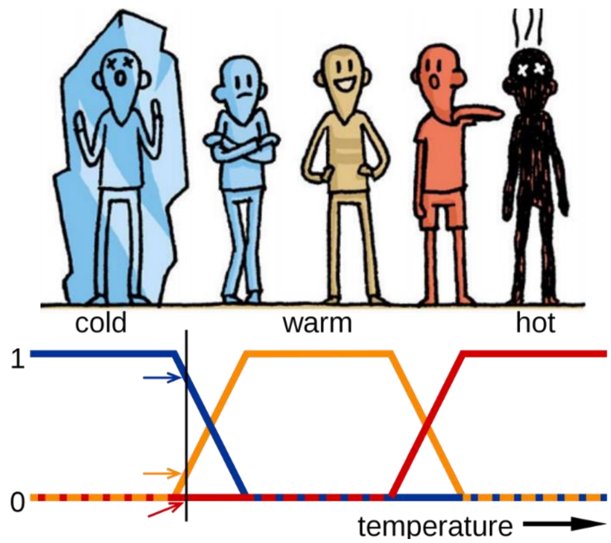
It is more adapted to the real world, not using fixed values, but a range of values and is able to adapt human expressions, tries to understand the quantifiers of quality for our inferences (much, little, very, etc.).

This logic also makes use of operations on sets such as union, intersection, difference, negation, etc. to carry out the treatment of information and arrive to a result.

Figure 9. Second Fuzzy logic example.



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In the Figure 9 can be seen the temperature, which contains 3 labels, corresponding to the trapeziums that are appreciated. Each one of these labels has a range of values, where in certain points the certainty is maximum (1, where there would be a maximum degree of belonging to the cold label), that is to say, it is sure that it is cold and others where the temperature begins to rise and depending on where it is, it can be considered cold in a certain degree or begin to get closer to a warmer temperature [7,8].

Fuzzy logic makes use of a series of heuristic rules, of the type IF (antecedents) THEN (consequent) i.e.:

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- If it is very cold then turn up the heating a lot.
- If it is not too cold then turn up the heating a little.
- If it is very hot then turn off the heating

This can help not only to control processes efficiently but also to deliver alerts that users can understand.

3. Methodology

In the first instance is the design and construction of the structure selected for the automated greenhouse, this based on a literature review on the type of crop to be implemented inside, defining the size of the beds, dimensioning the irrigation system, leaving space for the location of sensors and actuators in addition to the box with the required connections.

Next and based on the same bibliographic review, the different sensorial networks of the system are selected and implemented, for the case of the developed project emphasis is made in the control of the irrigation system, illumination and humidification, besides the monitoring of temperature and humidity to the interior of the structure, for these reasons the selection is directed towards sensors of humidity of the soil, detectors of light and monitors of temperature and ambient humidity.

In order to control the physical magnitudes from the variables measured with the sensory networks implemented, we proceed to select the actuators that will manage the irrigation systems, lighting and humidification, for this case were observed different models of irrigation systems, where their main characteristics in terms of actuators are focused on valves and pumps. In the case of lighting, in most cases, bulbs or LED lights are used to detect the amount of light that affects the greenhouse, and in the case of humidity, nebulizers are commonly used, but due to budget and size, a homemade humidifier was implemented.

It continues with the design of the irrigation system, was designed a drip irrigation system, given that it is considered the most appropriate for crops under cover, discarding surface irrigation, for its control and low accuracy, as well as pressure irrigation, for the considerable increase in humidity that would generate and given that under cover usually increases the temperature and would create an optimal space for the development of fungi and diseases in crops.

Once the irrigation system was selected and considering the size and the possible varieties that will be sown in the interior, the calculations corresponding to the hydric needs of the crops were made (which must be similar, given that the laminar water to apply will be the same).

Once all the systems are in operation, the characterization of all the sensors begins, verifying the operation of each one and taking control of the activation by the actuators.

Finally, a verification of the functioning of the system is generated by implementing the prototype for subsequent corrections, through the design of a basic Arduino fuzzy controller, where the databases, graphs and reference values are located.

4. Analysis and results

Initially the design of the structure is observed Figure 10., which was based on the physiological characteristics of the crops of Oregano, Parsley and Thyme, observing the root growth, the maximum altitude of the crop and also the water requirements.

The design was taken to the construction, adding a base in white acrylic and walls and roof in transparent acrylic, both complying with resistance indexes to avoid bending and to resist the possible adversities to which the greenhouse could be submitted.

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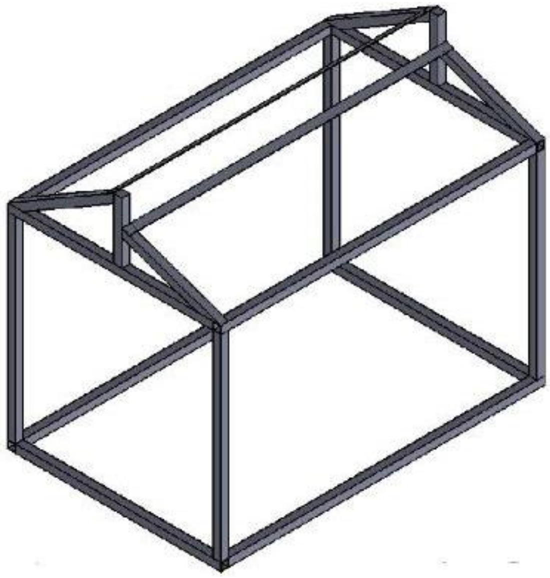
Figure 10. Structure design.



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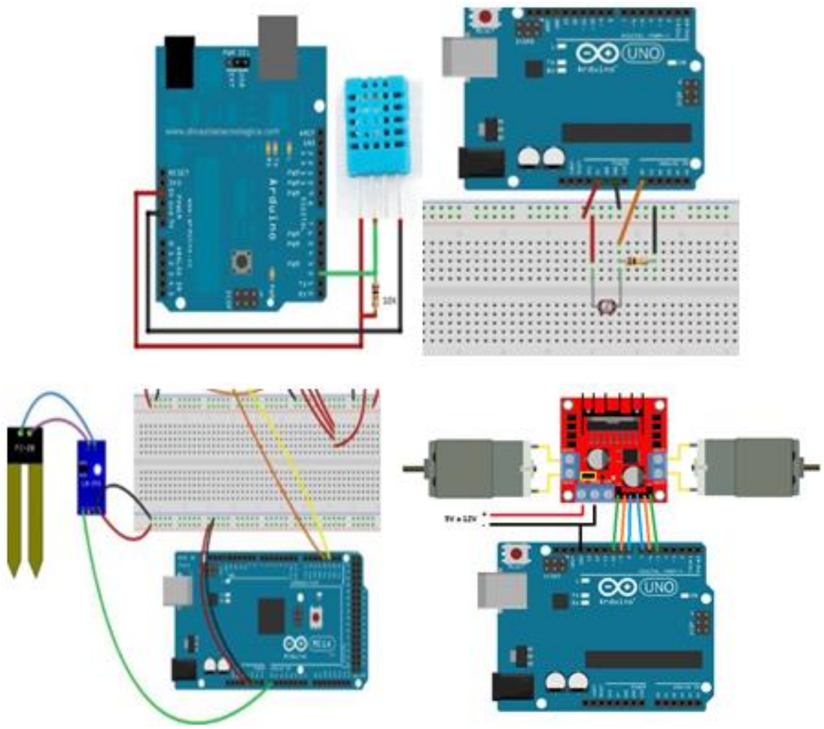
On the acrylic base were arranged bases for the location of a cover that will cover all internal elements (cables, tanks, actuators, control box), this cover also has holes for the location of cables and beds, hoses and stakes of the irrigation system, and the outlet of the humidifier.

The entire structure was covered with white tape for excess cables, also to get past the most distant connections (LDR, LED tape and ventilation engine).

In Figure 11. the connections of each one of the elements of the system are visualized, each one will go to the controller where the data will be processed.

The substrate that was used had 50 percent carbon slag, 25 percent rice husk and 25 percent coconut fiber, this looking for a good mixture of the substrate, which has an adequate porosity and good moisture retention, since this mixture is inert and does not have how to provide nutrients to the plant, it is recommended to use humus as an organic fertilizer.

Figure 11. DHT11, LDR, Soil Moisture, H Bridge connection, [4].



The yield curve of the substrate, allows to know in which values of humidity, the system must be maintained in terms of irrigation. Considering that the point of permanent wilt is the humidity obtained at 15 bar and the point of field capacity is given to 0.3bar.

Figure 12. Moist, humidity and temperature sensors, hoses and stakes (left), Light sensor (right).

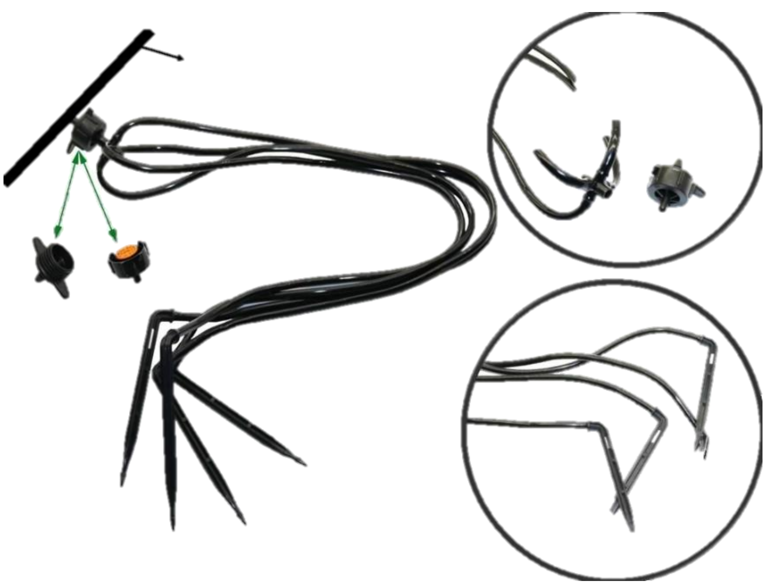
Source: own.

In the structure are added in the upper part the LDR sensor to measure the presence or absence of light Figure 12., under this is located the LED ribbon. The location of the ribbon is selected to capture the largest amount of ambient light, and the ribbon is located directly on the beds of cultivation.

In the lower part, that is to say on the acrylic, the beds of the culture are placed as well as the system of irrigation as it is seen in Figure 13. The humidity and ambient temperature sensors are close to the biomass, which is the place where the measurement is critical, the soil humidity sensors are buried on the substrate of the plants.

The irrigation system has 8 integrated drippers, 2 per bed, each one provides a flow of 2.3 lph, and are linked to each other over a main line.

Figure 13. Irrigation system.



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With all the construction completed Figure 14., the programming of all the sensors was obtained.

Figure 14. Automated greenhouse.

Source: own.

The code is divided into two parts, in the first are the initialization libraries, the definition of pins for each of the inputs and outputs. After the preliminaries is the setup, place where the behaviors of the pins are configured.

For the creation of the fuzzy controller, the labels or levels of each one of the variables to be controlled are created, then the fuzzy object is defined where the variables will enter and the signals will exit to the actuators. Finally, there is the set of rules that govern the fuzzy logic, these rules allow to convert, as it was seen in the theoretical frame, and finally to deliver the information to the user about the state of the system.

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Figure 15. Humidity behaviour.

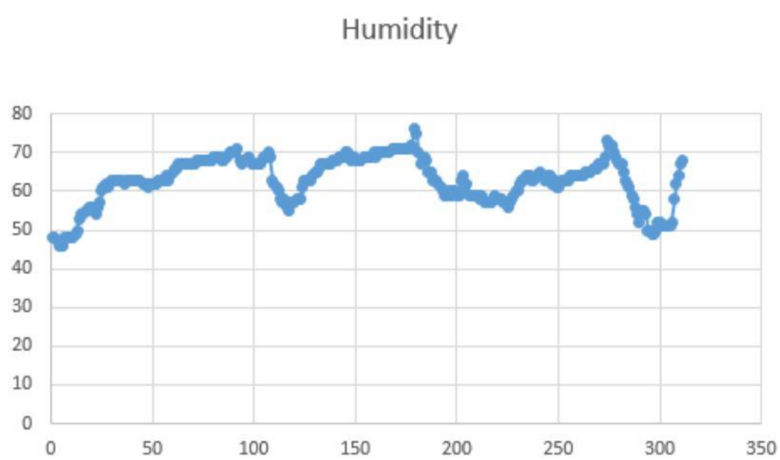

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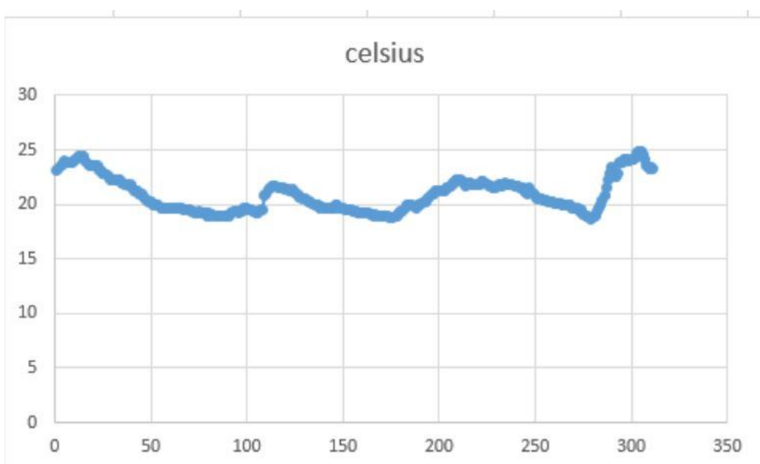
Figure 16. Temperature behaviour.



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As can be seen in the behavior graphs, Figures 15-17, the controller functioned in a suitable way for humidity and temperature, in the case of light can be noticed ups and downs, these are because at the time of measurement this was generated with the values of output current, these values were not accurate so it requires specialized equipment in taking light data.

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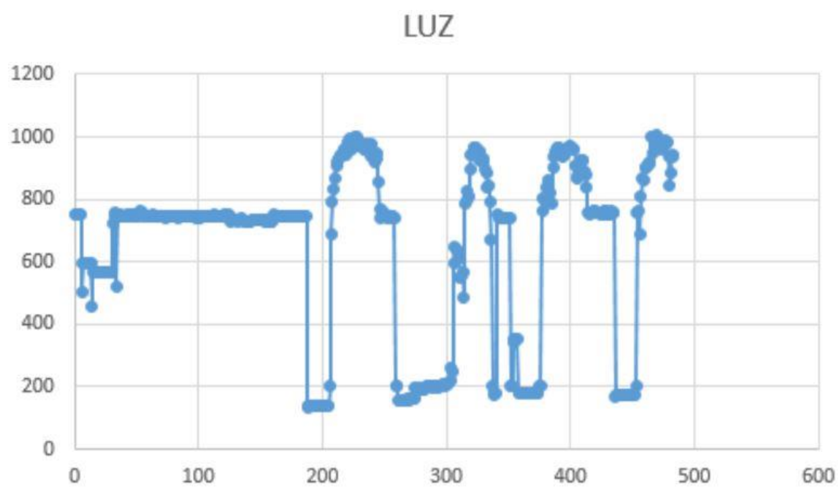
Figure 17. Light behaviour.



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5. Discussion

For the creation of the fuzzy controller can be observed some of the rules for conversion and control, due to problems in the programming and some conflicts was not possible to implement more rules to represent and control variables such as temperature fused with humidity for obtaining psychrometric calculations.

On the other hand, the location of the sensors was optimal so it was selected from a solid criterion on critical points of the system, which allows the controller to receive accurate values. Additionally, it can be seen that the location of the actuators gives the possibility that the leveling of the measured variables is much faster.

Due to inconveniences during the testing phase, it was not possible to implement the screen to see the fusified data, although it was taken into account and for future revisions of the prototype it will be possible to deliver the information to the user in a clear way, with linguistic labels that represent the current state and the requirements of the crop inside the greenhouse.

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In the case of having pastures or some agricultural products for the maintenance of the farm, the use of soil moist sensors is key for a proper and accurate irrigation application, are also useful in terms of detecting contaminants, as in the case of salts. In addition to facilitating the process of analysis of meteorological variables, like grazing days, the sensors could indicate whether the soil is suitable or not for this or other purposes.

Data collection can interfere with the sensor movement; a better measurement can be obtained if the sensor is left still with the same sample during the whole test. Changing the sensors to different soils can significantly change the samples.

It is necessary to consider that each sensor has a measurement range, which can affect the analysis and calculations, if this interval is not known for each one.

6. Conclusions

The work team developed and implemented the Greenhouse prototype where it is possible to control and monitor some of the fluctuating physical magnitudes of three crops of aromatic plants.

Thanks to the implementation of different sensors for soil moisture measurement, it is possible to have several references and calibrate the sensors according to the behavior of the drying curve.

The implementation of new controllers based on fuzzy logic allows a significant advance in agriculture in process control and analysis.

The design of this custom greenhouse will allow advancing control in environments where plant growth is not suitable.

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