**ORBIS**
**Revista Científica Electrónica de Ciencias Humanas / Scientific e-journal of Human Sciences /**
PPX200502ZU1935 / ISSN 1856-1594 / By Fundación Unamuno /
Montalvo Pablo, Barrera Helder, Abril Jorge, Vega Vladimir y Montes De Oca, Irma (2020)
**ALGORITMO DE LÓGICA FUZZY PARA SISTEMA DE SEGUIMIENTO SOLAR**
www.revistaorbis.org.ve / núm. ESPECIAL INTERNACIONAL(año 16) 18-34

# FUZZY LOGIC ALGORITHM FOR SOLAR TRACKING SYSTEM

# ALGORITMO DE LÓGICA FUZZY PARA SISTEMA DE SEGUIMIENTO SOLAR





Montalvo, Pablo[1] | Barrera, Helder[2] | Abril, Jorge[3] | Vega, Vladimir[4] | Montes De Oca, Irma[5]

**RESUMEN**
El propósito del estudio fue implementar un sistema de seguimiento solar de dos ejes controlado por algoritmo de lógica difusa, optimizando la recolección de energía respecto a paneles solares de orientación fija. El control difuso se realizó en plataforma LabVIEW, construyéndose un prototipo para verificar que un panel solar ubicado en un seguidor solar de dos ejes utiliza mejor la energía que el de una orientación fija. Se realizó la prueba U no paramétrica de Mann-Whitney. Como conclusión, el prototipo de panel solar de dos ejes permitió validar el algoritmo de control difuso para un seguidor solar de dos ejes.
**PALABRAS CLAVE:** Sistema de seguimiento solar, algoritmo de lógica difusa, paneles solares.

**ABSTRACT**
The purpose of the study was to implement a two-axis solar tracking system, controlled by a fuzzy logic algorithm, optimizing energy collection with respect to fixed orientation solar panels. The diffuse control was performed on the LabVIEW platform, building a prototype to verify that a solar panel located on a two-axis solar tracker uses energy better than that of a fixed orientation. The non-parametric Mann-Whitney U test was performed. In conclusion, the two-axis solar panel prototype allowed validating the fuzzy control algorithm for a two-axis solar tracker.
**KEYWORDS:** Solar tracking system, fuzzy logic algorithm, solar panels.

Fecha de recepción: mayo 2020
Fecha de aprobación: julio 2020

[1] Docente de Escuela Superior Politécnica de Chimborazo, Riobamba, Ecuador y Pontificia Universidad Católica del Ecuador, Ambato, Ecuador. Magister en Sistemas de Control y Automatización Industrial. pmontalvo@pucesa.edu.ec ORCID: https://orcid.org/0000-0002-8172-681X
[2] Docente de Universidad Técnica de Ambato, Ecuador y Pontificia Universidad Católica del Ecuador, Ambato, Ecuador. Magister en Docencia Universitaria y Administración Educativa hm.barrera@uta.edu.ec ORCID: https://orcid.org/0000-0001-8196-3797
[3] Docente de Universidad Técnica de Ambato, Ecuador. Magister en Administración de Empresas. Mención Planeación jabrilflores@yahoo.es ORCID: https://orcid.org/0000-0002-9491-5169
[4] Docente de Universidad Regional Autónoma de los Andes (UNIANDES), Ambato, Ecuador. Doctor en Ciencias Económicas (PhD) vega.vladimir@gmail.com ORCID: https://orcid.org/0000-0003-0140-4018
[5] Docente de Universidad Regional Autónoma de los Andes (UNIANDES), Ambato, Ecuador. Magister en Ciencias de la Educación irmaverónica15@yahoo.es ORCID: https://orcid.org/0000-0001-6286-6692

# INTRODUCTION

Currently, there is much debate about the energy crisis and the importance of supplanting traditional energy sources with cleaner renewable energies, that is to say, with little or no polluting effects, given that they are scarce and simultaneously have a high rate of pollution. For that purpose, one of the alternatives that manage to overcome this difficulty is solar energy, which is acquired from the use of electromagnetic radiation from the Sun. However, despite many investigations carried out recently, there is still no significant massification of the Distributed Generation (DG) as an alternative option (Correa, Marulanda, & Panesso, 2016).

According to Cabrera (2014), sunlight takes 8 minutes with 19 seconds to reach the planet, being initially with the Earth's atmosphere, (albedo), where there is a thermal balance between the amount of solar energy that enters and the amount that it is capable of releasing, which makes it possible for the average temperature of the planet not to change violently.

Fuzzy Logic has shown a significant expansion in recent times, and its application is being deployed in diverse areas of daily life, among which are the energy issues (Rivera, 2015). In this field, fuzzy modeling is widely recognized as a useful tool for creating very complex system models, especially for their integrating capacity from different sources, including physical laws, expert knowledge, creation of empirical models, among others (Fandiño, Sarmiento, & Rosales, 2016).

At the current time, knowledge has been transformed into a leading proponent of the generation of competitive advantages where the organizational management is increasingly involved in their ability to innovate processes, adapt to change and prepare according to the demands of the environment (Vega, 2017).

On the other hand, it is valid to point out that, according to a study by (Guisado, Vila, & Guisado, 2016); radical innovation has a positive and eloquent impact on the professional productivity of the organizations, as well as in the case of incremental change. Although it is not done significantly, its influence is equally positive.

Solar energy could supply electricity to two-thirds of the world's population by 2030 (Acevedo & Ricardo, 2015). It was an essential conclusion of the solar generation report, published by the European Photovoltaic Industry Association, in 2011, pointing out that solar photovoltaic electricity could supply energy to more than 4 billion people at the end of the third decade of this century.

Photovoltaic solar panels have a performance of around 15% and do not produce heat that can be reused; however, there are investigation lines on hybrid panels that allow generating electric and thermal energy at the same time.

In Ecuador, this type of energy could be used to a great extent; the one emitted by direct radiation has a more specific nature; due to its geographical location, it is in a favored position concerning other countries because it has a high level of solar incidence.

The problem this research deals with, is the control of the rotation angle (in the case of the system with a single axis one angle, or in the case of two axis and two angles) to define the correct angle of inclination of a solar panel; in such a way the acquisition of solar energy is optimized, always placing it perpendicularly to solar radiation. In that sense, the objective of this research is to implement a two-axis solar tracking system controlled by a fuzzy logic algorithm, optimizing energy collection with respect to fixed orientation solar panels.

# LITERATURE REVIEW

## SOLAR TRACKING SYSTEM

According to Machado, Lussón, Oro, Bonzon and Escalona (2015), a solar tracker is a mechanical device capable of searching for the position of the Sun at any time of the day, following the Sun from east to west. This system is used to position the radiation capture systems, so that they remain close to the parallel perpendicular of the solar rays, in order to convert the captured energy into heat or electrical energy.

In this regard, Arreola, Quevedo, Castro, Bravo and Reyes (2015) agree that solar energy monitoring systems must accumulate as much energy as possible in a certain place, this condition requires that the surface be, at all times, perpendicular to the solar rays.

According to what the authors have proposed, the solar tracking system is an automatic module capable of locating the solar position at all times, tracking the Sun in its east-west trajectory, being used to place the systems that attract radiation, with a view to that they stay close to the parallel perpendicular of the solar rays, thus trying to transform the energy attracted into electrical energy or heat.

## FUZZY LOGIC ALGORITHM

For Lara, Valencia and Vital (2015) fuzzy logic is a tool for solving control problems, since from real data on the performance of a system, it is possible to infer a set of functions or classification parameters that allow determining a control action to take.

According to, Forneron, Mendietam and Almeida (2019) argue that the fuzzy logic algorithm is a method that allows us to mathematically represent uncertainty and vagueness, providing formal tools for its treatment.

In this research the fuzzy logic algorithm is defined as the procedure represented by blurred mathematics, the uncertainty of a problem, relying on real data and its derivation, trying to find solutions to it.

## MATERIALS AND METHODS

For the developed experiment, the design method proposed by Archer (1963) was followed, since it presents the favorable conditions for the planning and development of this research.

The study was carried out during the first half of 2017 in the city of Riobamba, Ecuador, with the objective of implementing a two-axis solar tracking system controlled by a fuzzy logic algorithm, optimizing energy collection with respect to fixed orientation solar panels.

Diffuse control was performed from the LabVIEW platform. A prototype was built to verify the hypothesis that a solar panel located on a two-axis solar tracker uses solar energy better than one in a fixed orientation. A solar cell was assembled and incidence readings were taken, then the non-parametric Mann-Whitney U test was performed.

Light sensors will be available and placed in a suitable way to achieve the perpendicularity of the solar tracker towards radiation, so that, if the panel is correctly oriented towards the brightest point, they will all receive the same amount of light. Otherwise, two of them will be more illuminated than the other two.

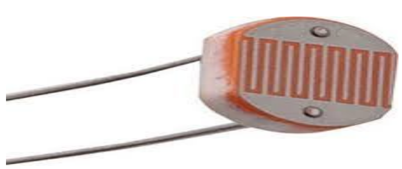
Therefore, this difference in brightness will be captured or acquired by the fuzzy logic algorithm; this will cause a servo motor to actuate and act on the inclination of the panel by rotating it until the luminous intensity is equal in all the sensors; at this moment, the panel will be perpendicular to the incidence of solar radiation.

A solar tracker with two axes of the Single Pole type (Post) will be done to obtain better use of solar energy; that is, with single central support on it, one axis and a rotary plate on the other axis. The control system was carried out with an algorithm based on fuzzy logic. The operation is based on the capture of light emitted by a light source; in this case, the sun, through four photoresistors (LDR) installed on a half bridge on a data acquisition card.

The photoresistors will be separated by two walls, one perpendicular to the other, and these in turn concerning the plate (see Figure 1). If the rotary plate is not perpendicular to the light rays emitted by the light source (see Figure 2), the walls will create shade over certain photoresistors, while others remain illuminated, which allows assigning a difference in voltage drop between the photoresistors. The difference is considered as an error that must be corrected by the fuzzy control algorithm until all the photoresistors are illuminated equally, at which time you will have an error equal to zero and the rotary plate will be directed perpendicularly to the rays of light.

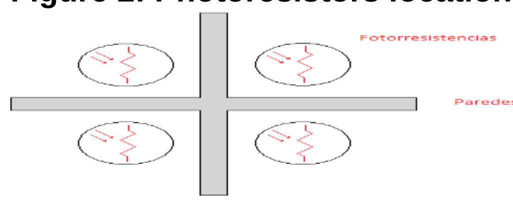
The error (difference in illumination of the photoresistors) will be corrected, as shown in Figure 3. The differences in the illumination of the photoresistors cause a variation in their resistance, and if these are connected in a voltage divider (half bridge), different voltage drops are obtained (see Figure 4). This voltage drop will be measured by a Data Acquisition Card (DAQ), as shown in Figure 5. These cards, following (Enríquez, Sifuentes, Bravo, and Castro, 2016), constitute devices created for the acquisition and measurement of signals that lie in taking samples of physical variables from the real world. The rotation of both the post and the rotary plate will be achieved through two stepper servomotors, as shown in figure 6.

**Figure 1: Photoresistors (LDR).**



Source: Montalvo, (2017)

**Figure 2: Photoresistors location**




Source: Montalvo, (2017).

**INPUT SIGNAL CONDITIONING**

The input signal for the control system is constituted by the error obtained when subtracting the voltage drops in the photoresistors; this voltage is not always equal in the four photoresistors, so it is necessary to prepare this signal, for which the following process should be followed:

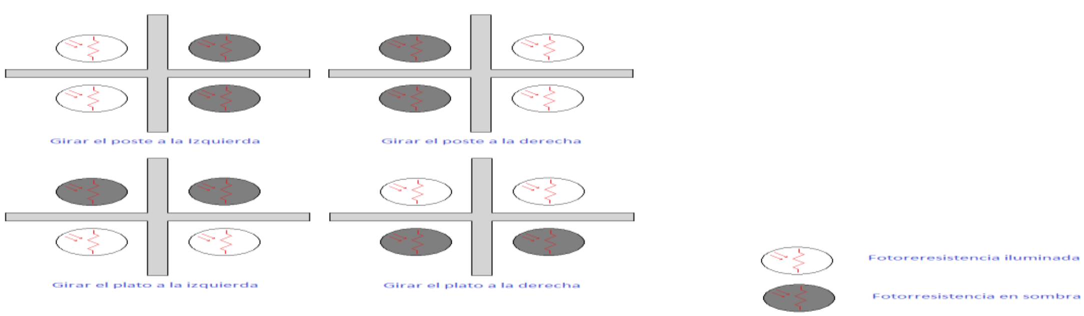
- The four photoresistors are placed without any illumination, and the voltage drop that they produce in the voltage divider is recorded (V min). This value is assigned an output value equal to zero.
- The four photoresistors are illuminated with a light source (as intense as possible); the voltage drop they cause is measured (V max), and an output value equal to 10 is assigned.
- A linearization graph is obtained (see Figure 7) with a scale from 0 to 10 in each of the four photoresistors.
- This process allows the four photoresistors to give similar value to the same lighting change, on a scale from 0 to 10.
- The corrected signals emitted by the photoresistors are shown in Figure 8.

## FUZZY LOGIC OF CONTROL

Fuzzy logic was used in this work since it allows tracking sunlight throughout the day regardless of the time of year and the geographic location of the panel. On the other hand, another control system would need to have equations that describe the solar movement for a specific location and date. The control logic was done with LabVIEW program of National Instruments with the following membership values:

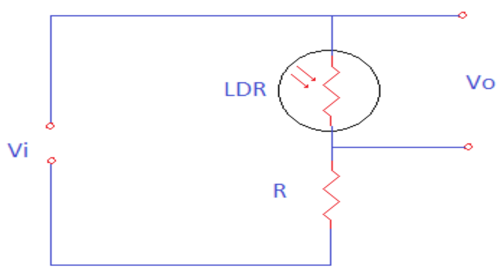
- Error position of the rotary plate (Figure 11).
- Error position of the post (Figure 12).
- Plate output (Figure 13).
- Post output (Figure 14).

**Figure 3: Action to be taken to correct the error.**



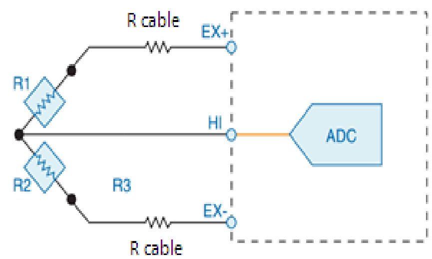

Source: Montalvo (2017).

**Figure 4: Voltage drop in photoresist (Voltage divider or half bridge). Where Vi (input voltage or power) and Vo (output voltage) dependent on the value of LDR.**




Source: Montalvo (2017).

**Figure 5: Reading of Drop Voltage by DAQ**



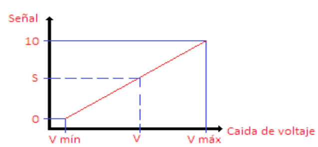

Ex (Input Voltage Vi). HI (Reading of voltage drop Vo) R1 resistance 1 (LDR) R2 resistance 2 of fixed value

Source: Montalvo (2017).

**Figure 6: Stepper servomotor.**

Source: Montalvo (2017).

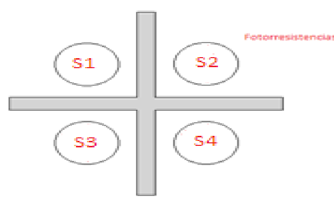
Figure 7: Input signal conditioning.




S= V (10/ (V Max-V mín))

Source: Montalvo (2017).

Figure 8: Corrected signals emitted by the photoresistors




Source: Montalvo (2017).

The corresponding control loop is shown in figure 9.

A. Obtaining the error

The error that enters the fuzzy control is found as follows:

Error position of the post

e_post = (S1+S3) - (S2+S4)

Error position of the plate

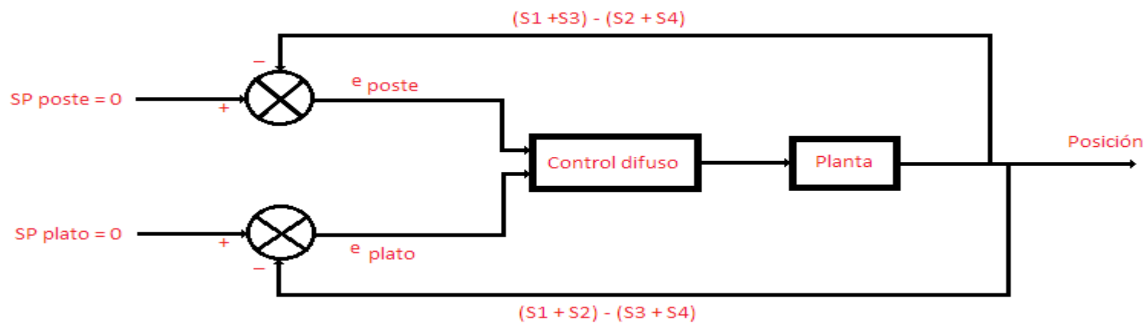
e_plate = (S1+S2) - (S3+S4)

B. Prototype

A prototype was constructed to develop and demonstrate the fuzzy control algorithm with the characteristics shown in Figure 10.

**ORBIS**
**Revista Científica Electrónica de Ciencias Humanas / Scientific e-journal of Human Sciences /**
PPX200502ZU1935 / ISSN 1856-1594 / By Fundación Unamuno /
Montalvo Pablo, Barrera Helder, Abril Jorge, Vega Vladimir y Montes De Oca, Irma (2020)
**ALGORITMO DE LÓGICA FUZZY PARA SISTEMA DE SEGUIMIENTO SOLAR**
www.revistaorbis.org.ve / núm. ESPECIAL INTERNACIONAL(año 16) 18-34

**Figure 9: Control loop.**




Source: Montalvo (2017).

With the definition of the memberships, the respective fuzzy rules, related in table 1, were raised:

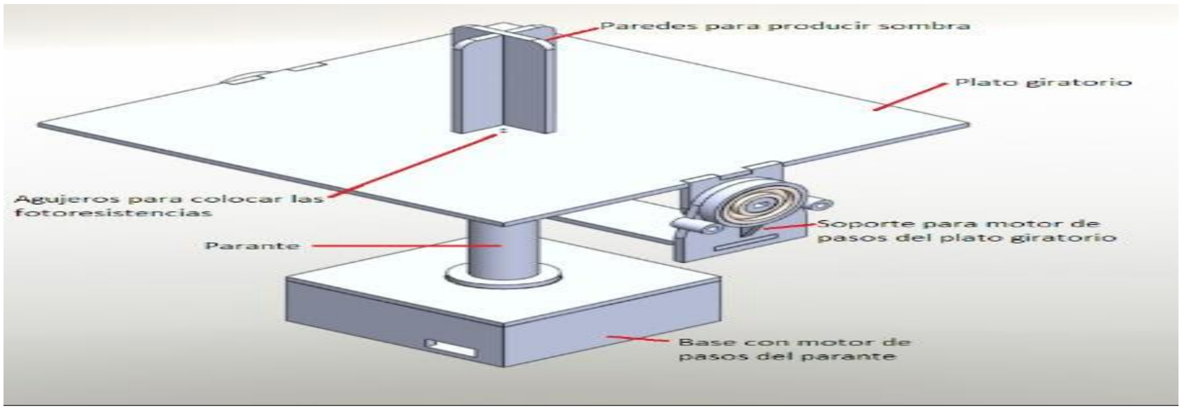
**Table 1: Fuzzy rules.**

| | | **AND 'Post error position' IS** | | | | |
|---|---|---|---|---|---|---|
| | | Very negative | Negative | In place | Positive | Very positive |
| **IF 'Error posición plate' IS** | Very negative | THEN 'Output Plate' IS ' turn too fast right' ALSO 'Output post' IS 'Turn too fast right' | THEN 'Output Plate' IS 'Turn fast right' ALSO 'Output post ' IS Turn fast right' | THEN 'Output Plate' IS 'Turn fast right' ALSO 'Output post' IS '' | THEN 'Output Plate' IS 'Turn Fast right' ALSO 'Output post IS 'turn fast left | THEN 'Output Plate' IS 'Turn very fast ' ALSO 'S Output post' IS 'Turn very fast left |
| | Negative | THEN 'Output Plate' IS 'Turn fast der' ALSO 'Output post IS 'Turn fast right' | THEN 'Output Plato' IS 'Turn right' ALSO 'Output post' IS Turn to the right | THEN ' Output Plate' IS 'Turn right' ALSO 'Output post' IS 'Keep' | THEN ' Output Plate' IS 'Turn right' ALSO 'Output post' IS Turn to the left | THEN 'Output Plate' IS 'Turn Fast der' ALSO 'Output post IS 'Turn fast left |
| | In place | THEN 'Output Plate' IS 'Keep' ALSO 'Output post' IS 'Turn fast' | THEN 'Output Plate' IS 'Keep' ALSO 'Output post' IS 'Turn to the right' | THEN 'Output Plate' IS 'Keep' ALSO 'Output post' IS 'Keep' | THEN 'Output Plate' IS 'Keep' ALSO 'Output post ' IS 'turn to the right' | THEN 'output Plate' IS 'Keep' ALSO 'Output post' IS 'Turn fast left |
| | *Positive* | THEN 'Output Plate' IS 'Turn fast left' ALSO 'Output post' IS 'Turn fast right' | THEN ' Output Plate' IS 'Turn left ALSO 'Output post' IS 'Turn to the right' | THEN 'Output Plate' IS 'Turn left' ALSO 'Output post' IS 'Keep' | THEN 'Output Plate' IS 'Turn left' ALSO 'Output post' IS 'Turn to the left' | THEN 'Output Plate' IS 'Turn fast right' ALSO 'Output post' IS 'Turn fast left |
| | Very positive | THEN 'Salida Plato' IS 'Girar muy rápi left' ALSO 'Output post' IS 'Turn very fast right | THEN 'Output Plate' IS 'Turn fast left' ALSO 'Output post' IS 'Turn fast right | THEN 'Output Plate' IS 'Turn fast left' ALSO 'Output post ' IS 'Keep' | THEN 'Output Plate' IS 'Turn fast left' ALSO 'Output post' IS 'Turn fast left' | THEN 'SOutput Plate' IS 'Turn very fast left ALSO 'Output post' IS 'Turn very fast left |

Source: Montalvo (2017).

The defuzzification was performed with the criteria of area centers, with antecedent connector and consequent minimum value.

**Figure 10: Prototype.**

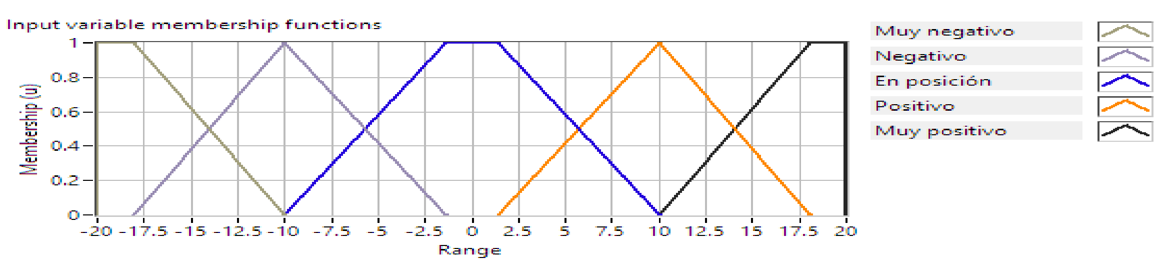



Source: Montalvo (2017).

The block diagram of fuzzy control in LabVIEW is shown in Figure 15. The data acquisition of the sensors (S1, S2, S3, S4), with their conditioning, is shown in Figure 16. Memberships and fuzzy control rules were made in LabVIEW Fuzzy System Designer. Figure 17 shows the rules and memberships in the Fuzzy System Designer.

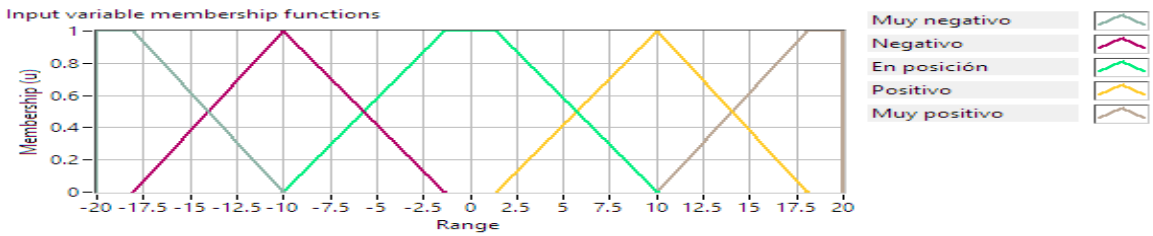
The signal acquired by the DAQ is processed mathematically to find the position error, both rotary plate, and post. The fuzzy rules analyze this error in a MIMO system (multiple inputs, multiple outputs), which show a result of the direction of rotation of the stepper motors, as well as the speed with which the plate and the post must rotate. Figure 18 summarizes the diffuse processing of the error position.

**Figure 11: Membership of the rotary plate error**



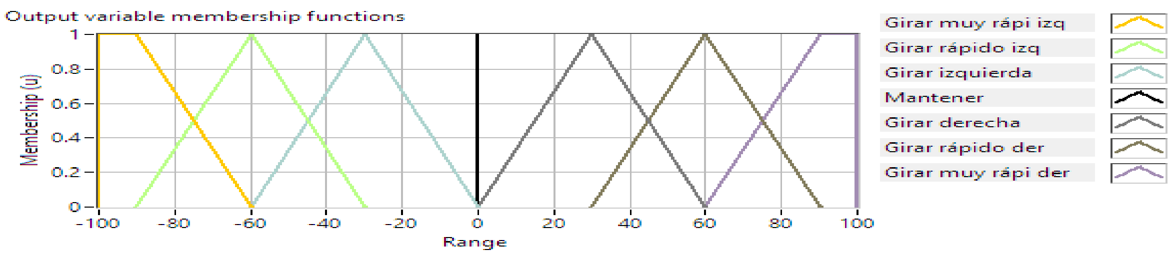

Source: Montalvo (2017).

**Figure 12: Membership of the post error.**



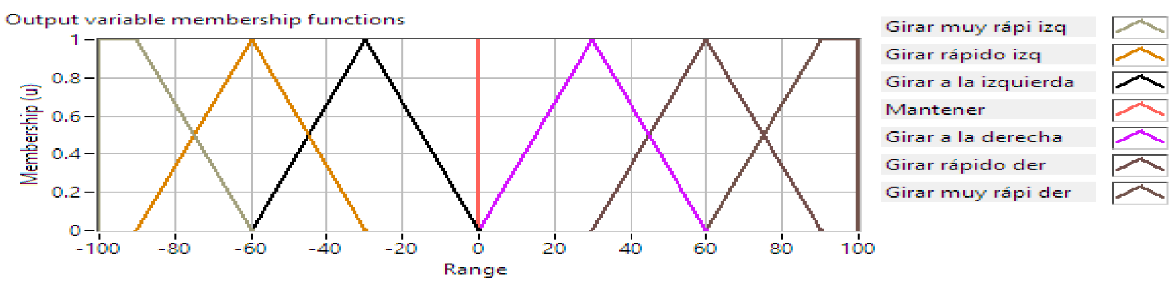

Source: Montalvo (2017).

**Figure 13: Membership of the rotary plate output**




Source: Montalvo (2017).

**Figure 14: Membership of the post output.**



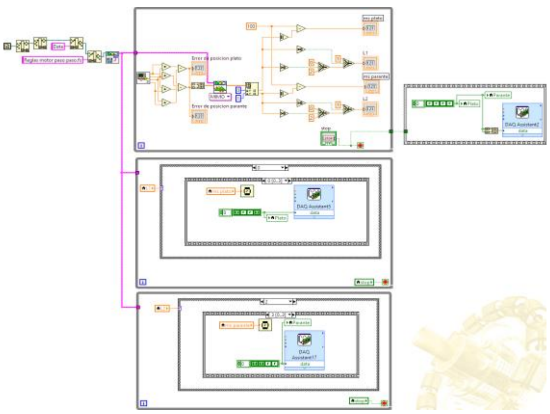

Source: Montalvo (2017).

The speed of rotation of the stepper motors is determined by the time in milliseconds that each motor step takes (ms of the plate and ms of the post). The variables L1 and L2 give the direction of rotation. The direction of rotation is controlled by a case structure, which sends the rotation sequence of each motor, as shown in Figure 19. When the program is stopped, a Boolean signal is sent through a four-bit array to de-energize the coils of the stepper motors as indicated in Figure 20.

The coupling of the output signal to the stepper motor is done with an optocoupler or Driver consisting of a 2003 ULN IC (Figure 21).

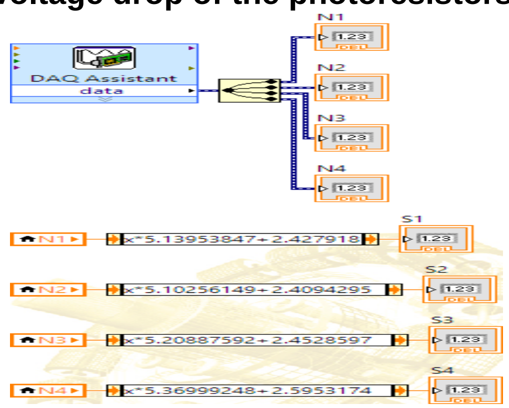
This Driver makes the connection between the stepper motor and the DAQ card, as shown in figure 22.

**Figure 15: Block diagram of the diffuse control (LabVIEW).**



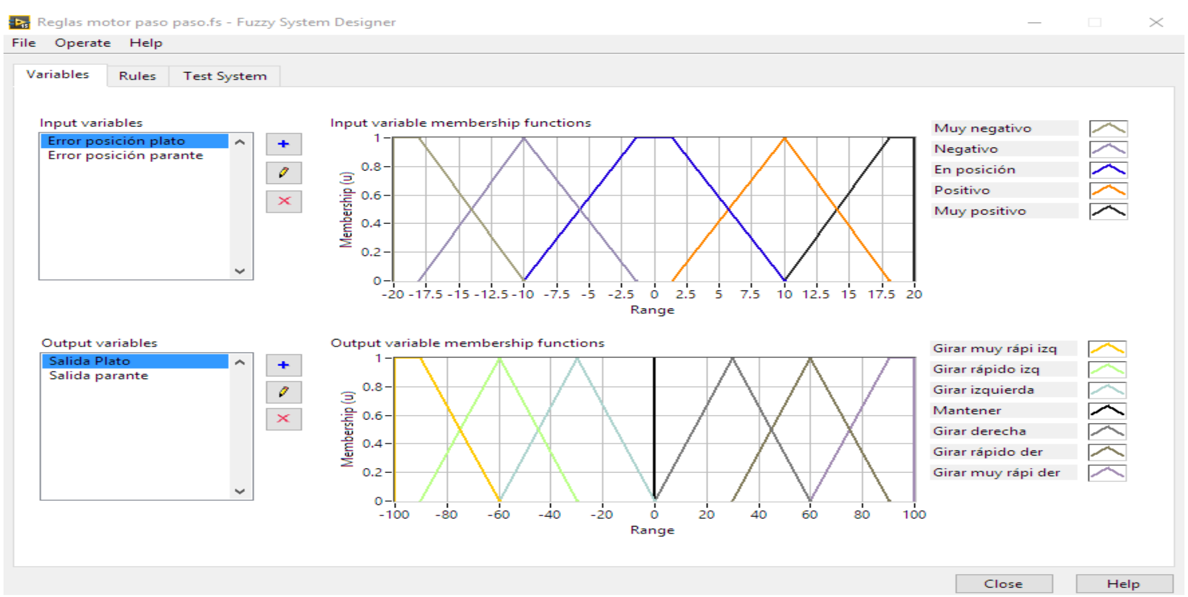
Source: Montalvo (2017).

**Figure 16: Acquisition and conditioning of the sensors signal (voltage drop of the photoresistors).**



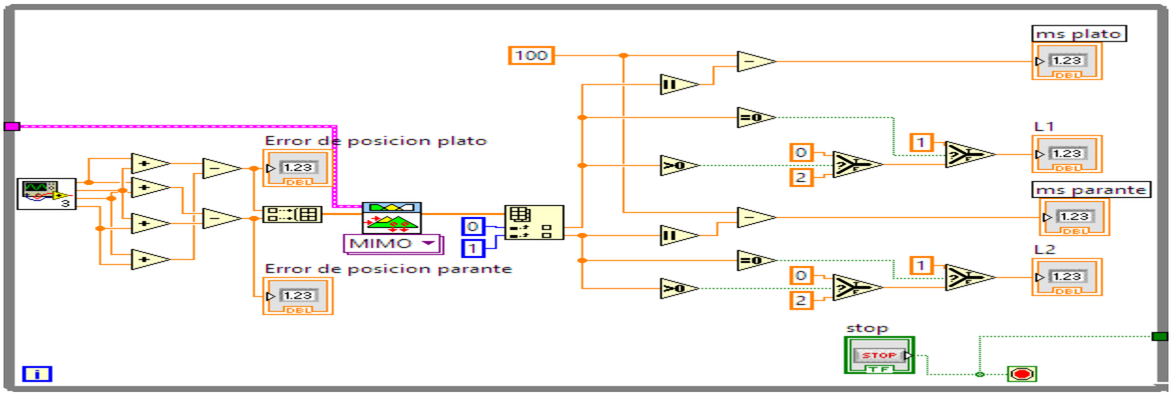

Source: Montalvo (2017).

**Figure 17: Rules and memberships in the Fuzzy System Designer.**



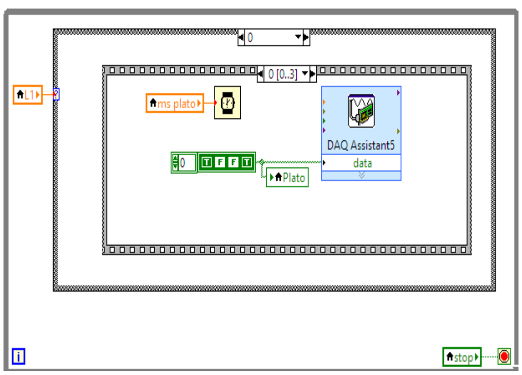

Source: Montalvo (2017).

**Figure 18. Fuzzy processing of position error**



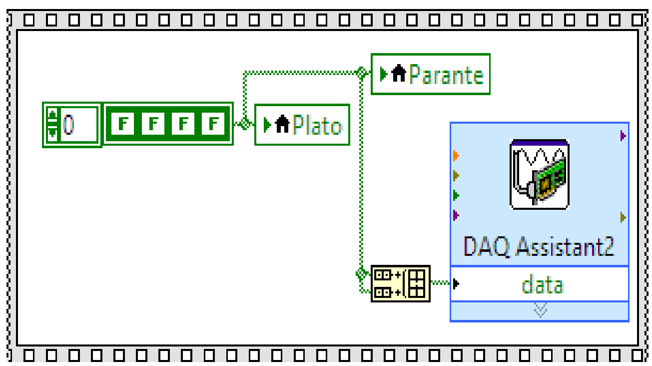

Source: Montalvo (2017).

**Figure 19: Direction and sequence of rotation of the plate stepper motor.**




Source: Montalvo (2017).

**Figure 20: Signal to turn off the coils of the stepper motors.**




Source: Montalvo (2017).

**Table 2: Incident energy on panels**

| **Incident energy on Panel x $10^3$ J/m$^2$** | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **Hour** | | 1ª day | | 2º day | | 3ª day | | Average | |
| | | Fixed panel | Two-axis panel | Fixed panel | Two-axis panel | Fixed panel | Two-axis panel | Fixed panel | Two-axis panel |
| **6:00** | 6:15 | 6987 | 6704 | 6640 | 6589 | 5980 | 6010 | 6535.67 | 6434.33 |
| **…** | … | … | … | … | … | … | … | … | … |
| **19:00** | 19:15 | 3500 | 4678 | 3258 | 4029 | 4010 | 5207 | 3589.33 | 4638 |
| **Average** | | 7390.26 | 7933.66 | 7347.66 | 8186.51 | 7233.66 | 8193.57 | 7323.86 | 8104.58 |

Source: Montalvo (2017).

From the data obtained, we determined the average values of incident energy in one day (6:00 a.m. to 7:00 p.m.), which are shown in Table 3:

**Table 3: Incident energy average**

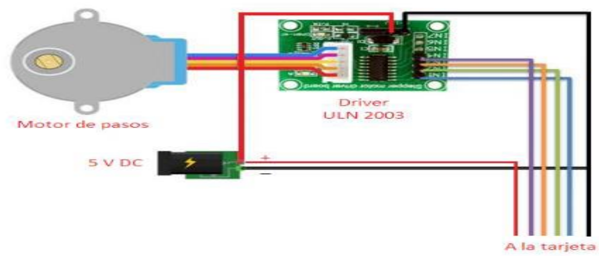
| Promedio | Fixed | Two-axis |
|---|---|---|
| | $7323.86 \times 10^3$ J/ m$^2$ | $8104.58 \times 10^3$ J/ m$^2$ |

Source: Montalvo (2017).

**Figure 21: CI ULN, 2003.**

Source: Montalvo (2017).

**Figure 22: Connection between the stepper motor and AQ card.**




Source: Montalvo (2017).

To know if this difference is statistically significant, the following tests were carried out for independent variables with a 95% reliability, that is, α = 0.05, as shown in Table 4.

**Table 4: Normality test of incident energy**

Normality tests

| | Kind of panel | Kolmogorov-Smirnov[a] | | | Shapiro-Wilk | | |
|---|---|---|---|---|---|---|---|
| | | Statistical | gl | Sig. | Estadístico | gl | Sig. |
| Incident energy | Fixed | ,136 | 53 | ,015 | ,819 | 53 | ,000 |
| | Two-axis | ,128 | 53 | ,029 | ,895 | 53 | ,000 |

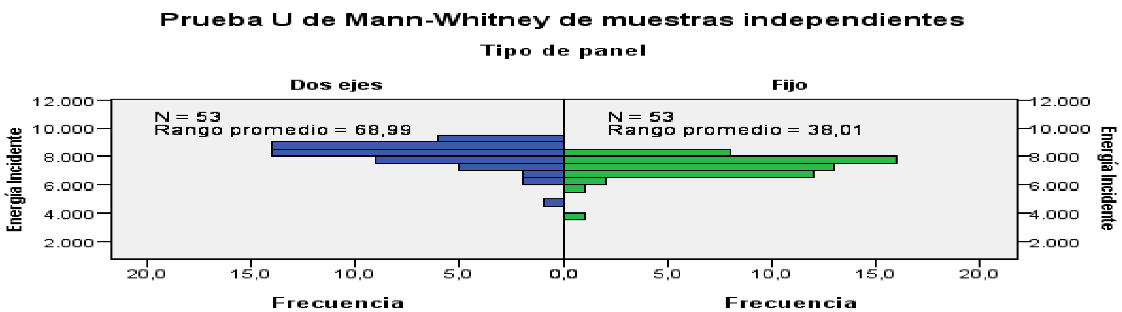
Source: Montalvo (2017).

As can be seen in the Kolmogorov-Smirnov test (Table 3), for samples higher than 30 cases, the significance value is 0.015 for the fixed panel and 0.029 for the two-axis one, as these are less than α = 0.05, it means that the data obtained do not have a normal distribution. As the samples were independent and not normal, the non-parametric Mann-Whitney U test was performed, comparing medium and not means, obtaining the result shown in Figure 23.

When having a value of significance of the test of 0.000 <0.05, the authors conclude that the means of incidence energy on the panels are not equal, that is, the hypothesis Ho, previously mentioned, is accepted. When determining that the energy of incidence in the panel of two axes is greater than the fixed panel, it was possible to determine the difference between them:

= (8104.58-7323.86) /7323.86 x 100 = 10.66%

**Figure 23: Results of the Mann - Whitney U test.**




| | |
|---|---|
| N total | 106 |
| U de Mann-Whitney | 2.225,500 |
| W de Wilcoxon | 3.656,500 |
| Probar estadística | 2.225,500 |
| Error típico | 158,262 |
| Estadística de prueba estandarizada | 5,188 |
| Sig. asintótica (prueba de dos caras) | ,000 |

Source: Montalvo (2017).

# RESULTS

The main results obtained in the present investigation were. A two-axis solar tracking system with fuzzy control was designed to take better advantage of solar radiation. The fuzzy control algorithm for a two-axis solar tracker was developed.
A two-axis solar panel prototype was built, which enabled the demonstration of the algorithm.
Measurements of the captured energy were obtained; it is that a two-axis solar tracking system with fuzzy logic allows capturing more solar radiation during the day.

The measurement of incident energy on a fixed panel tilted 15 degrees to the north was done, which is the recommendation to locate solar panels in the southern hemisphere, at the latitude of Ambato city. It was compared with the incident energy on a two-axis solar tracker panel.
The non-parametric Mann - Whitney U test was applied, since the incident energy captured on the panels did not comply with statistical normality.
Once the comparison of the incident energy captured in each panel was made, it was determined that the solar panel mounted on the two-axis tracker had an improvement of 10.66% with respect to the fixed one.

## DISCUSSION

The general importance of the present investigation consists in the design of the prototype of two-axis solar panel, it makes it possible to demonstrate the algorithm and to verify the hypothesis that a two-axis solar tracking system with fuzzy logic allows capturing a greater amount of radiation solar during the day.

The study acquires statistical validity, since the non-parametric Mann-Whitney U test is applied to demonstrate the hypothesis, since the incident energy that is captured on the panels does not meet statistical normality.

## CONCLUSIONS

The results obtained lead to the following conclusions: a two-axis solar tracking system with fuzzy control was designed and implemented, which makes the best use of solar radiation. The two-axis solar panel prototype allowed validating the fuzzy control algorithm for a two-axis solar tracker.

Through the measurements of the incident energy captured on a fixed plate system and a two-axis system, it is that a two-axis solar tracking system with fuzzy logic allows capturing more solar radiation during the day.

Although more energy is produced in this system, a higher amount of energy is also consumed by the consumption of the motors, but this is much lower than the energy gained by the system as a whole, due to the fact that the motors are low power and the materials used in the construction of the tracker, are light.

## REFERENCES

Acevedo, M., & Ricardo, E. (2015). *Evaluación de un sistema de suministro de energía eléctrica híbrido y un sistema de iluminación eficiente para reducir el consumo de energía eléctrica actual y mejorar el confort visual del Museo de La Salle.* Bogotá: Universidad de LA SALLE.

Arreola Gómez, Rubisel, Quevedo Nolasco, Abel, Castro Popoca, Martiniano, Bravo Vinaja, Ángel, & Reyes Muñoz, David. (2015). Diseño, construcción y evaluación de un sistema de seguimiento solar para un panel fotovoltaico. Revista mexicana de ciencias agrícolas, 6(8), 1715-1727. Recuperado en 09 de julio de 2020, de http://www.scielo.org.mx/scielo.php?script=sci_arttext&pid=S2007-09342015000801715&lng=es&tlng=pt.

Archer, B. (1963). Método sistemático para diseñadores. Revista Design. Inglaterra, 3.

Cabrera, F. (2014). Incidencia de la energía solar en los módulos de prueba ubicados en Atahualpa y El Laurel. *Yachana Revista Científica, 3*(1), 79-83.

Correa, C., Marulanda, G., & Panesso, A. (2016). Impacto de la penetración de la energía solar fotovoltaica en sistemas de distribución: estudio bajo supuestos del contexto colombiano. *Revista Tecnura, 20*(50), 85-95.

Enríquez, J., Sifuentes, E., Bravo, G., & Castro, A. (2016). Sistema Embebido para Validar el Funcionamiento de la Tarjeta de Adquisición de Datos USB-6009 de National Instruments. *Información tecnológica, 27*(5), 191-200. doi:http://dx.doi.org/10.4067/S0718-07642016000500021

European Photovoltaic Industry Association, Greenpeace. (2011). *GREENPEACE, E. P. I. A. Solar generation 6. Solar photovoltaic electricity empowering the world*. Obtenido de GREENPEACE: https://www.greenpeace.org/archive-international/Global/international/publications/climate/2011/Final%20SolarGeneration%20VI%20full%20report%20lr.pdf

Fandiño, L., Sarmiento, S., & Rosales, L. (2016). Ampliación del rango de operación de plantas no lineales usando algoritmos de control difuso basados en el modelo TSK-LMI. *Universidad, Ciencia y Tecnología, 20*(81), 136-147.

Fornerón Acosta, J. P., Mendieta Zárate, H. E. & Almeida Delgado, C. D., 2019. Sistema difuso de alerta de sueño al volante utilizando algoritmo de Viola-Jones. Revista Científica de la Juventud, Issue Número 1, pp. 219-229.

Guisado, M., Vila, M., & Guisado, M. (2016). Capacidad productiva, formación en el puesto de trabajo y productividad. *Cuadernos de Gestión, 16*(2), 77-92. doi:10.5295/cdg.140513mg

Lara-Valencia, Luis Augusto, y Valencia-González, Yamile, y Vital de Brito, José Luis (2015). Uso de lógica difusa para la administración de un sistema disipador de energía en estructuras compuestas por amortiguadores magnetoreológicos. Revista Facultad de Ingeniería Universidad de Antioquia, (74), 151-164. [Fecha de consulta 9 de julio de 2020]. ISSN: 0120-6230. Disponible en: https://www.redalyc.org/articulo.oa?id=430/43038629014

Machado Toranzo, Noel, Lussón Cervantes, Ania, Oro Carralero, Leandro Leysdian, Bonzon Henríquez, Jorge, & Escalona Costa, Orlando. (2015). Seguidor Solar, optimizando el aprovechamiento de la energía solar. Ingeniería Energética, 36(2), 190-199. Recuperado en 09 de julio de 2020, de http://scielo.sld.cu/scielo.php?script=sci_arttext&pid=S1815-59012015000200008&lng=es&tlng=es.

Montalvo, P. (2017). *Diseño de un sistema de control difuso de seguimiento solar de dos ejes.* Riobamba: Escuela Superior Politécnica de Chimborazo. Obtenido de http://dspace.espoch.edu.ec/handle/123456789/7331

Rivera, G. (2015). La lógica fuzzy como posible herramienta de medición y valoración del valor razonable en activos intangibles. *Revista del Centro de Investigaciones de la Universidad Libre - Cartagena, 10*(2), 113-122. doi:http://dx.doi.org/10.22525/sabcliber.2015v10n2.113122

Vega, V. (1998). Aplicación de la Matemática Borrosa al calculo del umbral de rentabilidad. *Revista Costos y Gestión, 28*.

Vega, V. (2017). Una mirada al concepto de Capital Intelectual. *UNIANDES EPISTEME: Revista de Ciencia, Tecnología e Innovación, 4*(4), 491-503.