Chapter 1 Application of finite automates for the light point trace in a solar tracking positioning system on two axes

Capítulo 1 Aplicación de autómatas finitos para el rastreo de punto luminoso en un sistema de posicionamiento para seguimiento solar en dos ejes

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Abstract

This article presents the application of finite automata for light point tracking in a two-axis solar tracking positioning system. The finite automaton sets the rules of reactive control when the ultraviolet radiation sensor is activated, estimating the averages of the signals sent by the photoresistors determines the angle of greats light incidence and codes the rules of motion to which the vertical axis and the horizontal axis must conform. The reactive control algorithm for the automaton is programmed in a C++ language and implemented in an Arduino UNO microcontroller. The validation of the results is carried out by manipulating the prototype of a two-axis solar tracking system that uses a photovoltaic solar panel as a collector. The results also show that the application of finite automata solves the problem of deviations between the positioning of the tracking system and the incidence of the sunbeam on the collector since it includes a self-adjustable function that verifies the correct orientation of the positioning system avoiding manual adjustments and mechanical recalibration alignments, this extends the service life of the system monitoring by reducing wear on the servomotors.

Finite automates, Positioning on two axes, Light point trace, Solar tracking

Resumen

Este artículo presenta la aplicación de autómatas finitos para el seguimiento de puntos de luz en un sistema de posicionamiento de seguimiento solar de dos ejes. El autómata finito establece las reglas de control reactivo cuando se activa el sensor de radiación ultravioleta, estimando los promedios de las señales enviadas por las fotorresistencias determina el ángulo de incidencia de la luz grande y codifica las reglas de movimiento a las que deben ajustarse el eje vertical y el eje horizontal. El algoritmo de control reactivo del autómata está programado en lenguaje C++ e implementado en un microcontrolador Arduino UNO. La validación de los resultados se realiza mediante la manipulación del prototipo de un sistema de seguimiento solar de dos ejes que utiliza un panel solar fotovoltaico como colector. Los resultados también muestran que la aplicación de autómatas finitos resuelve el problema de las desviaciones entre el posicionamiento del sistema de seguimiento y la incidencia del rayo solar sobre el colector ya que incluye una función de auto-ajuste que verifica la correcta orientación del sistema de posicionamiento evitando ajustes manuales y alineaciones mecánicas de recalibración, esto alarga la vida útil del sistema de seguimiento reduciendo el desgaste de los servomotores.

Autómata finito, Posicionamiento en dos ejes, Rastreo de punto luminoso, Seguidor solar

1.1 Introduction

Solar tracking systems play an important role in the performance of capture technologies as the amount of solar radiation that is absorbed by the collector determines the output power (Abadi I., 2019). A two-axis solar tracking positioning system allows automatic movements on the azimuth axis, from north to south, producing an elevation that ensures that sunlight always impacts perpendicularly on the top of the solar collector (Jing-Min, 2013).

In the state of the art, two approaches have been extensively researches to achieve a high degree of precision in the action of solar tracking: open loop tracking based on mathematical models that use a formula or a PID control algorithm to model the behavior of the solar tracking to be performed (Blanco Muriel, 2001) (Chong, 2009), the second approach uses loop control closed to adjust the photovoltaic panel towards a bright spot in the sky, (Arenas Rosales, 2017), as illustrated by Figure 1.

The closed loop tracking approach is carried out by means of a feedback control algorithm that adjust the positioning of the collector towards the light point based on the signal emitted from an array of sensors placed on the photovoltaic panel, (Toranzo, 2015), commonly formed by charge-torque (CCD) devices, or light dependent photo resistances (LDR´s), (Bajpai & Kumar, 2011) , these elements are also used to generated a feedback error signal and excite the controller to adjust the positioning system ensuring that the light beam impacts the surface of the photovoltaic panel, (Arturo, 2010), (Berenguel, y otros, 2004).

In this type of closed loop control, it has been reported in the state of art the use of adaptive algorithms with diffuse logic based on human experience or adaptative chronological tracking algorithms with solar trajectory tracking models, the latter offering reactive capabilities to correct the positioning error. Although there is research evidence on correcting the sensor array, (Celso de la Cruz Casaño, 2012), (Rizk J., 2008), and improving the accuracy of the solar tracking algorithms, in all cases, the control law requires the establishment of the initial conditions.

This paper proposes an empirical research approach that presents the application of infinite automata in the design of reactive control law that manages to fit a two-axis solar tracking system without initial conditions requirements.

The rest of this chapter is organized as follows: Section 2 describes rule modeling and the actions that the automaton must perform. Section 3 presents the experimentation that allows to check the performance of the automaton to perform the tracking of the luminous point. Section 4 presents the conclusion of the work carried out and proposals for improvement.

1.2 Metodology

1.2.1 Light point tracking in a two axis- solar positioning system

In the work done by , (Sidek, y otros, 2017), (Gregor, y otros, 2015) y (Fathabadi, 2016) , the control system was regulated by a microcontroller unit and auxiliary devices that included an encoder and a global positioning system GPS, which helped determine the path of the sun. In (Tharamuttam & Ng, 2017), a controller was developed that combined photo resistances with a magnetometer that served as a digital compass to determine azimuth. The authors demonstrated that the positioning system worked smoothly under all climatic conditions.

In addition, in the articles proposed by, (Sidek, y otros, 2017), (Ho, y otros, 2017) , the authors developed a solar tracker with controls based on GPS global positioning sensors and digital compasses, however, several evidences of random factors that cause the loss of the GPS signal such as atmospheric interference have been reported in the literature electromagnetic interference or climatic changes that modify solar activity, (Zhang, Gong, Dimitrovosky, & Li, 2013). Another problem of the electronic compass is the deviation caused by external magnetic interference especially in metallic reflectors, such deviation cannot be modeled numerically or compensated by calibration, (Lee, Kim, Yun, & Lee, 2005). Such a condition indicates that using an electronic compass and global positioning system, GPS, for the solar tracking system not cost-effective, (Jorge Arturo Pelayo López, 2020), (Nurzhigit Kuttybay1, 2020) when comparing the efficiency of tracking and tracking the light point as show in Table 1.1.

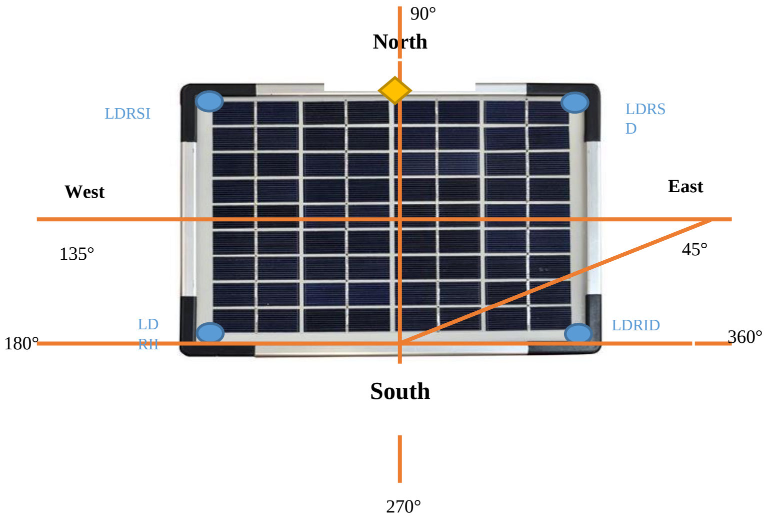
Table 1.1 Comparison on efficacy in solar system based on photo resistance

Parameters	Fixed	Developed LDR Solar Tracker	Developed Schedule Solar Tracker
Installation	Easy	Moderate	Moderate
Mechanism	No mechanism	Simple	Simple
Cost	Cheap	Moderate	Moderate
Design	Simple	Moderate	Moderate
Maintenance	Less	Moderate	Moderate
Efficiency at sunny weather	Reference efficiency	57.4% > Fixed system	57.4% > Fixed system
Efficiency at cloudy/rainy weather	Reference efficiency	>32,2 % Fixed system	> 37.7% Fixed system >4.2% than LDR ST

Source: (Nurzhigit Kuttybay1, 2020)

Based on this evidence, this paper proposes to use a light spot tracking system of a hybrid type consisting of an arrangement of 4 photo resistances, a grove type ultraviolet radiation sensor and a control algorithm based on a finite automaton embedded in an Arduino UNO microcontroller. The cellular array of 4 sensors detecting light or LDR photoresistences, are placed on the polycrystalline photovoltaic panel, oriented towards each of the cardinal points and strategically place in each of the corners of a solar panel, cell identifiers are described in the Table 1.2, the sensor that detects ultraviolet radiation is placed in the central part of the upper shaft as seen in Figure 1.1.

Figure 1.1 Sensor array on the photovoltaic panel



Source: Own elaboration

1.2.2 Description of the automaton modeling and generation of the ruler

The angle of incidence and the information it sent from the ultraviolet radiation sensor establish and adjustment rule so that the two-axis positioning system ensures that the motion of the photovoltaic panel is oriented towards the relative position of the sun, both at azimuth and altitude, a condition that involves controlling two servomotors placed perpendicularly, one on the vertical axis, which adjust the movements to make the tilt of the collector from north to south, and the other placed on the horizontal axis which adjust the movements from east to west, as illustrated in **Figure 1.1**.

Table 1.2 Cell array description

	Position	Identifier
Cell 1	Top left	ldsi
Cell 2	Top right	ldsd
Cell 3	Lower Left	ldii
Cell 4	Lower right	ldid

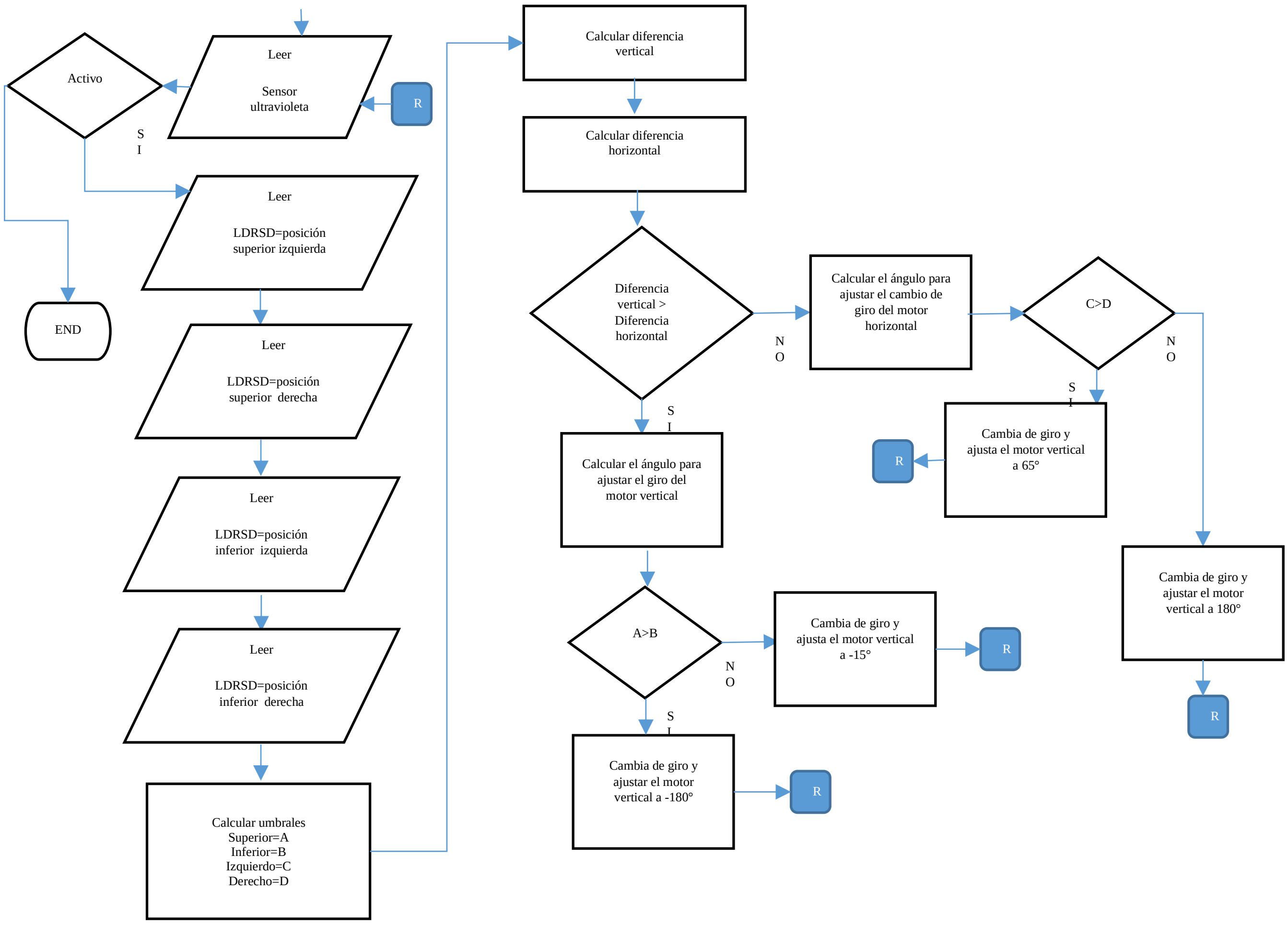
Source: Own elaboration

The light spot tracking rule is realized by a cellular automaton which is designed as an n-dimensional array of units called cells represented by each of the 4 LDR´s placed on the photovoltaic panel. Each cell has several finite states that interconnect whit each other in a known as described in the **Table 1.2.**

It should be noted that in the absence of a light beam, the cells send a zero-status bit to the data bus of the Arduino UNO microcontroller an in the presence of the light spots they send a status bit 1. The automaton, from the reading of light spots, calculates a series of thresholds and difference values that allow it to make decisions to adjust the movements of the horizontal and vertical servomotors in a neighborhood of 2^4 possible candidate solutions.

El comportamiento del autómata se fundamenta en el cálculo de umbrales que se utilizan para estimar un par de diferencias que regulan el ajuste de los servomotores vertical y horizontal para seguir el patrón de comportamiento que sigue el rayo luminoso durante el día, de acuerdo con el algoritmo de la **Figura 1.2.**

Figure 1.2 Flow chart that models the decision rule



Source: Own elaboration

The control rules are established from 4 thresholds=upper (1), B=lower (2), C=left (3), C=right (4). In these expressions it is observed that the thresholds are expressed by average of two signals sent by cells by the position in which they were placed on the photovoltaic panel where A represent the maximum upper horizontal threshold, B the maximum lower horizontal threshold, C the maximum vertical threshold of the cells placed on the right and D the maximum vertical threshold of the cells placed on the left. Table 1.3 describes the status variables related to the thresholds.

$$A = \frac{ldsi+ldsd}{2} \tag{1}$$

$$B = \frac{ldii+ldid}{2} \tag{2}$$

$$C = \frac{ldsi+ldii}{2} \tag{3}$$

$$D = \frac{ldsd+ldid}{2} \tag{4}$$

Table 1.3 Tresholds and their state variables

Threshold	State Variable	Descripction
A	00	The light is received by the upper LDRs.
B	01	Light is received by the lower LDRs
C	10	Light is received by the left LDR
D	11	Light is received by the right LDR

Source: Own elaboration

The automaton encodes the thresholds and estimates two difference-based rules, DH=horizontal difference (5), DV=vertical difference(6) to make control action decision and adjust the azimuth angle and altitude, both regulated from the two servomotors. Once the thresholds have been obtained, the control actions whit which the automaton adjust the movements of the left and right servomotor are modelled, according to the state variables defined by the thresholds, as show in **Table 1.4**.

$$DH = (A - B) \tag{5}$$

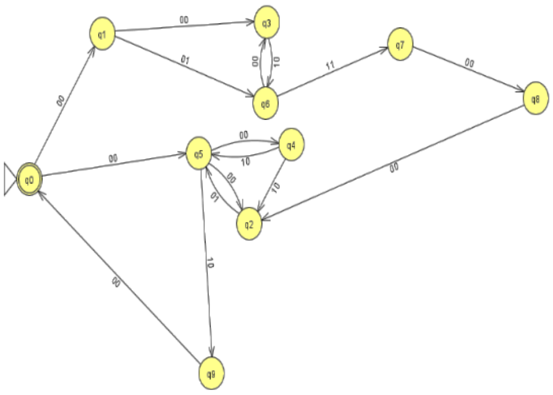
$$DV = (C - D) \tag{6}$$

Table 1.4 Set of actions to adjust the servomotor

Action	Vertical difference VD	Horizontal Difference HD	Description
q1	00	00	Calibrate the motors to the starting position
q2	01	00	Adjust horizontal motor to 80°
q3	10	00	Adjust vertical motor to 45°
q4	11	00	Change of vertical motor rotation to start 45° and set upper limit to 80° and lower limit to 15°.
q5	00	00	Disables vertical motor
q6	00	01	Adjust horizontal motor to 65°
q7	00	10	Adjust the motor horizontal a 180°
q8	00	11	Cambia de giro el motor horizontal y vuelve a la posición de inicio, 180|° y ajusta el límite superior a 65°.

Source: Own elaboration

Figure 1.3 Modeling the automaton in JFPLAP



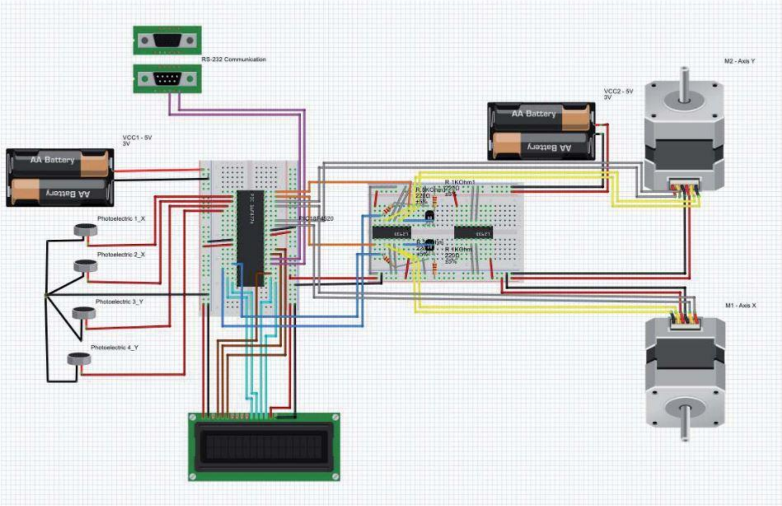
Source: Own elaboration

The modeling of the automaton is illustrated in **Figure 1.3** and JFLAP software was used to check its correct performance, and **Figure 1.4** shows the flow diagram that models the decision rule used by the automaton to track the luminous point.

1.3 Experimental Results

The automaton was programmed in C++ language and implemented in an Arduino UNO microcontroller as illustrates in **Figure 1.4**. The **Figure 1.5** shows the experimental facilities used for the validation of the results. The experiment was carried out at the facilities of Engineering and Chemical Sciences Unit, in the Poza Rica city, Veracruz, México. The purpose was to test performance of automaton to perform light beam tracking.

Figure 1.4 Schematic of the hardware for the implementation of the automaton

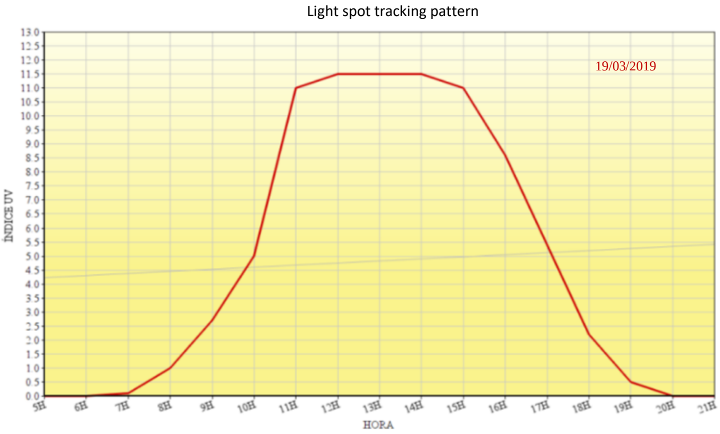


Source: Own elaboration

Figure 1.5 Experimental facilities

Source: Own elaboration

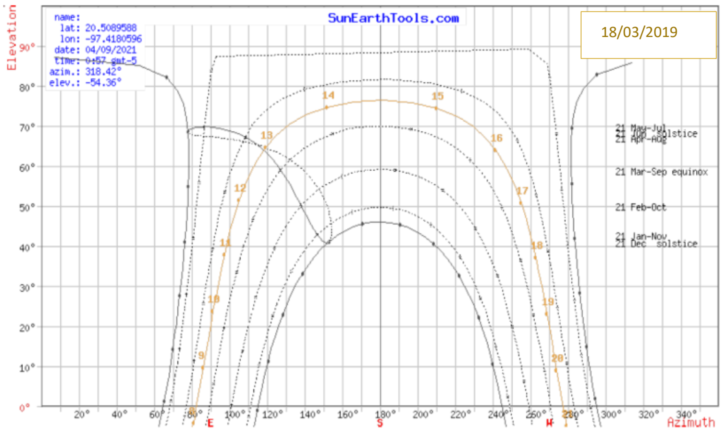
Figure 1.6 Validation of light spot tracking by the automaton



Source: Own elaboration

The results show that the control rules established in the automaton for the tracking of the luminous point manage to carry out precise tracking of the same, as illustrated in **Figure 1.6**, where it is observed that form 8 hours in the morning begins the follow-up of the luminous point and ends at 20 horas. This registry is checked by behavior pattern acquires from the UV radiation sensor.

Figure 1.7 Results validation in sun solar earth tools



Source: Own elaboration

This behavioral pattern of the luminous beam for the day and the experimental area was checked with software sun solar earth tools, as illustrated in the **Figure 1.7**.

1.4 Conclusions

In this chapter it was show that the use of automata is a useful tool to develop descriptive models of physical system since they can be modeled by means of state variables and simple rules of establishing transition functions.

The use of array of sensors whose signals from behavior patterns that define the control rules minimizes the computation since the automaton manages to make intuitive behavioral decision from the thresholds values also the calculation on the differences determines the incidence where the highest light point is located by adjusting the elevation of the photovoltaic panel trough the coding of the movement of the servomotors, without the need to use initial conditions.

The results also show that the application of finite automata solves the problem of deviations between the positioning of the tracking system and the incidence of the sunbeam on the collector since it includes a self-adjustable function that verifies the correct orientation on the positioning system and avoids manual adjustments and mechanical alignment to recalibrate the system, this extends the service life of the follow-up system as wear is reduced on the servomotors.

To evaluate the performance of automaton in tracking light spots, it´s recommended to extend the experimentation throughout the year under variable weather conditions.

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