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Dual Axis Solar Tracker With Fuzzy Logic Method

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***Abstract*— Solar trackers that use LDR as input are prone to losing tracking due to bad weather. In addition, solar trackers that use the calculation of the sun's movement cannot adapt to the environment when the weather is bad. As a solution to these problems, a two-axis solar tracker was made using fuzzy logic. The north south axis is moved once per day. The tilt angle of this axis is based on the calculation of the declination angle and the longitudinal position of the project installation. The east west axis will move every 10 minutes. The tilt angle of this axis is determined by the fuzzy logic output. The first input of this fuzzy logic is the difference between the west LDR and the east LDR. The second input of this fuzzy logic is the difference between the calculated east-west angle and the actual east-west axis angle. The output of fuzzy logic is the speed of the actuator and the direction. The actuator is two stepper motors. This project uses Arduino Mega as a data processing center and ESP-12E to send data to Blynk. The ESp-12E acts as the master while the Arduino Mega acts as the slave. These two modules communicate with the I2C protocol. In conclusion, this solar tracker can follow the movement of the sun and adapt to the environment or weather at that time.**

Keywords—solar tracker, dual axis, fuzzy logic. LDR, stepper motor, arduino mega, ESP-12E, solar panel

I. INTRODUCTION

Global warming issue has been discussed recently. The use of fossil fuels is one of the causes of global warming. To prevent the worsening of global warming, many researchers are developing renewable energy as a substitute for energy made from fossil fuels. Various kinds of renewable energy sources have been found, including: energy sources from wind, water, sun, geothermal, and biomass.

Renewable energy sourced from the sun is one of technologies that is quite popular compared to other renewable energy sources. The popularity of this technology is because it can be applied on a small scale. However, to be able to optimize the output of the solar panel, it must be perpendicular to the angle of the sun.

The sun has two types of angles in its motion: declination angle and the hourly angle. To be perpendicular to the sun, a tool is needed that can move the position of the solar panels. A device to adjust the position of the solar panel to the angle of the sun is called a solar tracker. Solar trackers are usually equipped with light sensors such as LDR to detect the presence of the sun. There are two types of solar trackers that can be applied: single-axis and dual-axis. According to a journal, it is said that two axis can produce 12% more energy than one axis [1].

Solar trackers that use LDR usually will lose the track when the weather is cloudy. To overcome these weaknesses, this system is equipped with inputs derived from the calculation of hourly angles and LDR. The purpose of this additional input is to make sure the system does not lose its tracking and can approach the most optimal angle even though the weather is bad. The data processing method of this system uses fuzzy logic. With this method, the design will be easier because we do not need a mathematical model of the system, but it is enough with several sets of rules for decision making [2]. To monitor the input and the output, Blynk application will be used. It is easier to display input, output data, and create graphs with this application.

II. DUAL AXIS SOLAR TRACKER DESIGN

The solar tracker in this project has two axis. The first axis is the north south axis. This axis is used to adjust the declination angle. The movement of this axis is only done once per day. Determination of the tilt angle on this axis is based on the calculation. The result of this calculation becomes the set point of motor movement. The second axis is the east west axis. This axis is used to adjust the movement of the sun from west to east. Tracking on this axis will be performed every 10 minutes using fuzzy logic.

The system will receive input from the west LDR, east LDR, and RTC during the tracking process. LDR is used to determine the difference in the intensity of sunlight on the west and east sides. RTC is used to inform the current time. Sun tracking will only be done as long as it is between 8 am and 4 pm. To determine the mechanical 0 point, this project uses limit switches as stoppers. Mechanical 0 point only determined in the first running of the machine.

Input processing, formula calculation, and fuzzy logic processing are performed by Arduino Mega. Arduino Mega acts as slave and ESP-12E as master. This configuration was chosen because the GPIO ESP-12E has a working voltage of 3.3V. If Arduino Uno is used as the master, it will potentially damage the GPIO ESP12-E when sending SDA or SCK signals with a value of 5V. The input and output data will be sent to the ESP-12E via I2C so that it can be displayed on Blynk. The result of the fuzzy logic is used to determine the speed and direction of the stepper motor. The data acquisition process will be carried out every 10 minutes.

The data that will be monitored with the Blynk application are: West and east sensor readings, angle of declination according to the formula, hourly angle according to the formula, the actual angle of the north south motor and east west motor, the last is the defuzzification value. Summary of this project can be seen in figure 1.

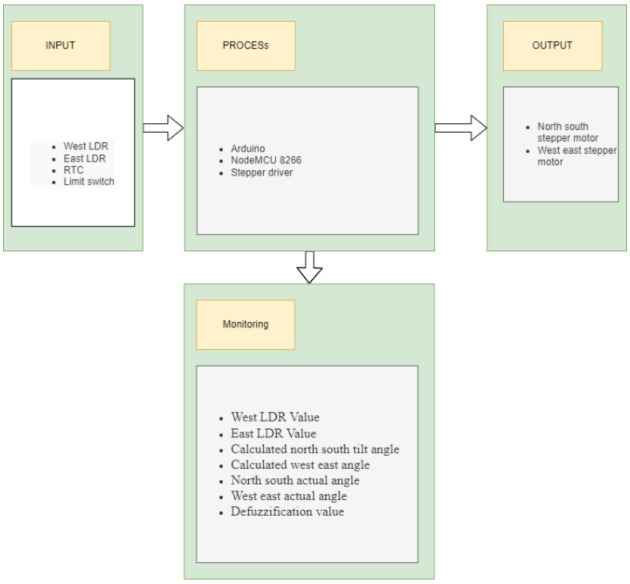

Figure 1 System block diagram

A. LDR

LDR is light dependent resistor. In this project, it measures the sun intensity [3].There are 2 LDR used in this project. The first LDR is installed on the west side of the solar panel while the second LDR is installed on the east side of the solar panel. This LDR is used to detect the intensity of light on the west and east sides of the solar panel. The LDR on each side is in series with a 2kΩ potentiometer to make it a voltage divider circuit. The output of this voltage divider circuit is fed to the analog input pin of the Arduino Mega.

The result of the Arduino Mega ADC is a value of 10 bits, in other words the value starts from 0 to 1023. To simplify processing the numbers, the value is converted again using a mapping function so the range starts from 0 to 100. When the light intensity is higher/brighter, it will produce a higher ADC value. On the other hand, when the light intensity is getting lower/darker, it will produce a larger ADC value. The mapping formula is: [4]

$$mapping\ value = \frac{ADC\ value}{1024} \times 100 \tag{1}$$

B. Limit switch

There are two limit switches in this project. The first limit switch is the mechanical 0 point of the north south axis. The second limit switch is the mechanical 0 point of the west east axis. The mechanical 0 point of these two axes is used as the initial reference for the angle of each axis. The mechanical 0 point of the north south axis is set at 30º to the north. The 0 point of the west east mechanical axis is set at 50º to the west.

C. Arduino Mega

Arduino Mega acts as a slave. This module is the center of data acquisition and decision making. The processes carried out by Arduino Mega include: determining operating hours, calculating the angle of both axis, converting LDR analog values into digital values, fuzzy logic, movement commands to the stepper driver, and I2C communication with the ESP-12E.

D. ESP-12E

ESP-12E acts as a master. This module will request data to slave every 1 minute with I2C protocol. The data obtained will be sent to Blynk [5].

E. Stepper motor driver

Stepper motor driver is used for driving stepper motor. It has a feature called microstepping. The microstepping improves the positioning accuracy of stepper motor [6]. This project uses two stepper motor drivers. The first driver is used to control the north south axis stepper motor. The second driver is used to control the east west axis stepper motor. Both of these stepper drivers use TB6600. This stepper driver can be supplied with 9-40 VDC. The current of this driver is 0.7-4A. This stepper driver can be used for Nema 17 and 23.

F. Stepper motor

This project uses two stepper motors, the first is the Nema 17 17HS6401s. This motor has a holding torque of 73 Ncm and a maximum current of 1.7A. This motor is used to drive the north-south axis. The second motor is the Nema 23 23HS10028. This motor has a holding torque of 250 Ncm and a maximum current of 3A. This motor is used to drive the east-west axis.

G. I2C

I2C is communication protocol for connecting multiple masters and multiple slaves. The original specification of this protocol is made for only 100kHz communications in which only 7-bit addresses. These 7-bit addresses can provide connection for 112 devices on the bus [7].

III. HARDWARE DEVELOPMENT

Figure 2 Dual axis solar tracker hardware

This project has two subframes. The first subframe is the north-south axis frame. This subframe holds the solar panels and moves north and south. This axis is driven by a 17HS6401s stepper motor. This motor is connected to the north-south axis using a GT2 timing belt. This axis ratio is 1:1.

The second sub-frame is the east-west axis frame. This subframe holds and moves the north-south frame to the west and east. This axis is driven by a 23HS10028 stepper motor. This motor is connected to the east west axis using the HTD5M timing belt. This axis ratio is 1:3.

The entire electronic circuit can be seen in figure 3 and 4. Figure 3 is the circuit for the LDR sensor. Figure 4 is the circuit for microcontroller components. Beside the microcontroller, we can also see how I2C protocol is wired in this system.

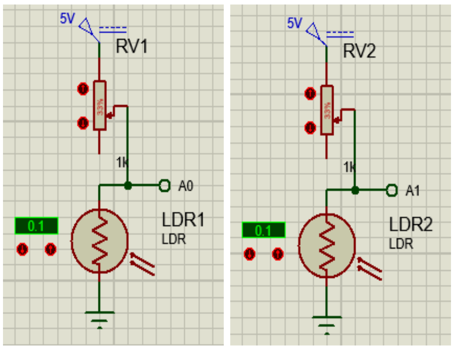

Figure 3 LDR circuit diagram

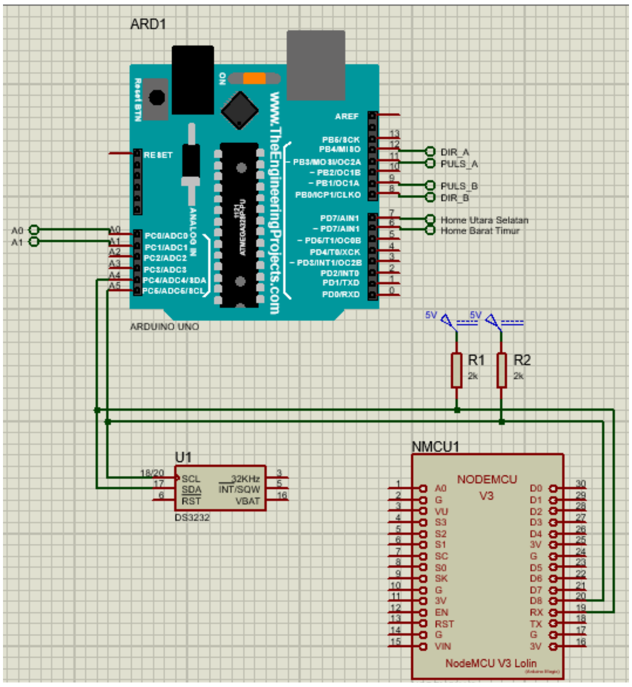

Figure 4 Main system circuit diagram

IV. IMPLEMENTATION

The angle of the north-south axis is set once every day based on the formula. In contrast with the north-south axis, the angle of the west and east axis is determined by fuzzy logic. Fuzzy logic in this project is designed to have 2 inputs and 1 output. The first input is the difference between the readings of the west and east sensors. The second input is the difference between the calculated angle value and the actual angle value on the east west axis. The output of fuzzy logic in this project is the movement speed and the direction of the stepper motor.

A. North South Axis tilt angle

The slope of the north-south axis is determined using the formula. The first step is to determine declination angle on that day using the formula below:

$$\delta = 23.45 \times sin\, sin \left[(284 + d) \times \frac{360}{365}\right] \qquad (2)$$

δ = declination angle
d = day of the year (1 < d < 365)

After knowing the declination angle, the tilt angle of the north-south axis is determined by the following formula:

$$\beta = \Phi - \delta \qquad (3)$$

β = tilt angle
Φ = latitude of installation location.
δ = declination angle

Figure 5 is a graphic that records the movement of the north-south axis in 1 year. In this data, the latitude of installation location is 7°. In the picture, it can be seen that the arduino/calculated tilt angle of the north-south axis matches with the actual angle of the north-south axis.

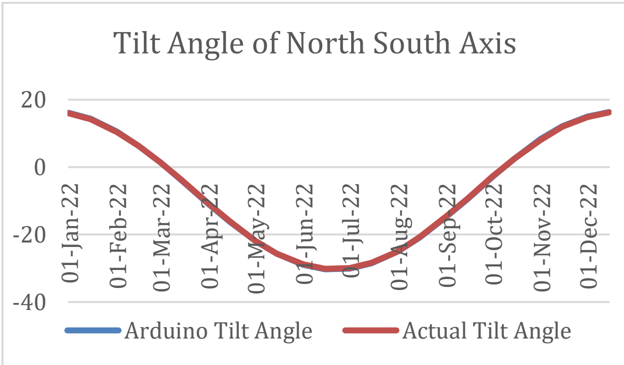

Figure 5 Tilt angle of north south axis

B. Fuzzification

The first step of fuzzification, the system will perform data acquisition from LDR. After obtaining the value as shown in Figure 6, the system will look for the difference between the western LDR and eastern LDR values. This value is the first input for fuzzy logic. The second step, the system will calculate the angle of the sun. These are formulas for calculating the angle of the sun:

$$\omega = -\left((12 - jam) \times 15°\right) + \left(\frac{menit}{60} \times 15°\right) \qquad (4)$$

Equation 4 is used at 00:00 until 11:59.

$$\omega = \left((jam - 12) \times 15°\right) + \left(\frac{menit}{60} \times 15°\right) \qquad (5)$$

Equation 5 is used at 12:00 until 23:59.

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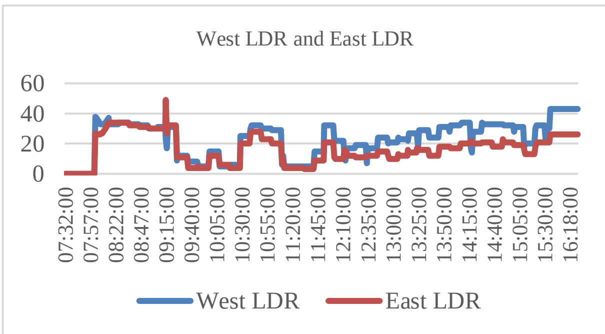

Figure 6 Value of west and East LDR

After obtaining the sun angle, the system will look for the difference between the calculated angle value and the actual angle on the east west axis. This value is the second input to fuzzy logic. The calculated angle value and the actual angle can be seen in Figure 7. The two inputs will be classified into a fuzzy set so that the degree of membership is known.

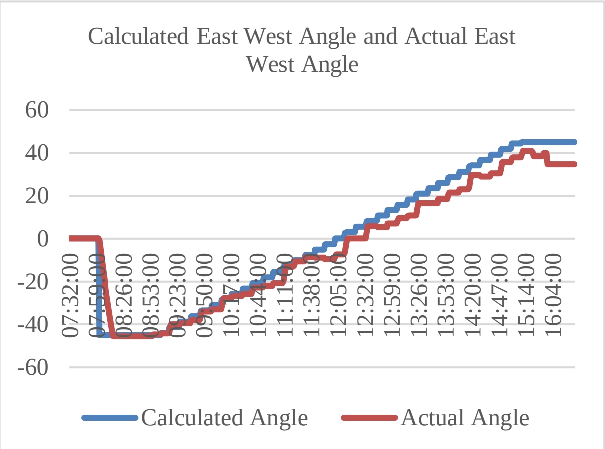

Figure 7 Calculated east west angle and actual east west angle

C. *Control Rule Base*

The fuzzy set group at the fuzzification stage is applied to table 1 to obtain a decision. The definitions of the abbreviations used in table 1 are explained in table 2. An example of a table 1 application is as follows:

If the LDR error is NB and the Angle error is Z then the output is NB and so on.

Table 1 Control rule base of logic controller

NO	Eω	1	2	3	4	5
NO	ELDR	NB	NS	Z	PS	PB
1	NB	NB	NB	NB	NS	Z
2	NS	NB	NB	NS	Z	PS
3	Z	NB	NS	Z	PS	PB
4	PS	NS	Z	PS	PB	PB
5	PB	Z	PS	PB	PB	PB

Table 2 Linguistic term definition

Linguistic Term	Label
Negative Big	NB
Negatif Small	NK
Zero	Z
Positive Small	PS
Positive Big	PB
ELDR	LDR error
Eω	Difference between calculated angle and actual angle in east-west angle

D. *Defuzzification*

The fuzzy value obtained from the application of table 1 will be searched for its crisp value using the center of gravity method. The formula for the center of gravity or centroid is as follows:

$$x^* = \frac{\sum u_x(x).x}{\sum u_x(x)} \quad (6)$$

Where x^* is the defuzzified output, $ux(x)$ is the aggregated membership function and x is the output variables.

The crisp value obtained is entered into the following equation to get the delay of the stepper driver trigger pulse:

If the out value is 0 or positive then the motor rotates clockwise and uses equation 7 to get the delay value

$$y = -200x + 1000 \quad (7)$$

If the out value is negative then the motor rotates counter clockwise and uses equation 8 to get the delay value.

$$y = 200x + 1000 \quad (8)$$

E. *System Response*

This project aims to track the movement of the sun and see the response of the system when the weather changes. Figure 7 shows the calculated angle is different from the actual angle under certain conditions. For example, at 13:53, the difference between the calculated angle and the actual angle (Eω) is 7.56º. At that hour, the sun should be at an angle of 26º to the west. Since the west LDR was darker than the east LDR, the system responded by positioning the east west axis at an angle of 18.44º to stay away from the darker area. LDR readings can be seen in Figure 6. In that picture, at 13:53 the west LDR is 31 while the east LDR is 18. Detail position of the system and the sun can be seen in figure 8

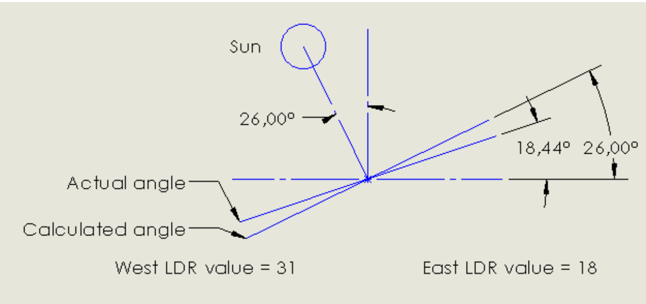

Figure 8 Sun and system position at 13:53

V. CONCLUSION

This two-axis solar tracker successfully tracks the sun on both axes. The arduino/calculated tilt angle of the north-south axis matches with the actual angle of the north-south axis. Moreover, as a result of a fuzzy logic method, the west-east axis is able to follow the sun's movement and adapt to the environment. The east-west axis will avoid moving in a darker direction to produce a more optimal output.

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