Initial Design of Dual-Axis Solar Tracker to Increase Efficiency of Monocrystalline Solar Panel

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Abstract -- Fossils and mines become the main sources of producing electricity in Indonesia. Due to the availability of the sources, the price gets higher and it has a bad impact on the environment. Therefore, we need a new source to produce the electricity. Solar energy can be a solution, it has unlimited availability and it's eco-friendly. The solar panel can be a medium to convert sun energy to electrical energy. The solar panel will be more efficient if the face of the panel always facing toward the sun. In this research, a panel will be designed so it can always move towards the sun's movement. The fuzzy logic method will be used for the tracking method because it can increase the efficiency higher. Fuzzy logic systems consist of 4 inputs and 2 outputs. The inputs are based on each LDR sensor and the output is the motor on each axis. Based on the calculation horizontal has a 0,73% error and vertical has 0,41%.

Keywords:
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Solar Energy
Solar Tracking
Solar Panel
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I. INTRODUCTION

Most of the electrical energy used in Indonesia today comes from non-renewable natural resources such as fossils and mines. Currently, the availability of fossils and mines is decreasing [1]. This matter results in increasing the price of those resources. Also, non-renewable natural resource exploitation causes pollution effects that are not environmentally friendly. Therefore, a new renewable energy source can be a solution to this problem. Solar energy, wind energy, and hydropower energy are part of renewable energy [2]. Solar energy, also known as solar energy is energy that comes from the sun where the amount is abundant, and Indonesia is a country located on the equator, so the sunlight that enters Indonesia will be very maximum. To take advantage of this, a tool is needed that can convert energy solar energy to become electrical energy. A solar panel can change solar energy into electrical energy.

Solar panels are divided into two, namely static and active [3]. Solar panels static has a drawback because the solar panels can't move while the sun moves and at a certain time the solar panels don't absorb the sun efficiently. To get maximum solar energy, the solar panel should face the sun all day long. The position of the sun each time will differ due to the rotation of the sun, so the solar panel must be able to follow the sun's movement. Active solar panels are divided into two, namely single-axis and dual-axis. Single-axis solar panel can move in one direction the dual-axis axis and solar panel can move on two axes.

In research [4], a single tracking system was designed on solar panels and produced an efficiency of 8.3% - 10%. In research [5], the dual-axis solar tracking method is used. The actuator used is one stepper motor and one linear actuator. The light sensor used is a photodiode and is controlled by Arduino. Efficiency on the solar panel increased by 18%. In research [6], used Arduino Mega 2560 Microcontroller with a linear actuator obtained an efficiency percentage of 27.62%. The study [7], used a dual-axis solar tracking method using an LDR sensor and linear actuator as the actuator of the solar panel, and the method watering every 4 pm. The efficiency of this research can be increased up to 43% with testing for 11 hours.

In research [8] a system has been created to increase the efficiency of solar panels monocrystalline by using the water treatment method. The experiment was done and showed that the most effective water treatment method is by using water to cool the solar panel. This paper will be about continuing from [8]. The watering method has been added to increase the efficiency, so in this paper, solar tracking dual axis will be added to the method. There will be a tracking method and watering method in one system. Design and fuzzy system calculation will be the main topic in this paper.

II. METHODOLOGY

The flowchart from the Figure 1 describes the study's process

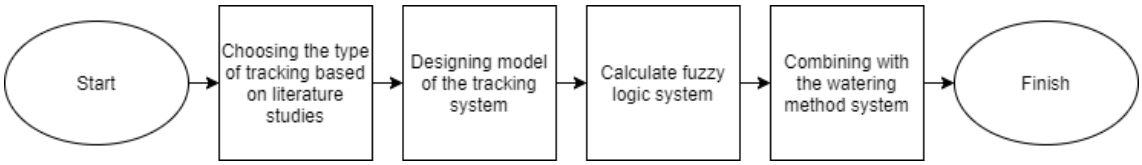

FIGURE 1.
Research Methodology Flow Chart

The first thing to do in this research is by choosing the type of tracking based on literature studies. From the studies, the tracking model and fuzzy logic can be calculated. Then the watering system can be combined with the system.

A. Watering Method Review

In this research, there will be an addition to the method. Based on [8] showed that, watering the surface of a solar panel when it gets hot can increase the efficiency of the solar panel. by 7,01%. Water will flow if the temperature of the solar panel goes to 74,53° and will be pumped for 1,17 minutes.

B. Determining Type of Tracking

Based on the study of literature, a table has been made. The single-axis has an efficiency between 8,3-18% and dual-axis has an efficiency between 23-43%. So dual-axis solar tracking has a higher efficiency than the single-axis, dual-axis is chosen for this research.

C. Designing Fuzzy Logic System

The initial step to determine the movement of the tracking is by calculating the system by fuzzy logic. According to [9], in Boolean Logic, the value obtained is in the form of 1 or 0. Fuzzy logic is usually called fuzzy logic because it aims to find a value between 1 and 0. Probability and fuzzy logic cannot be interpreted the same, because probability determines the probability that will occur, while fuzzy logic can get the value according to the prediction [10]. Based on the FLC (Fuzzy Logic Controller) diagram, is divided into 3 steps in the form of:

A. Fuzzification
B. Inference Mechanism
C. Deffuzification

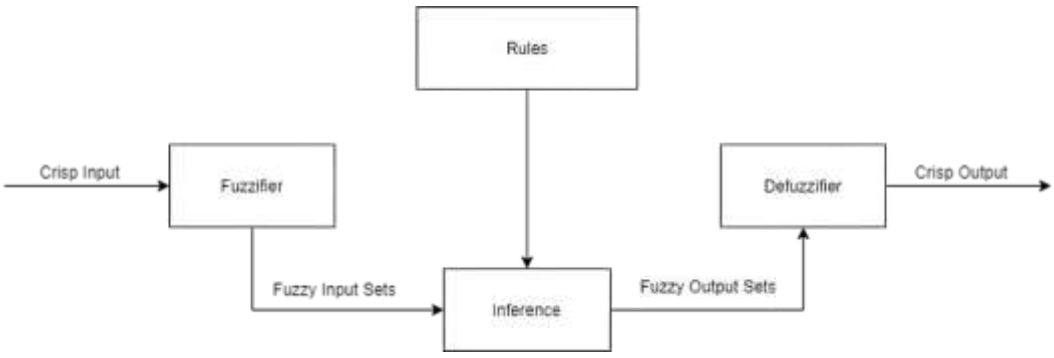

FIGURE 2.
FLC DIAGRAM

Based on Figure 2 fuzzy logic system begins with input, this input is crisp. The crisp value is a firm value generated by the sensor or user. The value of this crisp will be processed in the fuzzification process and the result of this process will be in the form of fuzzy input sets. This result will be processed again in the inference mechanism process. In the inference mechanism process, fuzzy input sets will be processed into fuzzy output sets using the rules or regulations that have been made in the rules table. The results of fuzzy output sets will be converted into crisp output in the defuzzification process. For a clearer explanation, will be explained one by one for each process,

A. **Fuzzification** is the initial stage in the design of fuzzy logic. In this process, the input value will be converted into a fuzzy value, because in the inference mechanism process, the input value must be a fuzzy value. This fuzzy value is also referred to as a membership function, each membership function has a different value based on the input set. The following is an example of a membership-function chart

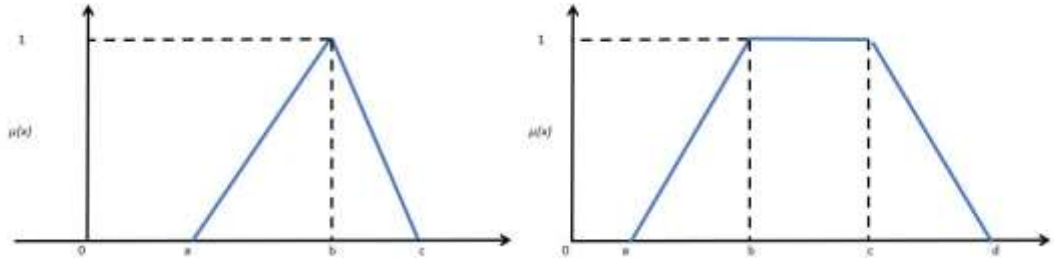

FIGURE 3.
Membership Function Graph

To get a fuzzy value, the membership function graph must be made first as shown in Figure 3 and Figure 4 is an example of a triangular-shaped graph.

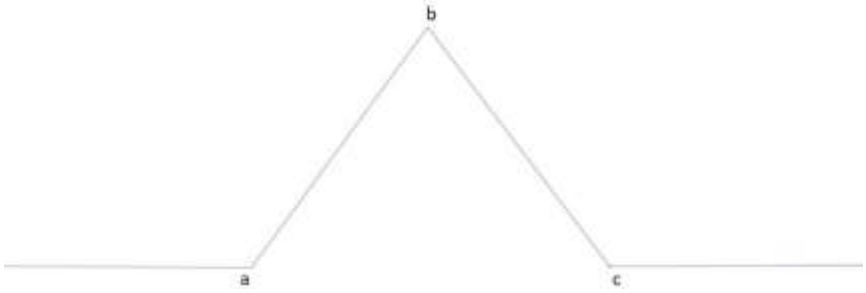

FIGURE 4.
Graph of Membership Function

To calculate the firm value from Fig.4, the following formula can be used:

$$f(x;a,b,c) = \begin{cases} x \le a, \quad \mu(x) = 0 \\ a \le x \ \le b\,, \quad \mu(x) = \frac{(x-a)}{(x-b)} \\ b \le x \le c, \mu(x) = \frac{(c-x)}{(c-b)} \\ \mathrm{c} \le \mathrm{x}, \quad \mu(x) = 0 \end{cases} \tag{1}$$

To calculate points a-b can be used equation 2,

$$a \le x \le b, \mu(x) = \frac{(x-a)}{(x-b)} \tag{2}$$

To calculate the point b-c can be used the formula 3

$$b \le x \le c, \mu(x) = \frac{(c-x)}{(c-b)} \tag{3}$$

From the two calculations above, the firm x value is obtained from the input value. Any point other than point a-b-c will have a value of 0, then equations 4 and 5 can be used

$$x \leq a, \mu(x) = 0 \tag{4}$$

and

$$c \leq x, \mu(x) = 0 \tag{5}$$

B. **The inference Mechanism** is an advanced process of fuzzification. The fuzzy value from the previous process will be used as input for this process. The fuzzy value will be input to the rule table so that it can produce a fuzzy output value.

Rules Table
In this rule table, decisions and rules will be generated based on the input from fuzzy logic. The resulting rule refers to an existing table and is operated using AND and NOT logic gates. This rule uses the format of if and then, so the condition used must be 2 or more.

C. **Defuzzification** is the final process of the fuzzy method. The output value of the inference mechanism will be reprocessed into a firm value. To determine the output, an equation is needed to calculate the fuzzy value so that it can be converted into a firm value. This value is a fuzzy decision, the following is the equation of a fuzzy decision:

$$Fuzzy\ Decision = \frac{\sum \mu(K_n) \times K_n}{\sum \mu(K_n)} \tag{6}$$

In (6) equation there are several components where:
A. μ is the crisp value obtained
B. Kn is the value of the category output

The defuzzification process has three working methods include:
A. Mamdani Method
B. TSK Method
C. Tsukamoto Method

Based on [11], research has been done to find the highest accuration, sensitivity, and precision. It showed that TSK Method has the highest value of the two other methods. So in research TSK Method will be used.

D. Energy Efficiency

Energy efficiency is used to calculate the energy that is consumed and gained. The movement of the tracking system will consume the energy and energy that is absorbed by the solar panel will count as the gained. To calculate formula can be used:

$$\eta = \frac{W_{out}}{W_{in}} \times 100\% \tag{7}$$

η = Efficiency
W_{out} = Consumed Energy
W_{in} = Gained Energy

III. RESULT AND ANALYSIS

The initial concept of this research is about the 3D design and fuzzy logic calculation. The 3D design is built from Solidworks software.

A. 3D Design System

Figure 5 is the isometric view from the initial design of the tracking system. I On the top of the panel there is 4 LDR sensor to track the location of the sun and there is 2 linear actuator to move the system. The size of the tracking system is 1300 mm x 720 mm. When the tracking system works, the actuator will move based on the sensor input to the actuator. The first actuator is to track south and north, and the second actuator is to track east and west.

FIGURE 5.
Isometric View

The solar tracking system is as follows:

1. Initially, the light sensor will read the LDR sensor whether there is light intensity coming in
2. If the light intensity data comes in, it will proceed to the solar panel temperature reading, otherwise, it will be read back by the LDR sensor.
3. Lux data that has been received will be processed in the fuzzification process. In this process, the incoming crisp values will be converted into fuzzy input set values.
4. In the inference section, the fuzzy input set values will be compared according to the rule set that has been created. So that the fuzzy output sets value can be obtained
5. In the defuzzification process, the fuzzy output sets values will be converted to crisp output values.
6. The defuzzification output will be the input to the linear actuator. The linear Actuator will move according to the final value of defuzzification.

B. Calculation of Fuzzy Logic

The design of dual-axis solar panels is designed using the fuzzy logic designer toolbox in Matlab. Fuzzy logic will be processed by the microcontroller Arduino Uno, and the output of fuzzy logic will be used to drive linear actuators. Figure 6 is a representation of the fuzzy logic design. The vertical and horizontal sections have the same input and output values.

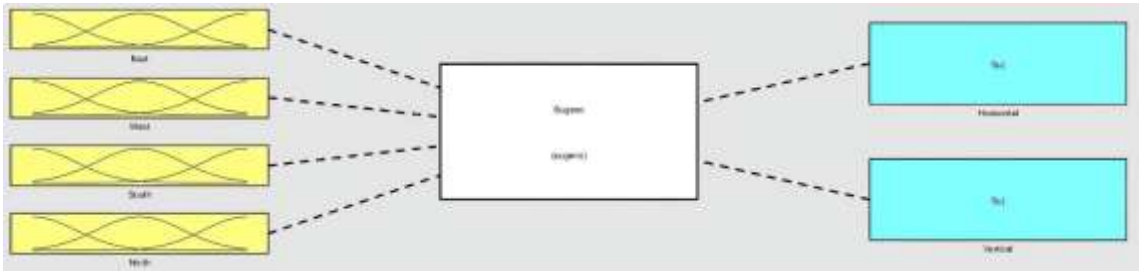

FIGURE 6.
Input and Output from Fuzzy Logic System

Figure 7 is a representation of the horizontal plane. The first thing to do is make the input and output in the membership function. The input from the light sensor is called the East Sensor and West Sensor. The light sensor membership function is divided into 4 fuzzy sets, namely: dim, dark, overcast, and bright. Each set has its own data range as shown in Figure 7

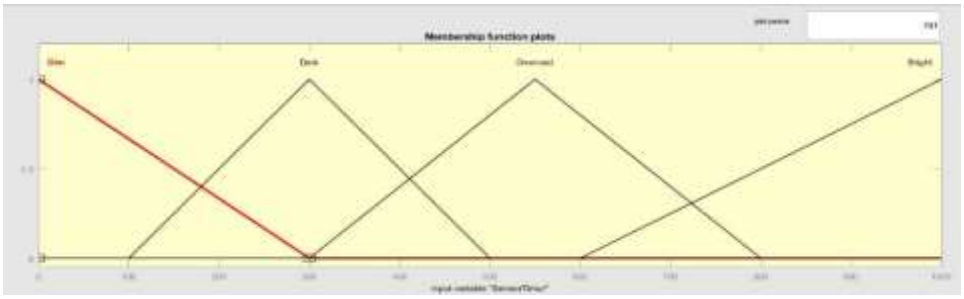

FIGURE 7.
Input from the Fuzzy Logic System

Figure 8 represents the output of the system. The output of this system has 7 sets that have their respective ranges. Results of this output will determine how much the actuator will monitor shriveled or shortened.

FIGURE 8.
Output from the Fuzzy Logic System

A. NB = Negative Big (1)
B. NM = Negative Medium (50)
C. NS = Negative Small (100)
D. Zero = (150)
E. PS = Positive Small (200)
F. PM = Positive Medium (250)
G. PB = Positive Big (300)

Table I is showing the rules from the horizontal line which consist between the east and the west line.

Table I.
Horizontal Rules

	West			
	Dim	Dark	Overcast	Bright
Dim	ZERO	PS	PM	PB
Dark	NS	ZERO	PS	PM
Overcast	NM	NS	ZERO	PS
Bright	NB	NM	NS	ZERO

East

Table II is showing the rules from the vertical line which consists between the north and the south line.

Table II.
Vertical Rules

	North			
	Dim	Dark	Overcast	Bright
Dim	ZERO	PS	PM	PB
Dark	NS	ZERO	PS	PM
Overcast	NM	NS	ZERO	PS
Bright	NB	NM	NS	ZERO

South

C. Case Study

A case study is giving a random number to the fuzzy logic and making a comparison to the Weighted of Average Method. The purpose of this case study is to find out if the fuzzy logic system is working accurately. To find out the percentage of the accuracy is by making a comparison between it. The unit of the calculation will be lux due to the intensity of light

Horizontal

A. Determine the lux of light on the east sensor and the west sensor in Matlab so the output can be calculated (actuator length).

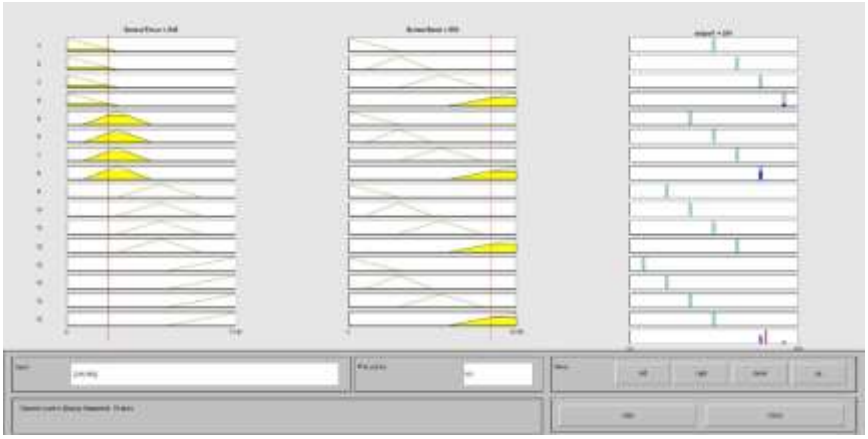

FIGURE 9.
Matlab Calculation

B. Figure 10 is an example of an east sensor input value and a west sensor that produces a horizontal output. If the east sensor has a value of 245 and the west sensor is 850 then the output from the horizontal will produce a value of 261. This output value can also be calculated by the weighted average from the graph.

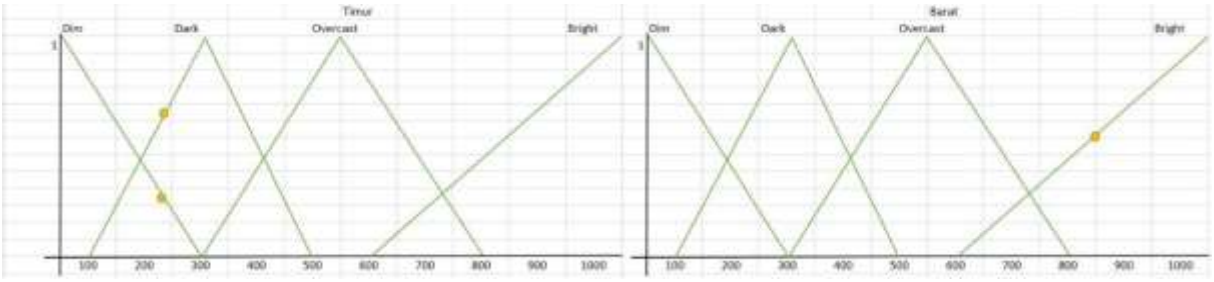

FIGURE 10.
Graph of East and West

C. Figure 10 is taken from the east and west sensor input values. There are 3 orange dots, this shows the point that hits the input. After getting these points, you must find the value of x at each point.

D. Comparing the smaller value between the east and west sensor.

Table III.
Rules Table

		East			
		0,1833	**0,725**		
		Dim	Dark	Overcast	Bright
West	Dim	ZERO	PS	PM	PB
	Dark	NS	ZERO	PS	PM
	Overcast	NM	NS	ZERO	PS
0,625	Bright	NB	NM	NS	ZERO

E. Output Calculation

$$Output = \frac{(0.1833 \times)+(0.625 \times 250)}{0.1833+0.625} = 261.3386 \quad (8)$$

D. Accuracy of Fuzzy Logic System

For knowing the accuracy of the fuzzy logic system, more cases have to be calculated. In each case it has different input and output, the purpose is for knowing the error in each case. After knowing the error in each case, the average error in horizontal and vertical lines can be known.

Table IV.
Horizontal Calculation

East Sensor	West Sensor	MATLAB	Weighted Average	Error
821	230	36.8	36.73	0.19%
690	237	59.42	60.8	2.26%
427	179	95.6	95.621	0.62%
887	179	20.1	20.335	1.15%

Table IV is the result of study cases from the horizontal lines. Different of 4 type study cases have been done and the error in each case can be known.

Table V.
Vertical Calculation

North Sensor	South Sensor	MATLAB	Weighted Average	Error
89,1	396	78.7	78.76	0.05%
180	900	24.9	25.5	2.35%
230	527	86.8	87.1	0.34%
250	839	39.1	39.19%	0.22%

Table V is the result of the calculation in vertical lines. Same as the Table IV 4 types of study case has been done. The purpose of the study case is to know the error between the system and manual calculation.

IV. CONCLUSION

Based on this research, can be concluded that the solar panel will be more efficient if the face of the panel always facing toward the sun. In this research, a panel will be designed so it can always move towards the sun's movement. The fuzzy logic method will be used for the tracking method because it can increase the efficiency higher. Fuzzy logic systems consist of 4 inputs and 2 outputs. The inputs are based on each LDR sensor and the output is the motor on each axis. Based on the accuracy of the fuzzy logic system, the horizontal line has an average error of 0,73% and the vertical line has an average error of 0,41%.

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