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Smart optimization of PV panel output using Fuzzy Logic Controller based solar tracker

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Abstract

Currently, more people choose renewable energy over conventional energy, such as solar energy, which is the most eligible renewable energy in Palembang and South Sumatra due to its strategic location in the equator. However, solar energy cultivation is experiencing various obstacles resulting in not producing maximum output, which is indicated by low output efficiency. Solar tracker or solar tracking system is one of the best methods to ensure the maximum sunlight received by the PV panels. This paper shows the effectiveness of a solar tracking system controlled by FLC compared to a fixed system. The data is taken for 15 days during the weather changing in Indonesia, from the rainy season to the dry season. The maximum power generated by dual-axis solar tracking and fixed solar panels is 96.4768 W and 63,5106 W, whereas the power generated by dual-axis solar tracking is 32.9662 W higher than fixed solar panels. The highest efficiency obtained by dual-axis solar tracking is 25%, while fixed solar panels are 16%. The application of dual-axis solar tracking can optimize and increase the efficiency of solar panels because the panels are always perpendicular to the position of the highest irradiance. Data results show that FLC-based solar effectively improves poweroutput and efficiency compared to a fixed solar panel.

Keywords:
Fuzzy Logic;
PV Panel;
Solar Tracker;

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INTRODUCTION

Currently, more people choose renewable energy over conventional energy and enjoy the benefit of an unlimited source of energy. Hence, more research in renewable energy is conducted to support the necessity of moving from diminishing conventional energy to beneficial renewable energy [1, 2, 3]. Solar Energy is the most eligible renewable energy in Palembang and South Sumatra due to its strategic location in the equator [4, 5, 6]. South Sumatra has a range of potential solar energy cultivation and application. PV installation on the lowland of Palembang [7]. PV installation on the body of water since South Sumatra has many rivers and connected brackish water, such as Junianto et al. and Sasmanto et al. in 2020 [8, 9, 10]. The open space of the Quarry Open Pit Mine was reported by Junaedi et al. in 2021 [11]. The advantage of highland with low temperature and high irradiance availability is presented by Sarwono et al. 2021 [12]. This type of renewable energy is applicable for remote areas can be monitored remotely using IoT Technology [13][14], and has many rooms for further application, such as automatic vehicles [15].

Indonesia Government has started a campaign to improve the application of renewable energy mix and reduce conventional energy [16][17]. However, solar energy's electrical energy is still minimal [5]. This renewable energy is still experiencing various obstacles resulting in not producing maximum output, which is indicated by low output efficiency [18]. Many types of research are dedicated to increasing the output and efficiency of a solar panel by eliminating factors affecting efficiency, such as overheated PV panel by installing an active cooling system [7] and setting the PV panels on the water body to cool down the panel [8, 9, 10]. The effort also includes ensuring maximum irradiance received by the panel, such as by setting the semi-flexible panels in arches [19], developing an algorithm for MPPT [20], and applying sun tracker [21, 22, 23]. Sun tracker application is also applied to thermal solar power [24][25].

Commonly, most solar panels are installed in a fixed position. At the same time, the earth constantly rotates around the sun, meaning that the sun's position will always move every minute along with the earth's rotation. This motion causes the position of the solar panels to be not perpendicular to the sun and results in not maximizing sunlight received by the solar panels. If the sunlight received by the solar panels is not optimal, the power output produced by the PV panel is not optimal. Therefore, adjusting the PV panels' position is necessary to get the maximum light intensity and increase the power output and system efficiency.

Solar tracker or solar tracking system is one of the best methods to ensure the maximum sunlight received by the PV panels. By using a solar tracking system, the energy is generated greater than without a tracker, such as investigated by Pangaribuan et al. [34]. The solar tracker installation to the PV panel ensures the panels always receive the maximum solar irradiance intensity, as concluded by Zakariah et al., 2015 [35]. The tracker directs the panel facing the sun all the time; thus, it moves as the sun moves during the day. The solar tracking system consists of light sensors to detect the position with most light which is interpreted as the position of the sun, a DC motor to move the PV panel, and a microcontroller to process the input from the light sensor and activate the motor.

Commonly, there are two types of solar tracking based on the number of axes used, namely single-axis or one axis [26, 27, 28] and dual-axis or two axes [29, 30, 31, 32]. Single-axis solar tracking can only move horizontally or vertically at a time, while dual-axis solar tracking can move horizontally and vertically at the same time. Therefore, by considering the number of axes used, dual-axis solar tracking has a better level of precision than single-axis solar tracking in positioning solar panels facing the sun's light.

The main problem with the solar tracker can make an unnecessary motion and consume the produced energy. This condition is the downside of the solar tracker system. Therefore, the PV panel should be activated only when the light is insufficient on one side and move to the brighter side. Furthermore, the system should be more intelligent, and installing artificial intelligence (AI) can be the answer to overcome this problem. One of the most applied AI is the Fuzzy Logic Controller (FLC). FLC is a control method that resembles the human mindset in making random or uncertain (vague) decisions between 0 and 1. FLC application makes the solar tracking system work more effectively because it can process the light sensor input towards the position of the largest irradiance to improve output optimization and system efficiency.

This paper shows the effectiveness of a solar tracking system controlled by FLC. The system effectiveness is compared with a fixed system to show how much the output increment and efficiency improved by applying a solar tracking system. The data is taken for 15 days during the weather changing in Indonesia, from the rainy season to the dry season.

METHOD

The Proposed Solar Tracking Dual Axis System

The dual-axis solar tracking system consists of a light sensor, microcontroller, and DC motors. The light sensor senses the position with most sunlight and gives the position to the microcontroller, which activates the DC motors. DC motor moves the PV panel to the sun direction. Figure 1 shows the block diagram of the proposed method considered in this study.

The light sensor applied in this study is the Light Dependent Resistor (LDR). In this system, 4 LDR GL-5539 sensors are used. Two sensors are installed vertically as sensors for the solar panel elevation axis, and two other sensors are situated horizontally as sensors for the rotating axis of the solar panel.

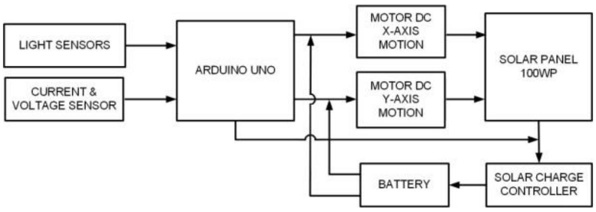


Figure 1. Block diagram of the proposed method

The microcontroller applied in this study is the Arduino, DC motors as actuators and system outputs, and a Solar Charge Controller as a regulator to prevent the battery from getting overcharged. Two DC motors are applied, one for horizontal (x-axis motion) and one for vertical motion (y-axis motion). The current and voltage sensors are installed as the input for Arduino to activate the solar charge controller.

Mechanical Design of Solar Tracking Dual Axis System

Two PV panels are applied in this research. One panel is a fixed panel as the comparison panel to show the effectiveness of the proposed method. Another panel is equipped with a solar tracking system, and Figure 2 shows the mechanical design of the proposed solar tracking dual-axis system.

Figure 3 shows the components installed in a solar tracking system, where no 1 is four light sensors, no 2 is sling rope, no 3 is controller box, no 4 is voltage and current sensor, no 5 is DC motors, and no 6 is PV panel.

Solar Panel Efficiency

The solar panel efficiency measures the output (Watt) compared to its surface area. The more efficient a PV system, the more power generated from it. Therefore, it is crucial to consider the system's efficiency. The efficiency of a solar panel is given by [33]:

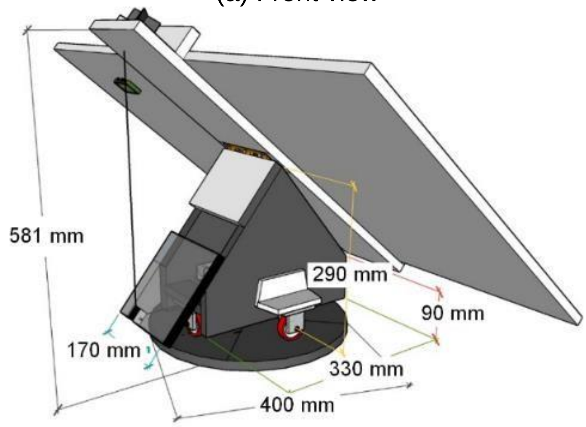
$$\text{n} = \frac{P_{max}}{G \times A} \times 100\% \tag{1}$$

Where η is solar panel efficiency, *G* is the irradiance receive by the panel (W/m^2), and A is the area of the solar panel (m^2).

Fuzzy Logic Controller Design

A fuzzy logic controller (FLC) is installed in this system to implant artificial intelligence (AI). The application of a solar tracking system is expected to optimize the output and efficiency of the solar panel system. However, the downside is that the light sensor might give unnecessary information that activates the motor and continuously moves the PV panel. This condition leads to energy waste and is detrimental to the system.

(a) Front view



(b) Side view and system dimension

Figure 2. The mechanical design of the solar tracking system considered in this study

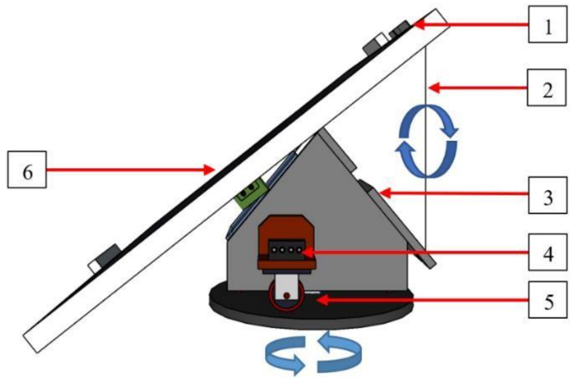


Figure 3. Block diagram of the proposed method

Table 1. Rule-based motor X-axis motion

		X2 - West		
		OVER CAST	CLOUDY	SUNNY
X1 - East	OVER CAST	Stop	Counterclockwise Slow	Counterclockwise Fast
	CLOUDY	Clockwise Slow	Stop	Counterclockwise Slow
	SUNNY	Clockwise Fast	Clockwise Slow	Stop

Table 2. Rule-based motor Y-axis motion

		Y2 - North		
		OVERCAST	CLOUDY	SUNNY
Y1 - South	OVER CAST	Stop	Clockwise Slow	Clockwise Fast
	CLOUDY	Counterclockwise Slow	Stop	Clockwise Slow
	SUNNY	Counterclockwise Fast	Counterclock wise Slow	Stop

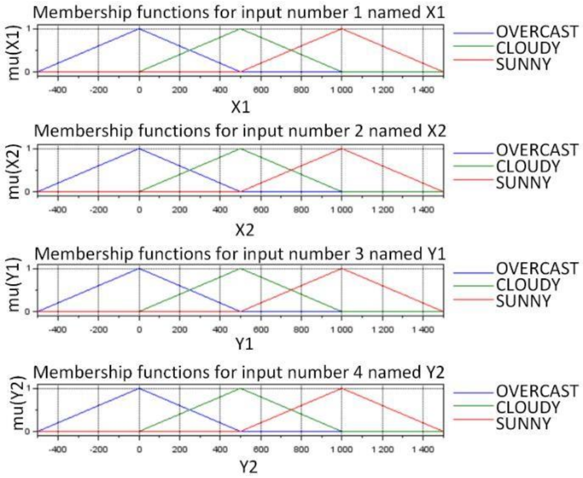
FLC helps the system decide whether it is necessary to rotate the panel. FLC utilizes the input from light sensors and moves the system based on the rule-based given in Table 1 for the X-axis and Table 2 for the Y-axis motion, then processed by Arduino to activate the movement of the motor. The rule-based is derived from three weather conditions; overcast, cloudy, and sunny.

The input variables in this system are Four light sensors (X1, X2, Y1, Y2) with three membership functions each which is presented in Figure 4.a (Overcast, Cloudy, Sunny), while the output variables are two DC motors with five membership functions given in Figure 4.b. The output of FLC is divided into two parts. The first FLC is for two light sensors X1 and X2 (horizontal sensor), with the output being a rotary axis DC motor movement (Motor X). The second FLC is for Y1 and Y2 (vertical sensor) light sensors with a lift-axis DC motor movement (Motor Y) output.

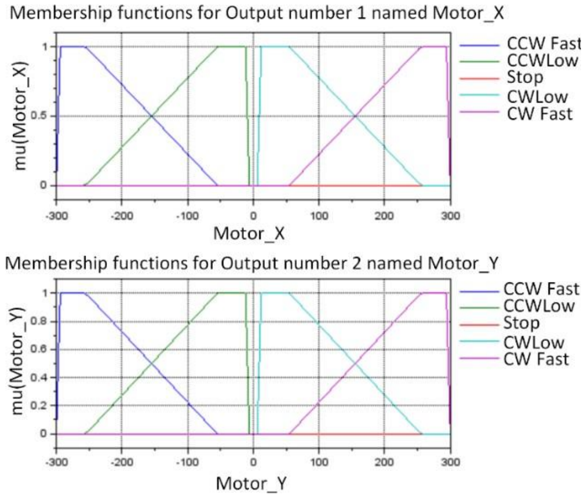
RESULTS AND DISCUSSION

This study investigated the effectiveness of the Fuzzy Logic Controller (FLC) application on the solar tracking system in energy saving. The energy-saving is conducted by only moving the PV panel when the irradiance intensity is below the standard to generate enough electricity. Therefore, this method prevents the Arduino from activating DC motors to move continuously as the irradiance may fluctuate temporarily.

This research applied two polycrystalline 100 WP solar panels. The two panels are situated, as seen in Figure 5. Figure 5(a) shows the PV panel with the solar tracking system, and Figure 5(b) is the fixed panel installed with a tilt angle of 15º facing north. The experiment was conducted from March 15 - 28, 2021, located in Plaju, one of the sub-districts of Palembang, South Sumatra, which is bordering Ilir Timur II and Seberang Ulu I. The latitude and longitude of the location are 2°59’43.3 "S 104°47'40.7"E, and Figure 6 shows the google map of the experiment location. This research was conducted when Palembang was experiencing a transition period between the rainy season and the dry season.



(a) Membership function of inputs



(b) Membership function of outputs

Figure 4. The membership functions of input and output

Figure 5. The experimental testbed of dual-axis solar tracking system and fixed panel.

Figure 6. Google map of experiment location on Palembang

Figure 7 shows the weather conditions during the experiment. The number or length of time indicates this weather's brightness level from sunny, cloudy, and overcast conditions. Figure 7 is determined based on the amount of irradiance received by the PV panel indicated by the irradiance meter. The weather is considered sunny if the irradiance is 500 W/m^2, cloudy if it is 100-500 W/m^2, and overcast is below 100W /m^2.

The weather brightness level is set to show the relationship between the weather condition and the generated power during a particular day. For example, weather on March 19th, 2021, was varied among sunny, cloudy, overcast; the weather brightness level of sunny conditions is "3", which means there were 3 hours of sunny weather out of a total of 12 hours of research. Furthermore, on March 20th, 2021, there was no sunny day, only cloudy with a weather brightness level of "6.5" and an overcast condition of "6" was on that day. Therefore, on March 20th, 2021, the generated power was not maximum due to cloudy weather.

The results of this study indicate that the position of the solar panels is very influential on the power generated by the solar panels. The more perpendicular the PV panels are to sunlight, the more power generated due to maximum irradiance received by the PV panel.

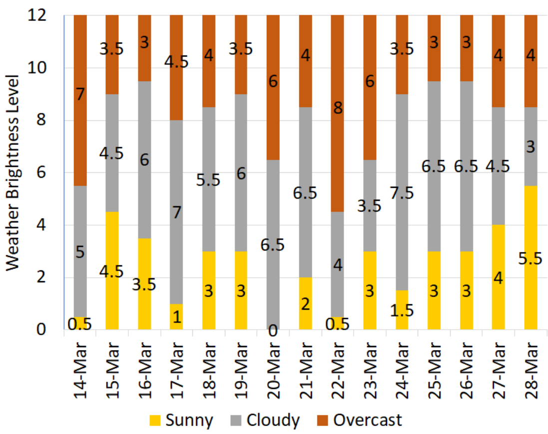


Figure 7. Weather condition during the experiment in 15 days

Figure 8 compares the power generated by the dual-axis solar tracking system (Figure 5(a)) and fixed PV panel (Figure 5(b)) on March 28th, 2021. The experiment was started at 07.00 AM with an irradiance of 89.6 W/m^2. The generated power by dual-axis solar tracking is 7.311 W, and the fixed PV panel is 5.156 W. The most significant irradiance received on that day is 1359.3 W/m^2 at 11.00 AM. The power generated by dual-axis solar tracking is 32.518 W. The fixed panel of 14.641 W. Therefore, it can be concluded that the dual-axis tracking system generates more power than the fixed panel. This condition is due to more sunlight being received by solar panels with dual-axis solar tracking than fixed panels because solar tracking always positions itself towards the position of the greatest irradiance. Figure 9 is a graph of the effect of irradiance on the power generated by the two panels for 15 consecutive days.

Figure 10 compares the maximum value generated power between the dual-axis solar tracking system and a fixed panel during the experiment for 15 days. From the data obtained, weather conditions and sunlight influence the power generated.

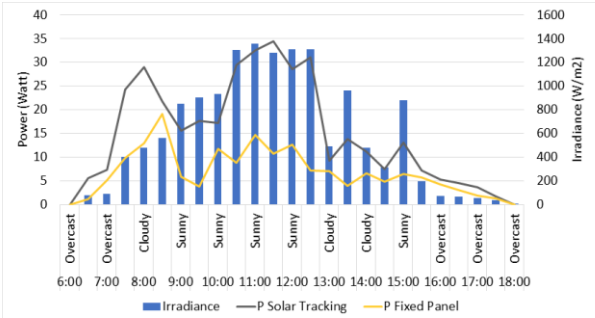


Figure 8. The comparison of generated powered on March 28th 2021

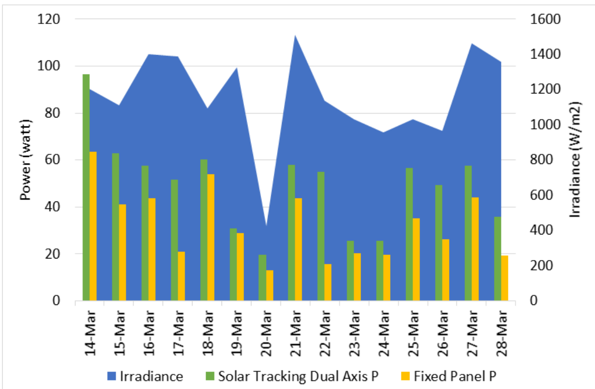


Figure 9. The comparison of maximum power generated by the dual-axis solar tracking system and fixed panel.

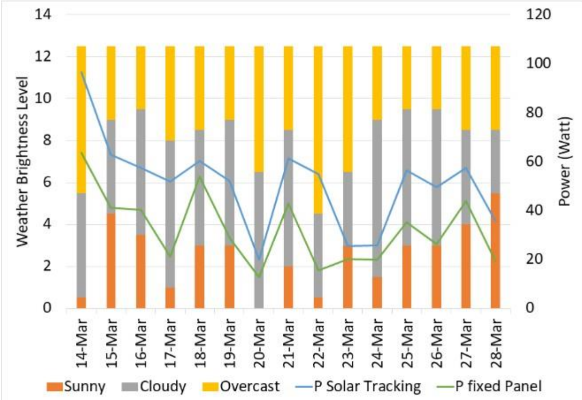


Figure 10. Overall generated power during 15 days of experiments

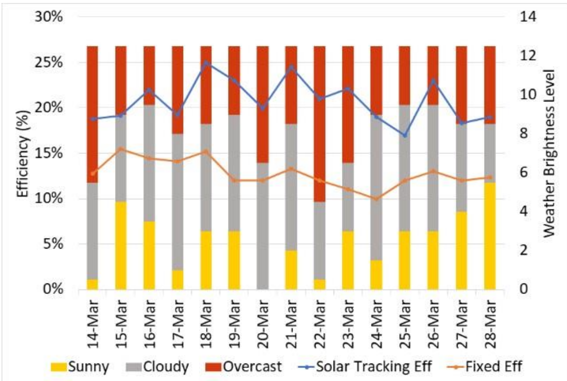


Figure 11. The efficiency comparison between solar tracking system and fixed PV panel

The maximum irradiance on March 14th, 2021, is 1203.2 W/m^2, this number of irradiance results on the maximum power generated by dual-axis solar tracking is 96.4768 W, and the fixed panel is 63.5106 W. On March 20th, 2021, the power generated was the lowest during the experiment; this low power is due to the prevailing cloudy weather conditions, which leads to less sunlight, where the maximum irradiance value is 422.5 W/m^2, with the maximum power generated by dual-axis solar tracking of 19.87818 W, while for fixed panels is 12.78522W.

The solar tracking system's average power produced per day is 62,5145 W, with the total energy generated being 375,084 Wh. The energy will then be stored in a 12 Volt 35 Ah battery with an energy storage capacity of 420 Wh to electrify four 20 W of LED lamps for 5 hours.

This research shows that using dual-axis solar tracking can generate more electricity than fixed solar panels to optimize the application of solar panels as a renewable energy alternative. Figure 11 shows that the highest efficiency for dual-axis solar tracking is 25%, while the highest efficiency value obtained is 16% on the fixed panel. The average efficiency value of dual-axis solar tracking and fixed panel is 20% and 13%, respectively. Therefore, from the data in Figure, it can be concluded that dual-axis solar tracking has a higher percentage of efficiency compared to fixed solar panels.

CONCLUSION

This paper presents smart optimization of PV panel output using a Fuzzy Logic Controller (FLC) based solar tracker. The application of FLC is to ensure that DC motors only move the panel when the irradiance level is below the assigned number to generate enough electricity. This condition optimizes the power required to move the tracker. As a result, the maximum power generated by dual-axis solar tracking and fixed solar panels is 96.4768 W and 63,5106 W. In contrast, the power generated by dual-axis solar tracking is 32.9662 W higher than fixed solar panels. Furthermore, the highest efficiency obtained by dual-axis solar tracking is 25%, while fixed solar panels are 16%. The application of dual-axis solar tracking can optimize and increase the efficiency of solar panels because the panels are always perpendicular to the position of thehighest irradiance of sunlight. Data results show that FLC-based solar effectively improves power output and efficiency compared to a fixed solar panel.

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