DEVELOPMENT OF DUAL-AXIS SUN TRACKER BASED ON TETRAHEDRON GEOMETRY USING PHOTOTRANSISTOR SENSOR

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Abstract
Solar energy is optimally obtained by the solar panel when the solar panel is perpendicular to the position of the sun, so a sun tracker is required to track the sun precisely. This study compares the electrical energy obtained in the proposed dual-axis sun tracker system with tetrahedron geometry of different sizes and using phototransistor sensors with previous research using tetrahedron geometry with more blunt triangular sizes and using LDR sensors. The results showed that the sun tracker in the proposed research obtained an average voltage value of 39.58%greate than the sun tracker of previous research. The average current value on the proposed research sun tracker is 41.42% greater than the previous research sun tracker. The value of electrical energy produced on solar modules using sun trackers is directly proportional to the value of voltage and current produced, that is, if the value of voltage and current is large, the value of electrical energy obtained is also greater. The average electrical energy yield of solar modules using sun trackers such as the proposed research is 60.55% greater than solar modules using sun trackers in previous research.

Keywords: *sun tracker, tetrahedron, cell array, phototransistor, fuzzy logic*

1. Introduction

Energy problems are an interesting thing to research over the years. Many efforts have been made by researchers in finding alternatives for electrical energy sources other than fuel oil and coal. The alternative is to change the source of electrical energy from nonrenewable energy to renewable energy. One source of renewable energy that has a very large opportunity is solar energy. The selection of solar energy is an alternative because the sun is a very wide, abundant, cost free, and environmentally friendly energy source [1][2][3]. Solar irradiance at the top of the atmosphere averages 1367 W/m^2. The sun's radiance does not all reach the earth's surface, because of the earth's atmosphere which can reduce insolation. Optimum insolation reaches 1000 W/m^2 in cloudy and clear weather during the day [4]. Sunlight is converted into electricity using photovoltaic or solar panels. Currently, despite the use of advanced technology, most commercial solar panels are only able to achieve fabrication efficiencies of around 14%20% depending on the constituent materials.

Solar panels will produce optimal efficiency if the solar panels have a perpendicular surface position (90°) to the sun's incident light at all times. In general, the use of solar panels installed to absorb sunlight is still immobile or static, this causes the acquisition of sunlight to be less than optimal, so that the electric power generated is not optimal. One way to make the position of solar panels changeable to be perpendicular to sunlight is to use a solar tracker/sun tracker.

Sun tracker is a device used to move solar panels to be perpendicular to the direction of sunlight [5][6]. In general, sun trackers consist of angle sensor components, light sensors, controllers, and actuators in the form of servo motors and batteries [3]. The sensor is used to provide information related to sunlight to the controller to provide control action. Light sensors that can be used in sun trackers are LDR sensors, photodiodes, and phototransistors. The most important thing in using light sensors for sun trackers is that the light sensors must have the same electrical characteristics between one sensor and so that the sun tracker can face sunlight accurately.

Recent developments of sun trackers used by previous researchers are single axis and dual-axis sun trackers. The results show that sun trackers can increase output efficiency at a threshold of 50%. The dual-axis sun tracker has an efficiency of, Senpinar, et al [7] 13-15%, Zakariah [8] 18.13%, Wang, et al [9] 28.31% for partly cloudy days, Ferdaus, et al [10] 25.62%, Sidek, et al [11] 26.9%, El Hammoumi, et al [12] 36.26%, Abdallah & Nijmeh [13] 41.34%, Jamroen, et al [14] 44.89%.

The shape of the sun tracker and the type of light sensor used in the sun tracker have been widely studied by previous research to track the exact position of the sun. The mechanical shape of the sun tracker has many shapes such as cone shape [15], compact shape [16], tube shape [17], cylinder shape [18], pyramid shape [19][20], tetrahedron shape [21], and others. Research from Esteban et.al [18] and Yoong et al [22] used 4 LDR sensors. Song et al's research [23] designed a cone-shaped sun tracker using 81 photodiode sensors. Fauzan et al's research [24] used 4 phototransistor sensors for solar trackers placed on 2 sensors on the west side and 2 sensors on the east side of the solar tracker, which showed the research results of the average phototransistor error of 1.24% and 1.27% on the eastern frame and 0.47% and 0.93% on the western frame.

Research by Away et al [21] implements a dual-axis sun tracker with tetrahedron geometry using three LDR sensors where one LDR sensor is placed on each side of the tetrahedron and uses a PID algorithm to drives a dual-axis sun tracker that produces a Field of View (FOV) of 289.4o, in this study is a study that produces a sun tracker that uses the least light sensor.

The amount of solar energy that can be obtained by the sun tracker is optimal if the sun tracker tracks the exact movement of the sun. Sun trackers in working require certain algorithms. Research [21] designed a dual-axis sun tracker with tetrahedron geometry using the PID algorithm. Research [25] applies a fuzzy logic algorithm to the sun tracker dual-axis tetrahedron geometry, this research produces simulations with input in the form of three LDR sensors that can affect the movement of servo motors in determining the direction of light. Research [26] compared the performance and optimization of two types of sun trackers with tetrahedron geometry using PID and Fuzzy logic algorithms. PID and Fuzzy logic algorithms were used to control the servo movement of the dual-axis sun tracker. The results show that the fuzzy logic algorithm controller works better than the PID controller which can be seen from the amount of load received by the solar cell. This research is a follow-up research from research [27], where the previous research used LDR sensors while this research it is proposed to implement a dual-axis sun tracker using phototransistor sensors.

2. Methodology

In this research, the system built is a sun tracker carried out by solar panels using an Arduino Uno Microcontroller. The solar panel is controlled using a servo motor. The proposed sun tracker system uses three sensors placed in a tetrahedron geometry position. In building the sun tracker system, the following tools and materials are needed.

a. Servo Motor

Servo motors are used as actuators that allow precise control of angle, speed, and acceleration. Servo motors can adjust the angle and speed of rotation accurately. The servo motor receives an input voltage of 7 Volts to drive the sun tracker. This research uses a continuous servo motor. The type of servo motor used is MG996R. In the servo motor used in this study there are 2 pieces with the MG996R type that can rotate 180^{o}. Each servo motor functions to drive one DC motor axis. Supplied with a voltage source from a power supply of 6 V.

Figure 1. Servo Motor Type MG 996R

b. Light sensors

The light sensor that will be used in this research is a phototransistor with the TEMT 6000 type. The sensor is placed at each point on the side of a triangle arranged in a tetrahedron geometry. The shape of the phototransistor sensor is in Figure 2.

Figure 2. Phototransistor Sensors

c. Arduino Uno microprocessor

The Arduino Uno microcontroller is a component that connects and fully controls other hardware components. The Arduino Uno used in this research is the Arduino Uno R3 type. Arduino Uno R3 is a microcontroller development based on the ATmega328P chip. This microcontroller has 14 digital input/output pin, and 6 analog input pins. Arduino Uno R3 can be seen in Figure 3.

Figure 3. Arduino Uno microcontroller

d. Data Loggers

This data logger is equipped with an SD card slot for data storage and a Real Time Clock (RTC) module to provide real-time to store data. The shape of the data logger used in this study can be seen in Figure 4.

Figure 4. Data Loggers

e. Voltage Sensors

The voltage sensor is used to obtain the voltage value generated by the solar panel when tracked using the sun tracker device. The input voltage for the voltage sensor module is 0-25 VDC. The shape of the voltage sensor used in this research can be seen in Figure 5.

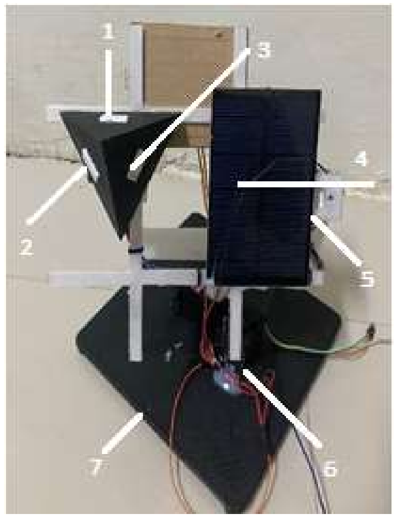
Figure 5. Voltage Sensor

f. Solar Module

Solar modules are a collection of solar cells arranged in series or parallel into one electrical circuit. Solar modules work at an electrical voltage value of 12 Volts or 24 Volts. The type of solar module used is a 12 V, 1.5 WP mini solar module of the polycrystalline type. The shape of the solar module used in this study can be seen in Figure 6.

Figure 6 Solar Module

The prototype sun tracker dual-axis sun tracker based on tetrahedron geometry using three phototransistor sensor produces the physical form of the prototype design in Figure 7. On the side of the sun tracker, a solar module is installed which functions to convert sunlight into electrical energy.



Noted: (1),(2),(3) phototransistor sensors; (4) module solar , (5),(6) servo motors; (7) control boxes

Figure 7 Prototype Sun Tracker

After the sun tracker system is completed, the next step is towards data collection. Testing the sun tracker system is done by outdoor testing with light from the sun. The construction of the proposed sun tracker prototype configuration can be seen in Figure 8.

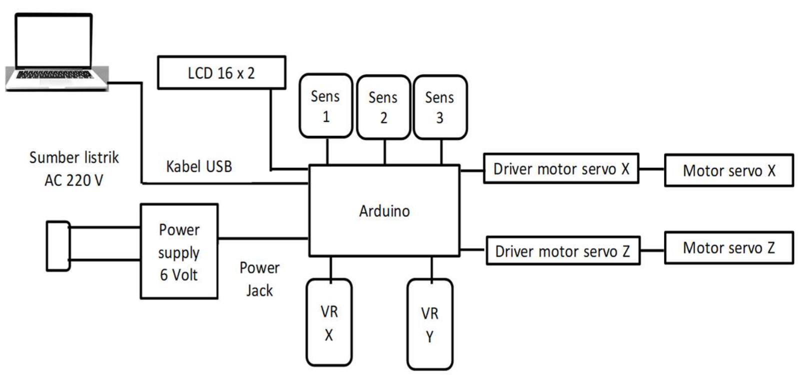


Figure 8 Circuit Diagram of The Sun Tracker System

Figure 8 shows that the Arduino Uno microcontroller is connected to a personal computer via a USB cable to upload the program and supply power to turn on the Arduino Uno. In addition to using voltage from a personal computer, a power supply is used which is connected to a 220 V AC power source to drive the servo motor. When the data is tested and collected, the voltage and current data generated by the solar cell are recorded by the data logger with Real-Time Clock (RTC). The voltage value reading on the solar panel uses a voltage sensor. The solar module is exposed to the sun, so the sensor reads the voltage value generated, then sent to the Arduino Uno and data logger to be recorded in real time.

3. Result and Discussion

Light sensors that can be used in a sun tracker are LDR sensors, phototransistor sensors, or photodiode sensors. Previous research [31] used LDR sensors as light sensors. In this study, the prototype built is a modification of the previous sun tracker research. In this study, testing and data collection using 2 sun trackers, each using three LDR sensors and three phototransistor sensors. The two sun tracker systems are carried out with the same control system settings and algorithms and the same control programming, but using different types of sensors, namely LDR sensors and phototransistor sensors. This is done to compare the values of the two light sensors for the accuracy of the light intensity generated by the sun tracker. More accurate tracking will result in more electrical energy captured by the solar module. Data collection for the sun tracker is done as shown in Figure 9.

Figure 9. The process of returning geometric tetrahedron sun tracker data using a phototransistor sensor

Figure 9 shows the prototype sun tracker made with the same construction as the previous study and the same control algorithm, namely PID. This is done to compare the results obtained from the two different types of sensors by looking at the electrical power and electrical energy generated by the solar module contained in the sun tracker.

During data collection, the sun tracker is allowed to move following the sunlight to get the electrical power output with different light sensors on the dual-axis sun tracker with tetrahedron geometry. RTC to record the voltage and current data generated by the solar module. The data is recorded every 10 seconds by the RTC. During the experiment, which was conducted in cloudy and sunny weather. Sun tracker testing from 08.00 to 16.00 During the data collection process, the weather tends to be unstable, cloudy weather occurs from 08.00 to 10.00. Sunny weather occurs from 10:00 to 14:00. Cloudy weather occurred from 14.00 to 16.00, and at 16.00 clouds began to cover most of the sky and started to rain so data collection stopped until 16.00. The results of the comparison of the voltage used by the LDR sensor with the phototransistor sensor are shown in Table I.

TABLE I. DATA COLLECTION RESULTS OF TETRAHEDRON GEOMETRY SUN TRACKER WITH PHOTOTRANSISTOR SENSOR

Time	V (Volts)	I (mA)	P (mW)	W(J)
08:00:00	3,726	25,699	95,765	0.958
08:10:00	3,836	26,452	101,457	1015
08:20:00	3,900	26,899	104,912	1,049
08:30:00	3,702	25,533	94,534	0.945
08:40:00	3,812	26,292	100,233	1,002
08:50:00	4.106	28,317	116,269	1.163
09:00:00	4,505	31,070	139,974	1,400
09:10:00	4,664	32,168	150,045	1,500
09:20:00	4,646	32,042	148,868	1,489
09:30:00	4,332	29,873	129,400	1,294
09:40:00	5.135	35,415	181,866	1819
09:50:00	5.158	35,573	183,485	1835
10:00:00	5554	38,303	212,732	2.127
10:10:00	5065	34,932	176,937	1,769
10:20:00	4,981	34,351	171,096	1,711
10:30:00	4,884	33,685	164,529	1,645
10:40:00	4,954	34,165	169,254	1693
10:50:00	5.129	35,370	181,404	1,814
11:00:00	4,994	34,441	171,993	1,720
11:10:00	5.158	35,570	183,456	1835
11:20:00	5.172	35,668	184,471	1,845
11:30:00	3,396	23,421	79,539	0.795
11:40:00	5,407	37,292	201,647	2016
11:50:00	4,594	31,685	145,572	1,456
12:00:00	4,505	31,070	139,974	1,400
12:10:00	5.157	35,564	183,398	1834
12:20:00	4,814	33,202	159,843	1,598
12:30:00	4,575	31,550	144,335	1,443
12:40:00	4,835	33,348	161,252	1613
12:50:00	5,321	36,696	195,259	1953
13:00:00	5.202	35,873	186,598	1866
13:10:00	4,660	32,137	149,757	1,498
13:20:00	4,990	34,413	171,712	1,717
13:30:00	4,012	27,671	111025	1110
13:40:00	3,727	25,705	95,807	0.958
13:50:00	4,254	29,337	124,794	1,248
14:00:00	3,931	27,112	106,584	1,066
14:10:00	3,982	27,460	109,340	1,093
14:20:00	2,459	16,960	41,710	0.417
14:30:00	2,495	17,208	42,935	0.429
14:40:00	3,506	24,182	84,794	0.848
14:50:00	4.205	28,997	121,919	1,219
15:00:00	3,867	26,668	103,123	1,031
15:10:00	4,025	27,755	111,702	1.117
15:20:00	3,807	26,255	99,955	1,000
15:30:00	4,093	28,230	115,555	1.156
15:40:00	3,836	26,458	101,500	1015
15:50:00	3,856	26,595	102559	1,026
16:00:00	2,385	16,446	39,220	0.392
Min	2,385	16,446	39,220	0.392
Max	5554	38,303	212,732	2.127
Average	4,353	30023	134,573	1,346

Based on Table I shows the data generated by the dual-axis sun tracker with the difference in the light sensor used in the sun tracker is different from the sensor used in previous studies. The results of the sun tracker that uses a phototransistor sensor, the sun tracker gets a maximum voltage of 5.554 Volts, a minimum voltage of 2.385 Volts, and an average voltage of 4.353 Volts. The maximum current value is 48.303 mA, the minimum current is 16.446 mA and the average current is 30.053 mA. The voltage and current data obtained are constant when the weather is also constant. But the situation that occurs when taking data for the sun tracker system, the weather in the morning is unstable, but in the afternoon the weather is stable so that the voltage obtained is more constant. The results of the acquisition of voltage and current on the sun tracker that uses phototransistor sensor are 41.42% greater than the sun tracker that uses an LDR sensor. The graphical form of voltage and current values can be seen in Figure 10 and Figure 11.

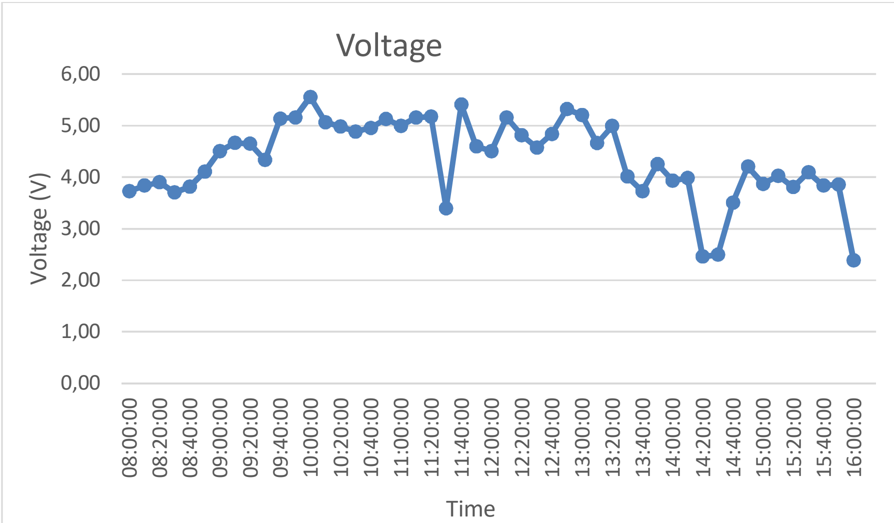


Figure 10. Voltage Gain Results on a Sun Tracker that uses phototransistor sensor

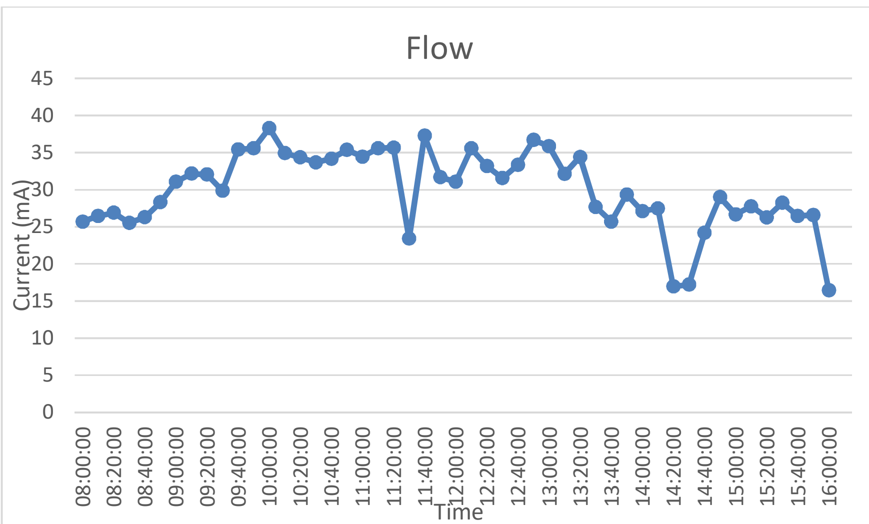
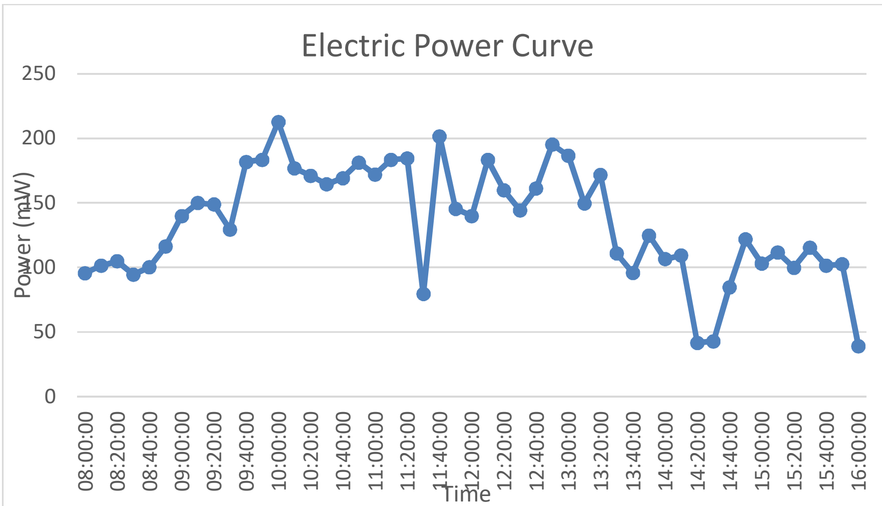


Figure 11. Obtained Results Current in a Sun Tracker Using Phototransistor Sensor

The results showed that the sun tracker using phototransistor sensors produced a maximum power of 212.732 mW or 0.212 W, a minimum power of 39.220 mW or 0.039 W, and an average power of 134.573 mW or 0.134 W. The total electrical power generated by the solar module using the tetrahedron geometry sun tracker using phototransistor sensors during tracking was 6.594 W while the previous research for tracking was 6.594 W. The total electrical power generated by the solar module using a tetrahedron geometry sun tracker that uses a phototransistor sensor during tracking is 6.594 W while previous research for a tetrahedron geometry sun tracker that uses an LDR sensor is 3.745 W.



Figures. 12. Results of Obtaining Electrical Power on a Sun Tracker Using Phototransistor Sensor

Based on the voltage, current and electrical power generated by the solar module using a tetrahedron geometry sun tracker that uses a phototransistor sensor can produce a total electrical energy of 65,941 Joules which is done for 8 hours to track the sun. While solar modules that use sun trackers that use LDR sensors obtain a total electrical energy of 37.452 Joules. Therefore, it can be concluded that the sun tracker in the proposed research produces more electrical energy than the sun tracker in the previous research with a difference of 45.66%. Based on the data obtained, it can be concluded that the tetrahedron geometry sun tracker using phototransistor sensors on each side of the tetrahedron collected 76.07% more energy than the previous research sun tracker using LDR sensors. The difference generated between the two sun trackers using different light sensors can occur because the phototransistor has shown greater light sensitivity than the LDR. The electrical response of the phototransistor to lighting shows a better variation profile in terms of sensitivity and precision. Light-based electrical values obtained from LDR and phototransistor, it can be seen that the use of phototransistor in illumination measurement devices will provide more consistent values [29].

4. Summary

A solar module equipped with a dual-axis tetrahedron geometry sun tracker where the light sensor used is a phototransistor sensor has been designed and tested. The performance results of this study have been compared with the performance of sun trackers in previous studies using tetrahedron geometry and using LDR sensors. The test results obtained can be concluded that the results of sun trackers using phototransistor sensors get an average voltage of 4.353 Volts and an average current of 30.053 mA. The results of the acquisition of voltage and current on the sun tracker that uses a phototransistor sensor are 41.42% greater than the sun tracker that uses an LDR sensor. When viewed from the average electrical power of 134.573 mW or 0.134 W.

The value of electrical energy generated in solar modules using sun trackers is directly proportional to the value of voltage and electrical power generated, that is, if the value of voltage and electrical power is value of electrical energy obtained is also greater. The average electrical energy yield of solar modules using sun trackers such as the proposed research is 60.55% greater than solar modules using sun trackers in previous research.

The results show that phototransistor sensors are more effective than LDR sensors in tetrahedron geometry sun trackers. The input of three phototransistor sensors on each prototype can influence the servo to determine the movement of the sun. Although the sensors have shown promising performance, there is still research to be done in the future such as using types of light sensors other than phototransistors, LDR. Or using other algorithms in the dual-axis sun tracker control system.

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