Performance Comparison Between LDR and Phototransistor Sensor for Dual-Axis Sun Tracker Sensor Based on Tetrahedron Geometry

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***Abstract*— Solar energy is optimally obtained by solar cells when the solar cells are perpendicular to the sun's position, so a sun tracker is needed to track the sun precisely. This research compares the electrical power used in two system dual-axis sun trackers with a tetrahedron geometry that uses an LDR sensor with a phototransistor sensor. The two sun trackers are built identically and the experimental data with the servo movement and the solar cell load are carried out side by side. The servo motor controls with Proportional Integral Derivative (PID) algorithm controls the movement of the dual-axis sun tracker. Data were obtained by recording the voltage and current received by the solar cells installed on the two sun trackers and comparing the results. The results showed that the phototransistor sensor performs better than the LDR sensor. This can be seen from the amount of power generated by the phototransistor sensor which is more than the power generated by the LDR sensor on the solar cell. The solar energy received by sun tracker uses a phototransistor sensor average 40% more than sun tracker uses an LDR sensor.**

***Keywords*— sun tracker, tetrahedron, solar cells, LDR, phototransistor**

I. INTRODUCTION

Electrical energy is interesting to study so far. Many efforts have been made by researchers in finding alternatives to sources of electrical energy besides oil and coal fuels. The alternative is to change the source of electrical energy from non-renewable energy to renewable energy. One of the renewable energy sources that have enormous opportunities is solar energy. The choice of solar energy as an alternative is because the sun is very widespread, abundant, free of charge, and an environmentally friendly energy source [1]-[2]. The solar radiation at the top of the atmosphere averages 1367 W/m^2. Not all of the sun's rays 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 sunny weather during the day [3]. Sunlight is converted into electricity using photovoltaic (PV)/solar cells. Currently, despite using advanced technology, most commercial solar cells are only able to achieve a fabrication efficiency of around 14% -20% depending on the constituent materials.

Solar cells will produce optimal efficiency if they solar cells have a surface position that is perpendicular (90°) to the incoming sunlight every time. In general, the use of solar cells installed to absorb sunlight still cannot move or be static, this causes the acquisition of sunlight to be less than optimal so the electricity generated is not optimal. One way to change the position of the solar cell to be perpendicular to the sunlight is to use a solar tracker/sun tracker. Sun tracker is a device that is used to move solar cells so that they are perpendicular to the direction of sunlight [4]-[5]. The sun tracker consists of actuators, controllers, angle sensors, light sensors, and sources of electrical energy. For a dual-axis sun tracker use two servo motors or stepper motors as actuators. The light sensor used on the sun tracker can be a Light Dependent Resistor (LDR) sensor, phototransistor, or photodiode. Sun tracker can predict coordinate differences in sun movement from east to west. Thus, solar cells with the installation of a sun tracker can maximize the power output of electricity compared to solar cells without a sun tracker.

The current development of the sun tracker used by previous researchers is a single axis and dual axis sun tracker. The research results show that the Sun tracker can increase the output efficiency at the threshold of 50%. For a dual axis Sun tracker, it has an efficiency, Senpinar, et al [6] 13-15%, Zakariah [7] 18.13%, Wang, et al [8] 28.31% for partly cloudy days, Ferdaus, et al [9] 25.62%, Sidek,et al [10] 26.9%, El

Hammoumi, et al [11] 36.26%, Abdallah & Nijmeh [12] 41.34%, Sungur [13] 42.6%, Jamroen, et al [14] 44, 89%, Bakos,et al [15] 46.46%, Amadi, et al [16] 31.4% more dual axis Sun trackers compared to single axis and 67.9% more dual axis than fixed solar panels , Hassan, et al [17] 31.4% and 29% when equipped with a single axis and dual axis Sun tracker.

The shape of the sun tracker and the type of light sensor used in the sun tracker have been extensively studied by previous studies to track the sun's position precisely. Research from Esteban et.al [18] and, Yoong et al [19] used 4 LDR sensors. Research by Song et al [20] designed a cone-shaped sun tracker using 81 photodiode sensors. Research by Fauzan et al [21] used 4 phototransistor sensors for a solar tracker. Research by Away et al [22] implemented a dual-axis sun tracker with a tetrahedron geometry using three LDR sensors. Research [22] is a study that produces a sun tracker that uses the least amount of light sensors. However, in this study using the LDR sensor. In this study, two sun trackers were built and arranged in a geometric tetrahedron, each using a type of light sensor in the form of an LDR sensor and a phototransistor sensor placed on each side of the sun tracker. Each side of the sun tracker with a tetrahedron geometry is placed with a light sensor so that a sun tracker uses three light sensors. This is done by researchers because they want to see a comparison of the performance of which light sensor has the best light intensity to track sunlight. The greater the intensity of light generated on the sun tracker, the greater the electrical power generated by the solar cells.

Developments in terms of the algorithm used for sun trackers in the form of research for dual-axis sun trackers using fuzzy controllers [23] provide research results with fuzzy logic controllers resulting in the output power generated by PV panels exceeding 47% compared to fixed solar panels. Researchers [7] use a fuzzy logic controller to provide the best decision regarding the direction the solar panel must rotate and the position must be fixed, thus providing high output power efficiency. Research using a PID controller [10] whose results showed the solar tracker accuracy was ±0.5°, and produced 26.9% and 12.8% higher power than a fixed PV system. Researchers [24] used a PID controller, with the results of the study showing an accuracy error percentage rate of 31.26% and a speed of 0.063 m/s. Researchers using the ANFIS algorithm [25] proved that ANFIS can be used adequately to design and implement sun tracking systems.

The final result of the research is a comparison of the electrical power generated on a dual-axis sun tracker with an LDR light sensor and a phototransistor light sensor. In this study, three LDR sensors and three phototransistor sensors were used. This prototype is a modification of the previous sun tracker research.

II. LDR AND PHOTOTRANSISTOR SENSOR

A. *LDR Sensors*

The LDR (Light Dependent Resistor) sensor is a type of light sensor that uses a working principle like a variable resistor. The physical form of the LDR can be seen in Figure 1. The working principle of the LDR is that the resistance value depends on the intensity of the light received. The greater the intensity of light received by the resistance value, the lower the resistance value because the material from the disc on the LDR will produce free electrons with a relatively small number, which results in only a few electrons carrying electrical charge, meaning that when the light intensity is low, the LDR sensor becomes the less current conductor. Well, it can be said LDR has great resistance. The less intensity that hits the sensor, the greater the resistance value because there will be more electrons released from the semiconductor material which results in more electrons carrying electrical charge, meaning that at this time the LDR becomes a conductor because it has a small resistance.

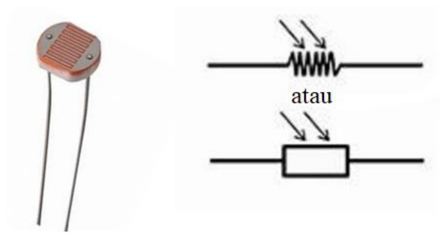


Fig. 1. The shape and symbol of the LDR sensor

B. *Sensor Phototransistors*

The phototransistor light sensor is a light sensor of the transistor type which functions to convert light energy into electrical energy which has an amplifying component. The amplifier component of the phototransistor provides better sensitivity than other light sensors. The shape and symbol of the phototransistor sensor are shown in Figure 2. The working principle of the phototransistor, the base current is controlled by the amount of light received. In general, the phototransistor has two collector and emitter legs while the base terminal is in the form of a lens which functions as a light detection sensor. If the base terminal receives a large amount of light, the current flowing from the collector to the emitter will be even greater.

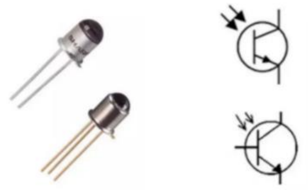


Fig. 2. The shape and symbol of the phototransistor sensor

III. METHODOLOGY AND DESIGN SUN TRACKER

A. *Sun Tracker Hardware Design*

This study builds two sun trackers with the same control system setup and algorithm and the same control programming, but using a different type of sensor, namely the LDR sensor and the phototransistor sensor. This is done to compare the values of the two light sensors for the accuracy of the light intensity produced by the sun tracker. More accurate tracking will result in more electrical energy being captured by the solar cells. The steps for determining the results of the two types of sensors can be seen in Figure 3.

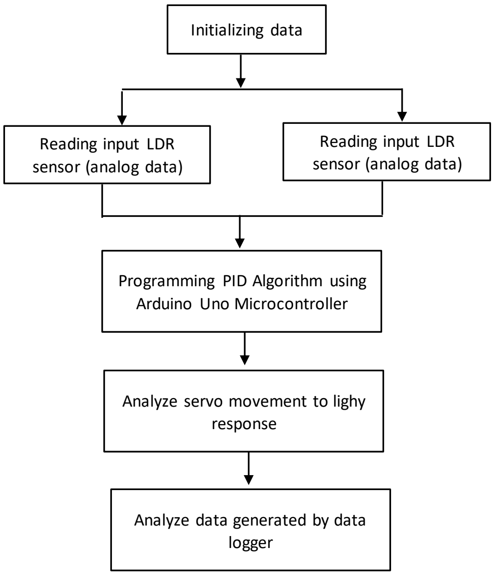


Fig. 3. Experimental procedure

The hardware components used in this study consisted of servo motors, phototransistor light sensors, Arduino Uno R3 microcontrollers, and data loggers.

- Servo motors

Servo motors are used as actuators that allow precise control of angle, speed, and acceleration. The Servo motor can adjust the rotation angle and speed accurately. The servo motor receives an input voltage of 7 Volts to drive the sun tracker. This study uses a continuous servo motor. The type of servo motor used is MG996R. Servo motor type MG996 in Figure 4.

Fig. 4.MG 996R servo motors

- Light sensor

The light sensor used in this study is an LDR sensor and a phototransistor sensor with the Temt 6000 type. The shape of the LDR sensor and phototransistor sensor is in Figure 5.

Fig. 5. (a). LDR sensor (b). Phototransistor sensors

- Arduino Microcontroller

Arduino Uno microcontroller is a component that connects and fully controls other hardware components. The Arduino Uno used in this study 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 pins, and 6 analog input pins, and uses a 16 MHz crystal, a power jack, an ICSP header, and a reset button. Arduino Uno R3 can be seen in Figure 6.

Fig. 6 Arduino Uno R3

- Data loggers

The data logger shield is a shield for storing data, and real-time clocks, as well as prototyping for Arduino Uno. This shield is equipped with an SD card slot for data storage as well as a Real Time Clock (RTC) module to provide timestamps for data to be stored. The form of the data logger used in this study can be seen in Figure 7.

Fig. 7. Data loggers

B. Control system design

The sun tracker system in this study uses the PID algorithm controller method which is calculated automatically by the Arduino microprocessor and follows the following mathematical equation.

$$u(t) = K_p e(t) + K_I \int_0^t e(t) + K_D \frac{d\,e(t)}{dt} \quad (1)$$

Where u(t) is the control signal, K_p, K_I, K_D are proportional gain, integral gain, and derivative gain respectively and e(t) is the error signal which is calculated by comparing the set point or reference input and sensor reading, which is calculated by the equation:

$$e(t) = r(t) - y(t) \quad (2)$$

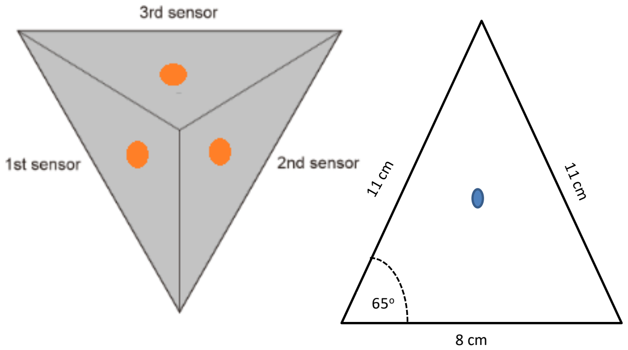
Where r(t) is the reference signal or input signal given to the system and y(t) is the response signal or output signal from the system.

Mathematical equations (1) and (2) are implemented into the Arduino microprocessor using the PID library. The appropriate duty cycle will be calculated automatically by the microprocessor to minimize errors. The PID control applied to the sensor has a dynamic set point because it refers to the sensor 1 value which will change with the movement of the sensor and changes in light intensity.

The controller of the sun tracker system adopts PID control which uses mathematical equation (5) with a value of $K_P = 0$, $K_I = 4.456$, and $K_D = 0$. The duty cycle will be calculated automatically by the microprocessor to minimize errors. The PID control applied to the sun tracker has set point dynamics because it refers to S_{ref} will change with the movement of the sensor and changes in light intensity.

C. Sensor algorithm design

The shape of the proposed sun tracker prototype is different in size for tetrahedron geometry, as shown in Figure 8. Three sensors are the reference sensor (S_{ref}), the first axis sensor (S_{AX1}), and the second axis sensor (S_{AX2}). Three sensors must have the identical electrical characteristics. The sensors are placed parallel and symmetrically to each side of the tetrahedron.



(a). Top view (b). The side view

Fig. 8. Physical structure of the sensor on the sun tracker

When all sensors are designed with the same value, it means that the sun tracker system will aim at the position that provides the greatest light intensity. The control algorithm on the dual-axis sun tracker uses a comparison method of sensor reading values. Three sensors are used which are divided as S_{ref}, S_{AX1}, and S_{AX2}. S_{ref} is a sensor that is used as a working reference for the sun tracker system, S_{AX1} is a sensor to control the azimuth and S_{AX2} is a sensor to control the altitude angle. Both S_{AX1} and S_{AX2} sensors will refer to the same value of S_{ref}.

The working principle of the sensor on the dual-axis based sensor sun tracker is represented in detail in Figure 9. Based on Figure 9, The sensor readings respectively S_{ref}, S_{AX1}, and S_{AX2} provide readings that are proportional to the achieved light intensity. Values with the analog type of the sensor are identified by the microprocessor. Then do the 1st alignment using sensor values and S_{AX1} will be read by comparing the values with each other to align the first axis to the light source. If the reading value for the S rev is greater than the S_{AX1} value, it means that the light is on the right side of the sensor. The servo motor controlled by the PWM signal will turn the sun tracker to the right. Conversely, the sun tracker will rotate to the left if the PWM duty cycle decreases When S_{ref} is smaller from S_{AX1}. The same principle is also applied to the 2nd alignment. However, the axle movement is based solely on the readings of the S_{ref} and S_{AX2} sensors. If the S_{ref} value is greater than S_{AX2} then the sun tracker will go up, but if S_{ref} value is smaller than S_{AX2}, then the sun tracker will drop down. Furthermore, the process will be continued with the PID controller.

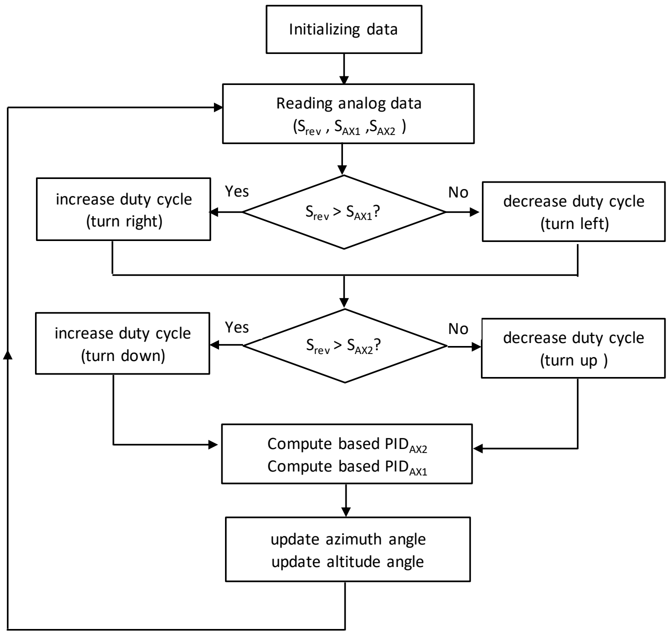


Fig. 9. The sensor algorithm

IV. RESULT AND DISCUSSION

A. Sun tracker prototype

The making of a sun tracker prototype was carried out to support the research results. To support the research results, it is necessary to make a prototype sun tracker dual-axis sensor based on geometric tetrahedrons as seen in Figure 10. Based on Figure 10, which left side is a sun tracker with LDR sensor and the right side is a sun tracker with a phototransistor sensor. After the prototype was designed, experiments were carried out three times to test the performance of the sensor.

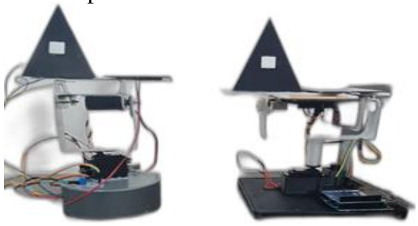


Fig.10. Sun tracker prototype

The first experiment was to test the sensor on the sun tracker by using a 1000 W light bulb, which was placed above the x, y, and z coordinates with the sun tracker sensor. The sun tracker prototype is placed at coordinate 0, while the light bulb is placed at arbitrary coordinates. The test results at this stage show that the sensor on the sun tracker is facing the light source with an angle of between the sun tracker and the light source is 90º angle. The second experiment was carried out by providing a light source for the sun tracker prototype with 2 light sources. In real life, this situation can occur when the sun is covered by clouds so that the light received by the sensor can come from some of the light reflected by the clouds. Testing for this stage is carried out by using two lamps placed in coordinates with a range of $0^o<\theta<180^o$ and $0^o<\varphi<90^o$. The same method was carried out as the first test, the final position of the sensor was obtained from the position of the light that has the greatest light intensity. The third experiment, the sun tracker prototype was placed outdoors by using sunlight as a light source. The purpose of the third experiment is to find out the performance of the two proposed types of light sensors in real conditions. To get comparison results, two sun tracker prototypes that use LDR sensors and sun trackers that use phototransistor sensors are operated simultaneously. The two sun trackers have the same hardware configuration and differ only in the type of light sensor. The sun coordinates in azimuth and altitude is obtained from the reference values, then stored in the Microprocessor EEPROM. The orientation of the sun tracker is set by using a compass so that the sun tracker can point to the sun properly. The two sun trackers can be observed in Figure 11.

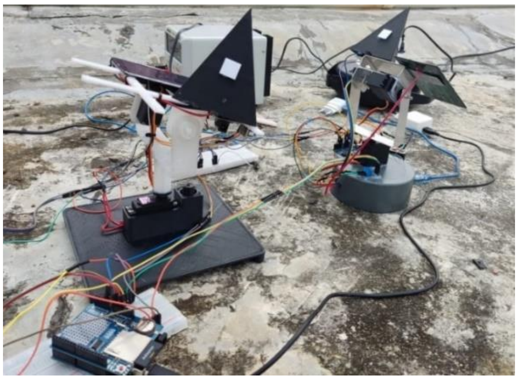


Fig. 11. Prototype Sun Tracker dual-axis based sensor

Figure 11 shows two prototypes made with the same construction and the same control algorithm, namely PID. The difference between the two prototypes is in the sensors used in the sun tracker. This is done to compare the results obtained from the two different types of sensors by looking at the electrical power generated by the sun tracker mounted on the solar cell.

B. Data Comparison

The sun tracker is allowed to move following the sunlight to obtain power output with a different light sensor of dual-axis sun tracker based on the tetrahedron. When testing the sun tracker in the field, the RTC records voltage and current data generated by the solar cell. Data is recorded every 10 seconds by RTC. During the experiment, which was conducted in cloudy and sunny weather. The testing for the sun tracker from 8:00 a.m. to 4:00 p.m. During the experiments, cloudy weather occurred is from 8:00 a.m. to 10:00 a.m. while clouds began to cover most of the sky. Sunny weather occurred from 10:00 a.m. to 02.00 p.m. while clouds began to little the sky. cloudy weather occurred from 2:00 a.m. to 4:00 a.m. while clouds began to cover most of the sky. The results of the comparison of voltage used LDR sensor with the phototransistor sensor are shown in Table I.

TABLE I
COMPARISON OF VOLTAGE OF SUN TRACKER DEVICES

No	Time	Voltage (Volt)	
		Sun tracker with phototransistor sensor	**Sun tracker with LDR sensor**
1	09:00	23.083	10.914
2	10:00	28.284	10.238
3	11:00	30.652	24.088
4	12:00	29.025	23.625
5	13:00	28.394	25.466
6	14:00	27.533	25.703
7	15:00	20.923	13.975
8	16:00	23.691	16.255
Average		30.227	21.466

Table I shows the movement of solar cell makes the value of average voltage 30.227 V in 1 minute when using a sun tracker tetrahedron based on a phototransistor sensor. The second solar cells with sun tracker based LDR sensor has an average voltage of 21.466 V in 1 minute. The result of the comparison of voltage used LDR sensor with the phototransistor sensor is shown in Figure 12.

Figure 12 shows the comparison between explaining the result of research for the voltage received by the solar cell when using the sun tracker with the phototransistor sensor and LDR sensor. The results show that a sun tracker using a phototransistor sensor generates more voltage than a sun tracker using an LDR sensor.

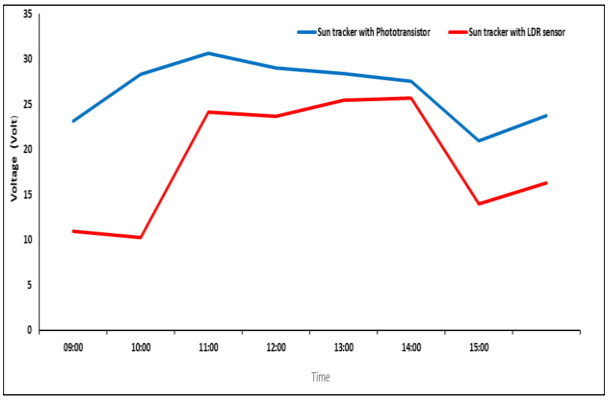


Fig.12. Performance comparison voltage of sun tracker devices

The results of the comparison of the current used LDR sensor with phototransistor sensor are shown in Table II. Table II shows the movement of solar cells makes the value of the average current. The current received by the solar cell when using the sun tracker with the phototransistor sensor has an average current value of 0.231 A in 1 minute, when using the LDR sensor has an average current 0.109 A.

TABLE II
COMPARISON OF CURRENT OF SUN TRACKER DEVICES

No	Time	Current (Ampere)	
		Sun tracker with phototransistor sensor	Sun tracker with LDR sensor
1	09:00	0.231	0.109
2	10:00	0.231	0.109
3	11:00	0.231	0.109
4	12:00	0.231	0.109
5	13:00	0.231	0.109
6	14:00	0.231	0.109
7	15:00	0.231	0.109
8	16:00	0.232	0.108
Average		0.231	0.109

The result of the comparison of the current used LDR sensor with the phototransistor sensor is shown in Figure 13.

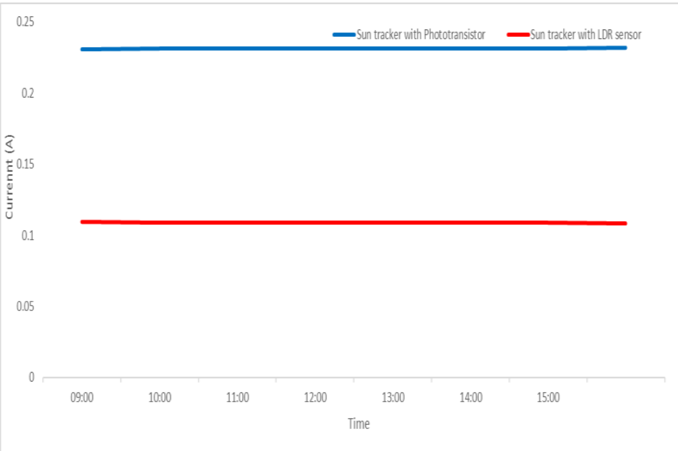


Fig.13. Performance comparison current of sun tracker devices

Figure 13 shows the comparison of current between a sun tracker using an LDR sensor and a sun tracker using a phototransistor sensor. The results show that a sun tracker using a phototransistor sensor generates more voltage than a sun tracker using an LDR sensor.

After getting the voltage and current data on each sun tracker, the power or energy generated can be determined. The results of the comparison of power used LDR sensor with the phototransistor sensor are shown in Table III. Table III shows the power output received by the sun tracker tetrahedron based sensor every 1 hour from 09:00 a.m. to 4:00 p.m. The sun tracker did show any significant change. The solar power received by solar cells in average 6.225 Watt when using the phototransistor sensor and an average 4.602 Watt when using an LDR sensor. The result of the comparison of energy used LDR sensor with the phototransistor sensor is shown in Figure 14.

TABLE III
COMPARISON OF POWER OF SUN TRACKER DEVICES

No	Time	Power (Watt)	
		Sun tracker with phototransistor sensor	Sun tracker with LDR sensor
1	09:00	5.328	2.519
2	10:00	6.532	2.365
3	11:00	7.080	5.564
4	12:00	6.706	5.458
5	13:00	6.562	5.885
6	14:00	6.367	5.944
7	15:00	4.841	3.233
8	16:00	5.487	3.764
Average		6.225	4.602

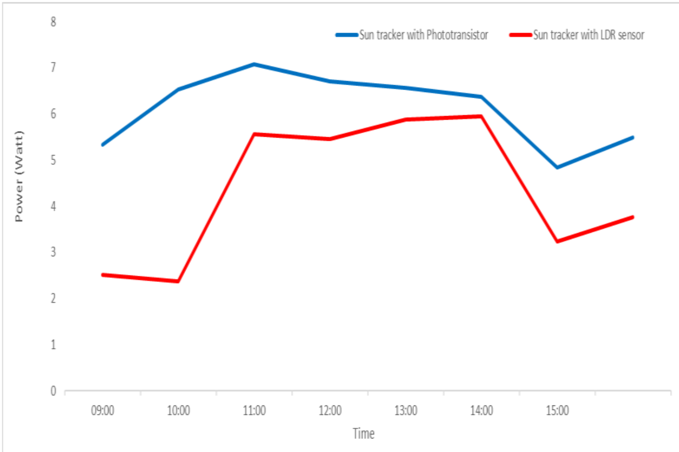


Fig.14. Performance comparison energy of sun tracker devices

According to the measurements in Figure 14, it was observed that the sun tracker using a phototransistor sensor on each side of the tetrahedron collects 40% more energy than the sun tracker using an LDR sensor. Figure 14 shows that the sensor light which is placed on each side of the tetrahedron sensor by the phototransistor sensor has a value difference when compared to the value difference in the LDR sensor. This may be to the phototransistors have shown greater light sensitivity than LDRs. The electrical response of the phototransistor about lighting shows a better variation profile in terms of sensitivity and precision. Light-based electrical values obtained from LDR and phototransistors, can be seen that the use of phototransistors in illumination measuring devices will provide more consistent values [26].

V. CONCLUSIONS

The result of the comparison between the two prototypes obtained shows that the phototransistor sensor is more effective than the LDR sensor on sun tracker based on tetrahedron geometry. The solar energy received by solar cells in average 40%. The input of three phototransistor sensors in each prototype can affect the servo to determine the sun's movement.

Even though the sensor has shown promising performance, there is still research to be done in the future such as using a type of light sensor other than phototransistor and LDR and using other algorithms in a dual-axis sun tracker control system.

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