JOURNAL OF ENERGY, MATERIALS, AND INSTRUMENTATION TECHNOLOGY

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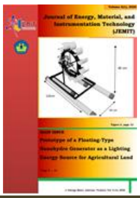

Design of Single Axis Solar Tracker Using Fresnel Lens Based on Internet of Things (IoT) For Optimizing Solar Cell Output Power

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Article Information

Article history:
Received April 25, 2024
Received in revised form October 10, 2024
Accepted October 15, 2024

Keywords: *ESP32, Fresnel Lens, Internet of Things, Light Intensity, Solar Tracker*

Abstract

A single-axis solar tracker using a Fresnel lens has been realized to optimize the output power of solar cells. The solar tracker system is monitored using a website that displays the value of voltage (volts), current (amperes), tilt angle (0), and output power (watt) in real-time. This single-axis solar tracker is designed using a 20 Wp solar panel, Fresnel lens, Solar Charger Controller, Accumulator, Arduino Nano, ESP32, Buck Converter, L298N motor driver, FZ0430 sensor as voltage meter, ACS712 sensor as current meter, MPU6050 sensor as angle meter. The method used in this research includes collecting data on voltage, current, tilt angle, power generated by solar panels, and light intensity and temperature emitted by the sun for 3 days without and 3 days using lenses. This tool can measure the voltage value of direct electricity with an error rate of 1.88%, accuracy of 98.12%, and precision of 99.15%. The electric current measurement has an error rate of 3.82%, an accuracy of 96.18%, and a precision of 96.84%. Light measurement has an error rate of 1.85%, an accuracy of 98.15%, and a precision of 98.78%. The angle measurement has an error rate of 5.95% and an accuracy of 94.05%. The single-axis solar tracker system using Fresnel lenses has a power efficiency of 37.09% compared to the single-axis solar tracker without Fresnel lenses.

Informasi Artikel

Proses artikel:
Diterima 25 April 2024
Diterima dan direvisi dari 10 Oktober 2024
Accepted 15 Oktober 2024

Kata kunci: ESP32, Intensitas Cahaya, *Internet of Things,* Lensa Fresnel, *Solar Tracker*

Abstrak

Telah direalisasikan pembuatan alat *single axis solar tracker* menggunakan lensa Fresnel yang bertujuan untuk mengoptimalkan daya *output* pada *solar cell.* Sistem *solar tracker* dimonitoring menggunakan *website* yang menampilkan nilai tegangan (volt), arus (ampere), sudut kemiringan (^{0}), dan daya *output* (watt) secara *realtime.* Alat *single axis solar tracker* ini dirancang menggunakan panel surya 20 Wp, lensa Fresnel, *Solar Charger Controller, Accumulator*, Arduino Nano, ESP32, *Buck Converter*, motor driver L298N, sensor FZ0430 sebagai pengukur tegangan, sensor ACS712 sebagai pengukur arus, dan sensor MPU6050 sebagai pengukur sudut. Metode yang digunakan dalam penelitian ini meliputi pengumpulan data pada tegangan, arus, sudut kemiringan, daya yang dihasilkan oleh panel surya dan intensitas cahaya serta suhu yang dipancarkan matahari selama 3 hari tanpa menggunakan lensa dan 3 hari menggunakan lensa. Alat ini mampu mengukur nilai tegangan Listrik searah dengan tingkat error sebesar 1,88%, akurasi sebesar 98,12%, dan presisi sebesar 99,15%. Pada pengukuran arus listrik memiliki tingkat error sebesar 3,82%, akurasi sebesar 96,18%, dan presisi sebesar 96,84%. Pada pengukuran cahaya memiliki tingkat error sebesar 1,85%, akurasi sebesar 98,15%, dan presisi sebesar 98,78%. Pada pengukuran sudut memiliki tingkat error sebesar 5,95% dan akurasi sebesar 94,05%. Sistem *single axis solar tracker* menggunakan lensa Fresnel memilki efisiensi daya sebesar 37,09% dibandingkan *single axis solar tracker* tanpa menggunakan lensa Fresnel.

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1. Introduction

The intensity of sunlight is an abundant renewable energy source in Indonesia (Handoyo et al., 2020). Indonesia, located on the equator, has rich solar energy resources, with an average solar radiation intensity of about 4.8 kWh/m² per day across its regions. This condition allows Indonesia to utilize solar energy as an alternative source for electricity generation (Pane et al., 2022). Solar energy can be converted into electrical energy using solar panels.

One of the main challenges in using solar panels is the drop in efficiency due to the sun's changing position throughout the day (Hidayatullah & Setyawati, 2024). Differences in the angle of sunlight at different times and the climatological conditions of a place can cause fluctuations in the power output of solar panels (Sadewo et al., 2022). The intensity of the sun and the temperature, which change over time, significantly affect the performance of solar panels. The performance of solar cells can decrease by 50% when the temperature rises from 46°C to 84°C (Weliwaththage & Arachchige, 2020).

In a study conducted by Prasetiyo et al. (2022), the use of static (non-moving) solar panels with a capacity of 100 Watt peak (Wp) for electricity generation produced average voltage and current of 20.34 V and 0.35 A, respectively. However, static solar panels have a drawback: they cannot adjust their angle to the direction of the sunlight, thus not producing optimal power output. Based on this research, it is necessary to develop a solar panel system that automatically moves following the sun's direction using a servo motor and light sensor, known as a solar tracker. The designed solar tracker is a single-axis type. The single-axis system is a solar panel system that moves east-west to produce optimal power output. This system is driven by an actuator with a single servo motor (Ardiansyah, 2023).

Putra and Aslimeri (2020) researched an Arduino-based single-axis solar tracker to compare static and single-axis tracker systems. This research obtained average current, voltage, and power data from the static system of 1.23 A, 15.38 V, and 19.41 W, respectively, while the tracker system obtained current, voltage, and power of 1.98 A, 16.81 V, and 33.24 W. The significant difference in power output, amounting to 13.41 W, shows that solar energy capture in the tracker system is more optimal than the static system.

The output power of solar cells can be influenced by environmental factors such as the ambient temperature on the solar panel, the tilt angle of the solar panel, and the amount of sunlight received or irradiation (Shaker et al., 2024). Over time, the electrical power capacity of solar panels can also be disrupted by mold and dirt on their surface (Ilham & Fithry, 2024). Power reduction is often undetected, except through continuous measurement. Real-time monitoring through continuous measurement is a more effective way to optimize the power capacity of solar panels (Rarumangkay et al., 2021). Real-time monitoring is crucial to improve reliability, evaluation, and implementation. The Internet of Things (IoT) system can address this issue. IoT technology utilizes continuous internet connectivity, enabling data sharing and system control. Developing IoT systems for solar panel power monitoring is feasible (Kurniawan et al., 2021).

In research conducted by Ratnasari (2022) titled "Monitoring Electrical Power on Solar Panels Based on the Internet of Things (IoT) Using Telegram Application," the aim was to measure the capacity of a 20 Wp solar panel in a static system (non-moving) over a period of 3 days. On the first measurement day, the average output power over 6 hours was 9.52 Wp. On the second day, the average output power measured was 9.56 Wp; on the third day, it reached an average of 9.59 Wp.

Solar cells generate power highly dependent on the intensity of sunlight falling on their surface, which is influenced by their location. Increasing sunlight intensity can be achieved using a convex lens above the solar panel, as demonstrated in research by Khaspurrohman et al., (2021). Another study conducted by Silviyanti & Purnomo (2023) titled "Influence of Adding a Convex Lens as a Solar Concentrator on the Performance of Solar Cooker with an Octagonal Panel" measured the output power of solar cells without a lens and with a lens. The solar panel's performance was tested for 2 hours in the morning. The results showed that adding a convex lens improved the solar panel's performance, with the highest temperature rising to 86°C and efficiency increasing to 22.3%. Adding one convex lens raised the temperature to 84.3°C with an efficiency of 21.5%, while the temperature without a lens rose to 70°C with an efficiency of 16%.

Based on previous research findings, a single-axis solar tracker system using a Fresnel lens based on the Internet of Things (IoT) must be developed. The single-axis solar tracker is designed based on IoT to enable remote monitoring, which will include voltage, current, power, and tilt angle values.

2. Research Methods

The tools and materials used in this research are a solar panel, Fresnel lens, Solar Charge Controller, Arduino Nano, ESP32, L298N motor driver, buck converter, switch, FZ4310 voltage sensor, ACS712 current sensor, MPU6050 angle sensor, LDR sensor, servo motor, lux meter, multimeter, jumpers and cables, and a laptop.

2.1 Research Stages

This research aimed to assess the power output of solar panels both before and after installing a Fresnel lens, as well as to investigate the impact of solar panel tilt angle on power output. The research involved measuring voltage, current, and tilt data produced by the solar panels. As for the measuring instruments (sensors), the sensor characterization procedure is carried out before they are implemented in the tracker system. The sensor characterization method is performed by comparing the output values generated by the sensor; the sensor output produces adc values on the voltage sensor, current sensor, and light sensor. The voltage sensor and current sensor use the comparison parameters of the multimeter standard measuring instrument and use a lux meter on the light sensor.

In contrast, the angle sensor produces a digital output value and is compared with the comparison parameters of the protractor standard measuring instrument. Then, to get varying values, the voltage sensor is connected to a direct current (DC) power supply source, and the voltage value in the power supply is varied. The current sensor measures the varying current produced by a DC motor source operating at different speeds. In the light sensor, measurements are taken in a dark room, and the light intensity varies; the source of the measurements used is an incandescent light bulb. The angle sensor measures the angle using solar panel media installed on the tracker system frame to determine the initial condition based on the standard line. Then, the angle of the solar panel is moved manually to produce a varied angle, and the measurement results displayed by the angle sensor and the arc are recorded in the calibration table. Sunlight intensity values in this study were obtained through field measurements using a lux meter. The measurements were conducted over two consecutive days from 08:00 to 17:00 (a total of 9 hours), with the first day involving solar panel evaluation without using a Fresnel lens and the second day with the Fresnel lens in use. The research procedure consisted of several stages, including tool and material preparation, tool design, development of a monitoring program, sensor characterization, tool fabrication, testing and data analysis, and the preparation of a final report. The research procedure is shown in **Figure 1.**

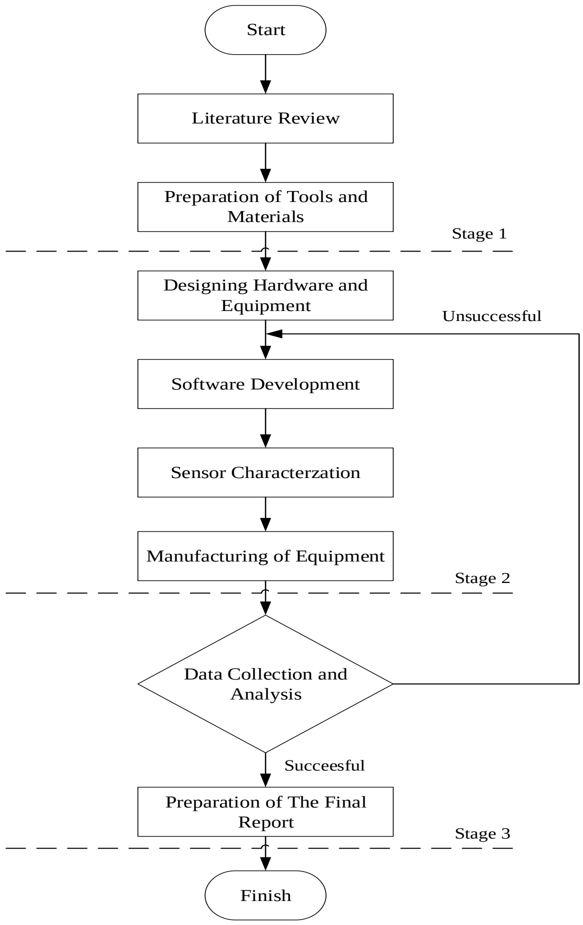


Figure 1. Research Flowchart

2.2 Sketch of Solar Tracker

The solar panel output is linked to the solar charge controller (SCC) and the battery. The SCC supplies power to the Arduino Nano and NodeMCU ESP32. A voltage sensor measures the voltage produced by the solar panel, while an ACS712 sensor measures the current. The tilt angle of the solar panel is detected by an MPU6050 sensor, with all three sensors positioned on the underside of the panel. The voltage sensor and MPU6050 sensor are connected to the NodeMCU ESP32, while the ACS712 sensor is connected to the Arduino Nano. A light tracking sensor (LDR) is also positioned on the side of the solar panel and connected to the Arduino Nano. The research tool design is depicted in **Figure 2.**

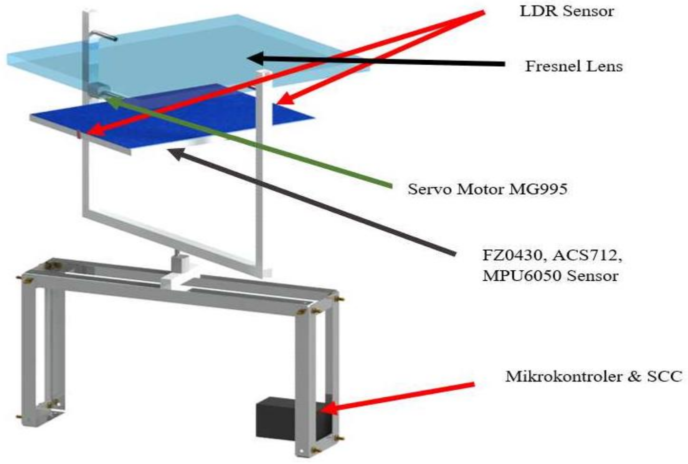


Figure 2. Sketch of Single Axis Solar Tracker

Based on **Figure 2**, the Fresnel lens is placed on the surface of the solar panel at a certain distance. Calculating the distance can be done using the following equation:

$$\tan a = \tan \beta \quad (1)$$

$$\frac{1}{2}\frac{P_1}{l} = \frac{1}{2}\frac{P_2}{2(l-x)} \quad (2)$$

where P_1 is the length of the Fresnel lens (cm), P_2 is the length of the solar panel (cm), l is the length of the focal distance produced by the Fresnel lens (cm), and x is the ideal distance between the Fresnel lens and the solar panel (cm) depicted in **Figure 3.**

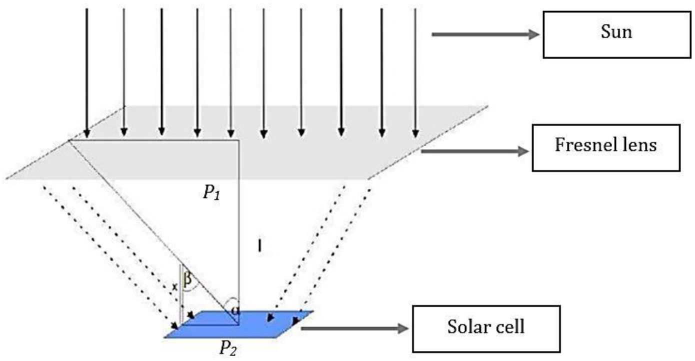


Figure 3. Solar Panel System Using Fresnel Lens (Ayu, 2024)

The Fresnel lens used in the study has dimensions of 55 cm long and 45 cm wide and has a focal distance of 70 cm. Meanwhile, the solar panel used has a capacity of 20 Wp and dimensions of 45 cm long and 35 cm wide. So, based on Equation 2.1 and Equation 2.2, the ideal distance between the Fresnel lens and the solar panel is 13.36 cm.

2.3 Hardware Design

The hardware used in designing the solar tracker system with solar panel output monitoring based on IoT includes Arduino Nano, NodeMCU ESP32, voltage sensor, ACS712 sensor, MPU6050 sensor, LDR sensor, android/laptop, and MG995 servo motor. The system's block diagram is shown in **Figure 4.**

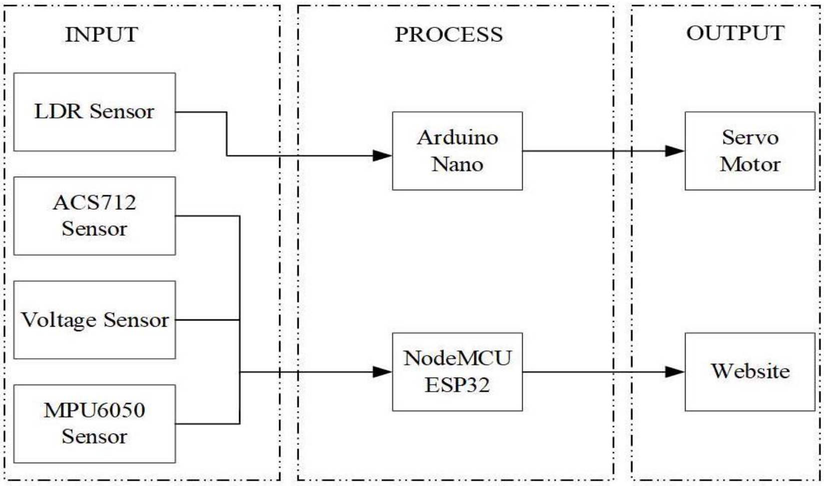


Figure 4. Block Diagram

Figure 4 depicts a block diagram divided into three parts: the LDR sensor input, the ACS712 current sensor, and the d voltage sensor with the MPU6050 gyroscope sensor. The input from the LDR sensor is processed using the Arduino Nano. The LDR sensor captures solar intensity signals, which are then used to control the servo motor. Meanwhile, the ACS712 sensor provides analog data, which is subsequently sent to the ESP32 via serial communication. The data from the ESP32 is then displayed on a website.

The overall circuit diagram of the solar tracker device can be seen in **Figure 5.**

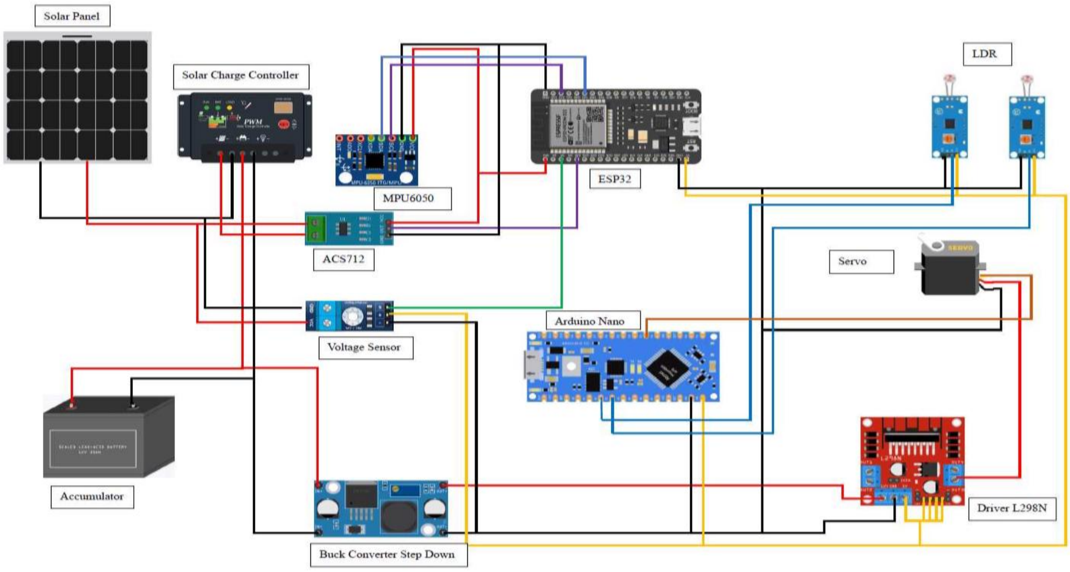
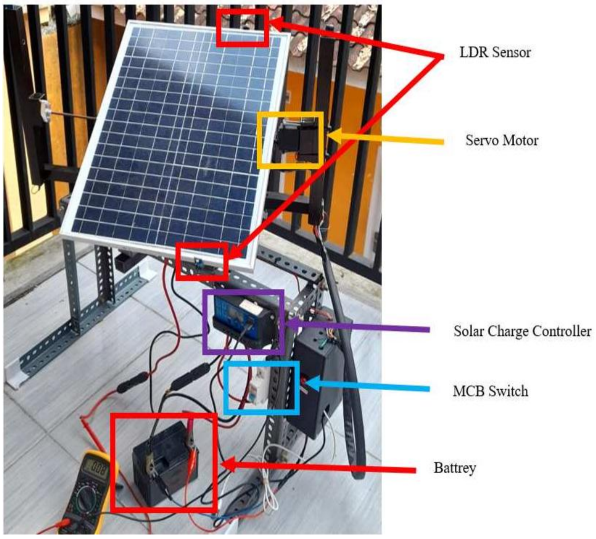


Figure 5. Circuit Diagram

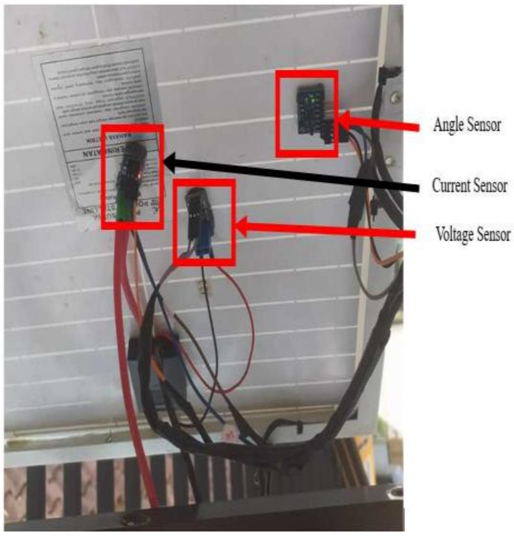
3. Results and Discussions

3.1 Components of The Hardware for Single Axis Solar Tracker Device

Based on the research, the design and construction of the dual-axis solar tracker have successfully functioned correctly. The solar tracker system utilizes four light sensors (LDR) and two servo motors. As each light sensor detects light intensity, the solar tracker system will orient the solar panel's surface toward greater light intensity. The device's realization is illustrated in **Figure 6.**



(a)



(b)

Figure 6. Realization of the Solar Tracker (a) Overall View (b) Bottom View

Based on **Figure 6**, the system can be turned on and off using the MCB switch. Battery charging is regulated by a solar charge controller with the maximum battery charge set at 13.7 volts. Additionally, the motor operation is managed by an MG995 servo motor, while another servo motor controls the solar panel's movement. The MPU6050 and ACS712 sensors are powered with 3.3 V, while the voltage for the sensor is supplied by the 5 V L298N motor driver obtained from the battery. Both servo motors are supplied with 6.4 V and connected to the Arduino Nano. The circuit realization is illustrated in **Figure 3.2.**

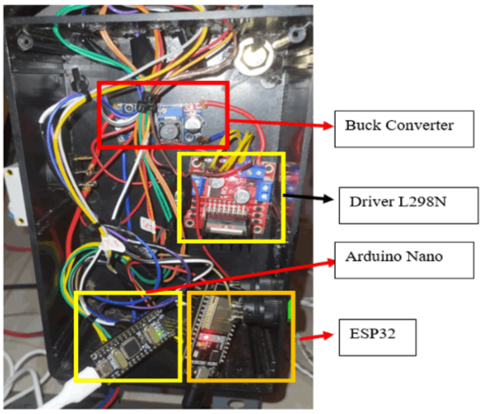


Figure 7. Wiring Control

Figure 7 displays the wiring within the control box of the solar tracker system. In this setup, a buck converter is used to reduce the DC voltage from the battery, which starts at 12 V, to 6.4 V. This 6.4 V supply powers the L298N motor driver. The L298N motor driver, in turn, divides the voltage into two types: 6.4 V for the two servo motors and 5 V for the ESP32 and Arduino Nano microcontrollers, as well as the voltage sensor and LDR sensor. The Arduino Nano controls the servo motors, while the LDR sensor sends its readings to the Arduino Nano. Pins A0 to A3 are connected to the LDR sensor signal pins, with pin A4 used for PWM servo 1, and pin D3 for PWM servo 2. On the NodeMCU ESP32 microcontroller, GPIO pin 36 connects to the voltage sensor, GPIO pin 34 to the ACS712 sensor, GPIO pin 21 to the SDA sensor MPU6050, and GPIO pin 22 to the SCL sensor MPU6050. The NodeMCU microcontroller serves as a data sender for sensor readings, and it can connect to the Wi-Fi, enabling users to access these readings via a website and utilize the Internet of Things (IoT) concept. A Fresnel lens is incorporated into the solar tracker system to maximize the power output of the solar panels, as shown in **Figure 8.** This lens is positioned on the surface of the solar panel.

Figure 8. Solar Tracker System Using Fresnel Lenses

3.2 Calibration of The Solar Tracker Device

3.2.1 Calibration of Voltage Sensor

Sensor testing and calibration are crucial in this research to maximize the sensor's utility by minimizing error values. The voltage sensor is calibrated to measure voltage values using Arduino IDE software. The output from this sensor is in the form of ADC sensor voltage, which needs to be converted into digital format. Accuracy, precision, and errors are determined through calculations using Equations 1, 2, and 3, as follows.

$$\text{Error (\%)} = \left|\frac{Y - X_n}{Y}\right| \times 100\% \tag{1}$$

$$\text{Accuracy (\%)} = \left(1 - \left|\frac{Y - X_n}{Y}\right|\right) \times 100\% \tag{2}$$

$$\text{Precision (\%)} = \left(1 - \left|\frac{X - \overline{X_n}}{\overline{X_n}}\right|\right) \times 100\% \tag{3}$$

where Y is the reference parameter value, X_n is the Measured parameters value n, and $\overline{X_n}$ is the Measured parameters average value n as for the calibration graph of the voltage sensor as shown in **Figure 9.**

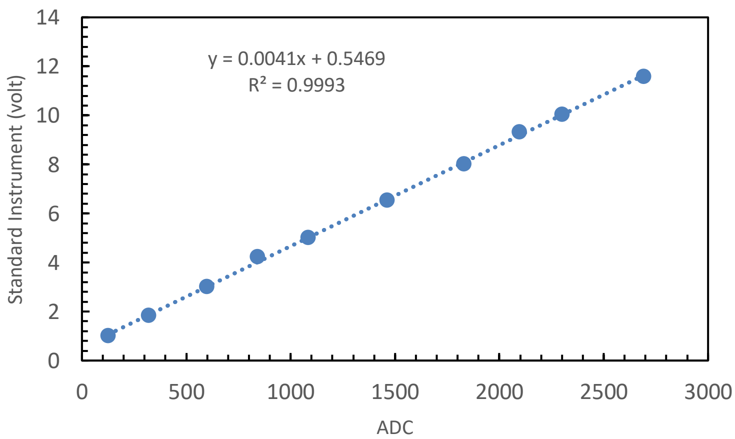


Figure 9. Voltage Sensor Calibration Graph

The FZ0430 voltage sensor, with an R^2 value of 0.9993, is excellent for measuring voltage. The sensor calibration and testing were performed ten times, each time with different voltage values, and each repetition was carried out three times with the same value to determine the sensor's error, accuracy, and precision values. In **Table 1**, the standard instrument column represents a multimeter capable of measuring direct voltage up to 20 volts. The instrument column containing 3 data variations represents the sensor measuring instrument (the type of voltage sensor used is FZ0430), and the attached value is the measurement result based on the calibration process carried out on the sensor.

Table 1. Voltage Sensor Calibration

No	Standard Instrument (volt)	Instrument (volt)			Instrument Average (volt)	Error (%)	Accuracy (%)	Precision (%)
		1	2	3				
1	6.08	5.99	5.96	5.91	5.95	2.0	97.92	99.51
2	1.91	1.88	1.81	1.86	1.85	3.14	96.86	98.56
3	2.27	2.25	2.14	2.13	2.17	4.26	95.74	97.65
4	3.32	3.25	3.19	3.22	3.22	3.01	96.99	99.38
5	5.17	5.07	5.21	5.05	5.11	1.68	98.32	98.70
6	4.83	4.76	4.64	4.68	4.69	2.83	97.17	99.05
7	12.25	12.14	12.2	12.22	12.19	0.52	99.48	99.74
8	11.59	11.51	11.53	11.6	11.55	0.43	99.57	99.69
9	7.23	7.2	7.25	7.28	7.24	0.46	99.54	99.60
10	9.71	9.67	9.74	9.75	9.72	0.38	99.62	99.66
Average						1.88	98.12	99.15

Based on **Table 1**, the FZ0430 voltage sensor has an average error value of 1.88%, accuracy of 98.12%, and precision of 99.15%.

3.2.2 Calibration of Current Sensor ACS712

The ACS712 sensor can measure currents up to 5A with a 185 mV/A sensor sensitivity. Sensor calibration involves reading the ADC sensor values, which are then varied with data types in the program, represented as a float. The ACS712 sensor input is connected to a DC motor with a current specification of 1.5 A. The speed of the DC motor is controlled using a potentiometer and a transistor connected to a 12 V power supply. The ADC values are varied to obtain 10 ADC data points. Subsequently, the recorded ADC values are used to determine a linear regression equation with a correlation to a standard instrument, as shown in **Figure 10.**

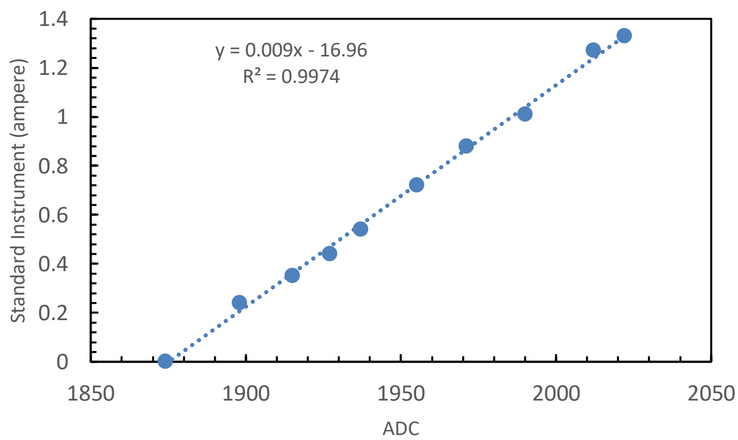


Figure 10. Current Sensor Calibration Graph

The ACS712 current sensor produces a correlation value R^2 of 0.9974, indicating that it is very suitable for current measurements. In **Table 2**, the column containing the standard instrument represents a multimeter capable of measuring direct current up to 5 amperes. The Instrument column containing variations of 3 data represents the sensor measuring instrument (the type of current sensor used is ACS712), and the attached value is the measurement result based on the calibration process carried out on the sensor.

Table 2. Current Sensor Calibration

No	Standard Instrument (ampere)	Instrument (ampere)			Instrument Average (ampere)	Error (%)	Accuracy (%)	Precision (%)
		1	2	3				
1	0.15	0.14	0.15	0.14	0.14	4.44	95.56	96.90
2	0.28	0.27	0.3	0.25	0.27	7.14	92.86	93.50
3	0.48	0.46	0.47	0.49	0.47	2.78	97.22	97.65
4	0.63	0.64	0.62	0.59	0.62	3.17	96.83	97.12
5	0.82	0.83	0.82	0.81	0.82	0.81	99.19	99.19
6	1.02	1.05	1.07	1.04	1.05	3.27	96.73	98.95
7	1.29	1.27	1.31	1.28	1.29	1.29	98.71	98.79
8	0.33	0.36	0.34	0.29	0.33	8.08	91.92	91.92
9	0.91	0.88	0.95	0.93	0.92	3.30	96.70	97.10
10	0.77	0.71	0.76	0.75	0.74	3.90	96.10	97.30
Average						3.82	96.18	96.84

Based on **Table 2**, the ACS712 current sensor has an average error value of 3.82%, average accuracy of 96.18%, and average precision of 96.84%.

3.2.3 Calibration of LDR Sensor

The calibration method utilizes a standard instrument, a lux meter, with a light source in the form of a 25 W AC neon lamp, whose light intensity can be adjusted using a dimmer. The LDR sensorlux meter and the light source are kept inside a closed box to prevent interference from external light**. Figure 11** is a light sensor calibration graph.

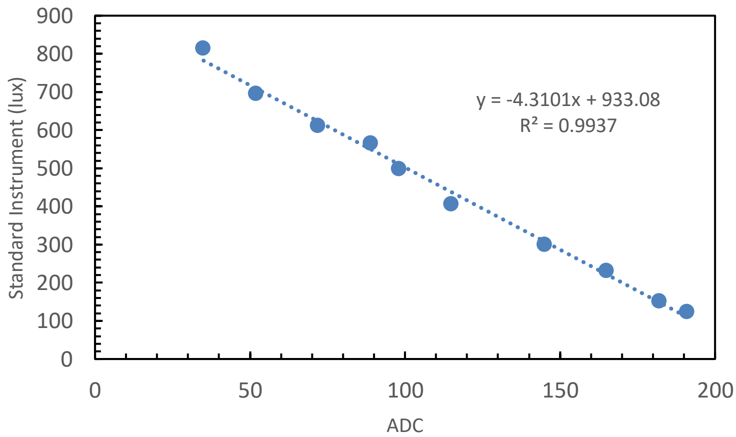


Figure 11. LDR Sensor Calibration Graph

The ACS712 current sensor produces a correlation R^2 of 0.9937, indicating that the LDR sensor is very suitable for light measurements. In **Table 3**, the standard instrument column represents a standard measuring instrument for measuring light units (in lux) using a lux meter. The instrument column repeats the measurement on the sensor after calibration (the type of light sensor used is an LDR sensor).

Table 3. LDR Sensor Calibration

No	Standard Instrument (lux)	Instrument (lux)			Instrument Average (lux)	Error (%)	Accuracy (%)	Precision (%)
		1	2	3				
1	124	127	131	123	127.00	2.96	97.04	97.90
2	156	164	160	168	164.00	5.13	94.87	98.37
3	253	246	266	250	254.00	3.03	96.97	96.85
4	302	306	303	307	305.33	1.10	98.90	99.49
5	361	357	365	357	359.67	1.11	98.89	99.01
6	419	414	415	417	415.33	0.88	99.12	99.73
7	488	486	481	490	485.67	0.75	99.25	99.36
8	677	668	669	684	673.67	1.18	98.82	98.98
9	832	820	824	840	828.00	1.12	98.88	99.03
10	957	940	943	962	948.33	1.25	98.75	99.04
Average						1.85	98.15	98.78

Based on **Table 3**, the ACS712 current sensor has an average error value of 1.85%, an average accuracy of 96.15%, and an average precision of 98.78%.

3.2.4 Calibration of Angle Sensor MPU6050

The MPU6050 sensor produces digital data output. A sensor program is created in the Arduino IDE to test and calibrate the sensor, providing angle readings. Subsequently, the angle displayed on the serial monitor is compared with a standard protractor instrument. In the calibration of the MPU6050 angle sensor, data is collected ten times by varying the angles displayed on the serial monitor in the Arduino IDE, which is then compared with a standard instrument. **Table 4** shows the error and accuracy values.

Table 4. Angle Sensor Calibration

Data to-	Instrument (^{0})	Standard Instrument (^{0})	Error (%)	Accuracy (%)
1	33	36	8.33	91.67
2	46	50	8.00	92
3	40	40	0.00	100
4	25	22	13.64	86.36
5	39	39	0.00	100
6	33	35	5.7	94.29
7	55	52	5.77	94.23
8	56	57	1.75	98.25
9	78	77	1.30	98.7
10	23	20	15.00	85
Average			5.95	94.05

Based on **Table 3.4**, the MPU6050 angle sensor has an average error value of 5.95% and an average accuracy of 94.05%.

3.3 Monitoring System Software

The monitoring system on the solar tracker reads real-time data generated from three sensors, measuring voltage, current, power, and the tilt orientation of the solar panels. Visual Studio Code is used as a text editor for designing the framework and structure of a website, encompassing both front-end and back-end components. The languages used for designing monitoring websites include HTML, CSS, JavaScript, and PHP. Website interfaces are designed using HTML, CSS, and JavaScript, while PHP is the database storage, connected to PhpMyAdmin and integrated with the Arduino IDE software. The monitoring parameters of the solar tracker system include voltage (in volts), current (in amperes), tilt angle orientation (in degrees), and power (in watt). Real-time data is presented in a card format, displaying the most recent sensor readings. In contrast, graphical data is continuously updated, with the graph showing the last 19 data points stored in the PhpMyAdmin database. **Figure 12** shows the web interface.

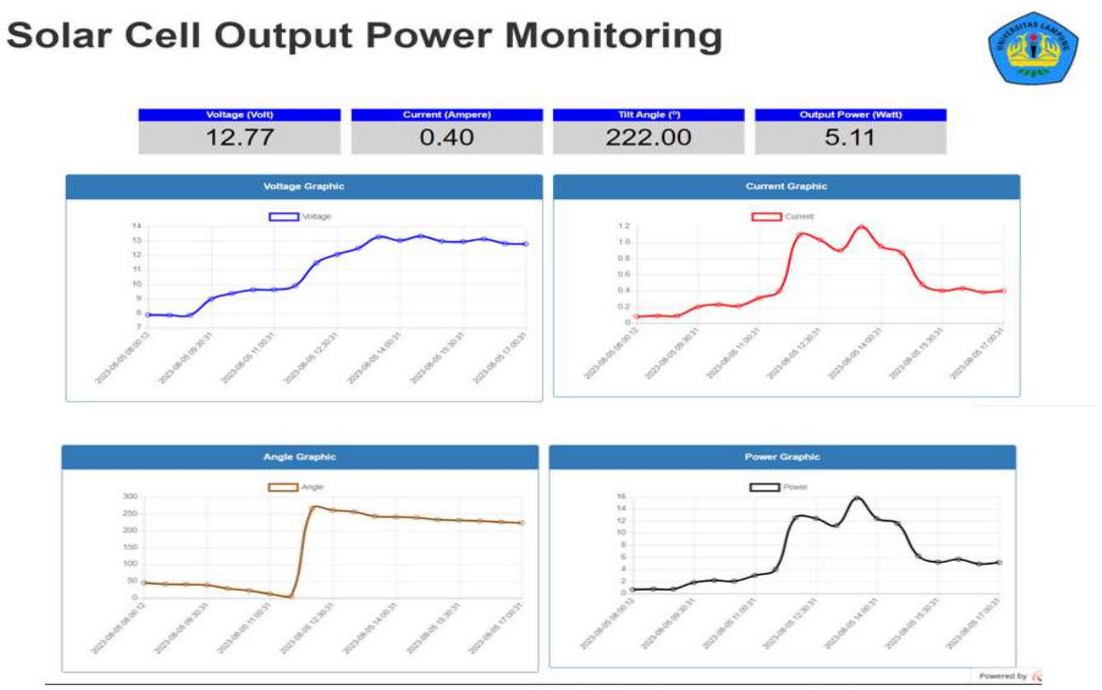


Figure 12. Web Interface

Based on **Figure 12** is a representation of the solar tracker system measurements for one day. The data read on the sensor is sent to the web server every 30 minutes, resulting in a variation of 19 data based on measurements taken from 8 am to 5 pm. The graphical measurement of the electric power produced is a multiplication based on the solar panel's voltage output value (in Volts) with the solar panel's current output value. The current value listed is the amount of current produced by the solar panel in the battery charging process (in amperes). In the tilt angle graph using an angle sensor, measurements are made based on the angle produced by the solar panel against the direction of sunlight hitting the surface of the solar panel. When the solar panel faces east, the value read on the sensor has a range of 00 to 600, while when the solar panel faces west, the value read on the sensor has a range of 2700 to 2100.

3.4 Testing Data Without Using a Fresnel Lens

The website displays monitoring data, including angle, voltage, current, and power values. The website represents voltage, current, power, and tilt angle values, with the y-axis indicating real-time values updated every 30 minutes. The graph uses two parameters: time on the x-axis and power (in watt) on the y-axis. **Figure 13** illustrates the relationship between time and light power/intensity when conducting tests without a Fresnel lens.

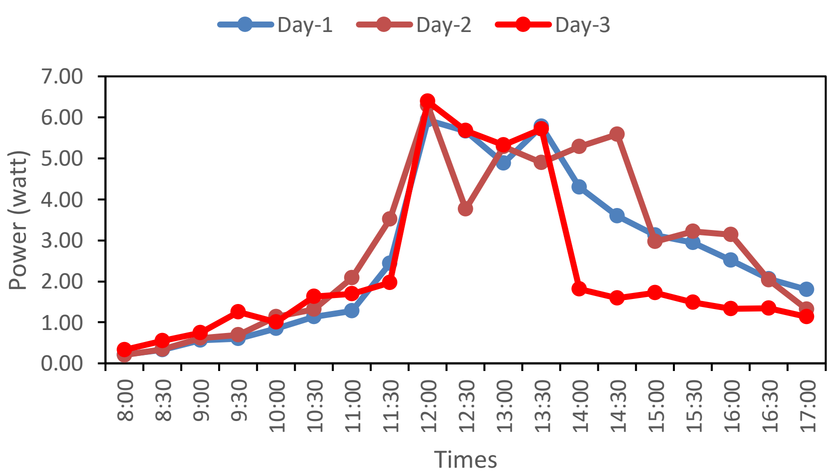


Figure 13. Data Without Using a Fresnel Lens

Based on **Figure 13** which is a variation of test data for 3 consecutive days without using a Fresnel lens. The graph presents a fluctuating power value. At 8 a.m. - 11.30 a.m., the solar panel's power shows a not too significant increase in power due to the intensity of sunlight (in lux units) emitted is not high, so the solar panel produces a relatively low power output. At 12 pm - 1.30 pm, the power output shows a high value due to the intensity of sunlight producing maximum lux value (hot weather) to illuminate the surface of the solar panel. There was a difference in output power on day 2 at 12.30 p.m., which experienced a significant decrease in power. It occurred due to a momentary cloudy weather, but at 13 noon, the weather returned to sunny. On day 3, from 2 pm to 5 pm, the average output power was lower than on day 1 and day 2 due to the lower light intensity values on that day compared to day 1 and day 2.

3.5 Testing Data Using a Fresnel Lens

The website displays monitoring data, including angle, voltage, current, and power values. The website represents voltage, current, power, and tilt angle values, with the y-axis indicating real-time values updated every 30 minutes. The graph uses two parameters: time on the x-axis and power (in watt) on the y-axis. **Figure 14** illustrates the relationship between time and light power/intensity when conducting tests without a Fresnel lens.

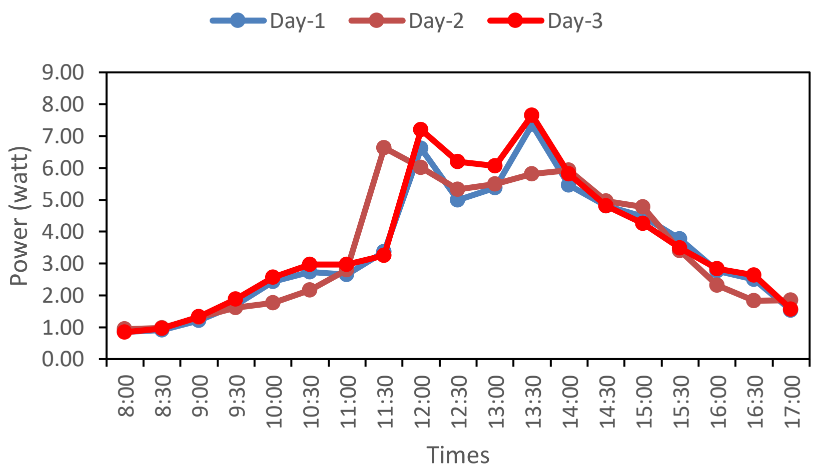


Figure 14. Data with Using a Fresnel Lens

Figure 14 shows the power output of solar panels using Fresnel lenses carried out for three consecutive days, which produces a significant increase in power compared to solar panel systems without Fresnel lenses. It can occur because the sunlight that is radiated before hitting the surface of the solar panel will pass through the surface of the Fresnel lens which functions to collect light and focus the incoming light and forward it to the surface of the solar panel (the light will be refracted if it passes through the Fresnel lens), resulting in an increase in light intensity (lux) from the actual light intensity emitted by the sun. This phenomenon will automatically increase the output power produced by the solar panel.

3.6 Comparison of Output Power Without Lens and Using Lens

The output power comparison displays the average output power from each test over a day (9 hours), including three sets of data without lenses and three sets of data with lenses. The comparison data and efficiency calculations are presented in **Table 5.**

Table 5. Output Power Comparison

Days to-	Without Lenses (W)	With lens (W)
1	2.63	3.45
2	2.83	3.47
3	2.25	3.65
Average	2.57	3.52
Efficiency	37.09%	

Based on **Table 5**, the average output power of solar panels using lenses has increased by 0.95 W with an efficiency of 37.09%. The data is compared in a graph shown in **Figure 15.**

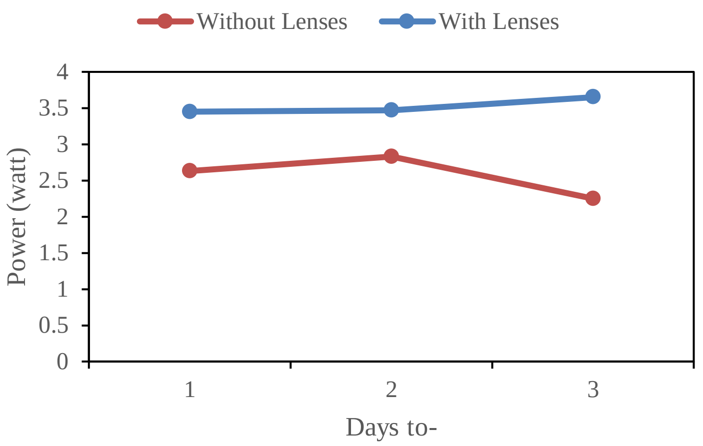


Figure 15. Power Efficiency Graph

According to **Figure 15**, the highest output power without lenses was 2.83 W on day 2, and the lowest was 2.25 W on day 3. In the lens-assisted tests, the highest output power was 3.65 W on day 3, while the lowest was 3.45 W on day 1. The power efficiency when using lenses is 37.09%.

4. Conclusions

Based on the test results and data discussion from the solar tracker's monitoring system, including voltage (Volt), current (Ampere), tilt (^{0}), and power (watt), conducted in this research, the following conclusions can be drawn.

1. The solar tracker system without a Fresnel lens has the highest average output power, 2.83 watts, while the system using a Fresnel lens has an average output power of 3.65 W.
2. Solar trackers using lenses have a higher output power than those without lenses, with a power increase of 0.95 watts. The output power efficiency of a dual-axis solar tracker using a lens is 37.09% compared to 37.09% for a dual-axis solar tracker without a lens.

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