IOT-BASED SOLAR TRACKER SYSTEM UTILIZING THINGER.IO FOR WEB MONITORING

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Abstrak

Salah satu faktor yang perlu diperhatikan dalam memproduksi energi listrik adalah kemampuan untuk menghasilkan energi dalam jumlah yang cukup dengan biaya yang wajar tanpa menimbulkan dampak buruk terhadap lingkungan. Penelitian ini bertujuan untuk menciptakan sistem yang memastikan panel surya selalu berorientasi menghadap matahari, sehingga mencapai tingkat intensitas cahaya setinggi mungkin. Efisiensi keluaran energi panel surya meningkat pesat, sehingga menghemat biaya dan mengurangi dampak lingkungan, sebagai akibat dari peningkatan intensitas cahaya yang diterima melalui penggunaan pelacak surya. Sistem pelacakan surya diuji dengan mengukur tegangan, arus, dan daya dengan instrumen yang dirancang khusus. Hasil penelitian menunjukkan bahwa penggunaan solar tracking menghasilkan peningkatan tegangan sebesar 9,87%, peningkatan arus sebesar 22,85%, dan peningkatan daya sebesar 27,54% jika dibandingkan dengan konfigurasi statis. Kesalahan pengukuran tegangan berkisar antara 0% hingga 1,4%, sedangkan kesalahan pengukuran arus berkisar antara 0% hingga 18%. Selain itu, sensor MPU-6050 menunjukkan kesalahan sudut kemiringan rata-rata sebesar 1,6%.

Kata kunci*: energi, panel surya, pemantauan, single-axis*

Abstract

One of the factors to consider when producing electrical energy is the ability to produce an adequate amount of energy at a reasonable cost without causing any adverse effects on the environment. The objective of this research was to create a system that ensures that solar panels are always oriented to face the sun, thereby achieving the highest possible level of light intensity. The energy output efficiency of solar panels is considerably improved, resulting in cost savings and a reduced environmental impact, as a result of the increased light intensity received through the use of solar trackers. The solar tracking system was tested by measuring voltage, current, and power with a specially designed instrument. The results indicated that the use of a solar tracker resulted in a 9.87% increase in voltage, a 22.85% increase in current, and a 27.54% increase in power when compared to a static configuration. The voltage measurement error ranged from 0% to 1.4%, while the current measurement error ranged from 0% to 18%. Furthermore, the MPU-6050 sensor exhibited an average tilt angle error of 1.6%.

Keywords*: energy, monitoring, single-axis, solar panel*

INTRODUCTION

Indonesia's electricity demand is increasing along with population growth and technological advances. The Energy Information Administration (EIA) estimates that by 2025 energy use will be dominated by fossil fuels such as natural gas, coal and oil due to the vast amount of coal reserves. This shows how the use of coal as a source of carbon dioxide emissions will impact climate change [1].

Therefore, to meet energy demand, renewable and alternative energy must be used instead of fossil fuels. Long-term fuel use in conventional power generation will reduce gas, oil and coal resources [2]. Significant energy production, economic efficiency, and minimal environmental impact are some of the things to consider when generating electrical energy. Indonesia, located along the equator and having abundant sunlight throughout the year, has great potential to be one of the attractive alternatives for developing solar energy sources [3].

Because of its tropical climate, Indonesia can use sunlight to produce energy. Sunlight does not produce the same pollutants as fossil fuel power plants, solar power plants are an environmentally friendly innovation in the production of electrical energy [4]. Solar panels convert solar energy into electricity, which can be used in everyday life to power street lights, parks, traffic and more [5]. In addition, it is necessary to consider the disadvantages of using solar panels as a fixed (conventional) system. This is related to the nature of objects attached to solar panels that are fixed [6]. The impact is that the reception of solar energy becomes less than optimal because at sunrise, the position of the panel is not exactly perpendicular to the sunlight. Therefore, it is necessary to adjust the position of the solar panel so that it can follow the movement of the sun so that it can obtain optimal utilization of sunlight.

Solar panels equipped with microcontroller-based light sensors can utilize innovative technology to solve this problem [6]. This model is equipped with 2 LDR sensors that provide information to the microcontroller chip as the main control unit. The information received is programmatically read and compared between the two LDR sensors. With this input, the microcontroller generates a pulse output that drives the system using a servo motor. This servo motor functions to automatically direct the solar panel towards the sun [7], [8].

Research related to solar trackers involves exploring topics such as: Design and Implementation of a Solar Tracker System, the operation of the experimental model of the device is based on a DC motor controlled by an arduino microcontroller, The signal received from the light sensor or called Light Dependent Resistor (LDR) is input to the microcontroller. Furthermore, the system was installed in the El Oued region in southeastern Algeria, which has a desert climate with high levels of solar radiation throughout the year. The results of the research indicated that the tracking system utilizing the LDR sensor resulted in a 20% increase in panel output power when compared to the fixed system [9].

The research, entitled Design and Performance of Dual Axis Solar Tracker

Based on Light Sensors to Maximize Photovoltaic Energy Output, proposes the design of a dual axis solar tracker to enhance energy production and discusses its function to track the location of the sun in an effective manner. This is achieved through the use of a light-dependent resistor (LDR) light sensor microcontroller Arduino mega 2560, and a linear actuator. The results of the research indicate that the tracking system produces a power increase of 18.56% compared to the fixed system [10].

The objective of research on smart solar tracking systems for optimal power generation is to increase energy production through the utilization of solar panels using LDR components, L293D motor drivers, and ATmega16 microcontrollers. The resulting efficiency is 24.5%, which is a notable improvement. There are different types of trackers that can be used to enhance the amount of energy that solar panels can obtain [11].

Previous research indicates that a system designed to move solar panels, or referred to as a solar tracker, functions to adjust the position of solar panels facing the sun. This is expected to optimize the sunlight absorbed by the solar panels. This research examines the utilization of the ESP-32 microcontroller in a solar tracker system. In addition to processing data from sensors and controlling actuators, the ESP-32 initiates a connection to the internet via WiFi. This integration of advanced IoT technologies demonstrates the potential for efficient monitoring and control. Furthermore, the utilisation of IoT cloud platforms such as Thing.io for the monitoring and management of connected products offers convenience in data management and online system integration, with the aim of providing integrated and effective monitoring technology to facilitate data analysis for future evaluation needs. The utilization of servo motors is anticipated to enhance the output power of solar panels by capitalizing on the angular precision of these components.

The solar tracking system, which will be developed based on the Internet of Things (IoT), will be used to monitor and measure the current and voltage generated by solar panels. The system that will be designed in this research employs several components that will be integrated into a system. These include the ESP-32 microcontroller, the Light Dependent Resistance (LDR) sensor as a light sensor, the INA-219 sensor as a current and voltage sensor, and the MPU. The 6050 sensor, which is a gyroscope sensor, is employed to detect the tilt of the object. The MG996R servo acts as an actuator, regulating the tilt of the solar panel in accordance with the light received by the light sensor and the thinger.io web monitoring and data storage system.

METHODS

System Design

The system design is comprised of both hardware and software components. The block diagram of the system to be designed is presented in Figure 2. The diagram is divided into three processes: input, process, and output. The input section includes two light sensors, a current sensor, and an MPU 6050 sensor. The light sensor utilized is an LDR sensor, which is designed to detect the light intensity at the test location. The LDR sensor is a type of sensor that exhibits a change in its resistance when exposed to light or in the absence of light. The position of the light sensor is determined by each sensor, which represents one cardinal direction. For example, LDR 1 represents east, and LDR 2 represents east [8]. The current sensor employed is the INA-219 sensor, which is designed to detect the flow of electric current and voltage in an electrical circuit. It is capable of measuring a maximum current of +/- 3.2 A and a maximum voltage of +/- 26 V [12]. Upon activation of the system, the two LDR sensors receive light input from the sun, resulting in the generation of an electrical signal output. The difference in value between these two sensors serves to determine the motion of the servo motor. Meanwhile, the INA-219 sensor is responsible for reading the voltage, current, and power generated by the solar panel. The MPU 6050 sensor has the capacity to ascertain tilt angles through the utilisation of data derived from accelerometer and gyroscope sensors. Furthermore, this sensor, which employs the I2C data line, is capable of functioning at a power supply voltage of 3-5 V [13].

In the process section, an ESP-32 microcontroller is employed to process input from sensors and actuators, as well as to initiate communication with the internet via WiFi on the ESP-32. Once the system is connected to the internet, the IoT concept can be applied, as illustrated in Figure 1. The IoT is a combination of internet network connectivity with devices or other physical devices that are continuously connected to obtain and process data in real time. Subsequently, the data can be processed and executed [14].

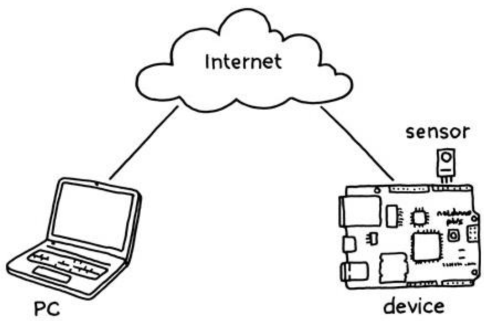

Figure 1. Internet Of Things Concept

The communication protocol utilized in this research is Hypertext Transfer Protocol (HTTP), an application layer network protocol employed for distributed, collaborative, and hypermedia information systems. HTTP is a request-response protocol, whereby the HTTP client (user) transmits a request (request) to the HTTP server, and the server responds in accordance with the request [15].

The software utilized as a client in this research is Thinger.io. Thinger.io is an Internet of Things (IoT) cloud platform that provides the requisite tools for the prototyping, scaling, and management of connected products in a straightforward manner. This platform provides a range of features, including dashboards, data buckets, hardware integration, and APIs that facilitate the connection of IoT devices to the internet and the collection of data from these devices [16]. The data generated by the INA-219 sensor is in the form of voltage and current values, while the power value is obtained through the calculation of the measured values. The data generated by the INA-219 sensor is in the form of voltage and current values, while the power value is obtained from the calculation of the measured values of the LDR 1 and LDR 2 sensors and the MPU 6050. The results of the measurements will be processed by ESP-32, and the data will be sent to the dashboard on the Thing.io website. The incoming data can be stored with the specified time range as the analysis needs. At the output, an MG996R servo motor functions as an actuator. This motor is employed to regulate the tilt of the solar panel, ensuring that it remains oriented towards the sun [17].

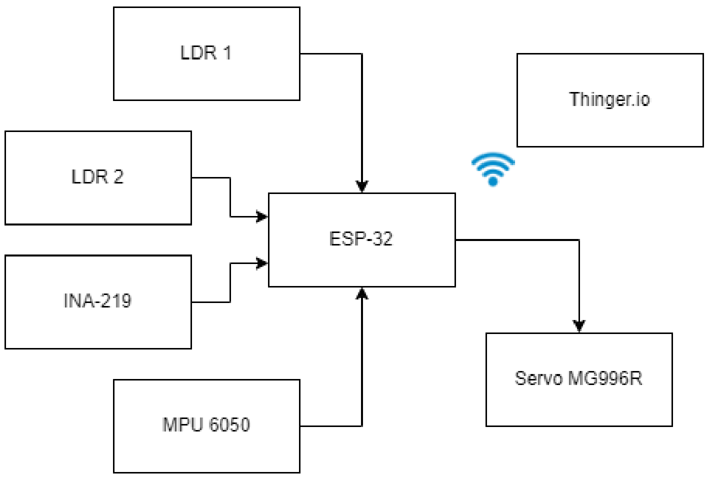

Figure 2. Block Diagram Solar Tracker System

In order to facilitate the programming process, a flowchart is created subsequent to the completion of the design phase. Figure 3 illustrates the designed flowchart. The microcontroller will initially attempt to establish a connection to the Wi-Fi network that has been entered into the program. Once this connection has been established, the microcontroller will then attempt to access the Thinger.io website, which has been configured with the username and access code that has been entered into the program.

Once the Wi-Fi and Thinger.io website have been connected to the microcontroller, the INA-219 sensor reading data, LDR 1 and LDR 2 sensors, and the MPU 6050 sensor read by the microcontroller will be transmitted and displayed on the Thinger.io dashboard. Subsequently, the servo position initialization stage is initiated, with the initial position of the servo set at 45°, the low limit of 45°, the upper limit of the servo at 135°, and the LDR difference tolerance (adjustable). The LDR is then considered. The light intensity values read by the LDR 1 and LDR 2 sensors will be compared. If the difference between the two values is greater than the tolerance, the servo degree will be increased by one degree until the difference between the two light intensity values is less than the tolerance, In the event that the aforementioned threshold is not reached, the servo will cease operation until the predetermined upper limit degree is reached. Conversely, when the difference between LDR 2 and LDR 1 is greater than the tolerance, the servo degree will decrease by 1° until the difference between LDR 2 and LDR 1 is less than the tolerance, or if it is not reached, the servo will cease operation at the predetermined lower limit degree. Subsequently, if the value of LDR 1 is equal to LDR 2, the servo degree will either increase or decrease by 0°, which is to say that the servo will cease until a difference in the values of the two LDR sensors is observed.

Once the servo adjustment process is complete, the microcontroller simultaneously initiates a monitoring phase. At this juncture, the microcontroller will persist in monitoring the values of the INA-219 sensor, LDR 1 sensor, LDR 2 sensor, and MPU 6050 sensor at regular intervals. The data obtained from these sensors will be transmitted in real time to the thinger.io dashboard for the purpose of data analysis. The incoming data can be stored with a time range that can be determined, and the data can be exported in several file formats, including CSV, ARFF, and JSON. Additionally, thinger.io offers the ability to send data or perform actions on external systems via HTTP requests, including GET, POST, PUT, and DELETE. This facilitates the integration of Internet of Things (IoT) devices with third-party web services, applications, or application programming interfaces (APIs), thereby expanding the functionality and interaction of the device with other digital ecosystems. It is possible for users to set custom headers and payloads for each request, thus enabling the delivery of application-specific data. IoT devices can initiate endpoints in response to specific conditions, like changes in sensor values or the occurrence of events the device has identified. Furthermore, endpoints are capable of processing responses from external servers, thereby enabling IoT devices to undertake action based on the response received. The endpoints feature allows for the integration of IoT devices connected to Thinger.io with a variety of web services and third-party applications, including cloud services and data management systems. Additionally, it enables the transmission of notifications to messaging or email applications. Examples of applications include the transmission of data from an IoT device to an external server for further analysis in response to changes in environmental conditions, or the receipt of commands from a web application hosted on a different server. The system thus provides effective monitoring and rapid, accurate responses to changing light conditions.

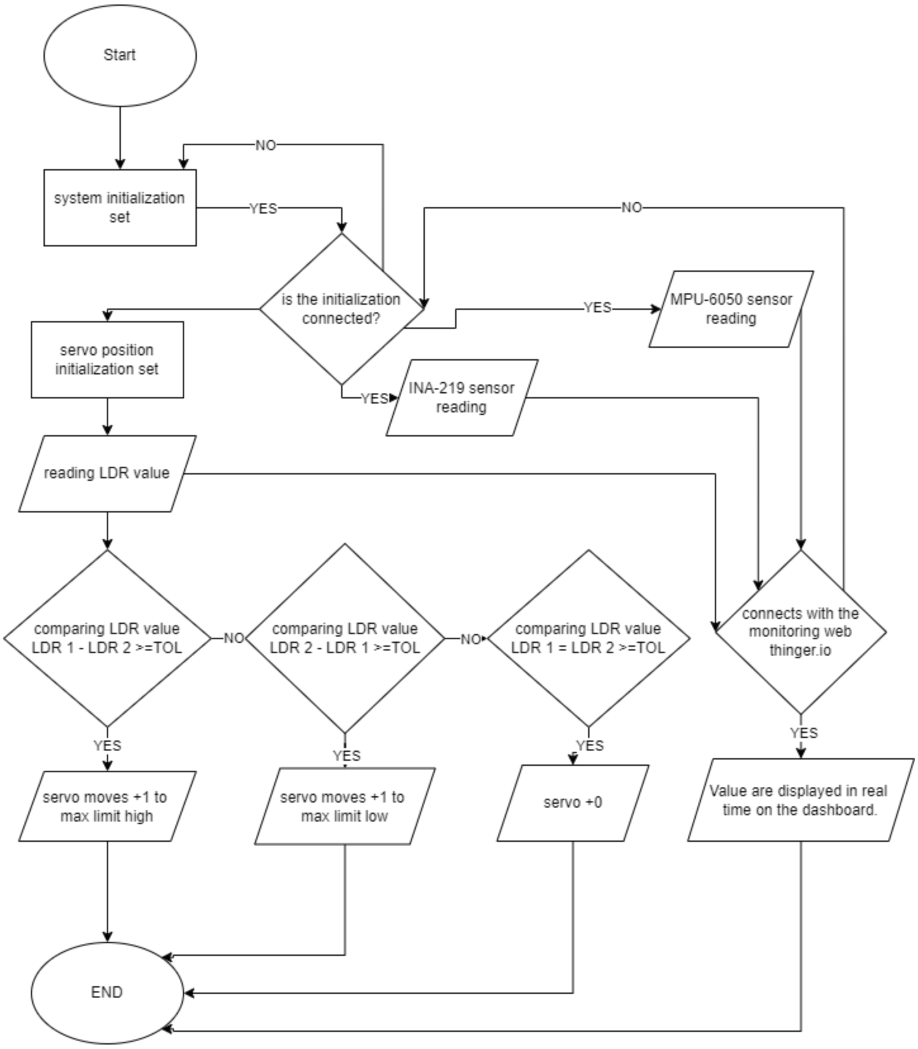

Figure 3. Flowchart Solar Tracker System

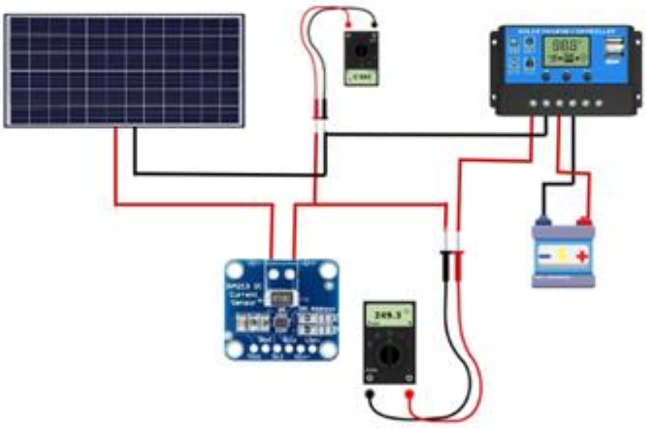

Figure 4. Device Testing Circuit

System Testing

The test method will focus on several aspects, namely the INA-219 sensor reading error rate, the light intensity received by the LDR sensor, the tilt of the solar panel, and the comparison of the output power generated by the static system and the dynamic system. The testing of measurement tools using the INA-219 sensor will be compared with a standard measuring instrument (AVO Meter) attached in Figure 4.

The INA-219 sensor is integrated into the circuit at the output of the solar panel. The measured value is displayed in real-time on the thinger.io page. Subsequently, periodic measurements are taken using standard measuring instruments. The error calculation is obtained through the comparison between the two values using equation (1).

$$Error = \frac{Value\ AVO\ meter - Value\ INA\ 219}{Value\ AVO\ meter} \times 100\% \quad (1)$$

RESULTS AND DISCUSSION

This research presents the results of testing the designed system, which includes both hardware and software. The performance of the designed system can be observed by examining the data collected from the power generated by the sunlight tracking system (dynamic) and the conventional sunlight system (static). The analysis process draws upon previous research to reach more concrete conclusions. The designed device is shown in Figure 5. The device, which has been designed, will be subjected to direct testing on the panel-mount prototype in order to demonstrate its applicability. Figure 6 illustrates the tool being tested on the aforementioned prototype.

The prototype begins with a 5-6V supply voltage that feeds all components, including the LDR sensor, INA-219 sensor, MPU-6050, and MG996R servo motor. When active, the solar panel is positioned at 45 degrees or facing one of the cardinal directions. Then, based on the comparison of light received by the LDR 1 and LDR 2 sensors, the panel moves towards the sunlight. In order to ensure that the solar panel receives optimal sunlight, the position of the panel will be determined by the brightness of the light.

The INA-219 sensor, MPU-6050, and LDR light intensity readings are received by the ESP-32, then transmitted and displayed in real-time on the Thinger.io web via a WiFi connection that has been connected to the ESP-32 thinger.io web dashboard. The display is shown in Figure 7. On the Thinger.io web platform, the data is displayed in six sections according to the input of the four sensor measurements. The dashboard displays six text values and one time series chart. Additionally, incoming data can be stored in the data bucket feature integrated on the Thinger.io web.

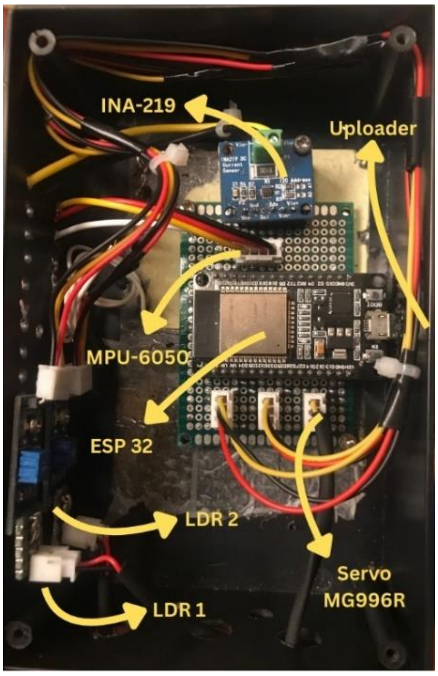

Figure 5. Microcontroller Device

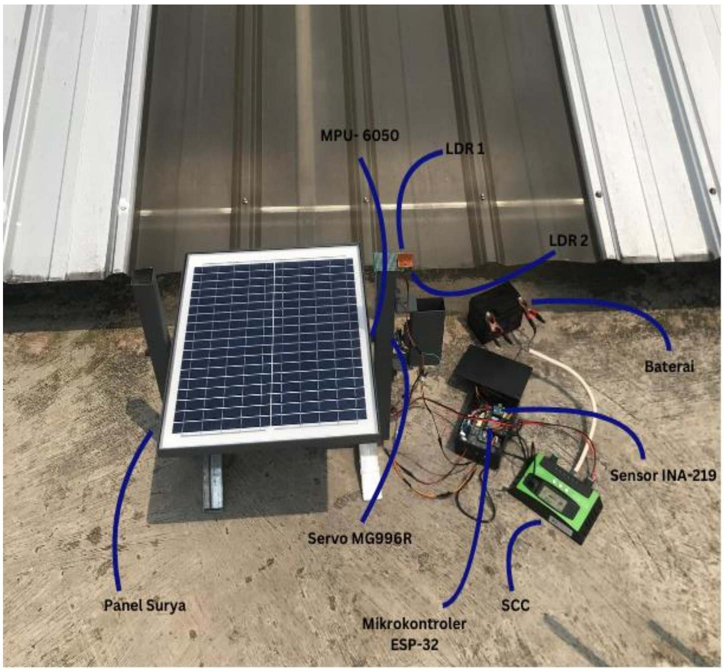

Figure 6. Prototype Testing

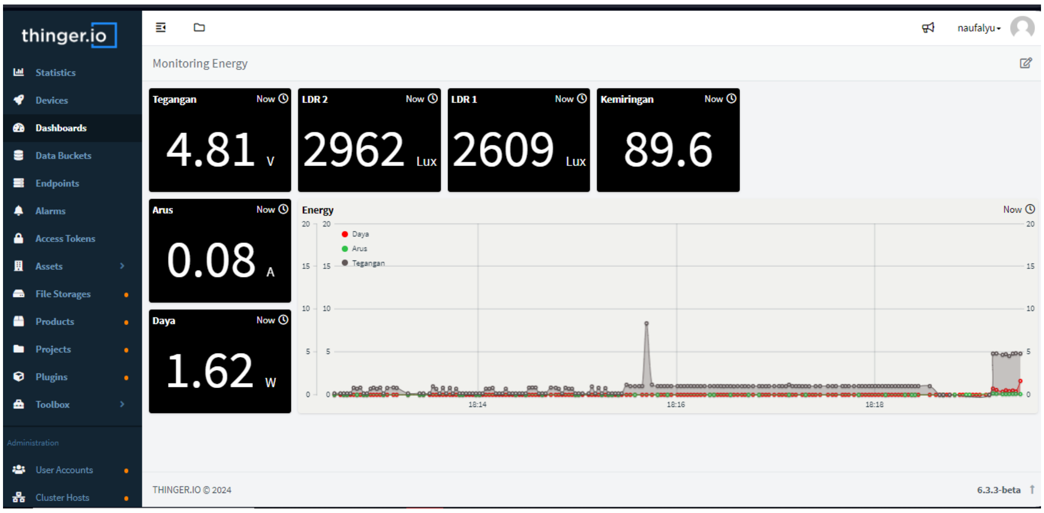

Figure 7. Dashboard View Of Thinger.io

Prototype testing with static systems and dynamic systems (trackers) is carried out for 8 hours, starting at 09:00-17:00 WIB with clear weather conditions, the results of the power output generated from the INA-219 sensor can be seen in Table 1 and displayed in graphical form in Figure 8 and Figure 9. The data bucket is obtained via the Thinger.io page with a sampling interval of 20 minutes. Subsequently, measurement data is obtained using an AVO meter at a specific time to determine the error value.

Table 1. Static and Dynamic Solar Testing

	Solar Static					**Solar Dynamic (Tracker)**					**Sensors (Lux)**		**Increase**
Time	**Voltage (V)**	**Current (A)**	**Power (W)**	**AVO (V/A)**	**Error (%)**	**Voltage (V)**	**Current (A)**	**Power (W)**	**AVO (V/A)**	**Error (%)**	**LDR 1**	**LDR 2**	**Power (%)**
09:00:00	13,2	0,16	2,11			14,8	0,30	4,44			4548	3692	110
09:20:00	13,2	0,18	2,38			14,9	0,31	4,62					94
09:40:00	14,0	0,23	3,22	14,1/ 0,24	0,7/4,1	14,3	0,29	4,15	14,1/ 0,31	1,4/ 6,4			29
10:00:00	14,4	0,25	3,60			15,3	0,30	4,59			5633	3904	27,5
10:20:00	14,3	0,29	4,15			15,1	0,35	5,29					27,4
10:40:00	14,3	0,35	5,01	14,3/ 0,35	0/ 0	16,3	0,34	5,54	16,3/ 0,34	0/ 0			10,5
11:00:00	14,6	0,36	5,26			15,6	0,38	5,93			19518	12486	12,7
11:20:00	14,5	0,45	6,53			16,8	0,46	7,73					18,3
11:40:00	14,9	0,45	6,71	15,1/ 0,46	1,3/2,2	17,7	0,44	7,79	17,8/ 0,45	0,5/ 2,2			16
12:00:00	15,2	0,46	6,99			17,5	0,40	7,00			40678	39403	0,1
12:20:00	16,6	0,41	6,81			18,6	0,39	7,25					6.4
12:40:00	18,5	0,39	7,22	18,5/ 0,38	0/-2,6	18,2	0,44	8,01	18,2/ 0,45	0/ 2,2			10.9
13:00:00	18,3	0,44	8,05			19,3	0,38	7,33			52491	53426	-8.9
13:20:00	16,5	0,35	5,78			19,1	0,46	8,79					52
13:40:00	17,7	0,33	5,84	17,6/ 0,34	0,5/ 2,9	18,1	0,41	7,42	18,2/ 0,38	0,5/ - 7,8			27
14:00:00	16,6	0,30	4,98			17,7	0,40	7,08			32694	38750	42,1
14:20:00	15,8	0,34	5,37			17,2	0,43	7,40					37,8
14:40:00	13,2	0,31	4,09	13,3/ 0,32	0,7/ 3	16,7	0,45	7,52	16,8/ 0,46	0,5/ 2,1			83,8
15:00:00	14,3	0,30	4,29			16,3	0,42	6,85			5728	8532	59,6
15:20:00	13,2	0,17	2,24			15,2	0,43	6,54					191
15:40:00	12,7	0,12	1,52	12,7/ 0,13	0/ 7	15,2	0,39	5,93	15,2/ 0,33	0/ 18			290
16:00:00	12,7	0,02	0,25			14,8	0,26	3,85			3581	6762	1440
16:20:00	12,5	0,05	0,63			14,1	0,19	2,68					325
16:40:00	12,4	0,07	0,87			13,2	0,14	1,85					112
17:00:00	12,4	0,05	0,62	12,5/ 0,05	0,8/ 0	13,4	0,05	0,67	13,5/ 0,05	0,7/ 0	2370	4298	8
Average	**14,6**	**0,27**	**4,18**	**14,76/ 0,28**	**0,5/ 2**	**16,2**	**0,35**	**5,71**	**16,26/ 0,35**	**0,45 /4,8**			**136,99**

The results of static solar testing indicate that the minimum voltage value produced by solar panels is 12.4 V, with the maximum voltage value produced by solar panels being 18.5 V. The average percentage error in measurement is 0.5%. The minimum value of the current produced by the solar panel is 0.02 A, while the maximum value is 0.46 A. The average percentage error in measurement is 2%.

The test results of the dynamic solar (tracker) indicated that the minimum voltage produced by the solar panel was 13.2 V, while the maximum voltage produced by the solar panel was 19.3 V. The average percentage error in measurement was 0.45%. The minimum value of current produced by solar panels is 0.05 A, while the maximum value of voltage produced by solar panels is 0.46 A. The average percentage error in measurement is 4.8%.

Subsequently, the results were obtained in the form of light-dependent resistor (LDR) sensor measurements, which were employed to determine the value of light intensity on each sensor. The MPU-6050 sensor was utilized to determine the tilt of the panel. The monitoring results of both LDR sensors and MPU-6050 sensors are presented in Tables 2 and 3. The data was obtained through the Thinger.io data bucket with a sampling interval of 60 minutes.

The data indicate that the LDR sensor measurement results demonstrate a high level of sunlight intensity between the hours of 09:00 and 17:00, with a peak intensity observed at 13:00, reaching 53426 lux. Furthermore, it can be posited that the LDR sensor readings influence the slope of the solar panel. When the value of one of the LDR sensors is greater, the position of the panel will be inclined to a certain slope determined by the servo motor. The results of the monitoring process, conducted using the MPU-6050 gyroscope sensor, indicated an average error value of 1.6% in the tilt angle reading, when compared to the servo set point

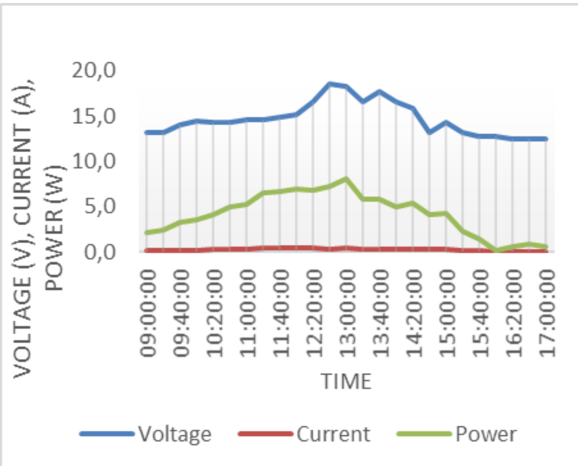

Figure 8. Static Solar Test Data Graph

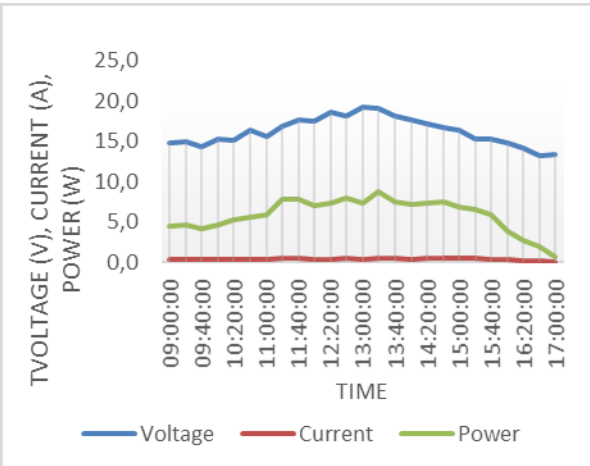

Figure 9. Solar Tracker Data Test Graph

Table 2. Monitoring Data LDR

Time	LDR 1 (lux)	LDR 2 (lux)
09:00:00	4548	3692
10:00:00	5633	3904
11:00:00	19518	12486
12:00:00	40678	39403
13:00:00	52491	53426
14:00:00	32694	38750
15:00:00	5728	8532
16:00:00	3581	6762
17:00:00	2370	4298

Table 3. Monitoring data MPU 6050

Set Point Servo (°)	MPU-6050 (°)	Error (%)
45	44,63	0,8
60	59,39	1,1
75	73,87	1,5
90	88,45	1,7
105	103,03	1,8
120	117,29	2,2
135	131,76	2,4

Table 4. Average Power Output

Time	Static solar	Dynamic solar	Increase (%)
09:00:00	2,57	4,40	71
10:00:00	4,25	5,14	18,9
11:00:00	6,16	7,15	16
12:00:00	7,00	7,42	6
13:00:00	6,56	7,85	19,6
14:00:00	4,81	7,33	52
15:00:00	2,69	6,44	139,4
16:00:00	0,59	2,26	283
17:00:00	0,62	0,67	8
Average	**3,92**	**5,41**	**68**

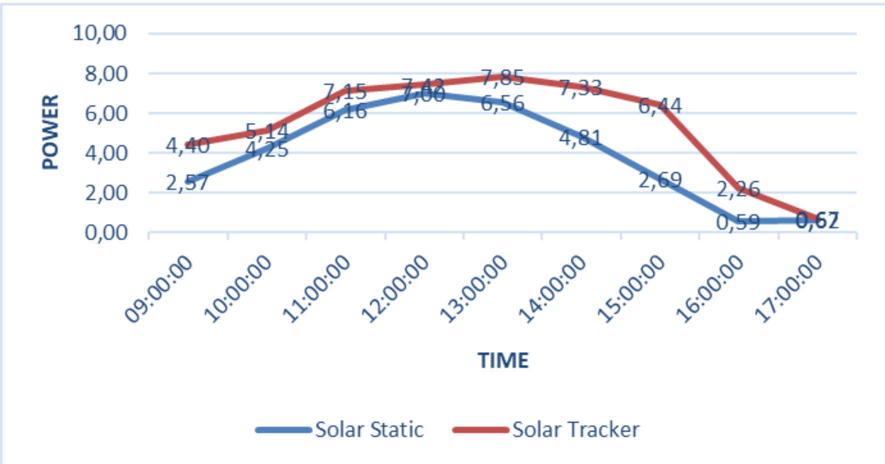

Figure 10. Graph Average Power Output

Based on the test results described above, average power output for solar panels in both static and dynamic conditions, which is presented in Table 4. Additionally, a graph of the difference in power generated from solar panels in static and dynamic systems is shown in Figure 10. The minimum value of power generated by solar panels is 0.62 W in static systems and 0.67 W in dynamic systems at 17:00. The maximum value of power generated is 7 W in static systems and 7.85 W in dynamic systems at 12:00-13:00.

Based on the results of voltage and current measurements conducted on solar panels, the next step is to calculate the percentage increase in current and electrical power generated by solar panels in the absence of solar trackers (static) and solar panels that use solar tracker systems. The percentage increase in electrical power generated by static solar panels and solar tracker panels is determined by the equation (2).

$$increase = \frac{dynamic\ power - static\ power}{dynamic\ power} \times 100\% \quad (2)$$

$$increase = \frac{5{,}41 - 3{,}92}{5{,}41} \times 100\%$$

$$Increase = 27{,}54\%$$

The data presented above indicates that the use of a solar tracker results in a 27.54% increase in power compared to a static configuration. This result demonstrates that the integration of a solar tracker can enhance the generation of power, enabling the solar panel to harness sunlight in a more effective and efficient manner.

CONCLUSION

This research successfully designed an IoT-based solar tracker monitoring system using ESP32 with LDR sensors, INA-219, and servo motors as actuators. The utilization of electrical energy from solar energy converted through solar cells is generally only in a static position, which is considered less than optimal. However, the use of a solar tracker enables the position of the solar panel to be adjusted to follow the movement of the sun, through the use of a light sensor (LDR), thereby allowing the utilization of solar energy to be maximized. Testing of the INA-219 sensor revealed an error in voltage measurement of 0% to 1.4% and 0% to 18% in current measurement, while the average tilt angle error value on the MPU-6050 sensor was 1.6%. The system exhibited an increase of 9.87% in voltage and 22.85% in current compared to the static system. The results of the calculations indicate that the average electric power generated by the solar panel with solar tracker is 5.41 W, while the solar panel without solar tracker is only 3.92 W. This represents a difference in the average energy output of 27.54% in the sample data taken every 20 minutes. The results demonstrate that the integration of solar trackers in solar panel production can enhance the output power of solar panel systems, thereby contributing to the development of renewable energy resources in a more efficient.

For further research related to the solar tracker system using thinger.io, it is recommended that the focus be placed on the development of more sophisticated control algorithms and the conduction of wider and larger scale field trials. These steps are expected to increase the efficiency and effectiveness of the solar tracker system, as well as provide a deeper understanding of the potential and benefits of this technology in optimizing the use of solar energy in an optimal and sustainable.

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