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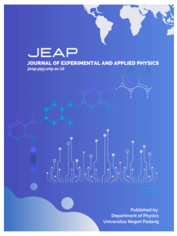

Solar Tracker Arduino

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Abstract: Electrical power is essential to human life, but dependence on non-renewable fossil fuels is driving the need for alternative energy development such as solar power. Conventional systems without solar trackers cause the efficiency of solar panels to decrease because they cannot optimally follow the movement of the sun. In this research, an Arduino-based dual-axis solar tracker is developed that can move on two axes (horizontal and vertical) to increase the efficiency of solar energy absorption and is equipped with a rain sensor to protect solar panels. This system has the advantage of maximizing energy absorption and providing additional protection from environmental conditions. The test results show the relationship between sunlight intensity and the voltage generated by the solar panel, the higher the sunlight intensity (lux), the higher the voltage generated by the solar panel. For example, at an intensity of 1,300 lux, the voltage reaches 4.7 volts, while at an intensity of 55 lux, the voltage decreases to 0.3 volts. The relationship between the light intensity and the analog reading of the LDR sensor shows that the higher the light intensity received, the higher the analog reading produced by the sensor. At low light intensities, such as 190 lux, the LDR readings at each position (top left, top right, bottom left, bottom right) tend to be different, reflecting the uneven distribution of light. In contrast, at higher light intensities, such as 500 lux, the LDR readings are larger and more evenly distributed, indicating that the solar panel is already in the optimal position perpendicular to the direction of incoming sunlight.

Keywords: Solar Tracker, LDR Sensor, Intensity, Voltage, Lux Meter.

1. Introduction

Electrical energy is an indispensable resource for people today. Various human activities, whether at home, in the office, in industry or in public facilities, rely heavily on electrical energy. However, the high human demand for electrical energy is not proportional to its availability. Currently, most of the electrical energy used is generated by power generators [1]. The source is obtained by using energy from non-renewable fossil fuels such as coal, gas and oil [2]. Therefore, alternative renewable energy is needed to replace fossil energy as the limited supply of fossil fuels continues to increase [3].

One such energy source is solar energy. Solar energy is an abundant, unlimited resource, and can be utilized in various locations. Earth receives about 1.8×10^{11} MW of power from the sun [4]. In a solar power generation system, energy utilization efficiency highly depends on an accurate tracking system. Therefore, a control system is required to optimize the orientation of solar panels based on the intensity of light received. While Indonesia itself is located in the equatorial region, so it receives abundant sun exposure, with an intensity reaching 4.8-6.0 kWh/m^2 per year and an energy potential of 207,898 MW [5]. This situation makes the utilization of solar panels has great potential to be developed in Indonesia [6]. In addition to its abundance, solar energy is also environmentally friendly because it does not produce pollution that can damage the ecosystem. Despite its enormous benefits in terms of sustainability and environmental preservation, its global utilization is still limited, only about 5% of the total annual energy consumption [7].

Sunlight can be converted into electrical energy through solar or photovoltaic cells [8]. A system capable of tracking energy is necessary to increase the efficiency of solar energy utilization during the day, given that the electricity generated by a solar energy system is highly dependent on the amount of solar energy absorbed by the solar panels [9]. The tracker serves to align the collector or solar panel with the position of the sun as it moves across the sky each day. With the presence of solar trackers, the amount of energy received by the collector increases, so that the production of electricity or heat becomes more optimal [10]. A solar tracker operates using a light sensor to determine the position of the sun and moves the solar panel through a servo motor to ensure it remains at the optimal angle. Solar panels generally use tracking systems with single-axis or dual-axis mechanisms [11]. The single-axis system uses one servo motor to follow the sun's movement from east to west [12]. Meanwhile, dual-axis systems use two servo motors to track the sun's position not only on the east-west axis, but also north-south [13]. This makes the tracking more efficient in optimizing solar energy absorption both vertically and horizontally [14]. The performance of solar panels is greatly influenced by the light intensity as well as the position of the sun which is constantly changing throughout the day [15]. In general, during the day, a tracker using a dual-axis system will move following the sun's position from east to west and north to south, while a single-axis system only moves from east to west with one degree of freedom according to the sun's position [16].

In previous studies, Lestariningsih et al. (2023) developed a single-axis solar tracker system on solar panels using an LDR sensor [1]. The advantage of this system lies in its ability to track the position of the sun; however, it has limitations as it can only move along a single axis, from east to west. Zahro (2023) also developed a dual-axis solar tracker system, which can track the sun's position more optimally along both the vertical and horizontal axes [8]. However, the drawback of this system is the lack of protection against corrosion and rust, especially during the rainy season. Ugale et al. (2023) demonstrated that an Arduino-based dual-axis solar tracker system can improve power efficiency by 40-60% compared to a fixed system. However, this study did not consider environmental factors such as rain, which can cause corrosion and degrade the performance of solar panels over time [17]. Meanwhile, Wiharja & Halim (2022) examined the use of reflectors and a water treatment system on a dual-axis solar tracker, which was proven to increase solar panel efficiency by 24-70%, depending on the type of reflector used. However, this study still has limitations, such as not considering weather factors that could affect device durability, and it employs a linear actuator, which, despite its high precision, consumes more power compared to a servo motor [18]. Furthermore, most previous studies have only focused on tracking efficiency, without considering external factors such as weather conditions, which can impact the durability of the device and the long-term performance of the system.

To overcome this problem, solar tracker technology was developed that is able to follow the movement of the sun. Unlike previous studies, this system not only optimizes the position of the solar panel based on light intensity but also adapts to changing weather conditions. Solar trackers function to adjust the orientation of solar panels to always face the sun optimally, thereby increasing the amount of energy that can be absorbed. Dual-axis solar trackers allow solar panels to move on two axes (horizontal and vertical), so they can follow the sun's movement more accurately throughout the day. In addition, the system is also equipped with a rain sensor that functions as a rainwater detector. If rain is detected, the solar panel will rotate to a certain position to prevent water from pooling on it. Thus, the performance of the solar panel is maintained and the risk of damage due to standing water is minimized. This research contributes to the development of an automated control-based tracking system that is more efficient, durable, and cost-effective, making it a better solution for solar energy utilization in various environmental conditions.

2. Materials and Method

The components of the designed system are geometrically arranged according to their specific functions. The design process includes the creation of block diagrams, hardware design, and software design as part of the overall tool development. The first step in building a system is to create a block diagram, which serves as a guide to ensure that the designed circuit matches the desired function. Developing a block diagram helps in explaining the system structure and working principle of the system being developed. Below is Figure 1 block diagram of the Arduino Solar Tracker system.

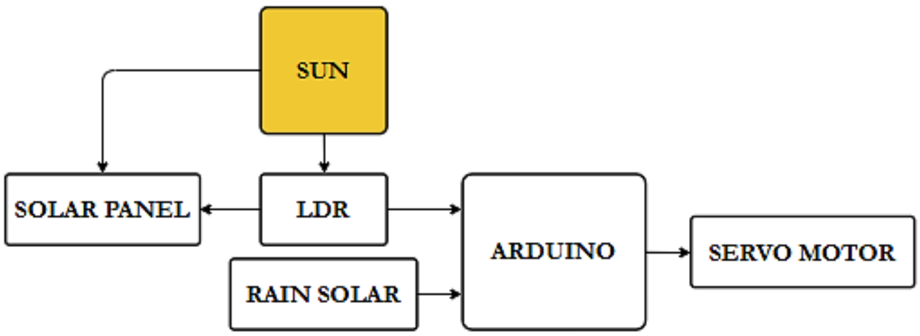

Figure 1. System block diagram

Figure 1 is an illustration of the Arduino Solar Tracker system consisting of four LDR (Light Dependent Resistor) sensors placed on one side of the solar panel with 4 angles to detect the intensity of sunlight from various directions. Arduino Uno as a microcontroller that receives data from the four LDRs to determine the optimal direction of the solar panel so that it is always perpendicular to sunlight. 2 servo motors as drivers, one for the horizontal axis (azimuth) and another for the vertical axis (elevation), which allows the panel to move dynamically following the position of the sun throughout the day.

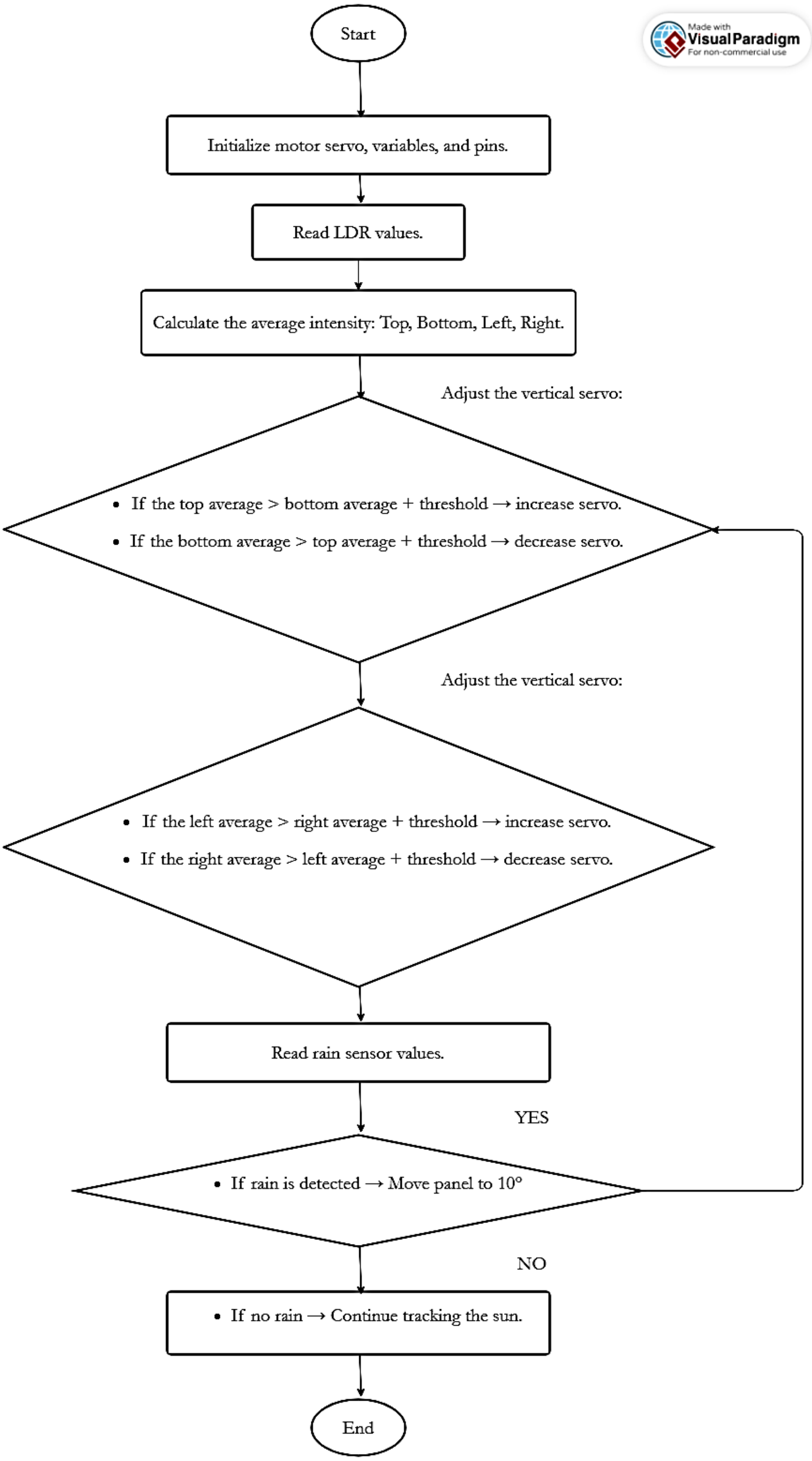

Figure 2. Flowchart of system programming algorithm

In addition, this tool is equipped with a rain sensor that functions to detect the presence of rainwater. If rain is detected, the Arduino prioritizes the command from the rain sensor and rotates the solar panel to a 10-degree position to prevent water from pooling on its surface. Once the rain stops, the system returns to work as usual, tracking the movement of the sun to maximize energy absorption. With the combination of four LDRs, two servo motors, and a rain sensor, it not only ensures the efficiency of solar energy absorption but also keeps the panel clean and protected in various weather conditions. The next design process is the software design shown in Figure 2. Figure 2 shows the flowchart of the design of the microcontroller devices in the system. The design process begins with the use of Arduino IDE software to create a program that will be uploaded to the Arduino Uno board. The first step taken is Servo Motor initialization to determine the pins used for input and output operations. After the device is turned on, the system starts reading the LDR value by calculating the average Intensity value to determine the position of the servo motor or the direction of the sun source. Where if the light intensity is large at the top flat then the servo is in a vertical position. However, if the sun's intensity is greater in the lower average then the servo motor is in a horizontal position. Furthermore, when rainwater touches the sensor surface, the Arduino uno will read the rain sensor value, and the servo motor position will move 10 degrees down to position the solar panel or protect it from rain. If there is no rain, the servo motor will return to tracking the presence of the sun. The next design process is Figure 3 Electronic circuit of the system.

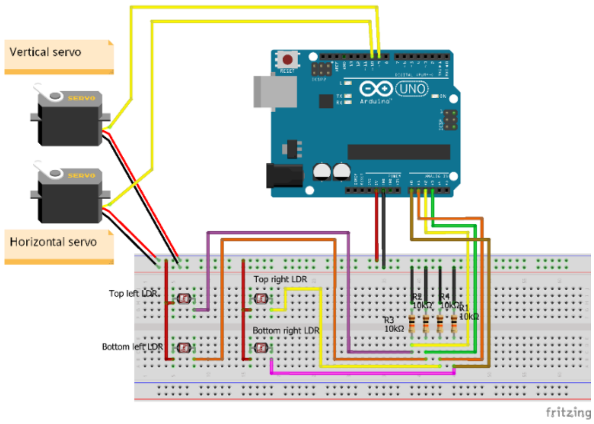

Figure 3. System electronics circuit

Figure 3 illustrates the detailed system circuit where Arduino Uno is used as the central microcontroller to control and process data from various components. In the circuit, Arduino Uno pin connections are made to integrate the functions needed in the solar tracker system. Pins A0-A3 are connected to one leg of the LDR1-LDR4 sensor which functions as a light source detector. LDR sensors work based on the principle of converting physical energy into electrical energy that can be processed by Arduino Uno. When the light hitting the LDR increases, its resistance decreases, so the output voltage in the voltage divider circuit changes. This voltage is then read by the Arduino analogue pin as a signal representing light intensity. Servo motors 1 and 2 are connected to digital legs 9 and 10 on the Arduino Uno which function as movers, one for the horizontal axis (azimuth) and another for the vertical axis (elevation), which allows the panel to move dynamically following the position of the sun throughout the day. Meanwhile, the rain sensor is connected to Analog pin 4 on the Arduino uno which functions as a conductive plate that detects the presence of water. When rainwater touches the surface of the sensor, the electrical conductivity increases, which results in a change in voltage or current value. This value is converted into an analogue or digital signal, which is also interpreted by the Arduino. With this principle, the two sensors transform physical phenomena into electrical signals, allowing the Arduino to analyze the data and take action as needed, such as driving a motor to position the solar panel or protect it from rain. The next design process is Figure 4 illustrates the system design created in the Solidworks application.

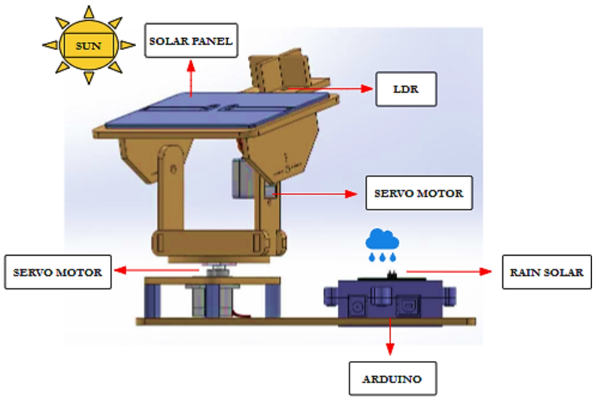

Figure 4. Illustration of system design

Figure 4 is an illustration of the system design that will be designed. Where the LDR sensor will be placed on the top side of the solar panel with 4 angles to detect the intensity of sunlight from various directions. Servo motor 1 is placed on the vertical axis and servo motor 2 is placed on the horizontal axis which allows the panel to move dynamically following the position of the sun throughout the day. Meanwhile, the rain sensor is placed on the top of the circuit box. If rain is detected, the Arduino prioritizes the command from the rain sensor and rotates the solar panel to a 10-degree position to prevent water from pooling on its surface. Once the rain stops, the system returns to its normal work, tracking the movement of the sun to maximize energy absorption.

3. Results and Discussion

The results show that the Arduino solar tracker is effective in maximizing energy absorption and providing additional protection from environmental conditions. The system collaborates several key components including the Arduino Uno microcontroller, LDR sensor, servo motor, and rain sensor. The Arduino Uno serves as the central component of the system responsible for processing inputs and outputs. The Arduino collects data from the LDR sensor and processes it and displays the results of the LDR sensor analog data reading on the serial monitor. The following are the results of the hardware implementation of the Arduino solar tracker system into a mechanical structure that can be seen in Figure 5 below.

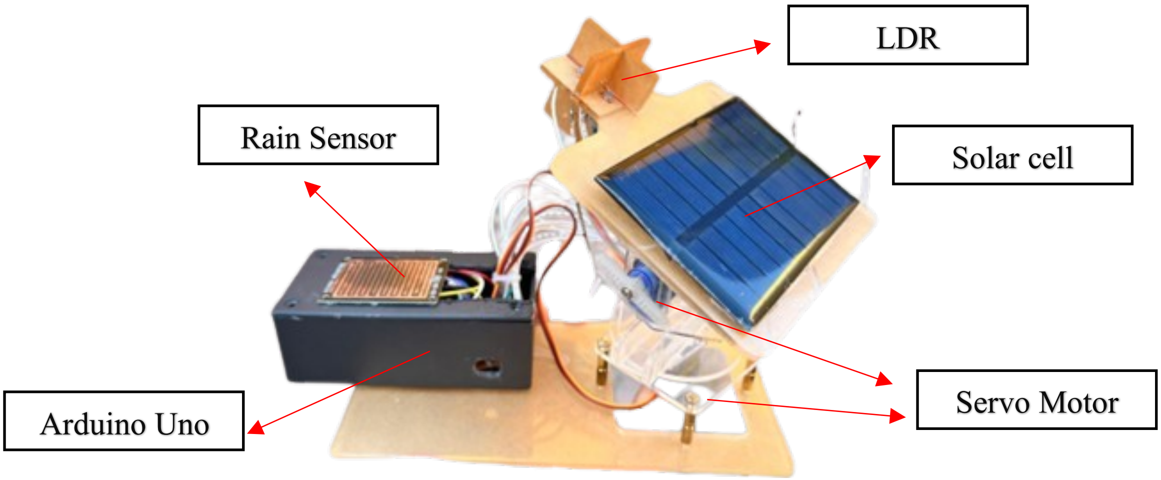

Figure 5. System Hardware

Figure 5 is the hardware implementation of the Arduino solar tracker system into a carefully designed mechanical structure. In this setup, all components are optimally positioned to ensure proper functionality. The use of four LDR (Light Dependent Resistor) sensors placed on one side of the solar panel with 4 angles to detect the intensity of sunlight from various directions. The data from these four LDRs is sent to Arduino to determine the optimal direction of the solar panel so that it is always perpendicular to the sunlight. The system uses two servo motors as drives, one for the horizontal axis (azimuth) and another for the vertical axis (elevation), which allows the panel to move dynamically following the sun's position throughout the day. In addition, it is equipped with a rain sensor that detects the presence of rainwater. If rain is detected, the Arduino prioritizes the command from the rain sensor and rotates the solar panel to a 10-degree position to prevent water from pooling on its surface. Once the rain stops, the system returns to work as usual, tracking the movement of the sun to maximize energy absorption. With the combination of four LDRs, two servo motors, and a rain sensor, this tool not only ensures the efficiency of solar energy absorption but also keeps the panel clean and protected in various weather conditions.

The data obtained from this experiment enables the development of solar absorption efficiency as an alternative energy source that will never run out. Following the data from the LDR sensor and processing it and displaying the results of the analog data reading of the LDR sensor in the Arduino IDE serial monitor, the data collection experiment was carried out 12 times.

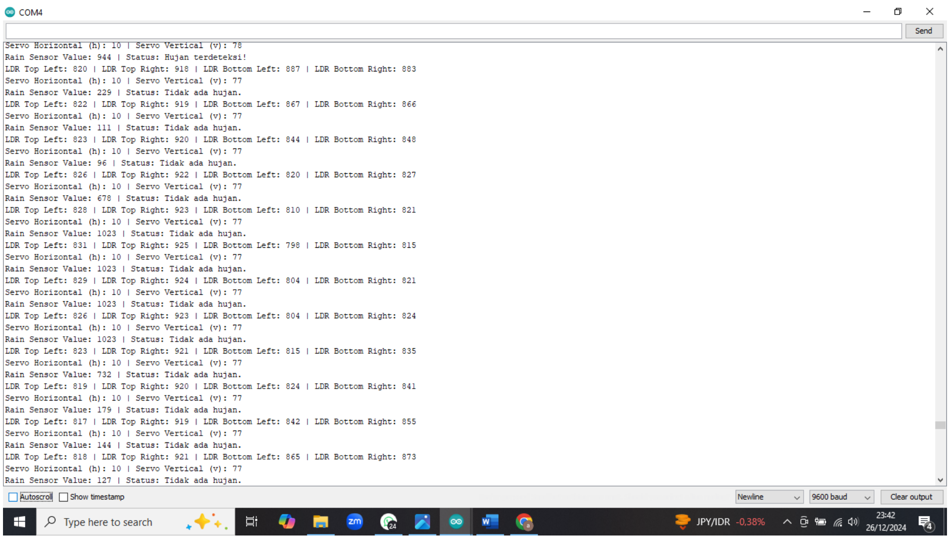

Figure 6. System software display

The testing of the Arduino solar tracker system, it is carried out through various stages, starting from the calibration process of the sensor system using a lux meter, Servo calibration at the starting point (0 degrees) then the solar tracker system data collection experiment is carried out and the experimental data is obtained as in the following table 1.

Table 1. Data on the relationship between sunlight intensity and voltage on the solar tracker

No	Intensity (Lux Meter)	Voltage (Volt)
1.	1.300	4,7
2.	1.000	4,5
3.	762	4
4.	670	4
5.	467	3,4
6.	295	3,2
7.	200	3
8.	180	2,4
9.	150	2
10.	130	1,8
11.	90	0,8
12.	55	0,3

In the first table, the relationship between sunlight intensity and voltage generated by the solar panel is shown, confirming the basic working principle of Photovoltaics: the higher the sunlight intensity (lux), the greater the voltage produced by the solar panel. For instance, at an intensity of 1,300 lux, the voltage reaches 4.7 volts, whereas at an intensity of 55 lux, the voltage decreases to 0.3 volts. This aligns with the working principle of solar panels, where the amount of electrical energy generated depends on the amount of sunlight absorbed, proving that the system functions according to the theory of light-to-electricity energy conversion. Below is Figure 18, which presents the graph of the relationship between sunlight intensity and voltage in the solar tracker system.

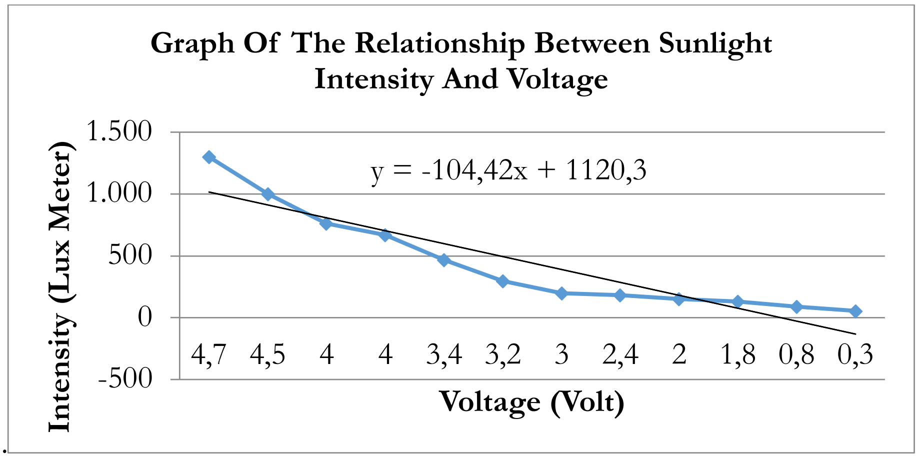

Figure 18. Graph of the Relationship Between Sunlight Intensity and Voltage in the Solar Tracker System

The next section presents the measurement and observation data of the system through 12 experiments. The measurements aim to determine the relationship between light intensity and the analog reading values from the LDR sensor. The system reads the LDR values by calculating the average intensity to determine the position of the servo motor or the direction of the sunlight, as shown in Table 2 below.

Table 2. Measurement and Observation Data of the Arduino Solar Tracker System

No	Intensity (Lux Meter)	LDR Value (Analog Reading)				Servo Motor Angle When Light Arrives		Weather Condition (Rain Sensor)
		1 (Top Left)	2 (Top Right)	3 (Bottom Left)	4 (Bottom Right)	1 (Vertical)	2 (Horizo ntal)	
1.	22	400	550	360	458	0°	180°	Not Raining
2.	90	616	743	738	737	32°	162°	Not Raining
3.	130	663	795	804	799	40°	195°	Not Raining
4.	150	725	843	860	851	35°	153°	Not Raining
5.	180	787	899	954	912	35°	180°	Not Raining
6.	190	719	848	874	867	13°	175°	Not Raining
7.	212	821	932	918	922	57°	180°	Not Raining
8.	250	757	637	885	583	10°	113°	Raining
9.	280	757	637	885	583	10°	113°	Raining
10	361	809	911	934	926	16°	64°	Not Raining
11	360	818	921	865	873	77°	10°	Not Raining
12	500	862	942	962	958	10°)	59°	Raining

The second table illustrates how the Arduino-based solar tracker utilizes four LDR (Light Dependent Resistor) sensors to detect light intensity from various directions. The LDR readings from four positions (top left, top right, bottom left, bottom right) are processed by the Arduino to determine the optimal servo motor angle, both vertically and horizontally. For instance, at an intensity of 361 lux, the LDR values show a different distribution, prompting the system to adjust the vertical servo motor angle to 16° and the horizontal angle to 64° to keep the solar panel aligned with the sunlight. Additionally, when the light intensity reaches 500 lux, the system detects rain through a rain sensor and automatically adjusts the panel to a vertical angle of 10° to prevent water accumulation. Once weather conditions return to normal, the system resumes dynamic sun tracking.

The graph of the relationship between light intensity and the analogue reading values of the LDR sensor shows that the higher the received light intensity, the greater the analogue reading value produced by the sensor. At low light intensity, such as 190 lux, the LDR readings at each position (top left, top right, bottom left, bottom right) tend to vary due to uneven light distribution. In contrast, at higher light intensity, such as 500 lux, the LDR readings are higher and more uniform, indicating that the solar panel is in an optimal position, perpendicular to the direction of incoming sunlight. This aligns with the working principle of LDRs, where resistance decreases as light intensity increases, resulting in higher analogue reading values. Below is Figure 19, which presents the graph of the relationship between sunlight intensity and the analogue reading values of the LDR sensor in the solar tracker system.

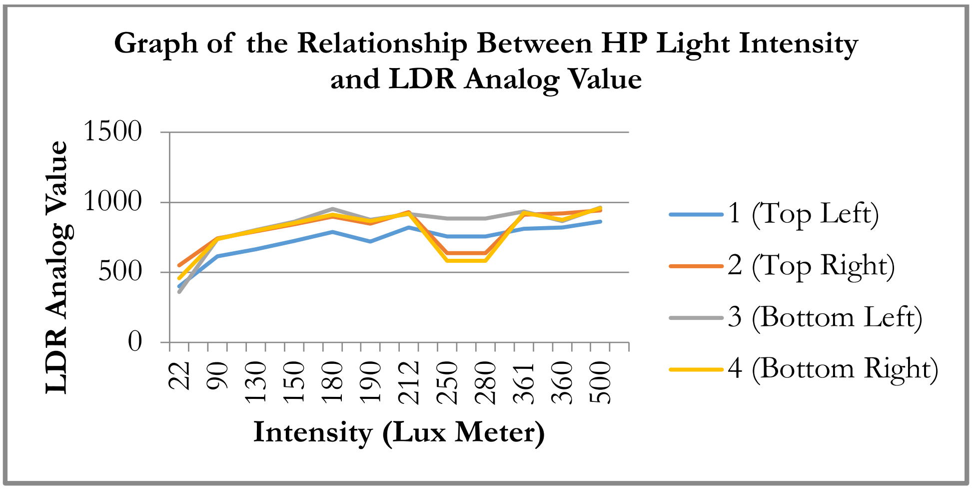

Figure 19. Graph of the Relationship Between Sunlight Intensity and the Analog Readings of LDR Sensors in the Solar Tracker System.

The solar tracker theory states that this device is designed to maximize solar energy absorption efficiency by keeping the solar panel perpendicular to the sunlight at all times. In an Arduino-based implementation, as shown by this data, the solar tracker operates by integrating LDR sensors to detect light intensity, servo motors to move the panel, and a rain sensor to protect the panel from extreme weather conditions. This system combination ensures the optimal performance of the solar panel, both in generating electrical energy and maintaining its reliability under various environmental conditions.

Several previous studies have also examined the implementation of solar trackers to enhance photovoltaic efficiency. For instance, a study by Lestariningsih, W., et al. (2023) found that a single-axis solar tracking system could not improve energy absorption compared to a dual-axis panel system [1]. Similarly, another study by Zahro (2023) developed a dual-axis tracking system that improved panel accuracy, leading to increased energy absorption [8]. This study differs in that it focuses on a more cost-effective Arduino-based system while integrating a rain sensor to enhance adaptability to changing weather conditions. While previous studies have primarily focused on improving energy efficiency, this research contributes by addressing practical challenges such as weather adaptation and real-time servo adjustments, thereby optimizing energy absorption and protecting the system from environmental conditions.

The research on Arduino-based solar tracker systems has significant implications for the development of automated renewable energy systems. By utilizing an Arduino-based solar tracker, solar panels can adapt to changes in sunlight intensity throughout the day and under various weather conditions. This enhances the efficiency of solar energy conversion into electricity, especially in regions with fluctuating light intensity. Additionally, the integration of a rain sensor provides extra protection for the solar panels, potentially extending their lifespan and reducing maintenance needs. From a practical perspective, this system can be implemented on both household and industrial scales as part of a green energy solution. With the efficiency improvements demonstrated in this study, the use of solar tracker systems can be an effective strategy to maximize the electrical energy output of solar panels without requiring manual intervention.

Although this study demonstrates the effectiveness of the Arduino-based solar tracker system, there are still several aspects that require further investigation. One key area is the development of a more adaptive algorithm to improve the accuracy of sun tracking by considering additional variables such as temperature and wind speed. To enhance efficiency, power management, remote monitoring, and real-time data analysis, the integration of an Internet of Things (IoT) network is needed in the Arduino-based solar tracker system.

4. Conclusion

The designed Arduino-based solar tracker was successfully developed to enhance solar energy absorption efficiency by keeping the solar panel perpendicular to sunlight at all times. Measurement results show a relationship between light intensity and the solar panel voltage, indicating that the higher the received sunlight intensity, the greater the voltage generated by the solar panel. With the help of the solar tracker, the panel can continuously adjust to the optimal position relative to sunlight, maximizing energy production even as light intensity fluctuates. Additionally, the angle adjustments based on sensor readings demonstrate that the LDR readings and servo motor angles adapt to the distribution of light intensity in different directions. This reflects the capability of the Arduino-based solar tracker to continuously align the solar panel with sunlight while also protecting it from weather conditions such as rain. This aligns with the theory that dynamic tracking improves system efficiency and reliability.

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