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Robust Solar Energy Tracking System Using Data Logger

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Abstract

Recent advancements in solar energy technology have gained momentum globally, with commercial solar power platforms becoming increasingly accessible in various regions. Over the past few decades, renewable energy sources have garnered significant interest, with solar energy standing out as one of the most vital. This energy source is environmentally friendly, producing no pollution, and remains naturally abundant without human control, making solar systems indispensable in modern power generation. Solar tracking technologies are designed to ensure that the solar panel surface aligns perpendicularly with incoming sunlight to optimize solar energy harnessing. This alignment maximizes light absorption, enabling the highest electrical energy output. Specifically, when sunlight strikes the panel at a perpendicular angle, it generates peak efficiency in energy conversion. This work focuses on developing a two-axis solar tracking system equipped with a data logger to record voltage and current readings from the solar panel. Sensors connected to an Arduino board are the system's primary controller, sending signals to motors that adjust the panel's position based on input from light-dependent resistors (LDRs). A Pyranometer, aligned with the solar panel, was used to provide accurate solar radiation and weather data. The system was validated to ensure reliable performance, with data collected aiding in power analysis and statistics.

Keywords: Solar Energy, Renewable Energy, Tracking System, Data Logger, Pyranometer,

INTRODUCTION

Interest in renewable energy sources has emerged in the past few decades, and one of the most important sources is solar energy. This is an important source that does not produce any environmental pollution and is not controlled by humans. It is a blessing from God Almighty to all human beings. Therefore, solar systems have seen progress. It included the principles of its work on the one hand and its techniques on the other (Anderson 2017).

Solar tracking technologies are also designed to fall perpendicular to the surface of the solar panel for optimal solar energy investment. Collecting the light at the angle of incidence of the sun-powered light on the surface of the solar panel, where the highest light energy is obtained, and, therefore, the highest electrical energy is obtained when the light falls perpendicular to the surface of the solar panel.

Recent advancements in solar energy tracking systems focus on improving energy efficiency, reducing costs, and integrating new technologies that are sensor-based controls and AI-based systems. A significant development in recent years is using dual-axis solar trackers equipped with ultraviolet (UV) sensors and micro-electromechanical systems (MEMS) sensors. These sensors improve tracking precision by measuring UV radiation and forecasting the sun's path. The data is processed using an Arithmetic Optimization-based PID (AOPID) controller, which optimizes the panel's position to maximize energy capture. Simulation tests showed improved energy output over fixed-tilt PV systems (Smith, 2022). (Pagliaro & De Rosa 2023) discussed the new technologies, which include:

1. **Digital Twins in Agrivoltaics:** In agrivoltaics, where solar panels are combined with agriculture, researchers are using digital twin technology to optimize tracker control systems. These systems balance the energy needs of solar modules with the light requirements of crops growing beneath them. AI-based predictive control algorithms adjust panel orientation based on microclimatic conditions and grid tariffs, ensuring optimized yields for both electricity and crops.
2. **AI and Machine Learning:** Incorporating AI and machine learning into solar trackers has improved their ability to predict and adjust for environmental changes. These systems can analyze weather data, sunlight intensity, and grid requirements to optimize energy production in real time, making solar energy systems more reliable and efficient.
3. **Industry Trends:** The adoption of solar tracking systems is expected to increase significantly, with forecasts predicting up to 60% market penetration within the next decade, driven by advancements in control systems and regulatory incentives for agrivoltaics and ground-mounted PV systems.

These developments highlight how solar tracking technology is evolving to meet the growing demand for renewable energy while optimizing land use and energy efficiency.Developing a solar energy tracking system with a data logger and verifying data accuracy using global reference databases has several applications (Miro, 2017). Some of these applications are as follows:

Solar energy system optimization: The solar energy tracking system can optimize the performance of solar panels by adjusting their angle and position to maximize the amount of sunlight they receive. This can increase the efficiency of the solar energy system, leading to higher energy production and lower energy costs.

Renewable energy research: The data collected from the solar energy tracking system can be used by researchers to study the performance of solar panels under different circumstances. This can help develop new and more efficient solar energy technologies.
Energy management (Irena, 2012): The data collected by the data logger can be used to monitor the energy production of the solar panels and to optimize the energy usage in a building or facility. This can lead to cost savings and more efficient energy use.

Environmental monitoring: The solar energy tracking system can also be used to monitor environmental conditions such as temperature, humidity, and air quality, which can impact the performance of the solar panels.

Climate change mitigation: The development of more efficient solar energy systems can help reduce greenhouse gas emissions and contribute to mitigating the effects of climate change.
Generally, developing a solar energy tracking system with a data logger and verifying data accuracy using global reference databases can significantly impact the development and optimiza-

tion of solar energy technologies and their applications in various fields.

The basic principle of developing a solar energy tracking system with a data logger and verifying data accuracy using global reference databases involves Installing a solar panel tracking system. The first step is to install a solar panel tracking system that can adjust the angle and position of the solar panels according to the movement of the sun. This can be done using various tracking technologies, such as single-axis or dual-axis tracking. A data logger is also needed to collect data on the performance of the solar panels, including the amount of energy produced, the angle and position of the panels, and environmental conditions such as temperature and humidity. The collected data can be used to analyze the efficiency of the solar panels and to optimize their performance (Paul, 2016). Moreover, verifying data accuracy is crucial and can be performed by comparing these data with data from global reference databases. These databases contain accurate and reliable data on solar radiation and other environmental conditions that can affect the performance of solar panels. Analyzing the data collected by the data logger and verifying for accuracy can be achieved to identify patterns and trends in the performance of the solar panels. This analysis can be used to optimize the performance of the solar panels and to make improvements to the solar energy system.

Solar energy tracking Systems: Generally, developing a solar energy tracking system with a data logger and verifying the data accuracy using a global reference database needs many hardware components to achieve a robust and accurate system (Al-Hashmi, 2017). These components can be explained as follows:

Pyranometer: A pyranometer is an instrument used to measure the total amount of solar radiation that reaches a horizontal surface (Klaus, 2014). It is often used in meteorology, climatology, and agriculture to study the amount of solar energy available at a particular location. Typically, it consists of a dome-shaped sensor coated with a black material to absorb incoming radiation and a thermopile to convert the absorbed radiation into an electrical signal. The electrical signal is then amplified and processed to measure solar radiation. Pyranometers are also used in various settings, including weather stations, solar energy installations, and agricultural research stations. They are often used with other instruments, such as pyrometers and net radiometers, to provide a complete picture of the Earth's energy balance (Swetansh, 2013). Figure 1 shows a Pyranometer that is globally mainly used.

Figure: (1) The Pyranometer.

Pyranometer Data to Optimize Solar Panel Placement: Engineers use pyranometer data to optimize solar panel placement by analyzing the amount and direction of solar radiation at a particular location. By understanding the solar radiation available at a given site, engineers can determine the optimal orientation and tilt angle for the solar panels to ensure that they receive the maximum amount of solar radiation throughout the day and the year.

The data from pyranometers can be used to create solar radiation maps of a particular site, showing the distribution of solar radiation across the site over time. Engineers can then use this information to determine the best locations for solar panels, considering factors such as shading from nearby buildings or vegetation. In addition to placement, the data from pyranometers can also be used to optimize the performance of solar panels by adjusting their tilt angle and orientation. For example, if the data shows that most solar radiation is received in the morning, the panels can be tilted towards the east to capture more of the early morning sun. Similarly, if the data shows more solar radiation during the summer, the panels can be adjusted to take advantage of this seasonal variation (Ting-Chia, 2014). Overall, pyranometer data is critical for engineers to optimize the placement and performance of solar panels, which can improve the efficiency and output of solar energy systems.

Motors: You must find at least one or two types of motors near you at any moment and place. From the vibrator in your mobile phone to the fans and CD players on your computers, the engines are all around us. Motors allow our devices to interact with us and the environment (Deruyck, 2011). The engine design and operation method differ from engine to engine due to an infinite number of applications that use motors.

Arduino: Arduino is an open-source hardware and software platform enabling users to easily create interactive electronic projects. It comprises a microcontroller board, an integrated development environment (IDE), and a community of users and developers sharing knowledge and resources.

The Arduino board is based on a microcontroller, a small computer on a single integrated circuit. The board provides input and output pins that can be used to connect the board to sensors, actuators, and other electronic components. The board also includes a USB port that can be used to connect the board to a computer for programming and communication.

Arduino IDE is a software application that is used to write, compile, and upload code to the Arduino board. The IDE includes a text editor, a compiler, and a serial monitor, which can be used to communicate with the board and monitor its output. Arduino boards are widely used for various applications, including robotics, home automation, Internet of Things (IoT) devices, and many others. Because of its open-source nature and large community, many resources and tutorials are available for learning and using Arduino. Arduino makes several different boards, each with different capabilities. In addition, part of being open-source hardware is that others can modify and produce derivatives of Arduino boards that provide even more form factors and functionality.

Solar Control Charger: A solar charge controller, also known as a solar regulator, as shown in Figure 2, is a device that regulates the voltage and current that is generated by a solar panel or array of solar panels. The primary function of a solar charge controller is to prevent overcharging and damage to the battery or batteries that are being charged by the solar panels. When a solar panel generates electricity, it produces a voltage that can vary depending on the amount of sunlight and the temperature. If the solar panel is connected directly to a battery, it can overcharge the battery, which can cause damage or reduce its lifespan. A solar charge controller regulates the voltage and current from the solar panel to ensure that the battery is charged safely and efficiently (Thomas, 2012).

Figure: (2). Solar Control Charger.

There are two main types of solar charge controllers: PWM (Pulse Width Modulation) and MPPT (Maximum Power Point Tracking). PWM controllers are more straightforward and less expensive but less efficient than MPPT controllers. MPPT controllers are more expensive but efficient and can provide up to 30% more power than PWM controllers (Margolis2011).

In addition to regulating the voltage and current, some solar charge controllers have features such as over-discharge protection, temperature compensation, and load control. Over-discharge protection prevents the battery from being discharged too much, which can also damage the battery. Temperature compensation adjusts the charging voltage based on the temperature to ensure the battery is charged properly at all temperatures. Load control allows the solar charge controller to turn off the load (such as lights or other devices) when the battery voltage gets too low to prevent damage to the battery. A solar charge controller is an important component of a solar power system. Figure 3 explains how the solar control charger connected to the circuit ensures that the battery is charged safely and efficiently, which can extend the life of the battery and improve the performance of the solar power system.

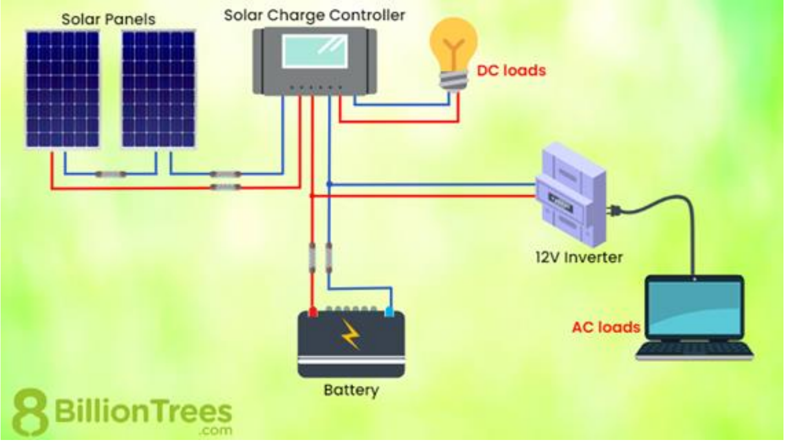

Figure: (3). A Solar Control Charger connection

In this work, the practical implementation of a solar tracking system will be studied; the system collects and stores energy data, consequently knowing the maximum capacity of the solar panel for the day, processing the data, and tracking the greatest capacity point via monitoring technology. It also gives control commands to move the solar panels in the appropriate direction based on the data processed through the light sensors. Evaluate the data stored with the scientific systems to know the capacity of the solar panel.

Main stages of the project: The methodology used to execute this project is as follows:

1) Building a Solar Tracking System Using Arduino
2) via pyranometers to measure the amount of radiation that reaches the solar panel
3) with a current sensor clamp/DC transformer HSTS016L to read the ampere from the solar panel
4) evaluate the reading of the data recorded in the system with the data of the global reference systems

Project Mechanism and System Block diagram: The operating principle of the device is to keep the photovoltaic modules constantly aligned with the sunbeams, which maximizes the exposure of solar panels to the Sun's radiation. As a result, the solar panel can produce more output power. The work of the project included hardware design and implementation, together with software programming for the microcontroller unit of the solar tracker. The system utilized an embedded ATmega2560 microcontroller to control the motion of two hybrid stepper motors (Type: 23LM-C352-G1V) driven by (L298N) driver, which rotates the solar panel in two axes. The microcontroller determined the amount of rotation based on inputs retrieved from four light-dependent resistor sensors (LDR: 10mm) installed next to the solar panel.

The solar panels are directly connected to an external charging device to provide power for charging (12 Li-ion) batteries (Type: 18650 connected to provide 12v, 30 Amp Hour / 360 Watt Hour) to Power up the proposed system, including the microcontroller and the two hybrid stepper motors. The microcontroller starts when the sensors detect the sunrise, and the generated voltage and current under different conditions will be measured and stored in a built-in real-time SD card; the project utilizes a current sensor (Type: Hall split core current sensor, HST016L, 100A) and SD Module with 8GB capacity. On the same frame that holds the solar panel, a Pyranometer was installed to measure and record solar radiation data in conjunction with the data obtained by the microcontroller from the voltage and ampere sensor, which is stored in the SD Module. A comparison will be conducted between the dual-axis solar panel system, in which output WATT (Voltages and Current) were measured every Hour, and the amount of solar radiation(SI) data measured by Pyranometer in watts per square meter (W/m^2), to evaluate the performance of the solar panel and its production capacity, Figure 4 below shows the Block diagram for the proposed system.

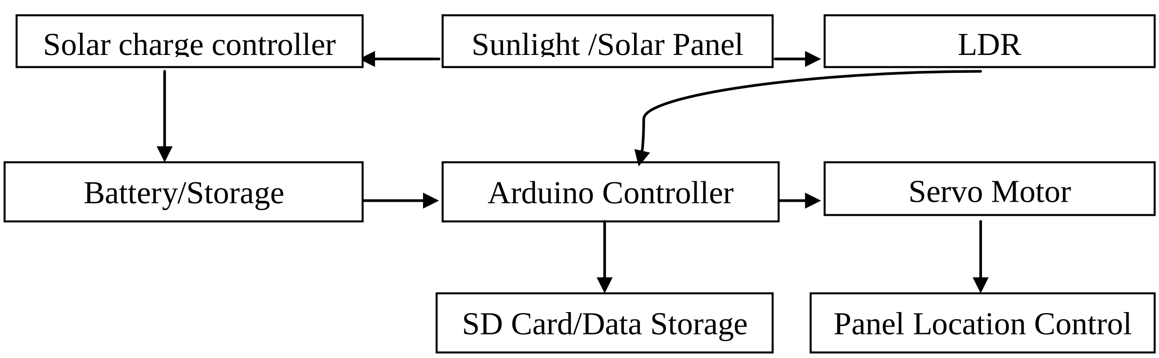

Figure (4): Block diagram for the proposed system

All project parts were assembled as illustrated in Figure 5, with the motors installed on the model, and the LDR light sensor installed on the metal frame and connected to the connection board and the controller. The solar panel was installed on the frame, and its output was connected to the voltage sensor and the current sensor, then to the solar controller. The pranometer was connected to the frame at the same level as the solar panels.

When turned on, the Arduino board and the sensors were placed in protection boxes to protect them from external factors, and the solar controller was also in a protection box. The wires were organized so as not to hinder movement and well wrapped so that moisture does not reach the connections and cause damage to them. An additional light sensor was attached to the back of the chassis to be used in the event of sunset, and when darkness falls, the device stops moving, and at sunrise, this sensor senses the light. The controller gives an order to the lower motor to move you 180 degrees in the direction of the sun. The base of the solar track system is connected to the rest of the hardware parts to finalize the project module as shown in Figure 5 below

Figure: (5). The Project Module

Project assumptions and evaluation: Before starting the project design, some assumptions are considered when running the module. Where this requirement determines the amount of energy needed to be produced, on which the project results will depend, such as the nominal production capacity of the solar panel, as well as its dimensions and weight, in addition to the size, capacity, and torque of the motors, frame material, ventilation design, and weights.

The weights of the components are as follows:
• Solar panel – 2.5 KG
• Frame of solar panel, motor, and bracing steel – 3KG

Another parameter that needed to be predetermined was the material to use for frame design. Since this design is to be made with materials that do not need to be specially ordered, The Aluminium HSN Code 761010 is chosen, and this choice is because this material is readily available, inexpensive, and relatively strong. Considering the environmental influences on the standard test conditions of the photovoltaic module, The PV is reviewed and calculated under Standard Test Conditions (STC: (1000 W/m2, AM1.5)). The three main elements of an STC are cell temperature, radiation, and air mass, which are variable conditions to which PV modules will be exposed after installation. Since these conditions affect the power output of the units, The value for each of these elements is defined and taken into account while compensating for differences in cell temperature and irradiance values because these two variables directly and measurably affect a PV module's voltage and current, where:

Voltage: The higher the cell temperature, the lower the module voltage – and vice versa.
Current: The higher the irradiance value, the more current is pushed through the module.
To maximize a PV module's electrical output, modify the design to keep the module as cool as possible and point it directly at the sun as much as possible by opening the backside of the frame to disperse the heat. Also, Determine the percentage change in voltage regarding cell temperature: The STC for cell temperature is 25 degrees Celsius or 77 degrees Fahrenheit. When a PV module operates in the sun, it typically gets much hotter than 25 degrees Celsius. Based on these calculations, the hybrid engine specifications were chosen based on the location and the way the module is mounted.

RESULTS AND DISCUSSION

The proposed system was introduced, presented, and finally implemented during all these project chapters to meet the target specifications. This chapter shall provide a brief and detailed presentation of all the results. The whole system had been tested for eleven full days of review (72 hours) in this project. The results were taken from the readings of the components, which are the voltage and current from the solar Panel and the reading from the pyrnometer. The reading circuit was programed to take readings of the previous component voltages every 15 minutes to record every change that may happen to the system and make a good track of the overall system.

Day 1 Results

On the first day, the sun tracking dual-axis method was used; the weather was very sunny and a bit dusty for a number of hours in the day, and the results were obtained in (June,16,2023). Figure 6 and Table 1 below show the data and the relation between the pyranometer and the efficiency of the panel.

Table :(1). The data results from the pyranometer and pannel efficiency of day 1

Date	Time	pyranometer(W/m2) X panel Area	Acquisition Watt (W/m2) For Panel
16/06/2023	5:30:00 AM	2.42743527	1.05063221
16/06/2023	5:45:00 AM	12.78875286	2.132790943
16/06/2023	6:00:00 AM	23.8953766	4.168694878
16/06/2023	6:15:00 AM	35.10425084	5.39599916
16/06/2023	6:30:00 AM	46.36729352	6.359266014
16/06/2023	6:45:00 AM	57.63635491	8.452494049
16/06/2023	7:00:00 AM	68.86308242	9.240711082
16/06/2023	7:15:00 AM	79.99959685	10.862887
16/06/2023	7:30:00 AM	90.99808661	12.62615333
16/06/2023	7:45:00 AM	101.811484	14.23379593
16/06/2023	8:00:00 AM	112.3935329	15.36691589
16/06/2023	8:15:00 AM	122.6989238	17.07525694
16/06/2023	8:30:00 AM	132.6836321	18.65167179
16/06/2023	8:45:00 AM	142.3047155	19.5836072
16/06/2023	9:00:00 AM	151.521125	20.28082942

Date	Time	pyranometer(W/m2) X panel Area	Acquisition Watt (W/m2) For Panel
16/06/2023	9:15:00 AM	160.2933668	22.257708
16/06/2023	9:30:00 AM	168.583841	23.24632654
16/06/2023	9:45:00 AM	176.3571116	24.44215046
16/06/2023	10:00:00 AM	183.5799065	25.15298167
16/06/2023	10:15:00 AM	190.2213207	25.71247961
16/06/2023	10:30:00 AM	196.252816	26.52664657
16/06/2023	10:45:00 AM	201.6486946	27.22041737
16/06/2023	11:00:00 AM	206.3857606	27.93027681
16/06/2023	11:15:00 AM	210.443794	28.9459505
16/06/2023	11:30:00 AM	213.8054825	28.88371223
16/06/2023	11:45:00 AM	216.4562864	28.89556995
16/06/2023	12:00:00 PM	218.3849799	29.17314322
16/06/2023	12:15:00 PM	219.583245	29.62212493
16/06/2023	12:30:00 PM	220.0459421	29.75610797
16/06/2023	12:45:00 PM	219.7712453	29.53589817
16/06/2023	1:00:00 PM	218.7602366	30.07106842
16/06/2023	1:15:00 PM	217.0171765	29.81965218
16/06/2023	1:30:00 PM	214.5497066	29.51017803
16/06/2023	1:45:00 PM	211.368309	28.47514516
16/06/2023	2:00:00 PM	207.4865766	27.83801371
16/06/2023	2:15:00 PM	202.9212806	27.19222374
16/06/2023	2:30:00 PM	197.6918973	26.40950691
16/06/2023	2:45:00 PM	191.8207432	25.90660523
16/06/2023	3:00:00 PM	185.3331106	25.27357094
16/06/2023	3:15:00 PM	178.2567259	24.05986014
16/06/2023	3:30:00 PM	170.6219534	23.22601596
16/06/2023	3:45:00 PM	162.4613887	21.64960509
16/06/2023	4:00:00 PM	153.8100622	21.37239754
16/06/2023	4:15:00 PM	144.7050328	19.95499133
16/06/2023	4:30:00 PM	135.1852531	18.40385261
16/06/2023	4:45:00 PM	125.2915017	17.3801244
16/06/2023	5:00:00 PM	115.06618	15.44652766
16/06/2023	5:15:00 PM	104.553042	14.48499111
16/06/2023	5:30:00 PM	93.79712675	13.06735718
16/06/2023	5:45:00 PM	82.84441979	11.86533977
16/06/2023	6:00:00 PM	71.74192124	10.47753919
16/06/2023	6:15:00 PM	60.53710455	8.269571828
16/06/2023	6:30:00 PM	49.27791656	7.293413448
16/06/2023	6:45:00 PM	38.01264223	5.925176369
16/06/2023	7:00:00 PM	26.78943127	4.40338485
16/06/2023	7:15:00 PM	15.65643339	3.040674659
16/06/2023	7:30:00 PM	4.668763788	0.734354347

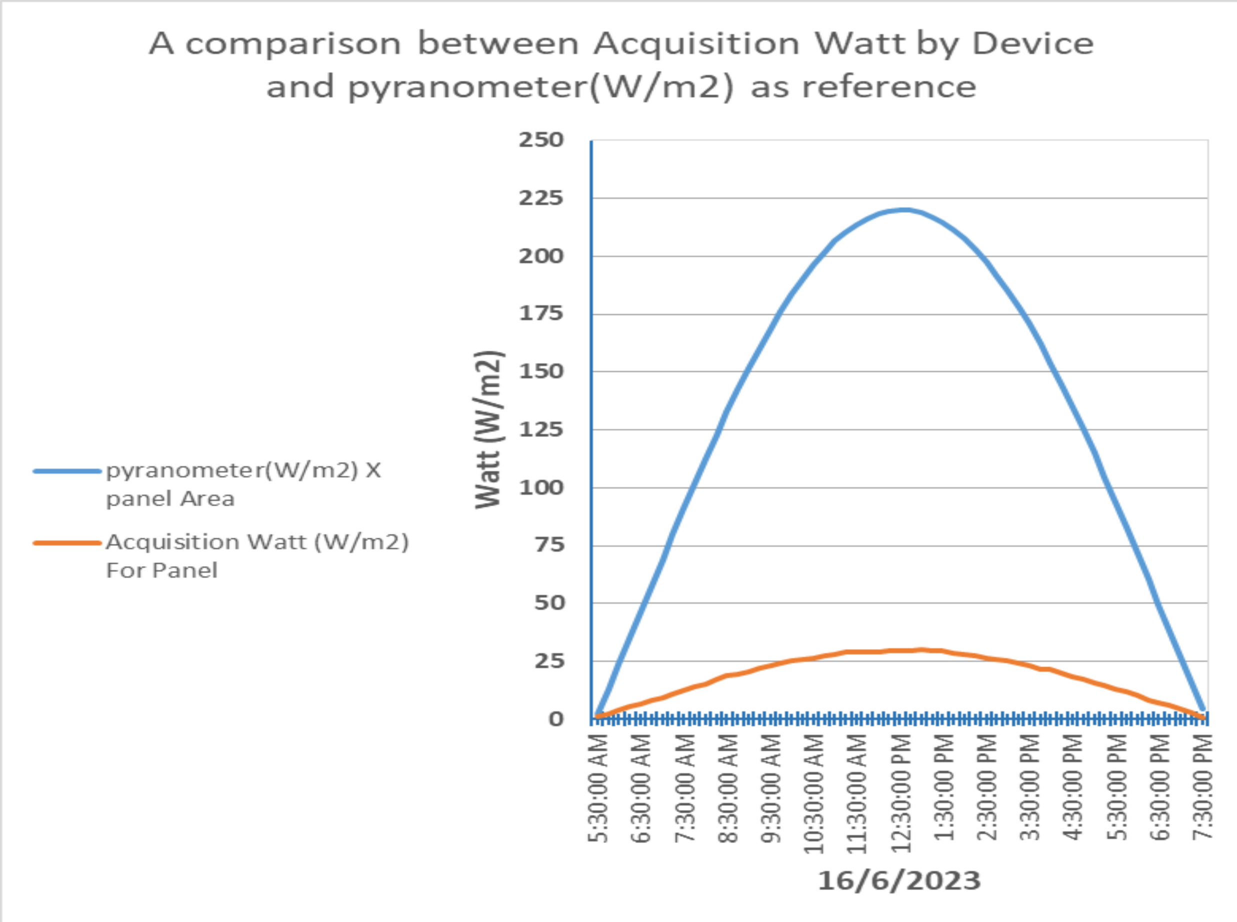

Figure: (6). The relation between pyranometer and efficiency of the panel- Day 1

So, from the results shown above, the efficiency is calculated using Equation 1:

$$efficiency\% = \frac{watt\ for\ panel(\frac{w}{m^2})}{watt\ for\ pyranometer(\frac{w}{m^2})} * 100\% \qquad 1$$

$$= \frac{30}{220} * 100\%$$

Efficiency on the first day =13.64%. Because the weather was very dusty and not very clean, it is clear that the efficiency is slightly low. This is identical to the acquisition watt (W/m2), which was also low, as seen in Table 1.

Day 2 Results

On the second day, the weather was not changed in comparison with day 1, so there was not any different in the data (June,21,2023), As shown in figure (7) and table (2) below.

Table :(2). The data results from the pyranometer and pannel efficiency of day 2

Date	Time	pyranometer(W/m2) X panel Area	Acquisition Watt (W/m2) For Panel
21/06/2023	5:30:00 AM	2.061849114	0.288536281
21/06/2023	5:45:00 AM	12.19689011	1.716070764
21/06/2023	6:00:00 AM	23.27599006	3.636612999
21/06/2023	6:15:00 AM	34.4606542	5.09563277
21/06/2023	6:30:00 AM	45.70300332	6.878898317
21/06/2023	6:45:00 AM	56.95495533	8.551019585
21/06/2023	7:00:00 AM	68.16829289	9.157580816
21/06/2023	7:15:00 AM	79.29500155	11.09264166
21/06/2023	7:30:00 AM	90.28754023	12.98382476
21/06/2023	7:45:00 AM	101.098706	14.32608306
21/06/2023	8:00:00 AM	111.6823102	15.383574
21/06/2023	8:15:00 AM	121.9929759	16.41320205
21/06/2023	8:30:00 AM	131.9866786	18.43478463
21/06/2023	8:45:00 AM	141.6204757	19.4223468
21/06/2023	9:00:00 AM	150.8532506	20.45981784
21/06/2023	9:15:00 AM	159.6453745	21.85067441
21/06/2023	9:30:00 AM	167.9592473	22.83886204
21/06/2023	9:45:00 AM	175.7592977	23.77945579
21/06/2023	10:00:00 AM	183.012051	25.27019906
21/06/2023	10:15:00 AM	189.6864667	26.00221436
21/06/2023	10:30:00 AM	195.7540067	26.48136328
21/06/2023	10:45:00 AM	201.1887025	27.2066684
21/06/2023	11:00:00 AM	205.9672233	27.72026735
21/06/2023	11:15:00 AM	210.069146	28.81187545
21/06/2023	11:30:00 AM	213.4768877	29.20693091
21/06/2023	11:45:00 AM	216.1758414	29.30572684
21/06/2023	12:00:00 PM	218.1544429	29.06881363
21/06/2023	12:15:00 PM	219.4043066	30.02283448
21/06/2023	12:30:00 PM	219.9200225	30.01138061
21/06/2023	12:45:00 PM	219.6993589	29.72607535
21/06/2023	1:00:00 PM	218.7433301	29.87480821
21/06/2023	1:15:00 PM	217.0559262	29.00137927
21/06/2023	1:30:00 PM	214.6444506	29.17140931
21/06/2023	1:45:00 PM	211.5192503	28.86480083
21/06/2023	2:00:00 PM	207.6936475	28.30860816
21/06/2023	2:15:00 PM	203.1841429	27.53397578
21/06/2023	2:30:00 PM	198.0099424	26.73460506
21/06/2023	2:45:00 PM	192.1931596	26.23691165
21/06/2023	4:00:00 PM	154.4337768	21.51458857
21/06/2023	4:15:00 PM	145.3733129	19.72646903
21/06/2023	4:30:00 PM	135.8957995	18.4734805
21/06/2023	4:45:00 PM	126.0417446	17.39006082
21/06/2023	5:00:00 PM	115.8533466	15.74302029
21/06/2023	5:15:00 PM	105.3742246	14.29561299
21/06/2023	5:30:00 PM	94.6493496	13.58077734
21/06/2023	5:45:00 PM	83.72450455	11.71633449
21/06/2023	6:00:00 PM	72.64648661	10.55400335
21/06/2023	6:15:00 PM	61.46276924	8.699728692
21/06/2023	6:30:00 PM	50.22123163	7.557195457
21/06/2023	6:45:00 PM	38.96995588	5.850284446
21/06/2023	7:00:00 PM	27.75715933	4.625090262
21/06/2023	7:15:00 PM	16.6307888	2.581269936
21/06/2023	7:30:00 PM	5.638453002	1.40022203

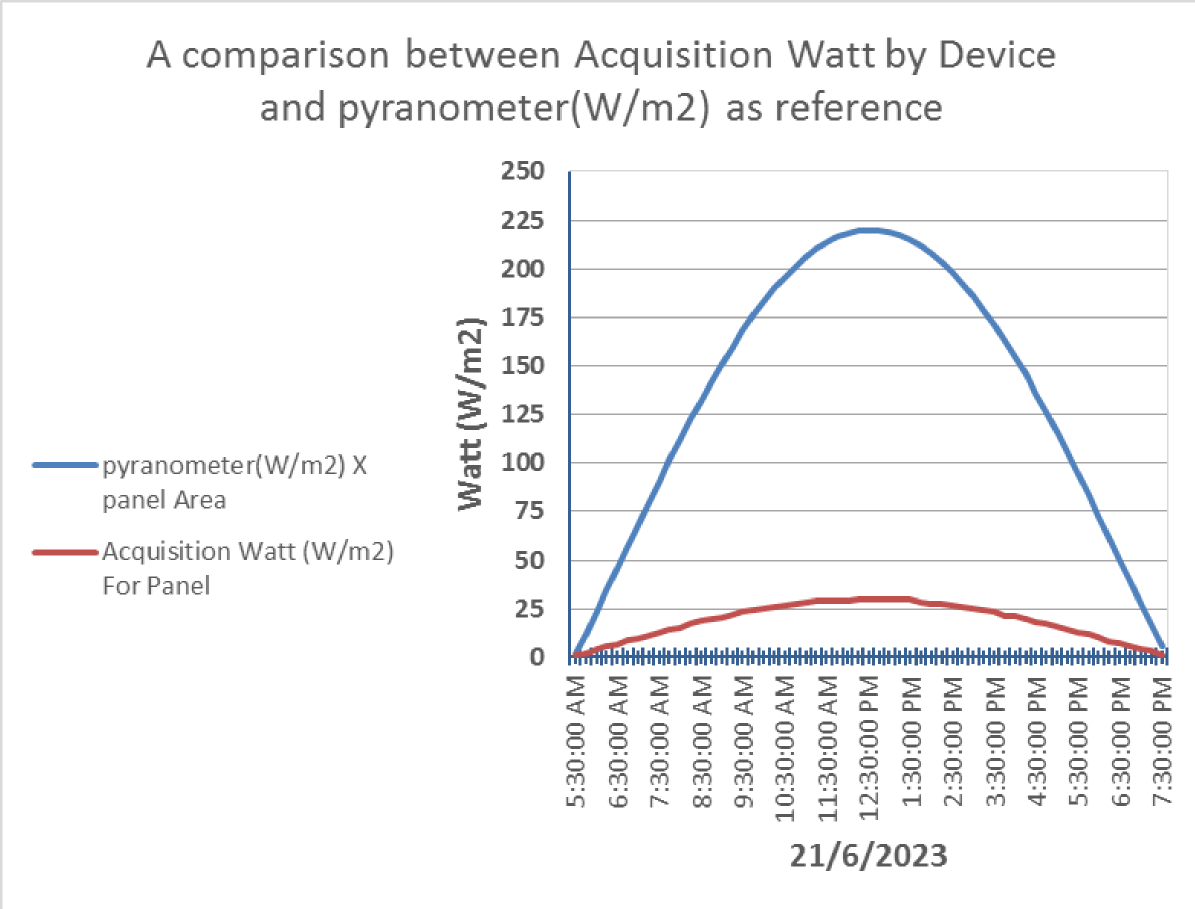

Figure: (7). The relation between pyranometer and efficiency of the panel- day 2

So from these results, and using the efficiency equation:

$$efficiency\% = \frac{watt\ for\ panel(\frac{w}{m^2})}{watt\ for\ pyranometer(\frac{w}{m^2})} * 100\% \qquad 2$$

$$= \frac{30.11}{219} * 100\%$$

Efficiency on the second day =13.75%; the efficiency was still low because the weather was also dusty and not very clean. This is also expected because the acquisition watt (W/m2) is still low, as seen in Table 2.

Day 3 Results

Even on this day, the weather was not very clear and dusty, so there is not much difference compared with the previous data from the past two days (June,26,2023). The last day and data can be seen from the figure (8) and table (3) below

Table :(3). The data results from the pyranometer and panel efficiency of day 3

Date	Time	pyranometer(W/m2) X panel Area	Acquisition Watt (W/m2) For Panel
26/06/2023	5:30:00 AM	1.500147558	0.924575641
26/06/2023	5:45:00 AM	11.24106422	2.069314365
26/06/2023	6:00:00 AM	22.30968215	3.595104812
26/06/2023	6:15:00 AM	33.48738081	4.492225786
26/06/2023	6:30:00 AM	44.72634863	6.94778734
26/06/2023	6:45:00 AM	55.97836826	8.382786581
26/06/2023	7:00:00 AM	67.19535763	9.640044992
26/06/2023	7:15:00 AM	78.32923465	10.96720338
26/06/2023	7:30:00 AM	89.3323906	12.31477234
26/06/2023	7:45:00 AM	100.1576902	13.84795248
26/06/2023	8:00:00 AM	110.7587419	15.40188719
26/06/2023	8:15:00 AM	121.0901688	17.08855703
26/06/2023	8:30:00 AM	131.1078111	18.14351336
26/06/2023	8:45:00 AM	140.7686586	19.16792804
26/06/2023	9:00:00 AM	150.0314594	20.95157153
26/06/2023	9:15:00 AM	158.8564495	21.43269813
26/06/2023	9:30:00 AM	167.205826	23.11871169
26/06/2023	9:45:00 AM	175.0438823	23.79881351
26/06/2023	10:00:00 AM	182.3370759	24.46871938
26/06/2023	10:15:00 AM	189.054096	25.55713158
26/06/2023	10:30:00 AM	195.1662691	26.76901423
26/06/2023	10:45:00 AM	200.6472888	26.91234683
26/06/2023	11:00:00 AM	205.4737564	27.67132957
26/06/2023	11:15:00 AM	209.625046	27.97659281
26/06/2023	11:30:00 AM	213.0832368	28.95236001
26/06/2023	11:45:00 AM	215.8336538	29.52895441
26/06/2023	12:00:00 PM	217.864395	29.54325243
26/06/2023	12:15:00 PM	219.1668717	30.04985125
26/06/2023	12:30:00 PM	219.7353359	30.04477492
26/06/2023	12:45:00 PM	219.5675558	30.0714836
26/06/2023	1:00:00 PM	218.6640724	29.49315379
26/06/2023	1:15:00 PM	217.0288081	29.66435628
26/06/2023	1:30:00 PM	214.6688636	29.14981838
26/06/2023	1:45:00 PM	211.5941799	28.84915294
26/06/2023	2:00:00 PM	207.817944	28.4064496
26/06/2023	2:15:00 PM	203.356454	27.2415096
26/06/2023	2:30:00 PM	198.2286449	26.44806543
26/06/2023	2:45:00 PM	192.4566305	26.34284419
26/06/2023	3:00:00 PM	186.0649591	25.40861103
26/06/2023	3:15:00 PM	179.0810869	24.66197939
26/06/2023	3:30:00 PM	171.534972	22.86133756
26/06/2023	3:45:00 PM	163.4588046	22.19658313
26/06/2023	4:00:00 PM	154.8872091	20.8931869
26/06/2023	4:15:00 PM	145.8569064	19.93864857
26/06/2023	4:30:00 PM	136.4065787	18.74346557
26/06/2023	4:45:00 PM	126.5766662	16.9571544
26/06/2023	5:00:00 PM	116.4091647	15.83563993
26/06/2023	5:15:00 PM	105.9477607	14.13238251
26/06/2023	5:30:00 PM	95.23708717	12.6908715
26/06/2023	5:45:00 PM	84.3231299	11.98277272

Date	Time	pyranometer(W/m2) X panel Area	Acquisition Watt (W/m2) For Panel
26/06/2023	6:00:00 PM	73.25255083	10.5375913
26/06/2023	6:15:00 PM	62.07275576	8.607543474
26/06/2023	6:30:00 PM	50.83155628	7.116171862
26/06/2023	6:45:00 PM	39.57710211	6.095454719
26/06/2023	7:00:00 PM	28.35761058	4.327130216
26/06/2023	7:15:00 PM	17.22102853	2.973882632
26/06/2023	7:30:00 PM	6.215099904	1.242455451
26/06/2023	7:45:00 PM	2.732158026	0.622780591

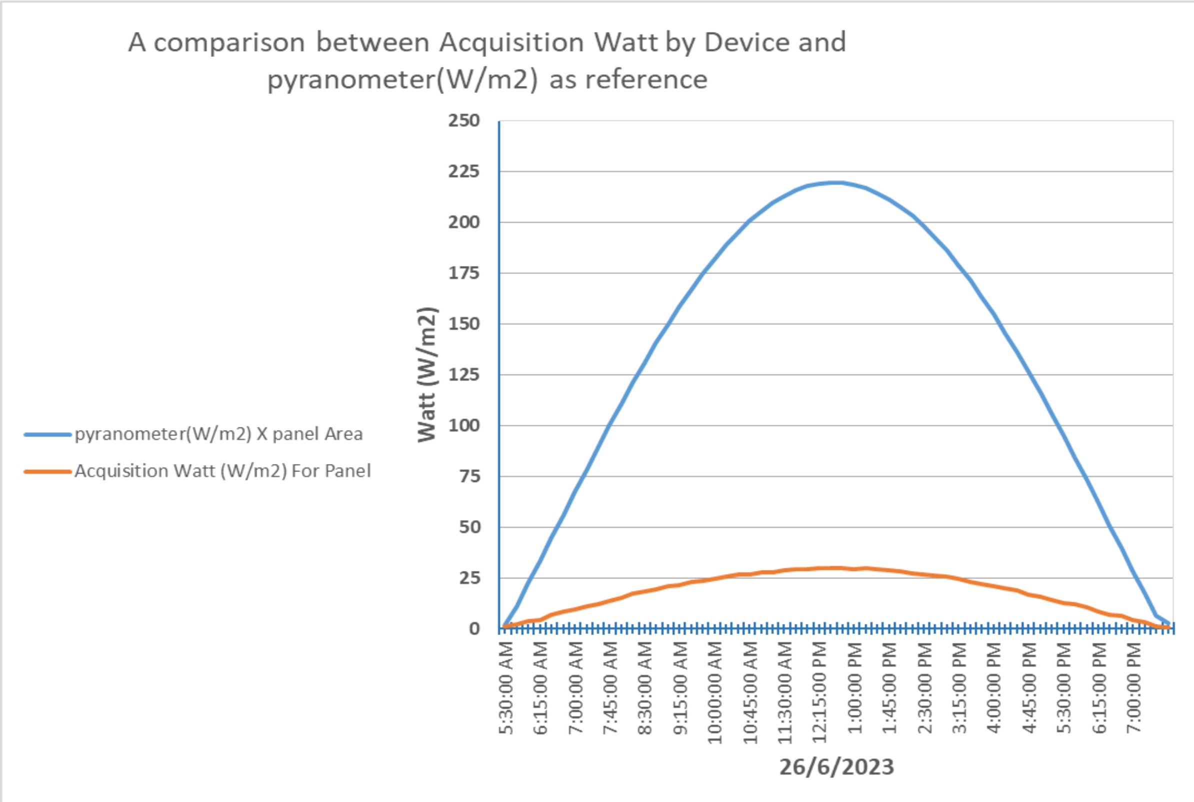

Figure: (8). The relation between pyranometer and efficiency of the panel- day 3

So, from the results shown above, the efficiency is:

$$efficiency\% = \frac{watt\ for\ panel(\frac{w}{m^2})}{watt\ for\ pyranometer(\frac{w}{m^2})} * 100\% \quad 3$$

$$= \frac{30.8}{219.2} * 100\%$$

Efficiency on the third day =14.05%. Once the acquisition watt (W/m2) slightly increased on average, as seen in Table 3, efficiency slightly increased compared with day 1 and Day 2 results. From this result, it is proved that once the acquisition watt increases, the efficiency of the board will be increased as well.

CONCLUSION

The project aimed to study the efficiency of solar panels and compare it with data from reference systems at the same level. The efficiency of the panels used in the standard conditions of the manufacturer was from 16% to 17%, and the productivity of the panels was 30 watts, the voltage was 18 V, and the current was 1.88 A.

The results obtained were excellent. The average output was 27 watts, the average voltage was 16.3 V, and the average current was 1.6 A. The average purity of the board on the 11th day on which the test was carried out, the results were very close, and that is because the weather was not changing, and the average efficiency among them ranged between 13.3 and 13.9 .The two-axis tracking system gave better results than the stationary method, resulting in better operation during daylight hours and faster charging to help the battery power the load at night. Their cost was relatively high due to the current conditions, and finding the right quality actuators was challenging. In the business model of tracking the slow work of several weeks, better LDR sensors can guarantee better tracking. The Arduino reads random signals from time to time, like when there is no voltage coming, but it keeps reading random values, which makes it very hard to make the system stable, and it takes much work to get rid of most of them to make a stable system.

Finally, the complete project is an original idea. The idea of creating a perfect system has led to many problems, bugs, and programming. The system began to take shape gradually until it finally achieved its goals.

Recommendations

- Although this project was considered successful, more can be done with the programming to guarantee better and more accurate tracking, switching, and monitoring.
- Connect the system with extra caution, especially since any mistake can lead to damaged equipment and cost a lot of time and money.
- Fuzzy logic technology can be included in the system so that it will be able to learn the seasonal changes and the sun movement directions along the year, which may increase the efficiency.

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