LEESOLA: A Locally Made Energy Efficient Solar Tracking System for Home Use

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Abstract

A solar tracking system is used to orient solar reflectors, photovoltaic panels, and other solar energy harvesting equipment toward the sun mainly to maximize energy output. The LEESOLA system offers an optimized way to increase the amount of energy produced by exposing the harvesting equipment to the sun's rays. This project is a crucial step towards a more sustainable future and reducing the reliance of humans on traditional energy sources. The system architecture of the LEESOLA solar tracker consists of a microcontroller-based control unit, an ultra-violet (UV) sensor module, motor drivers and PV panels. The UV sensor module detects the location of the sun and sends signals to the control unit. The control unit then passes signals to the motor drivers to introduce a change in the position of the solar panels. The control unit makes use of a suitable algorithm for keeping track of the location of the sun throughout the day and changes the angle of the PV panels accordingly. The UV sensor module makes use of essential optoelectronic components such as photodiodes or phototransistors to detect the position of the sun accurately. As a measure of eliminating any occurrence of misalignment due to factors such as weather conditions, the system has a built-in feedback mechanism that actively monitors the solar panel's position and adjusts the motor drivers to correct any misalignment. The proposed system obtained an improvement of about 69.29%, 59.41% and 184.96% mean percentage difference in the measured power readings for morning, afternoon, and evening durations respectively. Therefore, this LEESOLA system provided an all-rounded performance improvement over the limiting static methods.

Keywords: solar tracking, energy harvesting, photovoltaic, PV panels, light

1. Introduction

Solar panels are a popular and effective way to harness renewable energy from the sun. However, several factors influence the quantity of electricity produced by the panels. Notably, these factors include sunlight intensity, temperature, type of solar panel, its quality, condition, system design and configuration, shading and obstructions. In this regard, it is of paramount importance to comprehend and optimize these factors to maximize solar power generation and enhance overall system performance.

Imperatively, the amount of sunlight that a solar panel captures relies on its geographical location, this tends to also affect the amount of energy that can be produced. For instance, solar panels located in areas that receive more sunlight, such as areas closer

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to the equator, will generate more electricity than those located in areas with less sunlight. Therefore, higher sunlight intensity has a positive correlation on solar power generation. Thus, clear sunny days provide the best of conditions. The angle at which the solar panel is positioned affects the amount of sunlight that it can capture. To generate maximum energy, the solar panel should be placed at an angle that allows light rays to incident perpendicularly onto the surface of the panel to receive the maximum amount of sunlight. The magnitude of this angle varies based on both the latitude of the place and the season of the year.

The effectiveness of the PV panels is also a key factor in their energy output. This effectiveness refers to the amount of sunlight that is converted into electricity. High-efficiency solar panels can convert more sunlight into electricity than low-efficiency ones. The temperature also affects the energy output of a solar panel. Solar panels become less efficient as they get hotter, and this can reduce their energy output [1]. This is why solar panels are often installed with a gap between the panel and the roof to allow for ventilation and to prevent them from overheating. The condition of the PV panels also affects their energy output. Dust, debris, and other particles that accumulate on the surface of the PV panels can reduce their efficiency and energy output through shading and obstructions.

The problem with traditional solar panels that are stationary is that they are limited in their ability to capture the maximum amount of solar energy available. This is because they are fixed in one position and do not adjust their orientation to track the sun’s trajectory. As a result, they may not be positioned at the optimal angle to capture the highest amount of sunlight possible, which leads to a lower efficiency in energy production. In addition, factors such as shading, and weather conditions can also reduce the amount of solar energy captured by traditional stationary solar panels. These limitations can be addressed using a system that tracks the sun, by continuously adjusting the panels’ orientation to enable radiation from the sun to hit their surface perpendicularly.

This project seeks to design and implement a solar tracking system code named LEESOLA for solar panels that can improve the efficiency of power production. The proposed solution would constantly adjust the angle of PV panels to optimize their orientation in relation to the sun and would be able to efficiently capture solar energy regardless of weather conditions. And integrate user friendly data acquisition and monitoring software that will collect data on the power produced by the panels. The LEESOLA system will be optimized for the type of solar panel used, considering factors such as size, weight, and angle of inclination. The LEESOLA system has been optimized for two-panel types; Monocrystalline and Passivated Emitter and Rear Cell (PERC).

2. Related Works

Renewable energy sources have gained popularity in recent years due to their environmental benefits and sustainable nature. In a report by the International Energy Agency (IEA), energy from renewable sources made up two-thirds of the power added to the world's grids in 2020 [2]. Solar energy has turned out to be on top of the list when talking about most utilized renewable energy sources and it is also becoming increasingly affordable thanks to advancements in technology. Due to this, recent developments have led to the conceptualization and construction of various categories of solar tracking systems based on different principles. This segment comprises evaluations of constructed tracking systems. It also strives to highlight various principles and methodologies employed in building the existing solar trackers and their drawbacks.

Jamroen et al. [3] in their work, proposed an active tracking system that made use of a simple and effective logic design to improve the performance of the tracking system. The system featured light-dependent resistors (LDRs) installed in a simple orientation. The data from the LDRs are processed by a central microcontroller even without external internet control to follow the path of the sun. In the study, the device's operational effectiveness contrasted with that of the stationary PV system, the proposed design led to an increase in energy production by 19.97%.

In their research, Karabiber et al. [4] introduced an innovative method for designing solar tracking systems, named the "Asymmetric Solar Tracker (AST)". This system was made with a stand that similarly holds photovoltaic panels to traditional fixed solar systems. However, unlike fixed solar systems, the AST does not require concrete to anchor the tracking system to the ground. This approach is both cost-effective and efficient, as the AST was found to be more effective than traditional fixed solar systems. However, it should be noted that the AST is only suitable for use on the ground, and cannot be installed on rooftops or higher ground, which may limit its potential applications.

In an article by Mamodiya et al. [5], The importance of sun trackers in improving the efficiency of solar photovoltaic (SPV) power plants was discussed. The paper presents a SIMULINK-based model of an active sun-tracking system, which uses an electromechanical system with gear mechanisms, steel structures, bearings, motors, control circuits, and light-dependent resistors (LDRs). The article shows how the output of the current of SPV cells is in direct relationship with the irradiance value and how the variation in the sun's position can affect how solar cells produce power. The simulation outcomes indicate that the use of sun trackers can significantly improve the effectiveness of SPV systems and that a static PV system angle of 90° to the horizontal direction can maximize energy efficiency.

A study by Kuttybay et al. [6] discusses two methods used in solar tracking systems: one uses photosensors and the other uses mathematical computations of the sun's position using GPS and digital compasses. The second method applied a schedule for tracking. The schedule made use of weather data and astronomical calculations to predict the sun's position, considering the date and time. The initial method was limited by optical interference and adverse weather conditions, whereas the latter was hindered by factors such as atmospheric disturbances and electromagnetic interference. The study found that a solar tracking system dependent on the operation of a tracking schedule increased the efficiency of energy conversion by 4.2% compared to those based on photosensors in different weather conditions.

A study conducted by R.P. Singh et al. [7] and Y. Chaiko et al. [8] explores the benefits of single axis and fundamental solar tracking mechanism employing light sensors (LDRs) and a stepper motor. The authors designed, implemented, and experimentally tested the system, which employs a method called a triangular set-up made up of an LDR to detect changes in light intensity with two solar cells facing opposite directions. In the rest position, both solar cells capture equivalent amounts of sunlight as the angle of incidence, though not 90°, is the same in both cases. A straightforward approach was used in the design of the proposed solar tracking system, making it cost-effective and affordable. The overall power collection efficiency of the panels on the tracking device was high, as it extracts more power from the same solar panel, thereby reducing the cost per watt and making solar power more cost-effective than using fixed solar panels. However, the proposed solution has limitations. The experimental results of the system may not apply to different locations due to variations in solar radiation patterns. Moreover, it cannot be used for large-scale power generation where heavy PV panels are required, and in harsh environmental conditions.

Y. Zhu et al. [9] in their work did some analysis on the different types of tracking systems on dual-axis and single-axis and found out that the application potential of single-axis trackers had been extensively validated, especially at regions with lower latitudes. Taking this as a premise, their work presented a novel approach to tracking along a single axis. The system involved mounting a panel on a tilted axis of rotation and rotating it to closely mimic the movement of the sun. Mathematical equations were formulated, and MATLAB simulations were conducted by substituting different values to determine the solar radiation.

I.E. Nwankwo et al. [10] developed an intelligent solar tracking system and C. L. Sandoval-Rodriguez et al. [11] analyzed the application of solar tracking systems for small-scale photovoltaic systems. Based on seven defined attributes, the study in [11] compares the suitability of single-axis and dual-axis solar tracking subsystems. The process of formal concept analysis methodology was employed to assess the subsystems, and the resulting evaluation matrix was displayed through the utilization of a freely accessible tool known as Concept Explorer. After examining multiple factors, the researchers determined that for small-scale photovoltaic systems, dual-axis solar tracking systems outperform single-axis tracking systems in meeting a wider range of requirements. Hence, they are the most favorable option. This article serves as a reference for carrying out similar analyses that aggregate and connect multiple possibilities as a model for evaluating a predictable collection of qualities. While the article provides an interesting and informative analysis of formal concept analysis in the context of chemical data, it may not be applicable or relevant to other fields or contexts, and more empirical evidence and discussion of potential limitations would be beneficial. Even though the article suggests that the dual-axis solar tracking technology is more suitable for small-scale photovoltaic systems, design complexity and maintenance, cost, and energy consumption requirements of the components were factored into such a suggestion.

Diaz et al. [12] researched the development of a filtered sun sensor, which was designed to capture data that served as inputs for a single-axis solar tracking system. The system was based on rotation from east to west and utilized photodiodes to keep track of the path of the sun. The sun sensor was equipped with four photodiodes, which were equipped with IR and optic filters with linear polarizing abilities to enhance its capabilities. It was observed that the infrared optical filter resulted in the reduction of the tracking error by up to 75%. Although the version of the sensor that included an optic filter provided better performance it was discovered that the tracking system needed a sensor that had to be specially made for the application. However, this was not commercially available. Hence it would make the construction of the tracking system costly and complex.

Research by Munanga et al. [13] aimed to develop a smart single-axis solar tracking system that maximizes solar panel efficiency by positioning it to be always at an angle of 90° to solar radiation. The study examined three potential principles and employed the binary dominance matrix to identify the most suitable solution. The solar tracker system was composed of a solar panel, a motor, a Light Dependent Resistor (LDR) sensor, and an Arduino microcontroller. Experimental results showed a 25% improvement in efficiency in comparison to the stationary PV panel. The solar tracking device was constructed using materials that were available locally and had a manufacturing cost of USD 147, making it practical and cost-effective for commercial use.

In a study by J.Ghosh et al.[14], They discuss the use of a NodeMcu microcontroller to construct a solar tracking system that moves along a single axis. The Solar Tracking project uses a solar panel, a NodeMcu MCU, an L293D motor driver, two LDR sensor modules, a simple DC motor, a current sensor, and a 9V battery. The project was constructed on a wooden base with iron rods in a cross shape, connected by a hollow cylindrical rod with the DC motor attached. The circuit was divided into three sections: input, microcontroller programming, and driving circuit. Two LDR modules created a voltage divider circuit in the input stage, and the microcontroller was programmed using Arduino IDE software. The driving circuit used the motor driver to move the solar panel, with the motor attached to the motor output terminal and the LDR sensor modules attached to the NodeMcu analogue inputs. The LDRs are placed on both sides of the PV panels to track the sun's trajectory. This optimizes LDR efficiency, reduces saturation and in effect enhances the overall performance of the solar tracking system [15].

In their work, N.Al-Rousan et al. [16] based their implementation on a method called Adaptive Neural Fuzzy Inference System (ANFIS) to help step up the performance of their tracking system. The ANFIS is a merged machine learning methodology that amalgamates the benefits of artificial neural networks and fuzzy logic systems. The ANFIS architecture comprises distinct layers of nodes such as the input, fuzzy, and output layers, which are taught via a combination of gradient descent and backpropagation algorithms. To forecast the angle to which the solar tracking system is to be oriented, the proposed method considers the input variables of the date of the month and the solar time of the day. Although this method saw a substantial improvement in the solar tracking system’s performance, The training and validation processes entail considerable computational complexity and a reliance on a significant amount of historical data.

Shehu et al. [17] in their study, delved into investigating a solar tracking device that operates on a single axis, employing sensors to consistently detect the position of the sun, and altering the orientation of the photovoltaic panel to optimize the transformation of solar energy into electrical energy. The study found that the active tracking system is accurate and results in up to 40% additional energy in contrast to a fixed system. The system is most efficient in sunny conditions and shows minimal differences in cloudy weather. The maximum voltage output was obtained between 12:00 pm to 2:00 pm, while the intensity of sunlight diminishes in the morning and late evening.

In the research conducted by Hussain et al. [18], they presented proof that a single-axis solar tracker can substantially improve the energy production of photovoltaic systems and can also be a cost-effective approach to the generation of solar energy. Solar energy is one of the most abundant and widely available renewable energy sources, and the use of photovoltaic systems is rapidly growing worldwide. However, the efficiency of such systems is directly influenced by solar radiation and to optimize their output, it is imperative to implement solar tracking. Solar tracking systems enable solar panels to follow the sun's movement and orient themselves towards the direction of maximum radiation, thereby increasing the amount of energy generated. While there are various types of solar tracking systems available, a solar tracker that moves along a single axis tends to be a cost-effective solution that provides accurate tracking of the sun's movement. This experimental study provides evidence that a solar tracking system that operates along a single axis can increase the energy output of PV systems by approximately 28.3% compared to static systems. A mathematical model was utilized to construct an autonomous dual-axis smart solar tracking system in this paper, which is capable of automatically positioning PV panels to generate the maximum possible energy output in any location worldwide. The system integrates a microcontroller (μC), a Global Positioning System (GPS), a digital compass, and a gyro orientation sensor. MATLAB and Simulink were employed for the purpose of modelling and simulating the operational efficiency of the solar tracking system. The system uses a dual-axis solar tracker, which can track the sun's movement in both the horizontal and vertical axes, ensuring maximum exposure to sunlight throughout the day. The design was equipped with a controller that uses algorithms to continuously adjust the position of the PV panels, based on real-time data from sensors, thereby optimizing the orientation of the PV panels to the sun. One of the key advantages of the system is the integrated wireless communication module that enables remote monitoring and control of the system, making it easier to manage and maintain. Even though the design implementation has a lot of strengths as outlined above, it has some limitations and weaknesses which require further research to address it. The article focused on energy harvesting applications, which limits its applicability to other areas, such as residential and commercial use. As such, the system's design may need to be modified to cater to the specific needs of these areas. Additionally, the paper did not include a comprehensive cost analysis of the system, which is crucial for determining the feasibility and affordability of the technology.

3. Material and Methods

3.1 LEESOLA System Block Diagram

Figure 1 provides a visual block overview of the LEESOLA solar tracking system. The system is made up of four functional blocks with the central one being the intelligent unit. The intelligent unit is responsible for processing the input from the sensor module, using the processed input to control the motor block to allow movement of the PV panels and sending out power data over a wireless local area network to the user interface to be shown to the user in real time.

Table 1 summarizes the various system components and their detailed descriptions.

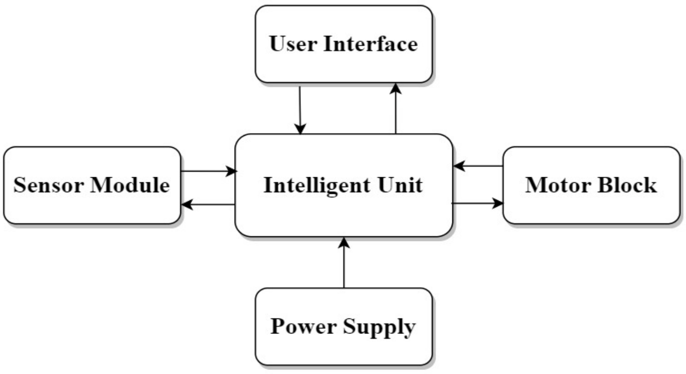


Figure 1: LEESOLA system block diagram

Table 1: LEESOLA system components and description

Unit	Purpose
Intelligent Unit IU	The intelligent unit is responsible for processing the data received from the sensor block and for controlling the movement of the PV panels to optimize their orientation towards the sun. The intelligent unit is made up of a microcontroller that will be well chosen to fit the purpose and the applications of this project. This intelligent unit is programmed based on a chosen algorithm to determine the optimal position of the light source (the sun) and sends control signals to the motor block to adjust the panels. The programming of the intelligent unit utilizes algorithms that are based on the readings from the sensor and takes the relative positions of the individual sensors into consideration. The unit includes features to improve the performance and reliability of the solar tracker system. This includes safety features such as over-current protection or limit switches to prevent damage to the solar panel or other components of the system. The intelligent unit is also responsible for system communication, the unit uses technologies such as Wi-Fi and UART to receive and send out data between components of the smart solar tracker.
Sensor Unit SU	This module is essential for detecting the position of the sun and providing input to the intelligent unit. The function of the sensor block is to ensure that the solar panel is always facing the sun in a perpendicular position, this helps to maximize its energy output and increase the efficiency of the system. The sensor block works by detecting the intensity of radiation using two sensors. The sensors can be either analog or digital and may use different types of photodiodes, such as PIN photodiodes or phototransistors.
Motor Unit MU	The motor block is responsible for adjusting the position of the PV panels based on the control signals sent from the intelligent unit. The motor block is made up of a control motor that is selected to adjust the orientation of the PV panels accurately and reliably.
Power Unit PU	This module provides power directly to the intelligent unit. The power supply unit is made up of a voltage regulator and rechargeable batteries to ensure continuous operation of the solar tracker even during periods of low sunlight or power outages. The power supply unit is designed to provide a stable and reliable power source to the solar tracking system. The voltage regulator ensures that the voltage supplied to each component is within the acceptable range and protects against voltage fluctuations that can damage sensitive electronic components. The energy storage devices, such as batteries or capacitors, can provide backup power in case of power outages or periods of low sunlight.
User Unit UU	The user interface block serves as the window into the entire solar tracking system, it provides a means for visualizing the power generated by the solar panels, this power is measured and sent over from the intelligent unit which also houses current sensors. With the user interface, data collection becomes easy. As the power data being collected is stored in a database system made available by a cloud provider, the user interface makes room for remote monitoring of the smart solar tracking system.

3.2 LEESOLA System Hardware Prototype

The system prototype comprises of both hardware and software components that contribute to the tracking of the movement of the sun and to the real-time display of power generated. This section provides details on the components that make up the prototype of the smart solar tracking system.

Figure 2 depicts a block diagram illustrating the individual components of the solar tracking system. It shows the interconnected subsystems that work together to produce the desired and expected outcomes.

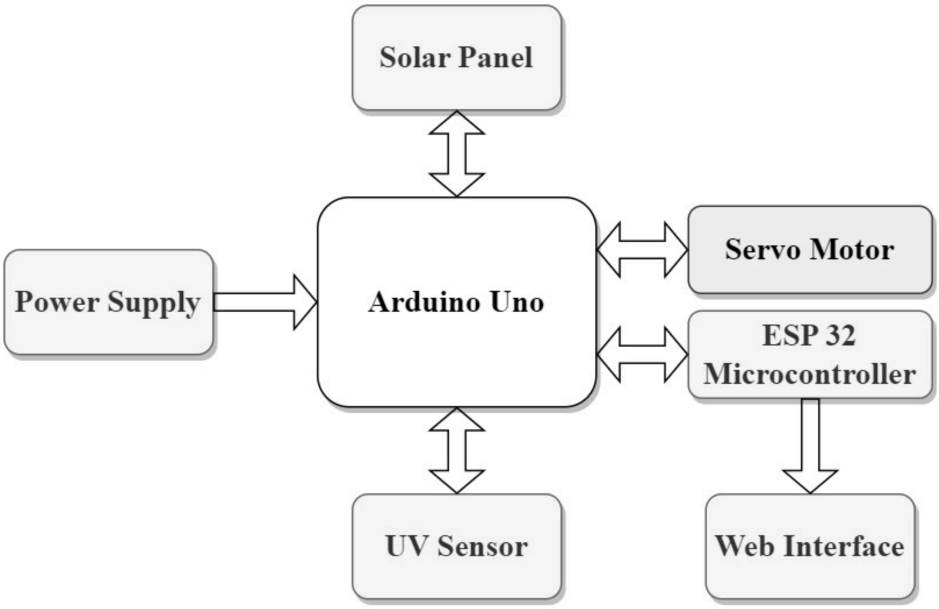


Figure 2. LEESOLA system prototype block diagram

The smart solar tracking system prototype uses an Arduino Uno microcontroller as the main intelligent unit. The Arduino Uno plays a pivotal part in the operation of the solar tracking system by acting as the brain that orchestrates the entire operation [19]. It receives input from the UV sensors to monitor the sun's position and processes this data to make decisions on adjusting the solar panel's orientation. Using its processing capabilities, the Arduino calculates the optimal angle for the solar panel to maximize energy generation by ensuring it remains perpendicular to the sun's rays throughout the day. Additionally, the Arduino interfaces with the servo motor to control the movement of the solar panel, fine-tuning its position based on real-time sensor feedback. Furthermore, it communicates with an ESP 32 microcontroller and a web interface to provide users with insightful data on energy production.

Figure 3 shows the system hardware prototype of the smart solar tracker with all the components put together. It comprises of a wooden structure that provides a frame for supporting the weight of 2 solar panels. It makes use of 2 UV sensors for tracking the position of the sun and a servo motor. The black box in the image contains an Arduino Uno and ESP32 microcontrollers along with some other electronic components to help in the smooth operation of the solar tracker. This prototype provides an impression of the appearance and operation of the solar tracking system after it has been built.

The individual components are listed in Table 2.

Figure 3. LEESOLA system hardware prototype

Table 2. LEESOLA system components list

Parts	Purpose
Solar panel	The chosen solar panels for the solar tracking system prototype are polycrystalline mini solar panels measuring 136mm × 110mm. These solar panels are small enough to fit in the design of the prototype. They have a rating of 12 V 2W and for the prototype two of these panels have been connected in series.
Servo motor	The prototype uses a DC servo motor, which comes with a gear arrangement that allows us to get a high-torque servo motor in a small and lightweight package. It plays a very crucial role in the solar tracking system by precisely adjusting the position of the solar panels to track the sun's movement. With the use of the PWM principle, the servo motor can provide accurate and controlled motion, making it a suitable choice for applications that require precise positioning and tracking. On receipt of signals from the control unit (Arduino Uno microcontroller), the servo motor uses an internal feedback mechanism to continuously adjust its position, ensuring the solar panels are aligned optimally with the sun.
UV sensor	The main sensor used by the prototype is a GUVA-S12SD UV sensor. It has a power pin (Vcc) that requires a voltage of 5V, a data pin (S) and a ground (GND) pin [20]. This UV sensor operates by detecting ultraviolet (UV) radiation from the sun. Upon absorbing UV photons, the semiconductor material used by the sensor generates electron-hole pairs, creating an electric current proportional to the intensity of the received UV radiation. The current is converted into a measurable voltage using an amplification circuit integrated into the UV sensor. The voltage signal is subsequently processed by the sensor's internal electronics, which include analog-to-digital conversion and calibration stages. The processed UV data is then communicated to the Arduino microcontroller, to be processed by our written algorithms to accurately calculate the sun's position relative to the sensor's location.

Parts	Purpose
ESP32 microcontroller	The ESP32 microcontroller board plays a central part in the system communication of the solar tracker prototype. It is responsible for receiving processed power data from the serial ports of the Arduino Uno and converting this data into the right format for transmission over the internet. The ESP32's integrated Wi-Fi module enables seamless communication with local networks, allowing the solar tracking system to connect to the internet and transmit data. Hence, the ESP32 is responsible for interacting with the web interface. It establishes a connection to the interface and sends out data concerning the power generated by the PV panels. This data is subsequently presented to users in a visually comprehensible manner, fostering real-time insights.
Power supply	The average voltage required by the components that make up the prototype is a voltage of 5.0 V. However, since these components have devices to help regulate voltage, a power supply between 4.0V and 9.0V is acceptable. The most preferred power supply is a 9V-rated Lithium-ion battery, this is attached to battery clip connectors and supplies power directly to the Arduino Uno board.

3.3 LEESOLA System Software Prototype

The software used in the smart solar tracker can be categorized into two primary groups: microcontroller software and web application software. These components serve distinct purposes in the operation of the system.

The microcontroller software contains different program flow logic that controls the operation of the subsystems and components of the smart solar tracking system. The source code was written in the Arduino IDE. The Arduino IDE uses a simplified version of the C/C++ programming language. This provides a means to interact with digital and analog pins, read sensors, control actuators (such as LEDs, motors, and servos), and communicate with other devices using various communication protocols like UART, I2C, and SPI. The image in Figure 4 shows a flow chart providing a general overview of the tracking algorithm used in the solar tracker application.

When turned on, the solar tracker sets the panel to face its initial position at 0 degree tilt angle due east (and subsequently adjusted at an interval of 15 degree tilt angle. See also Figure 10.), sets the “tolerance” variable which represents the allowable difference between the sensor readings to prevent unnecessary movements of the solar panel and initializes the serial port used for communication to the ESP32 microcontroller. The UV sensors constantly measure the UV rays from the sun with an interval of 1 second. Sensor readings from the UV sensors are compared, if the absolute value of their difference remains below the tolerance value, no change is made to the position of the solar panel. Otherwise, the solar panel is moved in the direction whose sensor value is the highest. Also, to provide a threshold for the angles to which the servo motor can turn, checks are made to keep the angle between 0 and 180 degrees. The entire loop is run after 500ms. Using the Universal Asynchronous Receiver/Transmitter (UART) serial interface the power measured from the solar panels is sent to the ESP32 microcontroller.

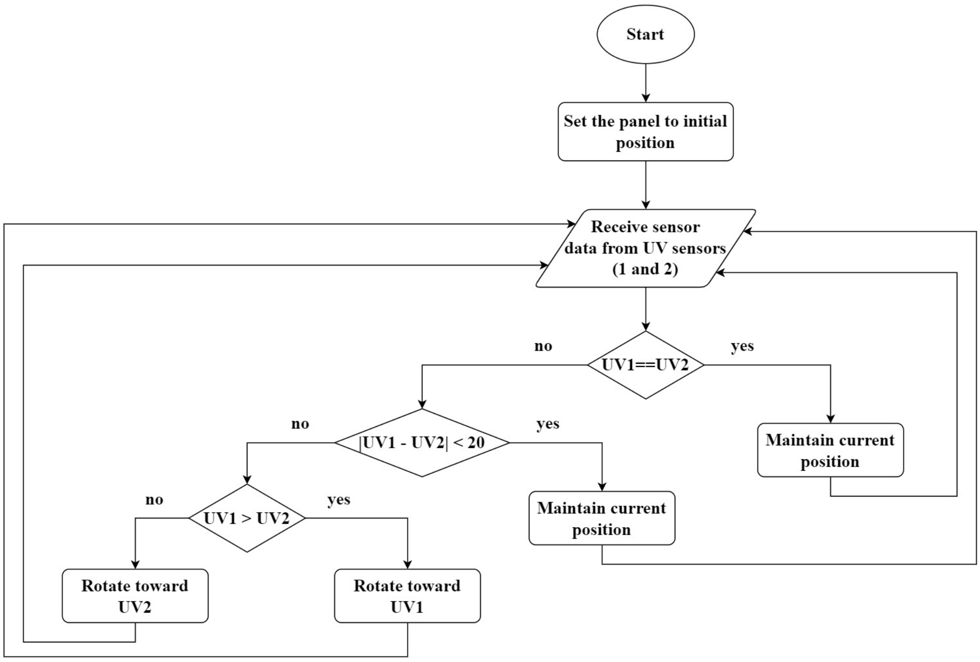


Figure 4. LEESOLA microcontroller software flow chart

With the system successfully tracking the movement of the sun, the power generated by the solar panel must be calculated. Using a voltage divider made up of two 220-ohm resistors, the voltage across these two resistors is calculated. On power on, the ESP32 board connects to a Wi-Fi connection whose SSID and password are stated in the code. It then initializes various serial ports to receive information coming in from the Arduino board. On receipt of power readings from the Arduino Uno, the data is formatted as a string and any trailing or initial spaces are removed. This loop is run after every 1000ms (1 second). To be able to send the power data to our server, the power readings are placed in JSON format before being sent out to be persisted in a database and displayed graphically on a web interface.

3.4 LEESOLA System Web Application Software

The LEESOLA system web application software displays power generated by solar panels, these power readings are collected and formatted using an ESP32 microcontroller. The application was built using Next.js for the frontend, which offers server-side rendering and seamless React integration. The project also employed a chart library for visualizing the power data, while React Query was used for efficient data fetching. At the backend, a Node.js server was implemented to handle API requests. The power readings were stored in a PostgreSQL database hosted on a cloud platform.

Figure 5 depicts the LEESOLA web application software workflow. The web application follows a client-server architecture. The frontend built with Next.js resides on the client side and communicates with the Node.js backend server via API endpoints. The server, in turn, interacts with the PostgreSQL database to read and write power readings. The server, using TRPC procedures (HTTP POST API endpoints) stores the power readings in the cloud database. The front-end requests power readings from the backend through GET HTTP requests. React Query manages data and updates the chart on the frontend. The frontend was developed using Next.js, providing smooth user experience with server-side rendering for faster loading times. Power readings were displayed using the chart library, offering visual insights into the solar panel's performance. React Query was used to efficiently fetch and manage data, reducing unnecessary requests and enhancing application responsiveness. The backend was built with Node.js, providing a lightweight and efficient server to handle incoming API requests. Security measures were implemented to prevent unauthorized access and ensure data integrity by providing authentication by using credentials.

Figures 6 and 7 show the LEESOLA software user interface.

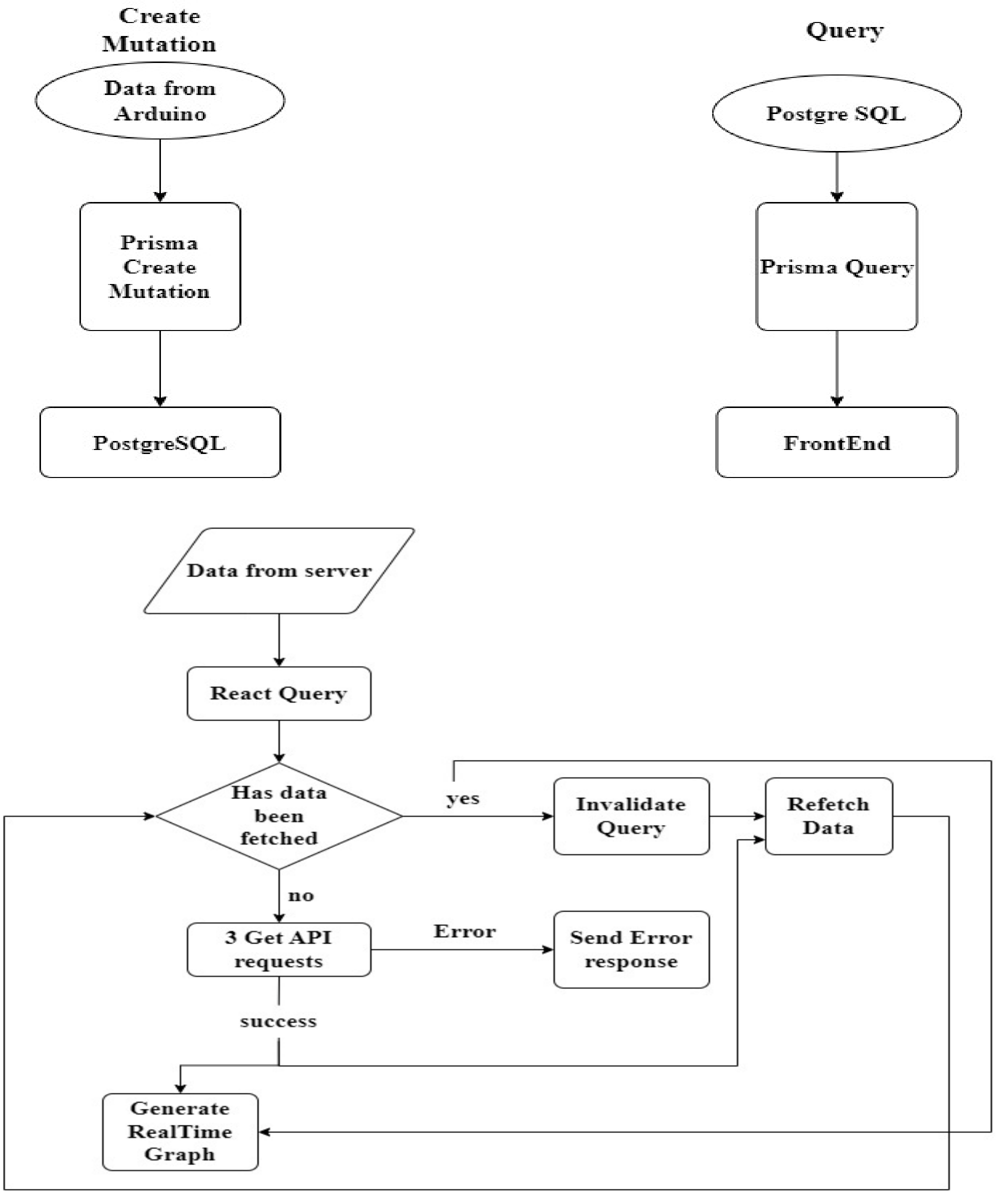
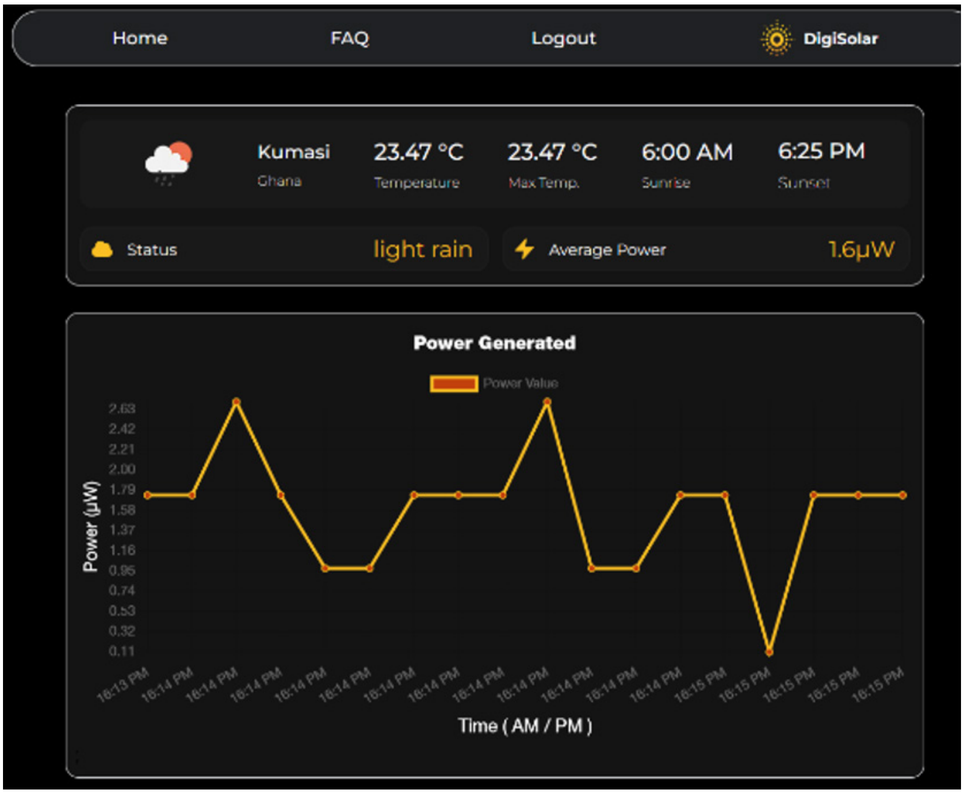


Figure 5. LEESOLA web application software workflow



Kumasi
Ghana
23.47 °C
Temperature
23.47 °C
Max Temp.
6:00 AM
Sunrise
6:25 PM
Sunset
Status light rain
Average Power 1.6μW

Figure 6. LEESOLA software user interface

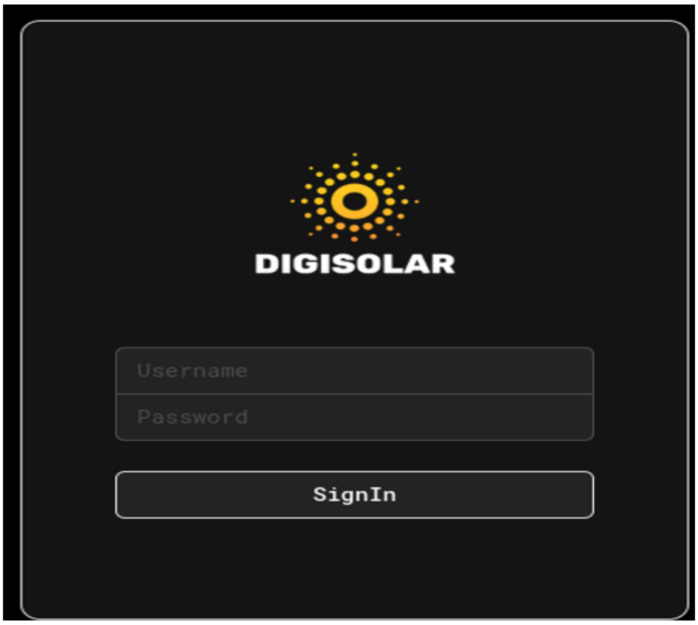


Figure 7. LEESOLA software user signin

PostgreSQL was selected as the database for this project due to its robustness, scalability, and support for complex queries. By hosting the database on supabase, the application benefits from increased availability and automatic backups. The PostgreSQL database was designed to store power readings, organized with relevant columns such as timestamp, and power value. Indexing was utilized to optimize query performance, allowing for faster retrieval of data. The backend server exposed API endpoints to handle data retrieval and storage. Two main endpoints were implemented:

- **`GET /api/getpower`**: Used to fetch the power readings from the database and provide them to the frontend for visualization.
- **`POST /api/createpower`**: Received incoming power readings from the Arduino and stored them in the database. The web application and database were deployed to cloud platforms, Vercel and Supabase respectively.

4. Results and Discussions

The solar tracking system was successfully integrated with a real-time web interface and the complete setup was tested to confirm its operational effectiveness. The setup was tested for a period of 8 hours, the system was seen to orient the solar panel arrays in the direction of the sun which tests the system's ability to move the panels in response to the movement of the sun. Data from the setup was then compared to that obtained from a static solar panel setup. Users were also able to log into the user interface successfully to access and monitor real-time power generated data. The system's output was collected and graphed in real-time on the web interface, offering users a clear and informative visualization of their power production.

The graphs in Figure 8 represent readings taken by a static panel setup by the solar tracker at different times in the day i.e., morning, afternoon, and evening. The difference in power generation can be realized from the graphs.

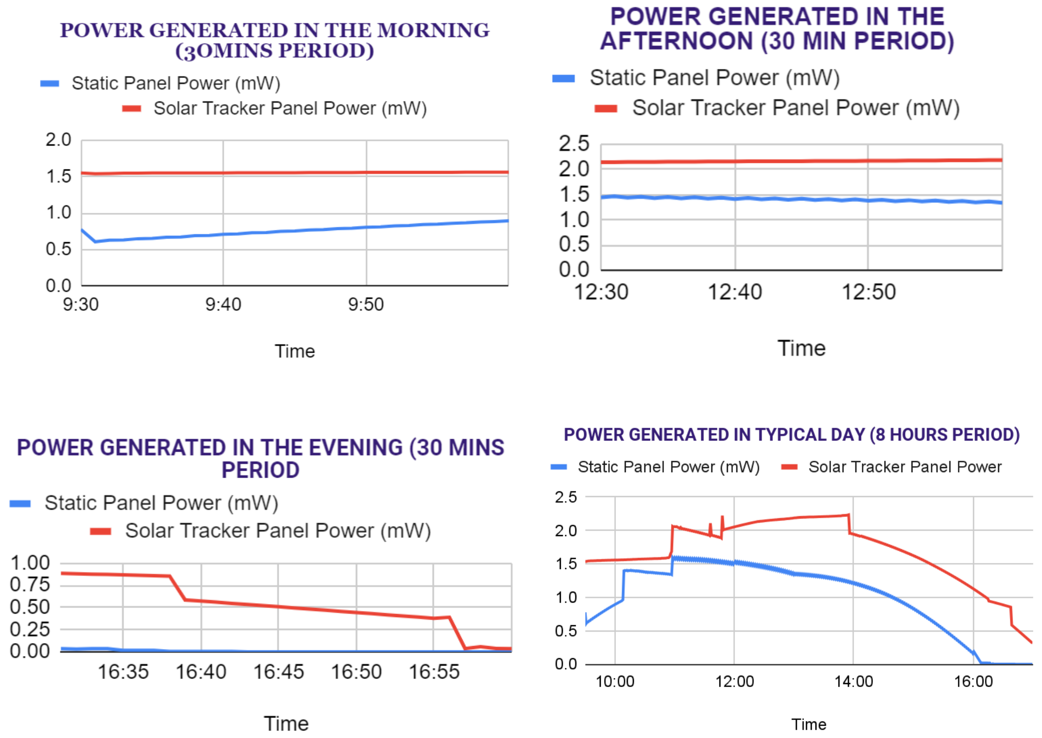


Figure 8. LEESOLA graphical power readings

Table 3 represents a summary of the ranges of power readings obtained at different times of the day. In the afternoon when the intensity of the sun’s radiation is highest, the values of power obtained by the solar tracker setup turn out to be consistent compared to those taken in the evening when the sun goes down and darkness begins to form. This is visualized more elaborately in Figure 9.

Table 3. Solar power readings at different periods

Time of Day	Power Reading (mW)		
	Static Setup	Solar Tracker	Percentage difference of the mean power readings
Morning (09:30 - 11:59) AM	0.6084 - 0.8946	1.5369 - 1.5594	69.29
Afternoon (12:00 - 3:59) PM	0.7887 - 1.5379	2.0554 - 2.2376	59.41
Evening (04:00 - 05:59) PM	0 - 0.0359	0.0366 - 0.8854	184.96

The percentage difference of the mean power readings is calculated using this equation:

$$\% \, Diff = \left| \frac{Mean\ diff}{Mean\ val} \times 100 \right| \tag{1}$$

$$Mean\ diff = mean\ of\ static\ setup - mean\ of\ solar\ tracker \tag{2}$$

$$Mean\ val = \frac{mean\ of\ static\ setup + mean\ of\ solar\ tracker}{2} \tag{3}$$

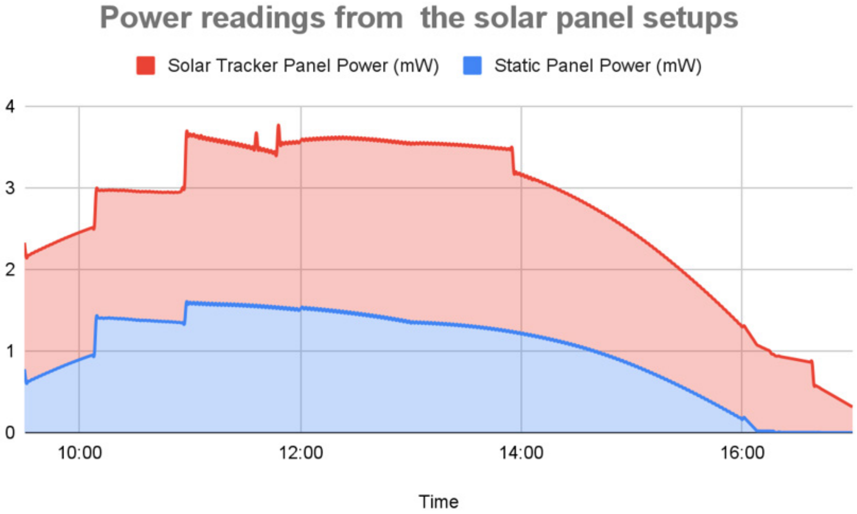


Figure 9. Power readings from the solar panel setups

The graph in Figure 10 illustrates the direct correlation between the tilt angle of the solar panel and the power generated. As the tilt angle increases from 0 to 45 degrees, the power generated also increases significantly, peaking at 2.0562 mW. However, at steeper angles beyond 45 degrees, the power generated starts to decrease slightly, emphasizing the importance of finding the optimal tilt angle for maximizing energy capture.

Unlike static or fixed panels whose optimum tilt angle is computed using the following equations:

$$\beta_{opt} = \phi - \delta \tag{4}$$

$$\delta = 23.45 \sin\left(360 \cdot \frac{284 + k}{365}\right) \tag{5}$$

β_{opt}, ϕ, δ and k represent the optimum tilt angle, observer's latitude declination angle and the number of a specific day respectively. As previously established, the optimum tilt angle varies throughout the day due to the rotation of the earth about its axis as it revolves around the sun (the apparent movement of the sun across the sky). Hence the single axis solar tracking system proposed in this design utilizes the UV sensors to facilitate the continuous movement of the panels to find this optimum tilt angle where harnessing solar power is maximum. Based on this approach, a cost-effective solution is provided with reduced complexity.

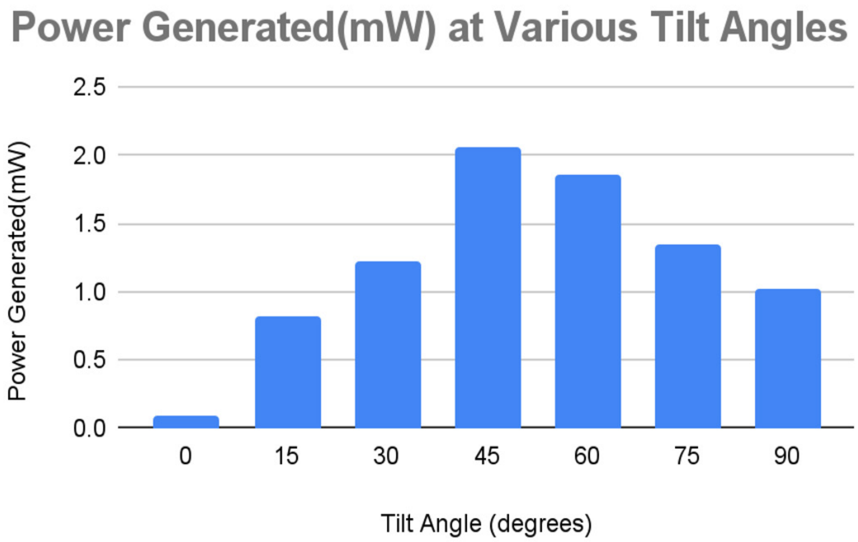


Figure 10. Graphical representation of the power readings against tilt angle of the solar panel

The results presented in Figure 9 and 10 show the correlation between tilt angle with time of data collection.

5. Conclusion

We have proposed and tested a system that efficiently monitors the sun as it moves across the sky during the day to help improve the amount of solar energy captured and converted to electrical energy. The use of UV sensors in place of the traditional Light Dependent Resistors (LDRs) has helped in detecting the position of the sun even in cloudy conditions. The performance of the proposed system achieved about 69.29%, 59.41% and 184.96% mean percentage difference in the measured power readings for morning, afternoon, and evening durations respectively. Thus, this system signifies an all-rounded improvement over the static approach. Future versions of the solar tracker should include current sensors that can more accurately assist with calculating the power generated by the solar panels and the introduction of a messaging queue that stores power data during internet outages and prevents any loss of data. The system should be able to track the amount of power generated by solar panels and used per day by connected devices as well as an integrated feature to send reports on the power generated per month included.

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