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COLLEGE OF ENGINEERING

DEPARTMENT OF COMPUTER ENGINEERING

SMART SOLAR TRACKING SYSTEM

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DECLARATION

This is to certify that the project titled "**Smart Solar tracking system**" submitted to Kwame Nkrumah University of Science and Technology, represents our original work. The project was conducted under the supervision of Ing. Benjamin Kommey, within the Department of Computer Engineering in the College of Engineering, as a partial requirement for the degree of BSc.Computer Engineering.

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DEDICATION

This work is dedicated to our families, friends, and mentors who have provided us with unwavering support and guidance throughout this project. Your encouragement and belief in our abilities have been instrumental in helping us to push through the challenges and achieve our goals. We also dedicate this project to future students who will embark on their own academic journeys, hoping that our work will serve as a source of inspiration and knowledge.

ACKNOWLEDGEMENT

Our greatest appreciation goes to God almighty for guiding us successfully through this project. Our appreciation goes to Ing Benjamin Kommey, our supervisor, for providing us with proficient direction and ongoing motivation all through the project. His valuable insights and constructive feedback have played a pivotal role in shaping the trajectory and extent of our efforts.

Finally, we would want to express our deepest appreciation to the staff of the Department of Computer Engineering for their support and resources, which have enabled us to complete this project successfully. Thank you all for your contributions to this project and for helping us achieve our academic goals.

ABSTRACT

A solar tracking system is used to orient solar reflectors, photovoltaic panels and other solar energy harvesting equipment toward the sun mainly to maximise energy output. The system design offers an optimised 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 the human race on traditional energy sources.

The system architecture of the smart solar tracking system consists of a microcontroller-based control unit, a sensor module, motor drivers and PV panels. The 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 also changes the angle of the PV panels accordingly. The sensor module makes use of light sensors, such as photodiodes, photoresistors, phototransistors or photovoltaic cells 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.

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ABBREVIATIONS AND ACRONYMS

PV	Photovoltaic
IEA	International Energy Agency
API	Application Programming Interface
ANFIS	Adaptive Neural Fuzzy Inference System
PWM	Pulse Width Modulation
SPI	Serial Peripheral Interface
Wi-Fi	Wireless Fidelity
I2C	Inter-Integrated Circuit
TRPC	Transactional Remote Procedure Call
UART	Universal Asynchronous Receiver/Transmitter
SSID	Service Set Identifier

1. INTRODUCTION

1.1 Problem Statement

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.

The amount of sunlight that a solar panel captures relies on its 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 to the equator, will generate more electricity than those located in areas with less sunlight. 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. 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.

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.

1.2 Objectives of the Project

This project seeks to design and implement a solar tracking system for solar panels that can improve the efficiency of power production. There are three specific objectives of the proposed project:

- To develop a system that can constantly adjust the angle of PV panels to optimise their orientation in relation to the sun.
- To design a solar tracking system that would be able to efficiently capture solar energy regardless of weather conditions.
- To develop and integrate data acquisition and monitoring software that will collect data on the power produced by the panels

1.3 Scope of the Project

This project is limited to industrial and commercial use only, which means that the system is specifically designed to cater to the energy requirements of these two sectors. The system will be developed with a focus on providing a cost-effective and scalable solution for these applications, considering the unique necessities and demands of industrial and commercial environments. The design of the system will need to be optimised to handle large and heavy solar panels and withstand harsh environmental conditions, making it suitable for industrial applications and commercial use. The system's performance will be based on its energy efficiency, energy output, and cost savings, ensuring that it provides significant benefits for these two sectors. Overall, the limited scope of the study will allow for a more focused and effective development of the smart solar tracking system, ensuring that it meets the unique needs and requirements of industrial and commercial applications.

The scope of our project is limited to the industrial settings of Ghana. This indicates that the smart solar tracking system will be devised while keeping in mind the specific environmental conditions of these regions. Considering the climate of Ghana, it is desirable to select a single-axis solar tracking system as compared to other options. The reason is that this system is tailored to monitor the motion of the sun along a single axis, which helps to optimize the orientation of the PV panels to ensure that it receives the maximum amount of sunlight. This design is especially appropriate for the weather patterns of Ghana, which are marked by elevated temperatures and a significant frequency of dust and sandstorms. A horizontal single-axis setup is more equipped to handle these situations since it has less exposure to the elements in contrast to other designs, thereby reducing the likelihood of dust or sand accumulation. Additionally, this design is also economical and comparatively straightforward to implement, making it a more pragmatic solution for fulfilling the energy needs of Ghana.

The advantage of a single-axis system over other types of solar trackers is that it is more cost-effective and delivers a high energy output. This is because a single-axis system requires fewer components and can be installed with relative ease, making it more affordable and straightforward to maintain. Additionally, this design gives the solar panel the ability to follow the sun's movement more accurately, maximising the amount of sunlight it receives throughout the day. As a result, solar panels can generate more electricity, which is essential for meeting the increasing energy demands of both commercial and industrial sectors. By using a solar tracking system that moves along a single-axis, we can deliver a reliable and efficient solution that is well-suited to the energy needs of our target audience.

Furthermore, since the project is limited to industrial and commercial use, the larger size of monocrystalline solar panels is not an issue. They are also more space-efficient, generating more power per square meter compared to other panel types. This makes them a good fit for the project's objectives of delivering a cost-effective solution that delivers a high energy output.

The system will be optimised for the type of solar panel used, taking into account factors such as size, weight, and angle of inclination. The system will be optimised for two-panel types; Monocrystalline and Passivated Emitter and Rear Cell (PERC).

1.4 Significance of the study

Solar tracking is a cutting-edge technology that can significantly increase how effective solar energy systems are. The significance of studying such a system is as follows:

Improved Efficiency: A smart solar tracking system can optimise the angle and direction of solar panels throughout the day, which can significantly improve the energy output of solar panels. The study of such a system can aid in determining the optimal design and configuration to maximise energy production.

Environmental Benefits: Solar power is an eco-friendly and sustainable energy option capable of curbing greenhouse gas emissions and lessening the impact of global warming. By improving the efficiency of these energy systems, a smart solar tracker can help increase the adoption of renewable energy and reduce reliance on fossil fuels.

Cost Savings: By improving how efficient solar energy systems are, a smart solar tracking system can potentially reduce the cost of solar energy production. It also reduces installation costs. Although a solar tracking system may require additional components, such as sensors and motors, it can still reduce installation costs by allowing for fewer solar panels to be installed to achieve the same energy output as a fixed panel system.

Technological Advancement: Studying a smart solar tracking system can also help advance studies related to renewable energy and advocate innovation in the development of sustainable technologies. By studying these devices, researchers can identify new opportunities for innovation, such as developing new sensors and control systems, improving the accuracy of solar tracking algorithms, and integrating renewable energy sources into existing power grids.

1.5 Organisation of the Study

1. **Introduction**
   - Purpose and objectives of the project
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6. **Conclusion**
   - Summary of the study
   - Future scope for the project

2. LITERATURE REVIEW

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 [1]. Solar energy has turned out to be on top of the list when talking about most commonly utilised renewable energy sources and it is also becoming increasingly affordable thanks to advancements in technology. Due to this, recent developments have led to the conceptualisation 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 also their drawbacks.

2.1 Related Works

2.1.1 Simulink Model of Electromechanical Solar Tracking System

In an article by Mamodiya et al.[4], 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.

2.1.2 Dual-axis Tracking Using Digital Logic Design

Jamroen et al.[2] 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 was contrasted with that of the stationary PV system, the proposed design led to an increase in energy production by 19.97%.

2.1.3 Active Single-Axis Solar Tracker

Shehu et al.[16] 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 alter 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.

2.1.4 A Schedule-Based Tracker With a GPS and Digital Compass

A study by Kuttybay et al.[5] 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, taking into account 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.

2.1.5 A NODEMCU Microcontroller Solar Tracking System

In a study by J.Ghosh et al.[13], 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.

2.1.6 Experimental Performance Evaluation of Single-axis Tracking Devices

In research conducted by Hussain et al.[17], 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.

2.1.7 Dual-Axis Tracking Using Gyro Orientation Sensors

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.

2.1.8 Triangular Solar Tracking System

A study conducted by Y. Chaiko et al.[7] explores the benefits of a 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.

2.1.9 Review of Solar Tracking For Small-Scale Photovoltaic Systems

A study by C. L. Sandoval-Rodriguez et al.[10] analyzed the application of solar tracking systems for small-scale photovoltaic systems. Based on seven defined attributes, the study 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 favourable 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.

2.1.10 Tilted-Rotating Axis Tracking

Y. Zhu et al. [8] in their work did some analysis on the different types of tracking systems ie. 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.

2.1.11 Filtered Sun Sensor For Solar Tracking

Diaz et al.[11] 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 a 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 a 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 would make the construction of the tracking system costly and complex.

2.1.12 Single Motor Dual-Axis Asymmetric Solar Tracker

In their research, Karabiber et al.[3] 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.

2.1.13 Single-Axis Solar Tracking Using Binary Dominance Matrix

A research by Munanga et al.[12] aimed to develop a smart single-axis solar tracking system that maximises solar panel efficiency by positioning it to be at an angle of 90° to solar radiation at all times. 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.

2.1.14 Adaptive Neural Fuzzy Inference System (ANFIS) - Based Solar Tracking System

In their work, N.Al-Rousan et al. [15] based theri 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 takes into account 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.

2.2 Summary

This chapter established the advantages of using solar tracking systems over fixed solar panels. Also, It reviews different literature related to works on various classifications of solar tracking systems (Single-axis, Dual-axis, active and passive trackers). It is observed that most solar trackers make use of light-dependent resistors (LDRs) as their main sensor module. These sensors make use of Cadmium sulphide nanoparticles (CdS) to detect visible light and send that data as input for tracking the sun's movement. LDRs regardless of their many advantages can be ineffective in low-visibility environments (eg. Cloudy or rainy weather conditions) and could also reach a level of saturation of light intensity. LDR saturation tends to occur when the device is exposed to maximum sunlight and the charge capacity of the photocells is reached. This then causes the tracking system to maintain its initial point of saturation instead of moving according to the sun's trajectory, hence making the system behave more like a fixed system [14]. Due to the extended hours of sunlight in Ghana, using these LDRs would not lead to the realization of the efficiency offered by solar trackers.

In order to address the deficiency of LDRs and also build solar tracking systems suited for Ghana, the proposed smart solar tracking system seeks to employ the use of much more modern sensors such as ultra-violet sensors as the main sensor module.

3. METHODOLOGY

3.1 System Architecture

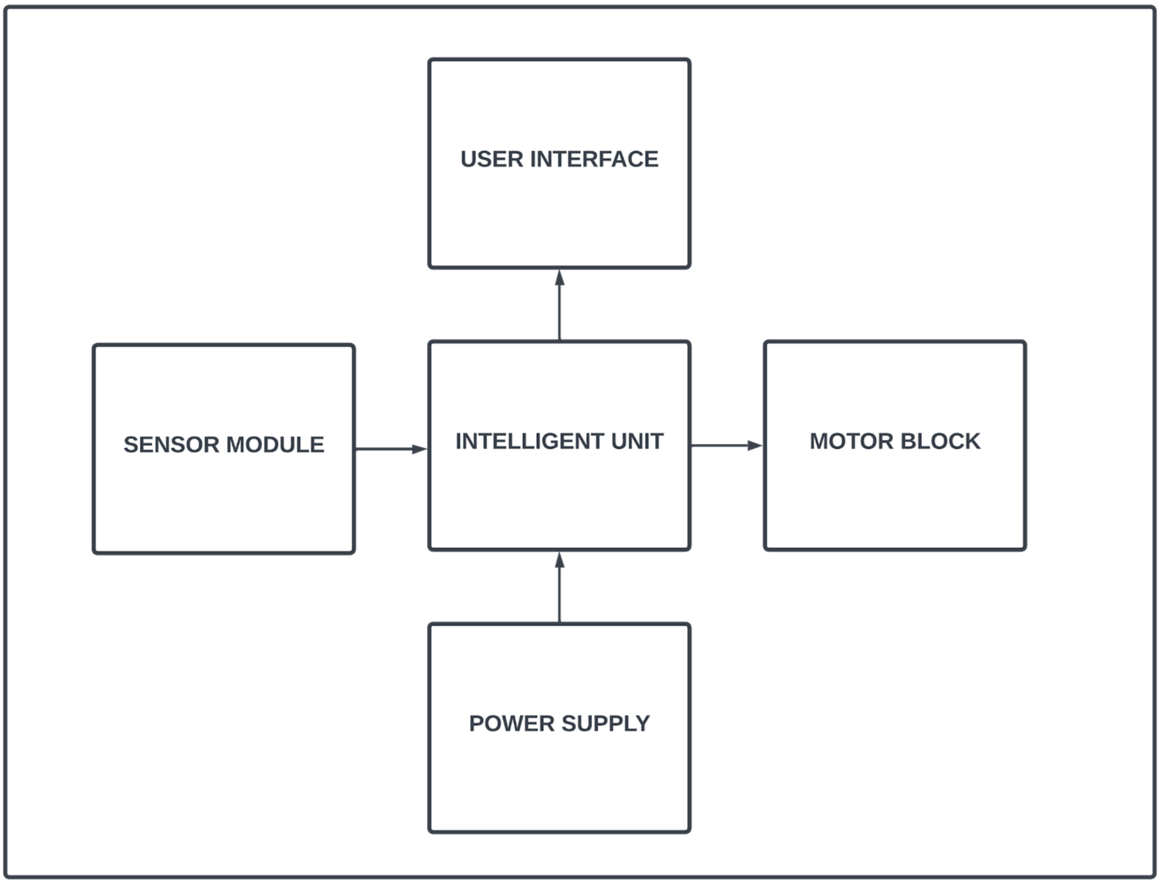


Figure 1: Proposed System Architecture

Figure 1 above provides a visual overview of the 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 also send out power data over a wireless local area network to the user interface to be shown to the user in real time.

3.1.1 The Intelligent Unit

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 the 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.

3.1.2 The Sensor Module

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 radiations using two sensors. The sensors can be either analog or digital and may use different types of photodiodes, such as PIN photodiodes or phototransistors.

3.1.3 Motor Block

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 in order to accurately and reliably adjust the orientation of the PV panels.

3.1.4 Power Supply Module

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.

3.1.5 User Interface

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.

4. SYSTEM PROTOTYPE

The system prototype comprises of both hardware and software components that contribute to the tracking of the movement of the sun and also 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.

4.1 Block Diagram

A block diagram illustrating the components of the smart solar tracking system is provided below. It depicts the interconnected subsystems that work together to produce the desired outcome.

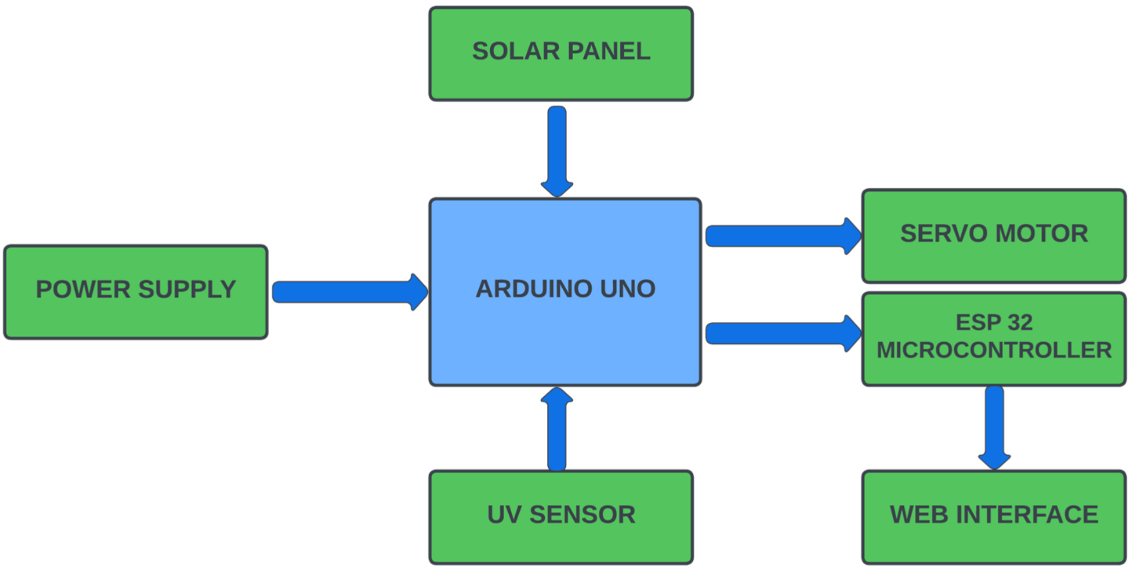


Fig 2 : Block diagram of system prototype

4.2 The Solar Tracker Microcontroller Board

The smart solar tracking system protoype 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. It receives inputs 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 maximise 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.

The image below highlights some key components of the Arduino Uno microcontroller

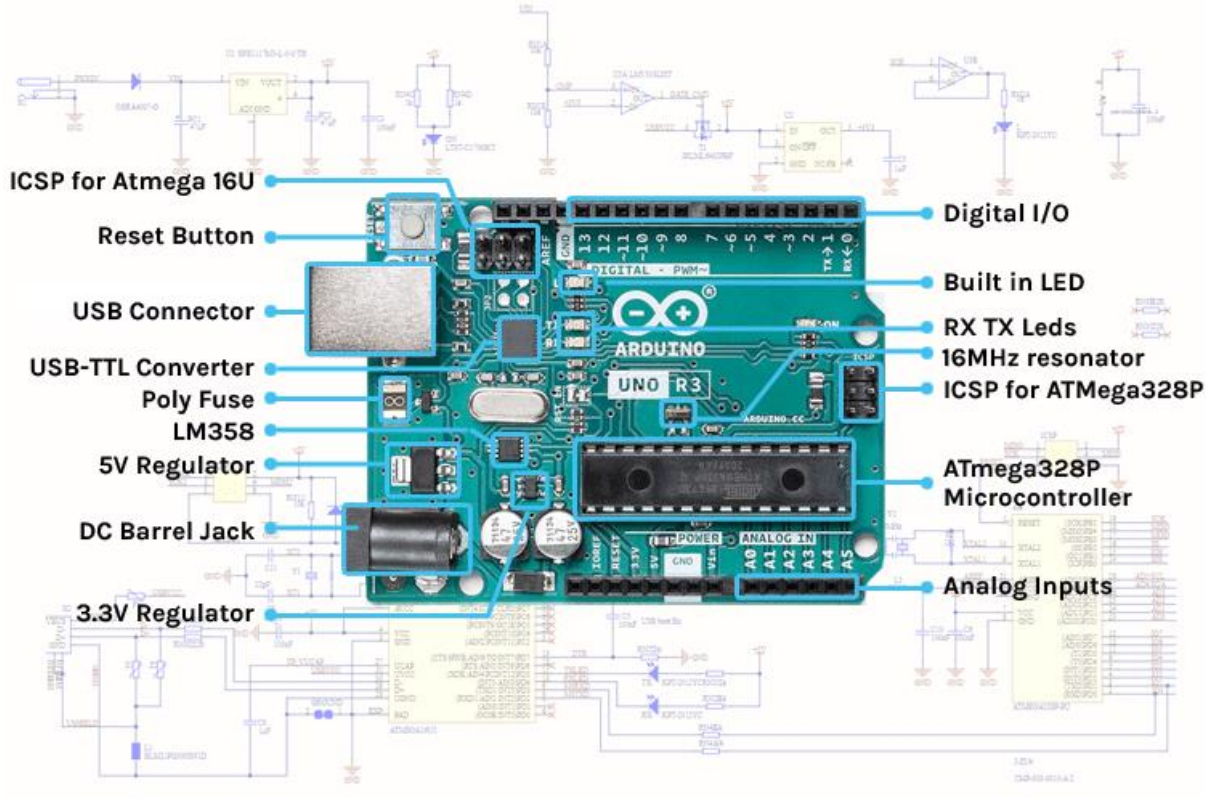


Fig 3: Arduino Uno key components (Source: Circuit Digest, 2022: Online)

4.3 Solar Panel

The chosen solar panels for the solar tracking system prototype are polycrystalline mini solar panels measuring 136mm X 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.

4.4 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 is able to 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.

4.5 Ultraviolet (UV) Sensor Setup

The main sensor used by the protoype 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. 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.

The image below shows the UV sensor used by the solar tracker.

Fig 4: UV sensor module
(Source: Usinainfo, 2022: Online)

4.6 ESP 32 Microcontroller

The ESP32 microcontroller board plays a central part in the system communication of the solar tracker protoype. 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.

4.7 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.

Fig 5: Prototype of smart solar tracker

Figure 6 above shows the 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.

4.8 Software

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

4.8.1 Microcontroller Software

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 below is a flow chart providing a general overview of the tracking algorithm used in the solar tracker.

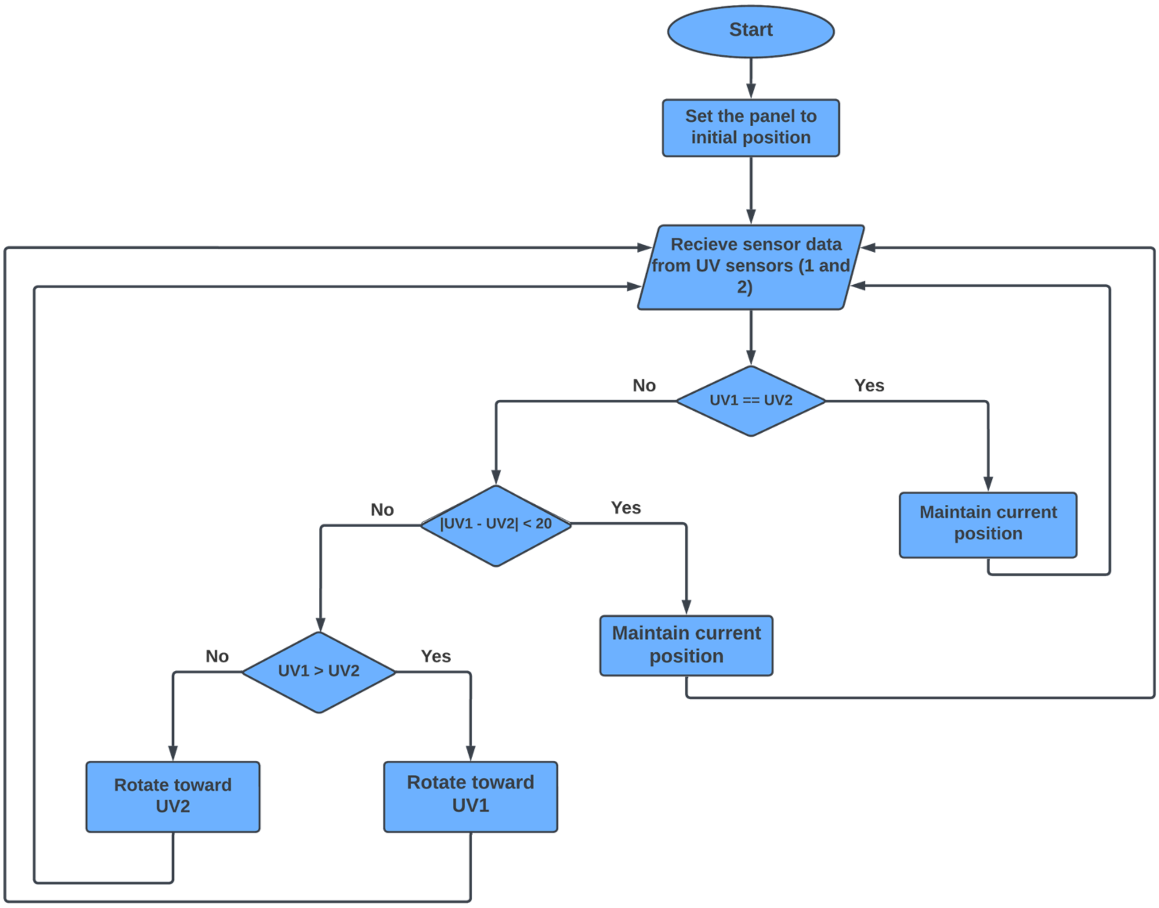


Figure 6 : Flow chart of microcontroller software

UV Sensor and Servo Motor Setup

When turned on, the solar tracker sets the panel to face its initial position (depending on where the sun rises from), sets the "tolerance" variable which represents the allowable difference between the sensor readings to prevent unnecessary movements of the solar panel and also initialises 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.

```
#include <Servo.h>

const int analogInputPin = A0; // Analog input pin
Servo mainServo;

int UvPin1 = 1;
int UvPin2 = 2;

int position = 90; // initial position of servo
int tolerance = 20; // allowable tolerance to prevent the servo
from being constantly in motion

int value;

void setup() {
  mainServo.attach(9);
  mainServo.write(position); // set servo to its initial position
```

```
  Serial.begin(9600);

  delay(1000); // allow a delay of 1 second to allow the solar panel to move to its initial position

}
```

Servo Motor Control

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.

```
 if(abs(value2 - value1) <= tolerance){} // Do nothing if the difference is within the tolerance range

   else{
```

```
    if (value1 > value2){
      position += 1;
     }

    if (value1 < value2){
      position -= 1;
     }
    }

  if(position > 180){
    position = 180; // set the maximum position of the servo
    }

  if(position < 0){
    position = 0; // set the minimum position of the servo
    }

  mainServo.write(position);
  Serial.println(power, 2); // Send the power value to the serial
communication port
  delay(500);
```

Using the Universal Asynchronous Receiver/Transmitter (UART) serial interface the power measured from the solar panels is sent to the ESP32 microcontroller.

Voltage and Power Calculation

With the system successfully tracking the movement of the sun, the power generated by the solar panel has to be calculated. Using a voltage divider made up of two 220-ohm resistors, the voltage across these two resistors is calculated.

```
int sensorValue = analogRead(analogInputPin); // Read analog input
value from the solar panel

float voltage = 2 * (sensorValue * (24.0 / 1023.0));// Convert
sensor value to voltage (assuming 24V reference)


int resistance = 220;

float current = voltage/resistance;

float power = current * voltage;
```

ESP32 Setup

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 in order to receive information coming in from the Arduino board.

```
#include <ArduinoJson.h>
#include <HTTPClient.h>
#include <WiFiMulti.h>

const char *AP_SSID = "Openwifi";
const char *AP_PWD = "wifipassword";

HardwareSerial powerSerial(2); // Use hardware serial port 2 (pins
16 and 17)
WiFiMulti wifiMulti;

void setup() {
```

```
  Serial.begin(9600); //Serial communication initialization
  powerSerial.begin(9600); // Initialize the software serial port

 wifiMulti.addAP(AP_SSID, AP_PWD);
   while (wifiMulti.run() != WL_CONNECTED) {
    delay(100);
    Serial.print(".");
  }
  Serial.println();
  Serial.println("WiFi connected");
  Serial.println("IP address: ");
  Serial.println(WiFi.localIP());
}
```

Formatting Power Data

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)

```
void loop() {
```

```
  if (powerSerial.available()) {
    String pvPower = powerSerial.readStringUntil('\n');
    Serial.println(pvPower);
    pvPower.trim();
    postDataToServer(pvPower);
    delay(1000);
    }

  delay(1000);
}
```

ESP32 POST Communication to Server

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 also displayed graphically on a web interface.

```
bool postDataToServer(String power) {
  // Block until we are able to connect to the WiFi access point
  if (wifiMulti.run() == WL_CONNECTED) {

    Serial.println("Sending JSON data to server...");
    HTTPClient http;
```

```
    http.begin("https://digisolar.vercel.app/api/createpower");
    http.addHeader("Content-Type", "application/json");

    StaticJsonDocument<200> doc;
    // Add values in the document
    String powerValue = String(power);
    doc["power"] = powerValue;
    String requestBody;
    serializeJson(doc, requestBody);
    int httpResponseCode = http.POST(requestBody);
    Serial.println(requestBody);

    if(httpResponseCode>0){
      String response = http.getString();
      Serial.println(httpResponseCode);
      Serial.println(response);
      return true;
    }
    else {
      Serial.println("Error occurred while sending HTTP POST");
      return false;
    }
  }
}
```

4.8.2 Web Application Software

The web application displays power generated by the 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. On 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.

Technologies Used

- Frontend: Next.js
- Chart Library: Chartjs
- Data Fetching: React Query
- Backend: Node.js
- Database: PostgreSQL
- Cloud Hosting: Vercel and Supabase

Software Architecture

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.

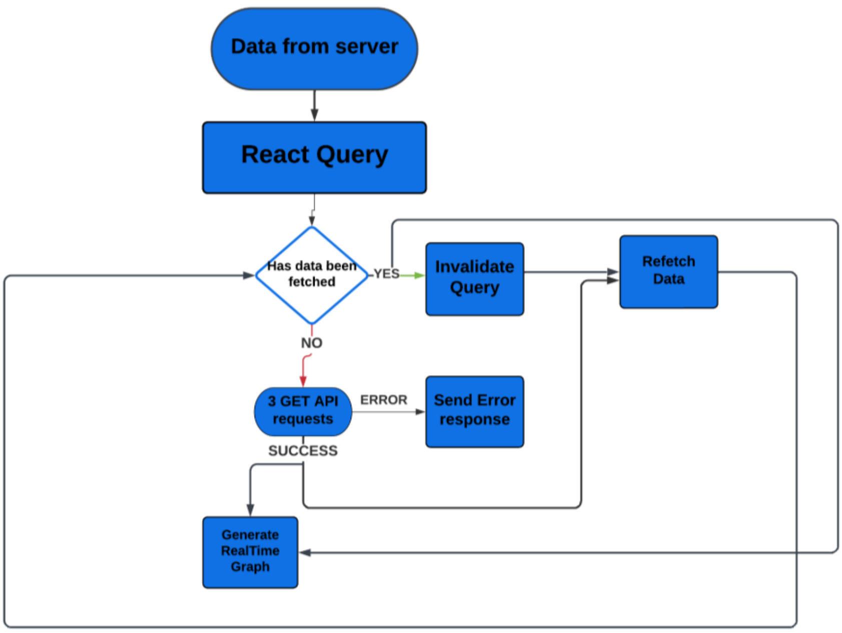


Fig 7: Flow chart of frontend architecture

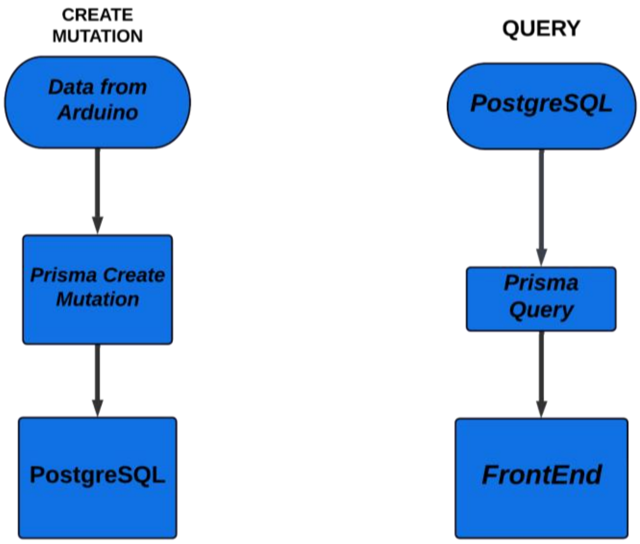


Fig 8: Flow chart of backend architecture

Frontend Implementation

The frontend was developed using Next.js, providing a smooth user experience with server-side rendering for faster loading times. The 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.

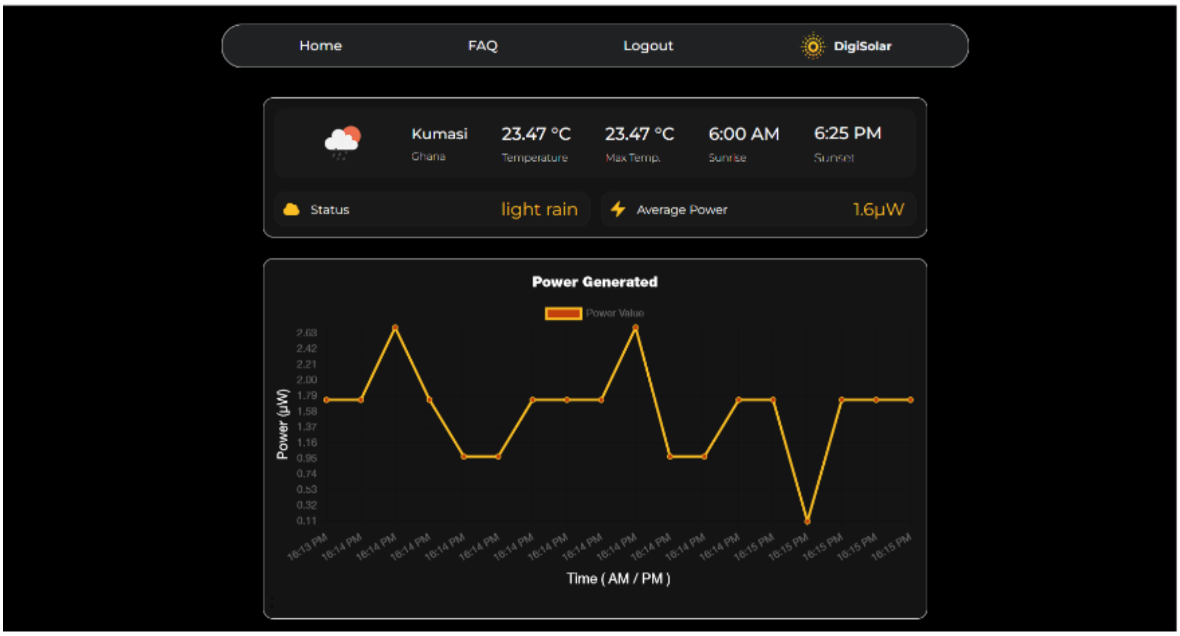


Fig 9: Screen showing generated power

Backend Implementation

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.

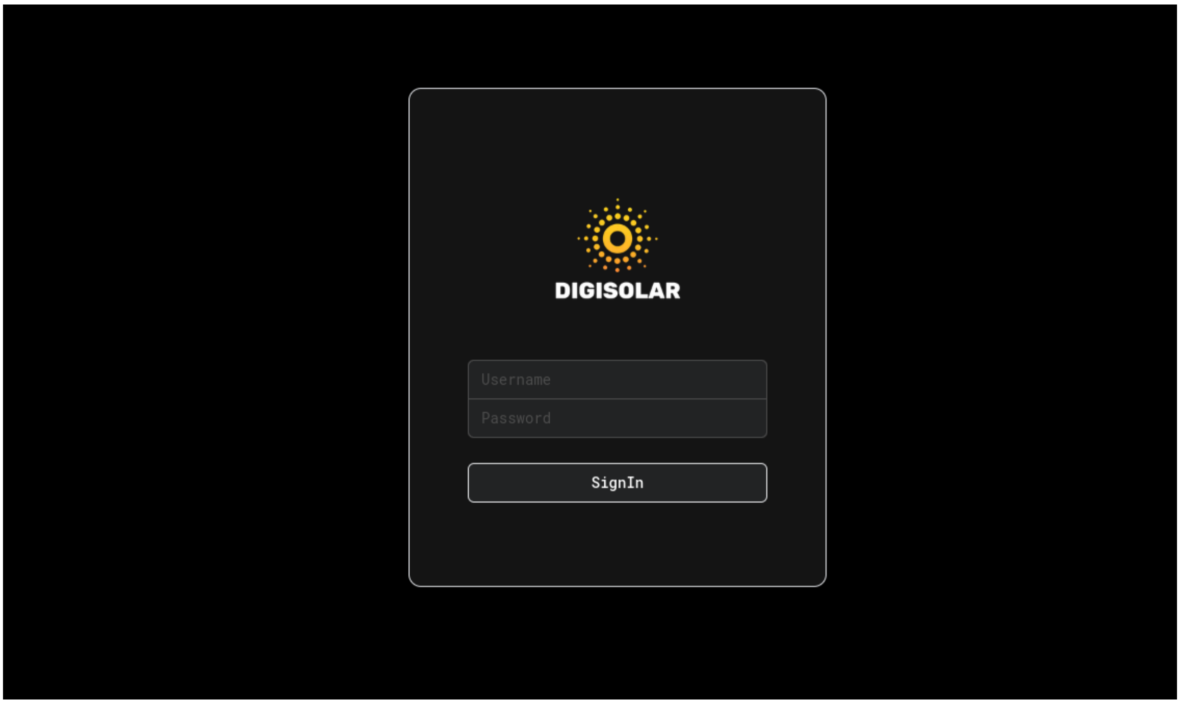


Fig 10: User
Authentication page

Database

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.

API Endpoints

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.

```
export const readingRouter = createTRPCRouter({
  getpower: publicProcedure
    .meta({
      openapi: { method: "GET", path: "/getpower/", enabled: true },
    })
    .input(z.void())
    .output(
      z.array(
        z.object({
          id: z.string(),
          createdAt: z.date(),
          power: z.string(),
        })
      )
    )
    .query(async ({ ctx }) => {
      return await ctx.prisma.power.findMany();
    }),
```

Fig 11. Controller for querying power readings

- **`POST /api/createpower`**: Received incoming power readings from the Arduino and stored them in the database.

```
createPower: publicProcedure
  .meta({
    openapi: { method: "POST", path: "/createpower/", enabled: true },
  })
  .input(z.object({ power: z.string() }))
  .output(z.object({ power: z.string() }))
  .mutation(async ({ input, ctx }) => {
    console.log(input.power);

    return await ctx.prisma.power.create({
      data: { power: input.power },
    });
  }),

```

Fig 12: Controller for persisting power readings

Deployment

The web application and database were deployed to cloud platforms, Vercel and Supabase respectively.

4. TESTING AND EVALUATION

4.1 Testing

The solar tracking system was successfully integrated with a real-time web interface and the complete setup was tested to confirm its operational effectiveness.

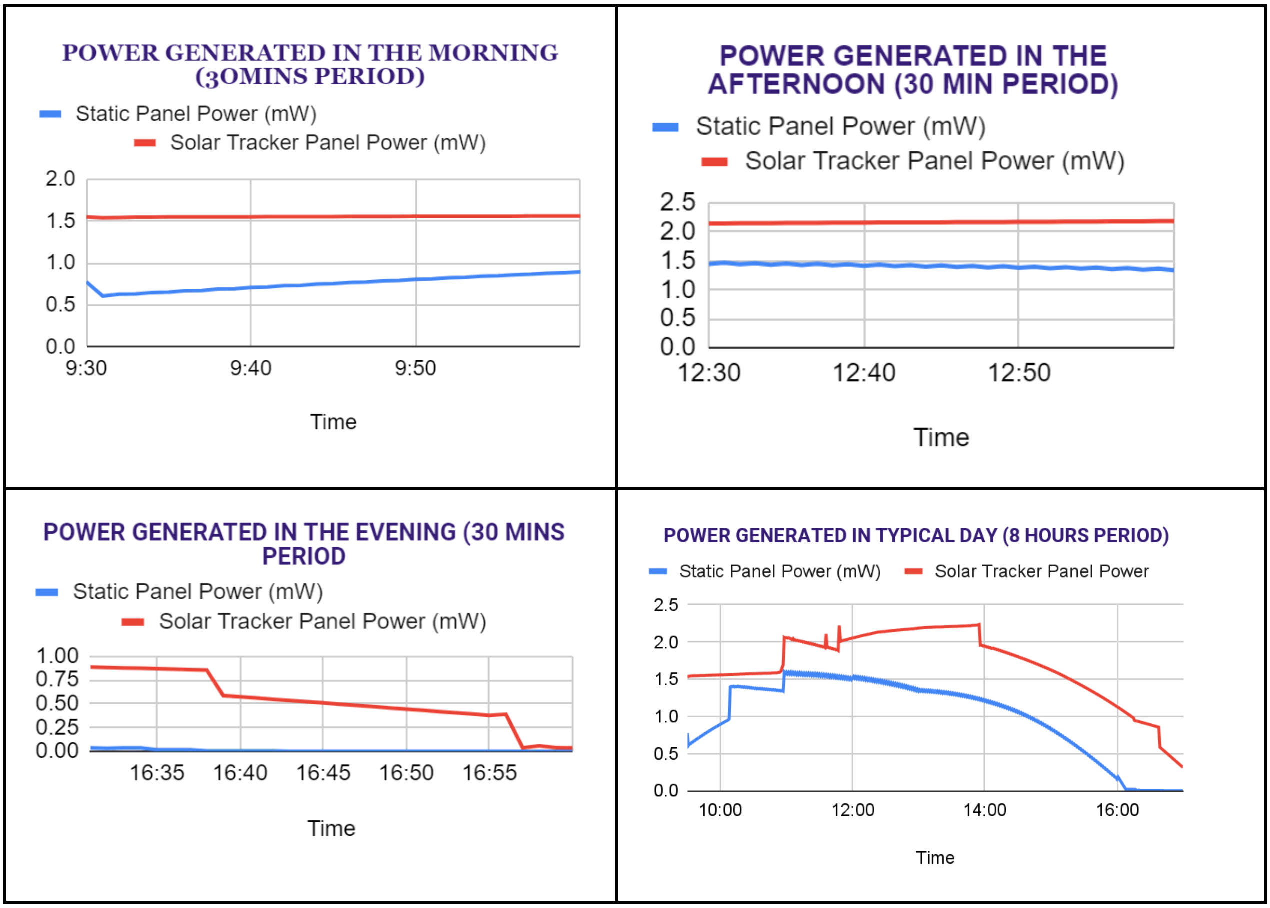
The setup was tested for a period of 8 hours, the system was seen to orient the solar panel arrays in the direction of the sun which tests the system's ability to move the panels in response to the movement of the sun. Data from the setup was then compared to that obtained from a static solar panel setup.

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.

4.2 Evaluation

Effect of time of day on the generation of power

The graphs below represent readings taken by a static panel setup and also by the solar tracker setup at different times in the day i.e. Morning, afternoon and evening. The difference in power generation can be realised from the graphs.



The table below 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 power values obtained by the solar tracker setup turn out to be consistent compared to that of those taken in the evening when the sun goes down and darkness begins to form.

Fig 13: Graphs of power generated at different times of the day

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

Fig 14: Summary of power generated at different times of the day

Consistency of Tracking System

The solar tracking system was able to adapt to the changing environmental factors and to capture energy effectively under both direct and diffuse sunlight. As the sun approached the horizon, the benefits of solar tracking began to diminish. However, even during these periods, the tracking system maintained a competitive edge over the static panel setup. While both systems experienced diminishing returns, the tracking system's power generation remained higher, demonstrating its ability to adapt to changing solar angles and maintained higher efficiency. The consistency of the tracking system is summarised in the graph of figure 15 below.

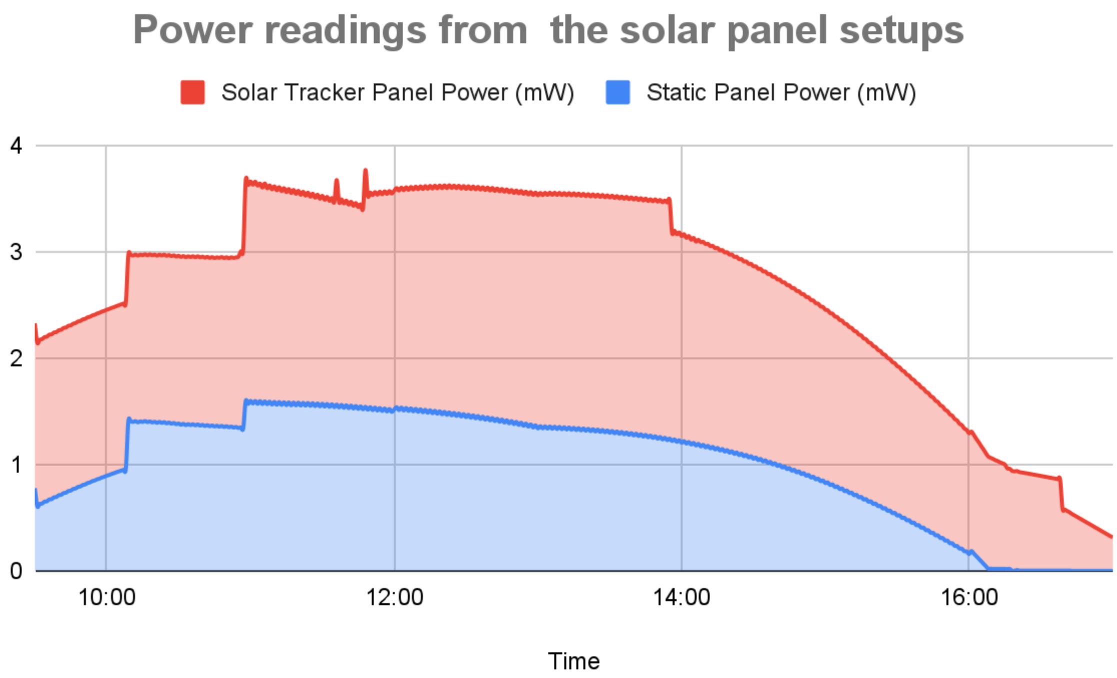


Fig 15: Graph of power generated over 8 hours of test time

Impact of Tilt Angles

During the evaluation phase, the impact of different tilt angles on the solar tracker's performance becomes evident. The tilt angle, which determines the inclination of the solar panels relative to the sun's position, plays a crucial role in optimizing energy generation. Varying tilt angles result in diverse exposure to sunlight throughout the day and across seasons. The graph below provides a summary of the various tilt angles and power generated at those angles

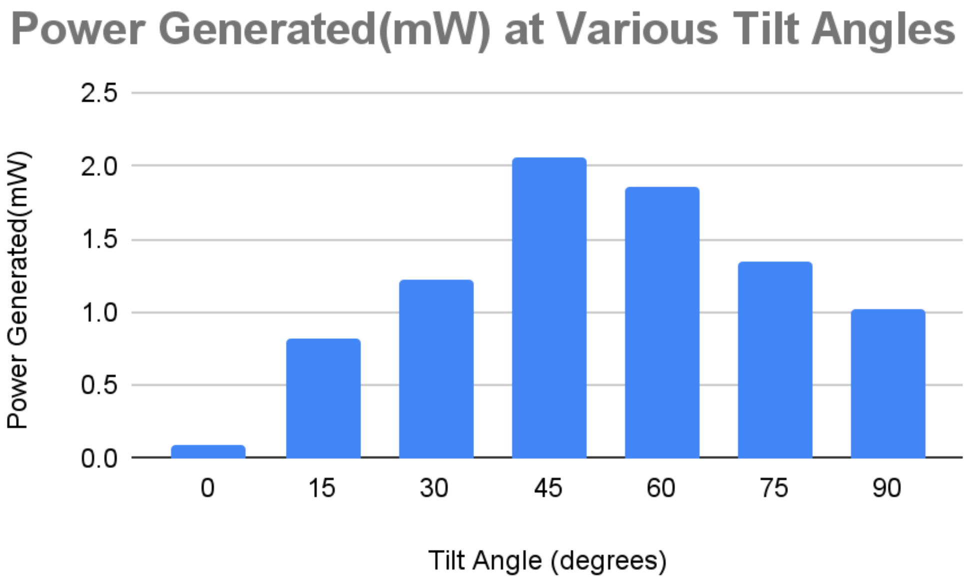


Fig 16: Graph of power generated at various tilt angles

The graph 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.

Some Challenges Faced During Testing and Evaluation

During the testing period, although the power readings were being obtained, the resistors used in the theoretical calculations heated up over an extended period.

Also, the interaction between the hardware and the user interface was also a hundred percent proficient. However, some readings that were sent from the ESP32 microcontroller to the hosted server ended up being lost.

This was attributed to factors such as internet outages and delays introduced during the transmission from the serial ports of the Arduino Uno to that of the ESP32 microcontroller.

5. CONCLUSION AND RECOMMENDATIONS

5.1. 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.

5.2 Recommendations

1. Future versions of the solar tracker should include current sensors that can more accurately help in calculating the power generated by the solar panels.

2. Introduction of a messaging queue that stores power data during internet outages and prevents any loss of data.

3. The system should be able to track the amount of power generated by the solar panels and also used per day by connected devices.

4. An integrated feature to send reports on the power generated per month can also be included.

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