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Prototype Development for Solar Energy Tracking Based on Arduino in QUEST Campus Larkana

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Abstract

The utilization of solar energy has become increasingly popular due to its renewable and sustainable nature. However, one of the primary challenges in solar energy harvesting is the optimization of the amount of energy that can be captured from the sun. The implementation of solar trackers is an effective solution that enables the automatic adjustment of the solar panel's position to face the sun throughout the day. In this project, an Arduino-based solar tracker prototype was designed and implemented to optimize the solar energy harvesting process. The system employs Light-Dependent Resistors (LDRs) to detect sunlight intensity and a servo motor to adjust the position of the solar panel accordingly. The system was programmed using the Arduino programming language and was tested using a small-scale solar panel. The increasing demand for cost-effective and easy-to-install renewable energy systems has led to a growing interest in photovoltaic solar energy for residential use. To optimize energy production, a two-axis photovoltaic solar tracker that orients the solar panel toward the maximum solar radiation is proposed in this study. The use of Free Computer Aided Design (CAD) 0.15 for the prototype's design, combined with Arduino technology, provides an affordable solution for mounting the solar tracker on flat roofs and other horizontal building elements. The performance of the solar tracker was evaluated under various testing conditions, showcasing an enhanced level of accuracy and energy production when compared to traditional fixed systems. The prototype's successful demonstration represents a significant advancement in the field, providing a practical solution for small-scale and residential solar energy applications. This research prototype was developed and installed on the roof of the Electrical department of QUEST, Campus Larkana, and validated through simulation results.

Index Terms: *Arduino, Light Sensor, Solar Energy, Servo Motor, Solar Tracker.*

I. INTRODUCTION

In recent years, the rise in energy usage due to the expansion of industrialized nations and their populations has led to energy-saving measures with negative effects globally, such as the depletion of non-renewable energy sources and climate change [1-3]. The implementation of renewable energy sources for heating and electricity has a significant impact on the building sector [4]. Among these sources, solar energy is the most widely used due to its unlimited power supply and minimal pollution produced during production. This is especially true for residential properties, where solar energy is commonly utilized for sustainable energy solutions [5-7].

Photovoltaic (PV) solar energy is a popular choice for residential properties due to its cost-effectiveness. and ease of installation compared to other options like Stirling dish parabolic collectors and parabolic cylinder collectors [8]. The renewed focus is being given to improving the performance of photovoltaic installations through various techniques, concentration lenses [9], integrated panels [10], advanced solar cell development [11], and optimized conversion stages are underway [12].

A tracking system is needed to optimize the orientation of solar panels to maximize solar radiation and energy production from photovoltaic modules. Several prototypes of photovoltaic trackers have been created for this purpose [13], and [14].

In a 2019 study published in the journal Energy Conversion and Management, researchers compared the energy output of a fixed-tilt PV system with a single-axis tracking system in a hot and arid climate and found that the tracking system increased the energy output of the PV system by 28.6% compared to the fixed-tilt system [15]. The researchers also found that the tracking system reduced the temperature of the solar panels, which improved their lifespan. Another 2019 study published in the journal 'Solar Energy', investigated the energy performance of a dual-axis solar tracking system in a temperate climate, and found that the tracking system increased the energy output of the PV system by 43% compared to a fixed-tilt system [16]. The study also found that the tracking system reduced the shading effect, which improved the overall energy efficiency of the system.

A 2020 study published in the journal ‘Energy Procedia’, analyzed the energy output and Levelized Cost Of Energy (LCOE), of a solar power plant with a single-axis tracking system in a desert climate [17]. The researchers found that the tracking system increased the energy output of the PV system by 24.6% compared to a fixed-tilt system. The study also found that the tracking system reduced the LCOE of the solar power plant by 8.7%, which made the system more economically viable. In a 2021 study published in the journal ‘Applied Energy’, researchers investigated the energy performance of a dual-axis solar tracking system in a tropical climate [18]. The study found that the tracking system increased the energy output of the PV system by 38.4% compared to a fixed-tilt system. The researchers also found that the tracking system reduced the variability of the energy output, which improved the stability of the system when integrated into the grid. The most efficient trackers are two-axis trackers, which move along both azimuthally and zenithal axis, and can greatly increase energy production compared to fixed panels [19], and [20]. These systems can be either open loop or closed loop, with closed loop being more efficient as it utilizes active solar radiation sensors for constant optimization [13], and [15]. The popularity of the open-source Arduino platform has grown, leading to its use by scientists for programming purposes [21], and [22]. Solar trackers combined with Arduino sensors are used to measure parameters in energy production systems and deliver cost-effective results [23], and [24]. This research introduces a novel photovoltaic solar tracker prototype with dual-axis functionality that utilizes Arduino technology. The system incorporates high-precision photodiodes and a stepper motor to enable azimuthally movement, as well as a linear actuator for inclination. The study aims to estimate the potential increase in energy output achieved by the new solar tracker design by comparing its energy output with that of a fixed solar panel positioned according to the local latitude. The system is affordable and can be easily installed on flat roofs and other horizontal exterior surfaces, thereby enhancing the efficiency of solar installations.

The rest of the paper is organized as follows:

Section II describes the Solar Tracking System.

Section III describes the Methodology.

Section IV describes the Simulation results and Discussion.

Section V describes the Conclusions.

II. SOLAR TRACKING SYSTEM

The figure I illustrates the detailed composition of the solar tracker within a complete development cycle [25]. The ideal angle between the solar panel surface and the incoming sun rays should be as perpendicular as possible [26]. The sensor block of the photovoltaic solar tracker utilizes photodiodes and a 741 operational amplifier, while the feedback controller is based on the Arduino platform [27]. These components are integrated into the design to enable the tracker to detect changes in solar radiation levels and adjust its position accordingly [26]. The block of photodiodes' output intensity serves as input to the comparator, which amplifies the signal and generates error voltage as feedback in case of imbalances caused by differences in the North-South and West-East sensor responses [27]. The two-by-two radiation-sensitive comparator either triggers the driver, allowing the stepper motor to rotate for improved azimuthally movement or activates the linear actuator, extending or retracting the rod to optimize elevation movement [28]. The photovoltaic solar tracker's feedback controller operates by continuously monitoring the solar radiation and photovoltaic panel [29]. Whenever there is a discrepancy in the radiation levels, the controller sends differential signals to adjust the panel's position until the error voltage is minimized [30].

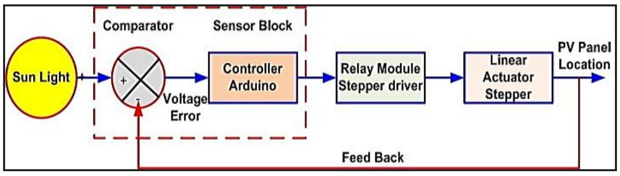

Figure I: Block Scheme of a Closed Loop Tracking System

The controller periodically collects data pairs consisting of azimuth and elevation values, which are stored by the Arduino platform [10]. These data are analyzed to determine the appropriate motor motions required to adjust the panel's position accurately [11].

III. METHODOLOGY

This section provides an overview of the development and production process involved in creating a prototype for a photovoltaic solar tracker. The design of the prototype was created using 'Free CAD 0.15', flexible software that supports different graphic design formats and provides a visual preview of the final product before fabrication. The figure II below shows the design of the solar tracker [31].

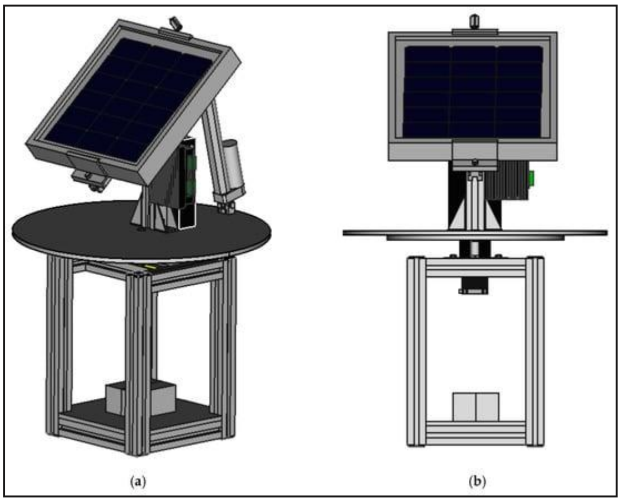

Figure II: 3D Design of Solar Tracker (a) Viewpoint, and (b) Front View

Before the construction of the photovoltaic solar tracker prototype, additional components such as wiring, protoboards, mortises, and others were utilized. A simulation model was also created to assess the prototype's performance under varying levels of incident solar radiation on the photodiodes [32]. To assess the validity of the design and evaluate the performance of the stepper motor and sensor block, a simulation model was utilized. The model analyzed the response of the sensor block to changes in radiation in various directions, such as North Photodiode (PDN), South Photodiode (PDS), East Photodiode (PDE), and West Photodiode (PDW). Both azimuthally and zenithal factors were taken into account during the evaluation process. These findings provide valuable insights into the performance of the system and can aid in further improving its efficiency directions [27]. The electrical system of the tracker was modeled using PSIM software (version 10.0.4, Powers Inc., Rockville, MD, USA). Figure III illustrates the electrical structure of the simulation [9]. The simulation utilized nonlinear resistance that adjusts intensity based on voltage and incoming radiation to simulate the photodiodes [26]. A relay module with two contacts managed the linear actuator's operation. The North relay was activated with 12 Volts when the radiation incident on the North photodiode exceeded that on the South photodiode, causing the linear actuator to extend [33]. If not, the South relay activated, retracting the motor rod. The simulation employed the properties of the NEMA 23HS9430 stepper motor, which had inductance values of 6 and 6.8 mH [34]. The DM542a driver supplied the motor with power from the batteries and provided control logic for each step of the motor's activation and rotation direction [35]. This stepper controlled the azimuthal movement based on the radiation levels in the West and East photodiodes [36].

The control algorithm was developed as a flow diagram based on the block diagram, as shown in figure IV [4]. Radiation level, which varies from zero during the day to zero from dusk to dawn, regulates the tracker's movement. The tracker points west after the end of a measurement day and before the start of the next. The measurements were taken every ten minutes to reduce the frequency of capture and prevent system saturation and mechanical vibration damage to components caused by frequent motor starts and stops. Figure V shows the wiring diagram for the components of the prototype [1]. The photodiode sensor block was designed with a cross-shaped structure to increase sensitivity to changes in the sun. The real manufacturing started when the prototype's design and simulation were finished. Design recommendations from the preceding section were adhered to, and an actual wiring system for the prototype's sensors block and two motors was implemented by PSIM's simulation. position and observe variations in radiation levels [23].

This wire layout was put into practice within a Polyethene (PE) box that was specially manufactured, to meet the circuitry's ventilation needs and prevent any potential overheating [37]. Figure VI illustrates the regulation of the manufactured prototype through laboratory tests or dynamic simulators that simulate the irradiance and energy generation parameters [33].

In figure VII, a solar photovoltaic installation is shown with a south-facing orientation and a 30° inclination, utilizing the same type of photovoltaic panel as the solar tracker prototype [3]. By using this setup, a comparison can be made between the two systems to evaluate the difference in energy production they generate.

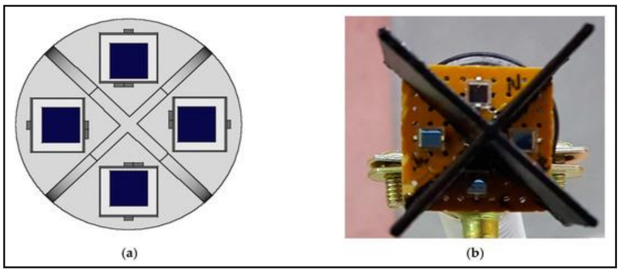

Figure III: Block Diagram for Sensors. (a) Design Phase; and (b) Built Prototype

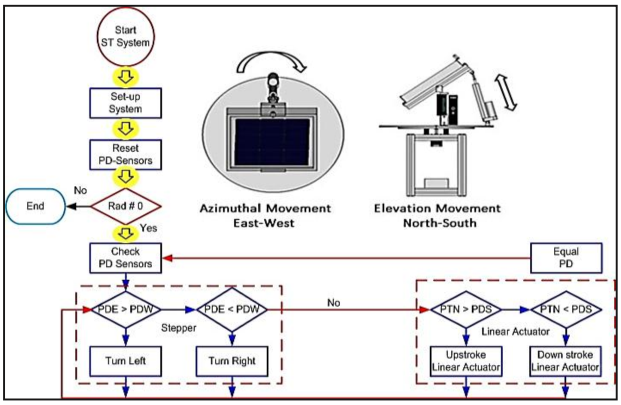

Figure IV: Solar Tracking Flow Chart Diagram

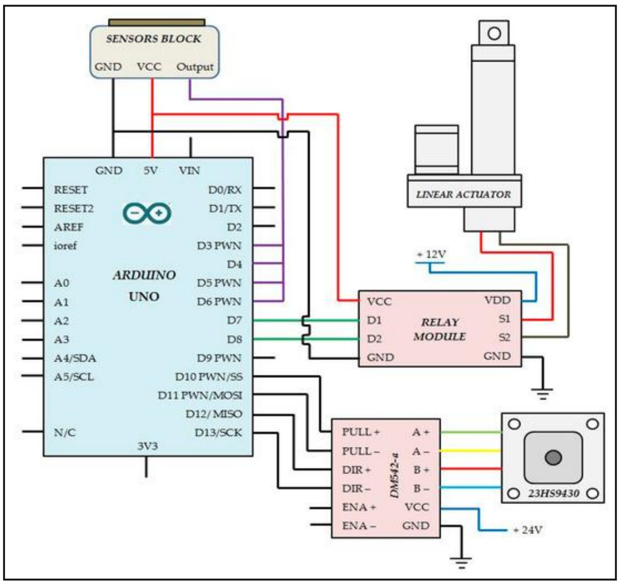

Figure V: Real Wiring Diagram for the Components of the Prototype

Figure VI: Designed Photovoltaic Solar Tracker: (a) Front view; and (b) Side view

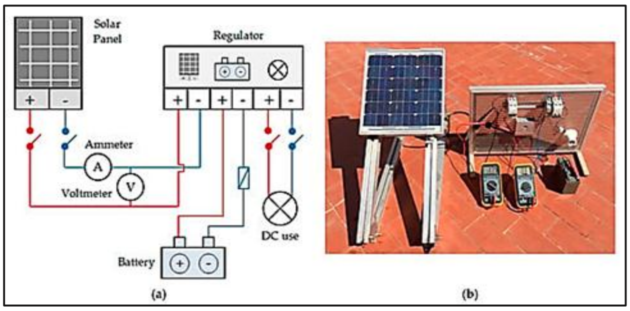

Figure VII: (a) The Static Installation's Connection Strategy; and (b) The Installed Application

IV. SIMULATION RESULTS AND DISCUSSIONS

The components in table I were utilized to get the results [9]. Simulation results show that the linear actuator moves when North radiation exceeds South radiation, as indicated by the output voltage from the Arduino, and that the stepper motor operates based on the difference between East and West radiation levels, requiring 3A for each movement. One complete wave is generated every 5 seconds with a simulation time of 25 seconds, and a photodiode radiation variation frequency of 0.2 Hz.

Table I: Components Used in the Prototype

Component	Description
Metal Structure	The Aluminum Structure of 27 kN/m^3 according to CTE DB SE-AE
Arduino UNO R3	Programmable ATmega328 Electronic Tracking Controller with 14 Digital Inputs, 6 Analogue Inputs, and a 16 MHz Clock
Solar Panel	ISOFOTON 25 Wpmono Crystalline Silicon Photovoltaic Panel
LA-10	Elevation Movement with a Linear Actuator
Double Relay Bridge	Integrally Controlled by an Arduino Sheet, this component is in charge of Activating and Moving the Linear Actuator.
BPW34	Light Semiconductor Photodiodes that Communicate with Arduino to deliver the Signal that causes the Movement
Driver DM542a	The Controller is in charge of Sending 0.9 degree/step-Accurate Rotating Movements to the Stepper Motor
NEMA-23HS9430	Azimuthally Movement with a Stepper Motor
Victron Energy Battery	Batteries with a Capacity of 12 V and 2.1 Ah are used to Power the Prototype Alimentation and Tracker.

Figure 8 (a) and (b), illustrate the functioning of the comparison stages at the start of the linear actuator's and stepper motor's operation.

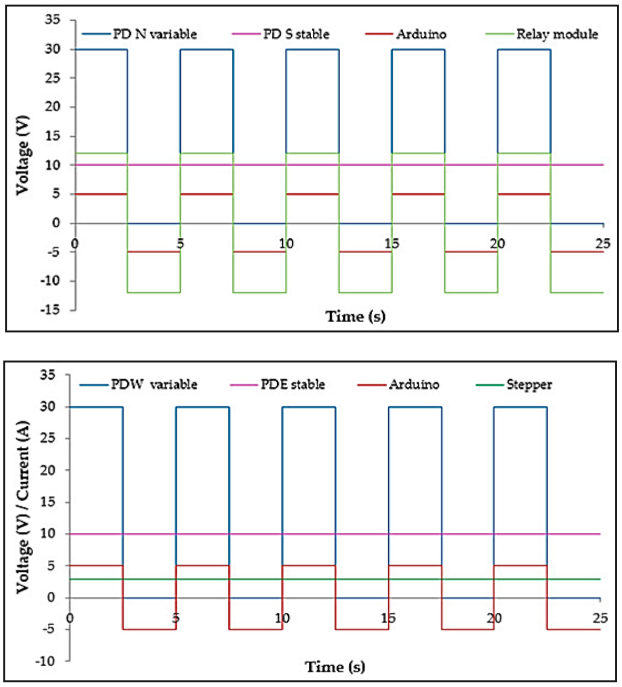

Figure VIII: (a) The Assessed Simulation of the Performance of the Linear Actuator's Reaction; and (b) The Assessed Simulation of the Performance of a Stepper Motor's Reaction

A. *Obtaining Production and Gathering Data from the Tracker*

The results of the prototype and static panel manufacturing process between January and May are presented in figure IX. The prototype was installed on the roof of the Electrical Department at the Quaid-e-Awam University of Engineering, Science and Technology (QUEST) Campus in Larkana, which is situated at a Latitude of 40.37° and Longitude of -3.75°. Data was collected from the prototype every 30 minutes, and the average daily energy production of the panel was calculated based on the data collected. The energy production data collected in the months of January through May 2022 shows that the energy production levels are directly related to the local weather conditions. The days with the most energy production were those with clear skies and higher temperatures. The data also demonstrates that the use of a solar tracker prototype, as opposed to a static panel, leads to a roughly 18% increase in energy output, which is consistent with previous studies using different sun-tracking devices. Hence, Arduino can be considered an effective tool for designing low-cost solar trackers. Figure X illustrates the correlation between the average output power and the average incidence radiation on the surface of the solar tracking panel. The graph demonstrates a clear correlation between the two variables, indicating that the panel's output power increases in proportion to the amount of incident radiation received by the panel.

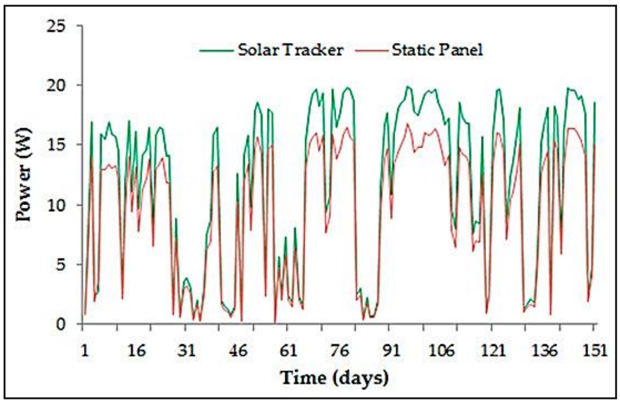

Figure IX: The Solar Tracker's Average Daily Production was Obtained

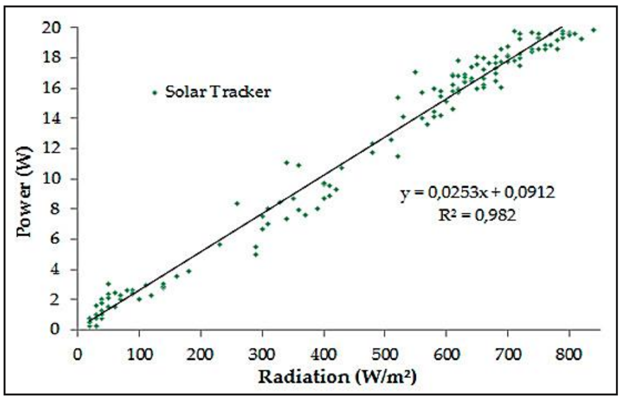

Figure X: Correlation between Radiation Incident and Electricity Generated

Consequently, the solar tracker prototype has the potential to boost photovoltaic systems' efficiency by 18% in comparison to a static panel. The linear relationship between average incident radiation and average output power can be used to calculate maximum performance in a specific location. The motor consumption must be subtracted from the acquired energy, but the output can be further increased by calibrating the sensors and optimizing the tracking frequency to local environmental conditions.

The manufactured solar tracker prototype is expected to cost roughly 900 dollars, making it affordable for small-scale, low-power systems installed on flat surfaces, according to reliable commercial sources. The lightweight design of this prototype, which can be used in homes without placing loads on the structure or causing vibrations, is one of its benefits. Additionally, using an Arduino as an electronic control card makes it cheaper than commercial PLCs, and its freeware applications make it feasible for modeling, programming, and mimicking historical behavior. Thus, this type of prototype is a suitable option for household installations as it is cost-effective and does not pose significant technological challenges.

V. CONCLUSIONS

This study offers a new and cost-effective photovoltaic solar tracker prototype built on the Arduino platform that can move on its own and on a regular basis in a variety of irradiance conditions. Additionally, a prior simulation of the tracker's behavior was accomplished, allowing for the prediction of the prototype's movement during the design process. However, five months of data were used to confirm the tracker's performance. The results showed a strong link between the prototype's energy output levels and the area's daily maximum radiation levels. The prototype solar tracker's output increased by 18% when compared to the reference static panel, according to the results of the experiment. The photovoltaic panels utilized by both systems were of the same kind. These results illustrate the device's possible uses in structures, gardens, plots, and photovoltaic-producing facilities while demonstrating its efficacy. The versatility of the Arduino platform allows for the integration of environmental management, making the complete design of the solar tracker ready for commercial production. Last but not least, the prototype is competitive for installation in homes despite having a performance that is approximately 12% lower than that of other commercial equipment. This is because it is inexpensive to manufacture, easy to integrate into buildings, and simple to program and update tracking software. After all, it is a member of the Arduino community.

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Authors Contributions

The contribution of the authors was as follows: Abdul Hameed Soomro's contribution to this study was the concept, technical implementation, supervision and correspondence. The methodology to conduct this research work was proposed by SanaUllah Talani, and Talha Soomro along with data collection, data compilation, and validation. Faraz Ali Khushk's, and Ahmer Ali Bhatti's contribution was project administration and paper writing.

Conflict of Interest

The authors declare no conflict of interest and confirm that this work is original and not plagiarized from any other source, i.e., electronic or print media. The information obtained from all of the sources is properly recognized and cited below.

Data Availability Statement

The testing data is available in this paper.

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