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Enhanced Sunlight Intensity Measurement with Solar Tracking System

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Abstract

Sunlight intensity measurement plays a crucial role in various applications, particularly in the context of solar energy utilization. However, traditional static acquisition devices often fail to provide precise measurements throughout the entire daylight period. This limitation necessitates the development of more advanced methodologies for accurate sunlight intensity assessment. In this studynn, we propose a novel approach utilizing a solar tracking system integrated with a measurement device to achieve precise sunlight intensity measurements from sunrise to sunset. By employing a cost-effective combination of the GY-302 module and an A6 GSM/GPRS module, both based on the Arduino Pro-Mini microcontroller, we establish a reliable system for real-time data acquisition. This setup enables the continuous monitoring of sunlight intensity and facilitates the posting of measurement data on a web server for remote access and analysis. Furthermore, our research investigates the correlation between sunlight intensity and the voltage generated by solar panels. Through comprehensive comparative analysis, we elucidate the intricate relationship between these variables, providing valuable insights for optimizing solar energy harvesting systems. An additional noteworthy outcome of our study is the self-sustainability of the measurement device, which can be powered independently by a solar panel. This feature enhances the reliability and longevity of the system, making it suitable for long-term deployment in various environmental conditions. Moreover, we leverage the collected data to generate a sunlight intensity map, offering a visual representation of sunlight distribution in a given area. This mapping capability holds significant implications for the establishment of solar power plants, enabling informed decision-making regarding site selection and infrastructure development. Overall, our research contributes to advancing the field of solar energy technology by providing a comprehensive framework for precise sunlight intensity measurement and analysis. The proposed methodology holds promise for enhancing the efficiency and effectiveness of solar energy utilization, ultimately facilitating sustainable development and renewable energy integration into existing infrastructure.

Keywords: Sunlight intensity measurement, solar tracking system, solar panel voltage correlation, sunlight intensity map, renewable energy integration

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INTRODUCTION

India has emerged as a significant player in the global renewable energy landscape, with solar power leading the charge in its ambitious renewable energy goals. As one of the sunniest countries in the world, India possesses immense solar energy potential, which it is actively harnessing to meet its growing energy demands while simultaneously combating climate change and reducing dependence on fossil fuels.

The introduction of solar power plants in India marks a pivotal shift towards clean and sustainable energy generation. These solar facilities utilize photovoltaic (PV) technology to convert sunlight directly into electricity, offering an environmentally friendly alternative to conventional energy sources.

Furthermore, advancements in solar technology, coupled with declining costs of solar components, have made solar power increasingly competitive with conventional energy sources. This has spurred rapid growth in the Indian solar industry, driving down tariffs and accelerating the deployment of solar power plants nationwide. India's solar power installed capacity was 81.813 GWAC as of 31 March 2024.

Despite these advancements, challenges such as land acquisition, grid integration, and intermittency remain key considerations in the expansion of solar power capacity in India. Addressing these challenges requires continued collaboration between government agencies, industry stakeholders, and research institutions to ensure the efficient and sustainable growth of India's solar power sector.

BACKGROUND OF SOLAR TRACKING SYSTEMS

The variability in solar irradiance due to Earth's orbital motions defines the solar constant, representing the consistent energy received per unit area outside the atmosphere at the average Earth-Sun distance. This fundamental quantity, often denoted by Equation (1), provides a standard measure for solar energy flux.

$$G_{sc} = \sigma . T^4 . \left(\frac{4\pi R}{4\pi D}\right)^2 = 1367\ W/m^2 \tag{1}$$

where σ denotes the Stefan–Boltzmann constant (5.67×10^{-8} $Wm^{-2}K^{-4}$), R is the radius of the Earth (6371 km), and D denotes the average distance between the Sun and Earth ($148\ .72\times 10^9$ km).

The abundance of daily solar irradiance has spurred the adoption of solar energy across diverse sectors such as water pumping, telecommunication, and illumination [1]. Consequently, the development and deployment of solar photovoltaic panels have become prominent, facilitating the conversion of solar energy into electrical power. However, the efficacy of energy production directly correlates with sunlight intensity, prompting the need for systems capable of tracking the Sun's trajectory. Hence, the emergence of solar tracking systems, which dynamically adjust panel orientation to optimize solar energy absorption. Notably, Figure (1) illustrates the disparities and constraints between fixed and dynamic solar tracking systems.

METHODS

Solar Tracker

A solar tracker, as outlined in [2], is engineered to align solar panel surfaces perpendicular to the Sun's rays, optimizing solar power conversion. This device typically employs a dual-axis design, enabling precise orientation adjustments in both east-west and north-south directions for enhanced solar energy capture.

In accordance with the research objectives, the solar tracker is tailored to orient a miniature 1 Watt solar panel utilized for solar power measurement, while a static attachment accommodates a 10-watt solar panel for battery recharging purposes. Employing insights from [4], two economical mini servo motors (SG90) serve as actuators for precise panel adjustments. As depicted in Figure 2, the vertical axis (v-axis) governs east-west panel alignment, while the horizontal axis (h-axis) facilitates clockwise or counter-clockwise rotation for north-south orientation.

To regulate the servo motors, four Light Dependent Resistor (LDR) sensors are integrated, each corresponding to a cardinal direction. By comparing the readings from the east and west sensors, the system identifies the direction of higher sunlight intensity.

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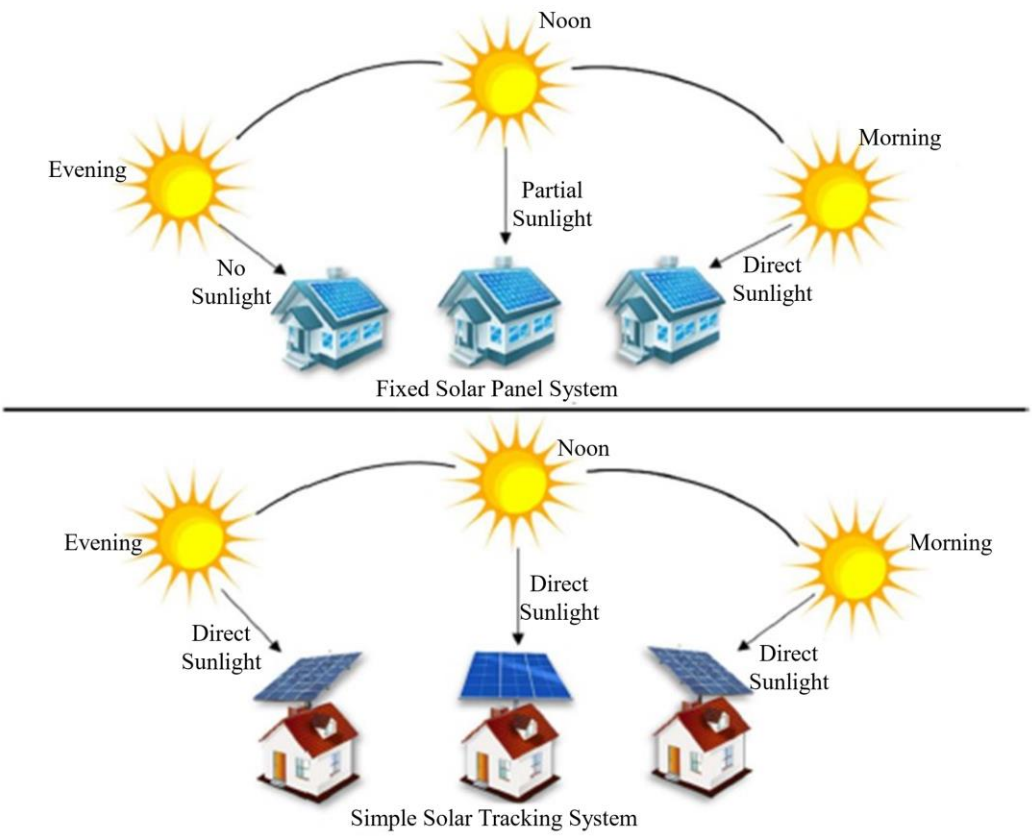

Figure 1. Comparison between Fixed and Simple Solar Tracking Systems.

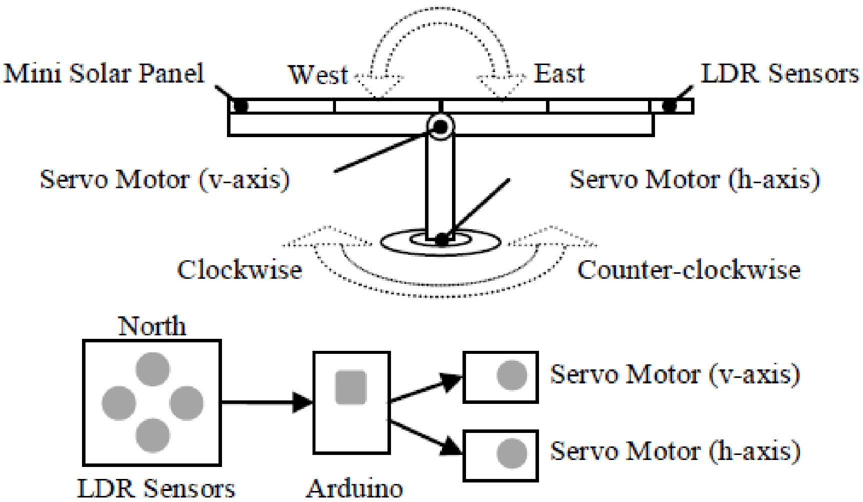

Figure 2. Solar tracker Design.

Utilizing the Arduino Pro-Mini, the servo motor responsible for vertical orientation (v-axis) adjusts the panels towards the area of greater sunlight intensity. Similarly, the system compares the north and south sensor readings to determine sunlight intensity disparities, prompting the servo motor responsible for horizontal orientation (h-axis) to rotate the panels clockwise or counter-clockwise accordingly.

Sensors Measurement

Sunlight intensities are quantified in lux, defined as one lumen per square meter. Leveraging the cost-effective GY-302 module, sunlight intensities are precisely measured via the Arduino Pro-Mini microcontroller. In accordance with specifications from the BH1750 datasheet [3], the module accommodates light intensity readings ranging from 1 lux to 65535 lux. To capture sunlight intensities exceeding 100,000 lux, additional sunlight filter sheets are incorporated, facilitating accurate measurement comparisons.

The juxtaposition of lux and Watt serves as a basis for estimating the power output of the solar panel within the measurement region. Power measurement of the solar panel is facilitated through a MAX471 voltage and current sensor module. According to the specifications outlined in the datasheet [4], voltage measurement employs a voltage divider technique capable of measuring up to 25 volts. Concurrently, current measurement entails the incorporation of a 220 Ω resistor and an LED as the load. This enables the calculation of the solar panel's power output using Equation (2), thereby facilitating comparison with lux measurements.

$$\text{Power (P)} = \text{Voltage (V)} * \text{Current (I)} \tag{2}$$

Sending Data via HTTP Post

The acquired data from various devices undergoes transmission to a designated web server utilizing the GPRS network. Employing a cost-effective A6 GSM/GPRS module optimized for HTTP post requests via the GPRS network, our study ensures efficient data transmission. It is imperative to adhere to the correct format for the post request to prevent encountering error codes during transmission. Previous research [5] highlights that utilizing the A6 module results in data posting intervals of approximately 10.2 seconds. Despite this prolonged duration, attributed to module response times and inherent delays within the Arduino IDE, the frequency suffices for the current research objectives. Given the context, the collected data, when aggregated on a daily basis, adequately meets the requirements for subsequent analysis and interpretation. Therefore, while acknowledging the temporal constraints, the periodicity of data transmission remains viable for the scope and objectives of this study.

While numerous studies have explored GPRS communication methodologies, many have relied on costlier modules such as the SIM800 series [6]. However, our research adopts a simpler approach by utilizing the A6 module in conjunction with Arduino, establishing communication via serial wiring, as depicted in Figure 3. This setup enables the Arduino to transmit AT commands to the A6 module at predefined intervals, facilitating communication with the Base Transceiver Station (BTS). Subsequent to receiving a response from the module, the Arduino executes the next AT command in sequence. To address instances of unresponsiveness from the A6 module, a "time out" countdown mechanism is implemented, allowing for module restarts when necessary. This streamlined communication protocol not only reduces costs associated with hardware procurement but also simplifies the implementation process, making it accessible to a wider range of researchers and practitioners. Through this approach, our research aims to demonstrate the efficacy of utilizing affordable components in GPRS communication systems, paving the way for more accessible and cost-effective solutions in various applications [7].

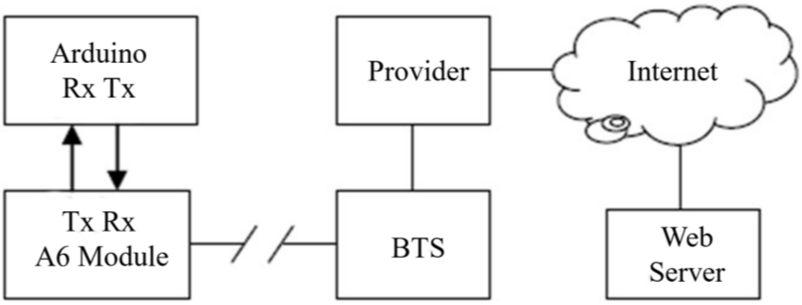

Figure 3. A6 and Arduino communication diagram.

A6 module

The A6 module, also known as the Ai-Thinker A6, is a small, cost-effective, and power-efficient GSM/GPRS module designed for wireless communication applications. It is developed by Ai-Thinker.

Key features of the A6 module include

1. *GSM/GPRS Connectivity:* The A6 module supports GSM (Global System for Mobile Communications) and GPRS (General Packet Radio Service) protocols for wireless communication over cellular networks.
2. *Small Form Factor:* It comes in a compact form factor, making it suitable for integration into various electronic devices and applications where space is limited.
3. *Low Power Consumption:* The module is designed to operate with low power consumption, making it suitable for battery-powered devices and applications requiring energy efficiency.
4. *AT Commands Interface:* Communication with the A6 module is typically done using AT (Attention) commands over a serial interface. This makes it relatively easy to integrate into different microcontroller-based projects.
5. *SIM Card Interface:* The module requires a SIM (Subscriber Identity Module) card for authentication and access to the cellular network.
6. *Support for SMS and GPRS Data Transmission:* The A6 module supports sending and receiving SMS (Short Message Service) messages and can also transmit data over GPRS for applications such as IoT (Internet of Things) and remote monitoring.
7. *Built-in TCP/IP Stack:* It features a built-in TCP/IP stack, allowing it to communicate with remote servers over the internet.
8. *GPIO Pins:* The module typically has GPIO (General Purpose Input/Output) pins that can be used for interfacing with external sensors, actuators, or other peripherals.

Arduino

Arduino is an open-source electronics platform based on easy-to-use hardware and software. It consists of a range of microcontroller boards, typically featuring an Atmel AVR or ARM processor, along with a development environment for writing and uploading code to the board.

Key Components of the Arduino Platform Include

1. *Arduino Boards:* These are the physical hardware components that form the core of the Arduino platform. There are several types of Arduino boards, each with different features and capabilities. Some popular Arduino boards include Arduino Uno, Arduino Nano, Arduino Mega, and Arduino Due.
2. *Integrated Development Environment (IDE):* The Arduino IDE is a software application used to write and upload code to Arduino boards. It provides a simple and easy-to-use interface for writing, compiling, and uploading sketches (programs) to the board. The IDE also includes a serial monitor for debugging and communication with the Arduino board.
3. *Programming Language:* Arduino sketches are written in a simplified version of C/C++, making it accessible even to beginners with little programming experience. The Arduino programming language is based on standard C/C++ syntax but includes a set of predefined functions and libraries for interacting with the hardware components of the Arduino board.
4. *Libraries:* Arduino libraries are collections of pre-written code that extend the functionality of the Arduino platform. They provide ready-to-use functions for tasks such as controlling LEDs, reading sensors, and communicating with external devices. Arduino libraries help simplify the development process by abstracting low-level hardware details.
5. *Community and Ecosystem:* Arduino has a large and active community of users, makers, and developers. This community contributes to the platform by sharing projects, tutorials, and resources, making it easier for beginners to get started and for experienced users to expand their knowledge and skills. Additionally, there is a vast ecosystem of compatible shields, modules, sensors, and accessories available for Arduino, further extending its capabilities.

Independence Power Supply

The device operates on four 18650 batteries and utilizes a 10 Watt solar panel for recharging, making it ideal for extended usage in remote areas lacking access to conventional power sources. To support this setup, a mini charger module and a voltage step-up module, illustrated in Figure 4, are integrated, guaranteeing continuous operation even in off-grid environments [8]. This configuration ensures sustained functionality and autonomy, enabling the device to operate reliably over extended periods without reliance on external power grids or infrastructure [9].

RESULTS AND DISCUSSION

Implementation of the Device

The design and implementation of the sunlight intensity measurement device are depicted in Figure. 5, with detailed specifications outlined in Table I. Utilizing readily available materials like zinc plates, PVC pipes, and others, we ensure the accessibility and affordability of the device components without compromising measurement accuracy. Notably, the selection of low-cost materials is prioritized to maintain cost-effectiveness while maximizing functionality. Additionally, the solar panel serves as a stationary power source for charging the device's batteries, enhancing its sustainability and autonomy. This approach aligns with our objective to develop a practical and accessible solution for measuring sunlight intensity, suitable for a variety of applications and environments. Back side of solar panel is shown in Figure 6.

Testing of the Device

The solar trackers undergo testing to ascertain their efficacy in locating the sun's position and orienting the solar panels perpendicular to its rays, while also tracking its movement until sunset [10]. Analysis presented in Table I indicates that the solar tracker's capacity to adjust the solar panels towards the east or west is constrained by its mechanical configuration. Consequently, the testing reveals a need for enhancement in the mechanical design for panel rotation to accommodate a broader field of view, contingent upon the device's attachment. These findings underscore the importance of refining the mechanical aspects of the solar tracker to optimize its functionality and ensure precise alignment of the solar panels with the sun's trajectory throughout the day.

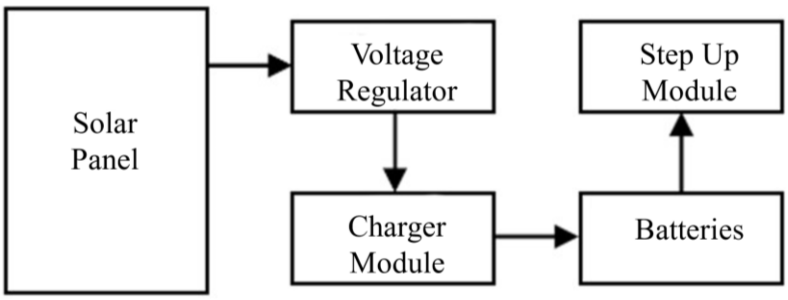

Figure 4. Solar charging scheme.

Figure 5. Sunlight intensity measurement device with solar tracking system.

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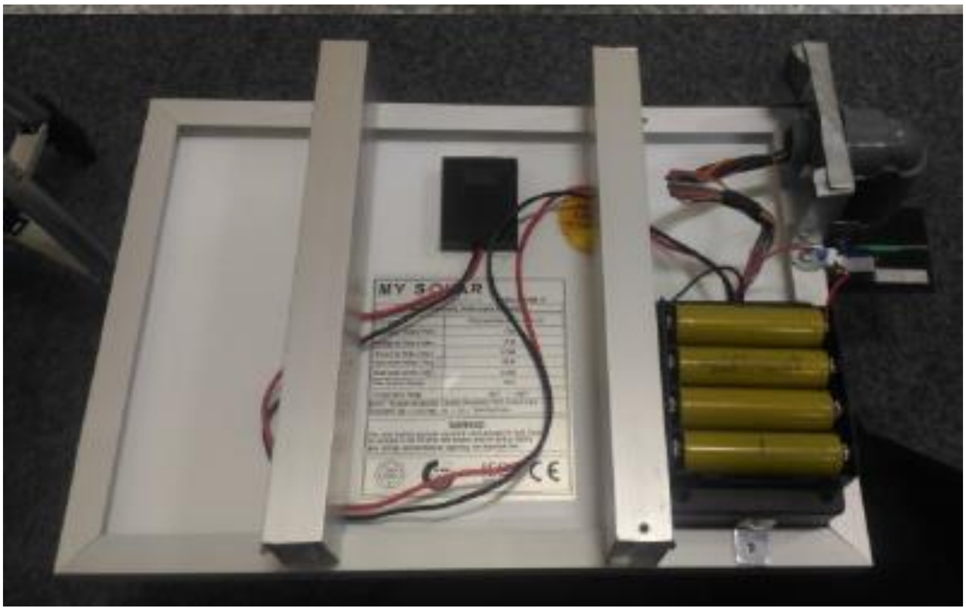

Figure 6, Back side of solar panel.

Table 1. Comparison of the current between fixed PV and using the proposed system.

Time	**Current using a fixed PV (Amp)**	**Current using the proposed system (Amp)**
8:00 am	0.42	0.70
9:00 am	0.55	0.85
10:00 am	0.75	0.93
11:00 am	0.81	0.96
12:00 pm	0.92	0.98
01:00 pm	0.95	0.99
02:00pm	0.88	0.97
02:30 pm	0.76	0.87
3:00 pm	0.74	0.85
3:30 pm	0.71	0.84
4:00pm	0.65	0.88
4:30 pm	0.58	0.89
5:00 pm	0.42	0.71
5:30 pm	0.10	0.26
6:00 pm	0.01	0.15

CONCLUSION

This paper presents a universal multi-function solar tracker system, designed with a simplified architecture utilizing arduino. At the core of this system lies the control mechanism, serving as the brain, responsible for orchestrating the movement of a small PV panel along three axes. This functionality enables the system to ascertain and adjust the panel's orientation to capture the maximum output current. By leveraging a reduced complexity architecture centred around a microcontroller, the proposed system offers versatility and efficiency in solar tracking operations. This approach streamlines the design process while ensuring robust performance, making the system accessible and adaptable for various applications. Through the integration of precise control algorithms and hardware components, the system demonstrates its capability to enhance energy harvesting from solar panels, contributing to advancements in renewable energy utilization.

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