International Journal of Scientific Research in Engineering and Management (IJSREM)
Volume: 09 Issue: 02 | Feb - 2025 SJIF Rating: 8.448 ISSN: 2582-3930

Smart Solar-Powered Street Lighting with Automated Tracking System Using Arduino

Kiran M. Nerli
Department of ECE
Hirasugar institue of Technology
Nidasoshi, India
nerlikiru@gmail.com

Aishwarya B. Chougala
Department of ECE
Hirasugar institue of Technology
Nidasoshi, India
aishwaryachougala046@gmail.com

Rahul J. Teradal
Department of ECE
Jain College of Engineering and Research
Belagavi, India
rahulteradal45@gmail.com

---***---

Abstract - The need for more energy-efficient and sustainable urban lighting solutions calls for the development of smart solar-powered street lighting systems. Generally, conventional solar streetlights suffer from low efficiency in energy utilization because the lighting source is of fixed orientation, leading to decreased power generation. The proposed system is a Smart Solar-Powered Street Lighting System with Automated Tracking Mechanism for Arduino, aiming at maximizing solar energy absorption and thus improving energy efficiency.The system uses Light Dependent Resistors (LDRs) for detecting sunlight intensity, and solar panel angle adjustment is done using servo motors. A dual-axis tracking system keeps the panel perpendicular to the sun's rays throughout the day, thus maximizing power generation compared to fixed panels. The Arduino microcontroller processes real-time data from sensors for precise control of panel movement and also adjusts the functioning of LED street lights according to the intensity of ambient light.Experimental results show a 25-40% increase in energy absorption of the tracking system compared to stationary panels, which can now achieve prolonged lighting hours and less battery dependence. It runs automatically, therefore lowering associated maintenance costs, as it offers a cost-effective and scalable system for urban and rural street lighting.This research contributes to sustainable urban infrastructure by integrating automated solar tracking with smart lighting control. Future developments could explore AI-based optimization algorithms for enhanced tracking precision and wireless monitoring systems for real-time performance analysis. The proposed system serves as a viable alternative to conventional street lighting, promoting renewable energy adoption and reducing carbon footprints.

***Key Words*:** Smart Solar Street Lighting, Automated Solar Tracking, Arduino-Based System, Energy Efficiency, Renewable Energy.

Ⅰ. INTRODUCTION

Solar energy is one of the most sustainable and renewable sources of power, offering an eco-friendly alternative to conventional energy sources. Solar panels harness sunlight and convert it into electricity through the **photovoltaic (PV) effect**. A solar panel consists of multiple **solar cells**, which are made up of layers of silicon, phosphorous (providing a negative charge), and boron (providing a positive charge). When sunlight strikes the panel, photons energize electrons, knocking them free from their atomic bonds. These free electrons are then directed into a **current flow**, generating electricity.

However, the efficiency of solar panels is significantly influenced by the angle of sunlight. Generally, a fixed solar panel can convert only 30 to 40% of the incident solar radiation into electrical energy due to misalignment with the sun's position. To optimize energy absorption, an automated sun-tracking system is required. This system ensures that sunlight falls perpendicularly on the panel throughout the day, maximizing efficiency.

A prototype dual-axis sun-tracking system has been developed to address this issue. The system continuously adjusts the solar panel's position to follow the sun's movement, ensuring optimal exposure. This principle is also applied in smart street lighting systems, where solar-powered lamps use rechargeable batteries to store energy, providing illumination during the night. These sustainable solutions contribute to energy conservation and environmental sustainability.

Ⅱ. LITERATURE REVIEW

In recent years, solar tracking systems have garnered significant attention for their potential to enhance photovoltaic (PV) efficiency. A comprehensive review by [1] delves into the advancements and challenges of automatic solar tracking systems, highlighting that dual-axis trackers can outperform stationary systems by over 27% in overall efficiency. Similarly, [2] gives an extensive overview of solar tracking designs, analyzing different mechanisms and comparing their performance against fixed systems across different PV configurations. The study emphasizes the importance of design parameters, construction types, and drive system techniques in optimizing solar tracking. Further, [3] classified the solar tracking systems into single-axis and dual-axis trackers, which indicated that these systems may increase energy capture by 15-30% compared to fixed-tilt setups. The classification would then help understand specific applications and benefits of each type of tracking. Moreover, [4] gives a comprehensive review of the state-of-the-art research in PV tracking systems and discusses their role in electrical energy production and a basis for future innovations in solar technology.

In [5], the sustainable development of solar PV tracking technology was explored, detailing the present states, limiting factors, and future trends. The paper emphasizes the potential of solar tracking to optimize energy generation efficiency in as many applications as possible, similarly being applied across the board, from solar power plants to the industry. In addition, [6] makes a detailed survey of literature concerning the state of the art on PV systems from the material usage point of view, module geometries, tracking technologies, and the problems which need to be overcome to open up more use. [7] concentrates on time-based solar tracking systems that review different designs and suggest taxonomies in order to reveal trends and possible lines of future research. This paper looks to fill existing gaps in the literature by widely reviewing such axis rotation and drive type-based systems. In an international review, [8] discusses the optimum design of bifacial tracking solar farms. An example here indicates that these kinds of configurations offer up to a 45% energy gain against fixed-tilt bifacial PV near the equator. The study also provides benefits of tracking bifacial PV, like improved temperature sensitivity and better collection of diffuse and albedo light. The various technological aspects of photovoltaic power stations include solar array arrangements and tracking mechanisms that are depicted in [9]. This paper explains a couple of mounting structures, fixed arrays and dual-axis trackers, and their energy output impact. Finally, [10] reports on the dominance of bifacial solar modules combined with single-axis trackers in the U.S., noting that this combination has led to the lowest solar costs worldwide. The article highlights the reduction in the levelized cost of electricity by 16% compared to monofacial systems and discusses future advancements in tracker technologies.

Ⅲ. PROBLEM STATEMENT

The increasing need for renewable energy has led to increased dependence on solar power. However, conventional fixed solar panels have a major limitation in that they can only convert 30-40% of the incident solar radiation into electrical energy due to improper alignment with the sun's position throughout the day. Since the sun moves continuously, a static solar panel does not receive optimal sunlight, resulting in reduced efficiency and power generation. To overcome this challenge, a solar tracking system is required. A dynamic solar panel that follows the sun's movement can significantly enhance energy absorption. The key problem lies in designing an automated, cost-effective, and efficient tracking system that can continuously adjust the panel's position to maintain a perpendicular angle with sunlight, maximizing energy output.

In addition, traditional tracking methods are associated with high costs, complex mechanisms, and maintenance issues. Many systems lack precision, leading to tracking errors that further reduce efficiency. Additionally, single-axis tracking limits optimization, whereas dual-axis tracking offers better accuracy but increases system complexity. This project aims to establish a low-cost, automated solar tracking system with LDR sensors, servo motors, and an Arduino-based control mechanism. The system would ensure real-time solar tracking and improve energy conversion efficiency while minimizing energy loss. With the implementation of this technology, solar power may become a more reliable and sustainable source of energy by addressing the worldwide need for clean and efficient renewable energy solutions.

a) **Objectives:**

- To Enable manual and automatic control of the solar tracker using a controller.
- To Ensure the solar panel follows the sun from east to west for maximum sunlight exposure.
- To Maximize solar energy absorption through an efficient tracking system.
- To Enhance and optimize the solar panel design for improved performance.

Ⅳ. PROPOSED METHODOLOGY

1. Block Diagram

The hardware implementation uses Arduino IDE, with LDRs as light sensors and two servo motors to adjust the solar panel. The Arduino microcontroller processes sensor data to track sunlight efficiently. For east west tracking, the top and bottom LDRs are compared if the top receives more light, the vertical servo moves upward; if the bottom does, it moves downward. For angular adjustment, the left and right LDRs guide the horizontal servo in the brighter direction. This ensures maximum solar energy absorption throughout the day.

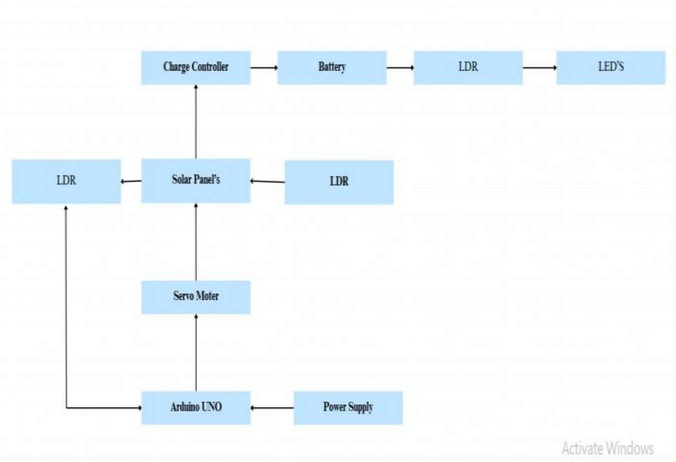

Fig 1. Block Diagram

2. Components / Tools Involved

a) A **Solar panel** absorbs sunlight to generate electricity or heat using the photovoltaic effect. It consists of crystalline silicon **or** thin-film cells, protected from damage and moisture. Panels can be rigid or semi-flexible**,** with cells connected in series for efficient energy conversion.

Fig 2. Solar panel

b) **A Light Dependent Resistor** (LDR), or photoresistor, is a light-sensitive semiconductor

International Journal of Scientific Research in Engineering and Management (IJSREM)
Volume: 09 Issue: 02 | Feb - 2025 SJIF Rating: 8.448 ISSN: 2582-3930

device whose resistance decreases with increasing light intensity. In darkness, its resistance can reach several megohms (MΩ), while in bright light, it drops to a few hundred ohms. When exposed to light of sufficient frequency, absorbed photons energize electrons, enabling conduction.

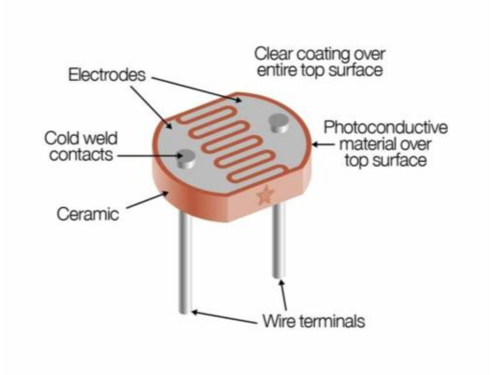

Fig 3. LDR sensor

c) A **Servomotor** is an actuator that precisely controls position, velocity, and acceleration**.** It consists of a motor, a position feedback sensor, and a controller for closed-loop operation. While not a specific motor type, it is commonly used in automation and robotics for precise motion control.

Fig 4. DC servo motor

d) The **Arduino Uno** is a microcontroller board based on the ATmega328P. It features 14 digital I/O pins (6 supporting PWM), 6 analog inputs, a 16 MHz quartz crystal, USB connection, power jack, ICSP header, and reset button. It is easy to use and can be powered via USB, AC-to-DC adapter, or battery. The ATmega328P chip is replaceable, making it beginner-friendly and cost-effective.

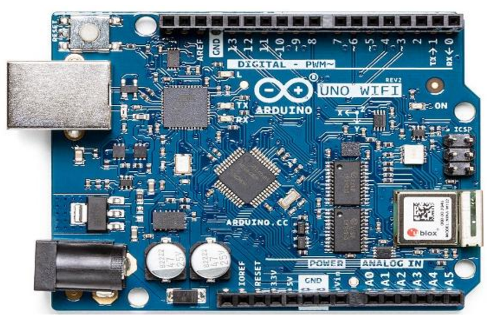

Fig 5. Arduino Microcontroller

e) **LEDs** are commonly used as the light source in modern solar streetlights due to their high efficiency and low power consumption. Compared to traditional lighting, LEDs produce higher lumens while consuming less energy**,** making them ideal for solar-powered applications. Their long lifespan, durability, and low maintenance requirements further enhance the reliability of solar street lighting systems.

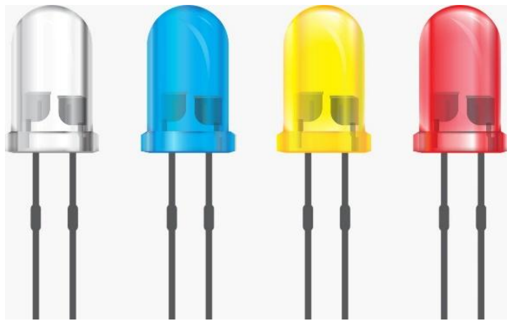

Fig 6. LED bulbs

3) Circuit Diagram

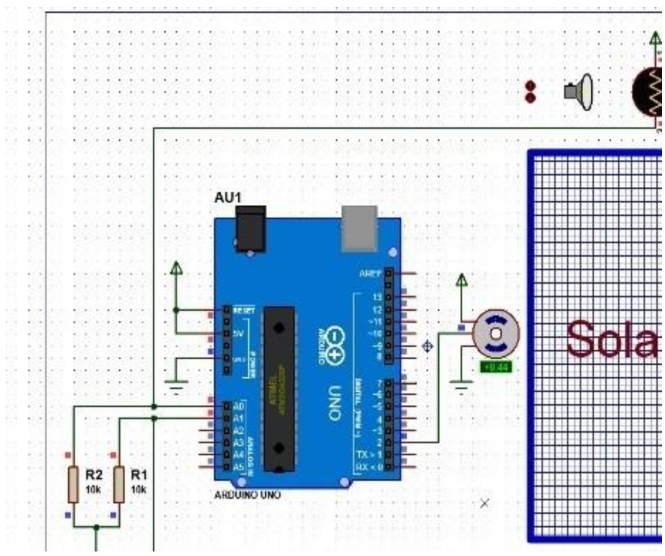

Fig 7. Circuit diagram

Pin details

The Arduino Uno is connected to various components for solar tracking. An LDR sensor is wired with one side connected to 5V, while the other is linked to analog pin A0, with a 10kΩ pull-down resistor to GND. A servo motor, responsible for adjusting the solar panel, has its control pin connected to digital pin 9, with VCC and GND linked to the Arduino's 5V and GND, respectively. A buzzer, used for alerts, is connected between digital pin 7 and GND. If an LCD display is present, its SDA and SCL pins are connected to A4 and A5 for I2C communication, while VCC and GND are powered by 5V and GND. The Arduino itself is powered via USB or an external supply through the Vin and GND pins. This setup enables real-time solar tracking with efficient energy absorption and monitoring.

V. WORKING OF THE SYSTEM

a) **System Initialization**: The Arduino Uno initializes all inputs and outputs to zero. The LDR sensors are placed in four positions: top, bottom, left, and right to detect sunlight intensity.
Two servo motors control the panel's movement:
   i. Servo 1 adjusts the vertical tilt (up-down).
   ii. Servo 2 adjusts the horizontal rotation (left-right).

b) **Light Intensity Detection**: The LDRs continuously measure sunlight intensity. If the center LDR receives no light, the system waits (longer delay).

c) **East-West (Horizontal) Adjustment:**
   i. If the top LDR detects more intensive light than the center, and the bottom LDR detects less light, Servo 1 moves up.
   ii. If the bottom LDR detects more intensive light than the center, and the top LDR detects less, Servo 1 moves down.

d) **North-South (Vertical) Adjustment:**
   i. If the right LDR detects more intensive light than the center, and the left LDR detects less, Servo 2 moves right.
   ii. If the left LDR detects more intensive light than the center, and the right LDR detects less, Servo 2 moves left.

e) **Continuous Tracking:** Steps 3 and 4 repeat continuously, ensuring the panel always aligns perpendicularly to sunlight. The system runs in a closed loop to dynamically track the sun's movement throughout the day.

f) **Power Generation:** The optimized alignment ensures maximum solar energy absorption, increasing the system's efficiency. The collected energy is stored in a rechargeable battery, which powers streetlights or other connected loads.

VI. RESULTS AND DISCUSSION

a) Solar Tracking System Implementation

The hardware implementation of the solar tracking solar panel has been successfully designed and tested. The system automatically adjusts the solar panel to align with the sun's position throughout the day, ensuring maximum energy absorption.

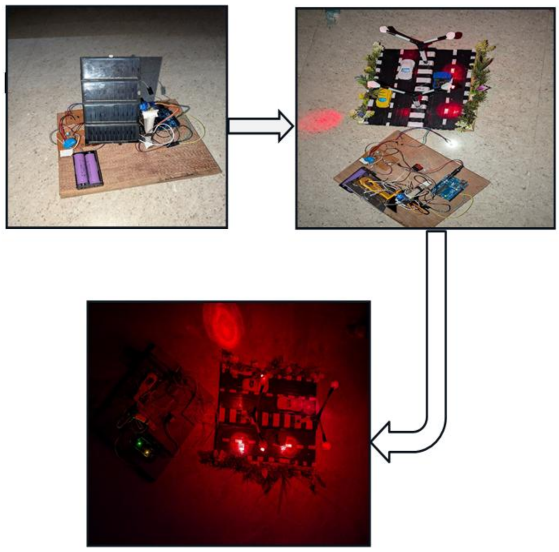

Fig 8. Results

b) Efficiency Improvement

The results indicate that a solar tracking system significantly improves efficiency compared to a fixed solar panel. Normally, conventional panels convert only **30-40%** of the incident solar radiation into electricity. However, with automated tracking, the system maintains optimal orientation, increasing power output.

c) Cost-Effective and Automated Design

The proposed tracking system is fully automated, requiring no manual intervention. Additionally, it is cost-effective, utilizing LDR sensors, servo motors, and an Arduino-based control system to achieve efficient solar energy harvesting with minimal expenses.

d) Prototype Testing and Performance

The prototype was developed and tested under various lighting conditions. As shown in the images:
   i. The solar panel absorbs sunlight and charges a battery.
   ii. The stored energy powers smart streetlights, which automatically turn on in low-light conditions.
   iii. The system functions efficiently during both daytime and nighttime, ensuring reliable power generation.

VII ADVANTAGES AND DISADVANTAGES

a) Advantages:

   i. **Simple Design** – Easy to implement with basic components.
   ii. **Renewable Energy** – Uses unlimited solar power.
   iii. **Cost-Effective** – Reduces electricity bills and energy dependence.
   iv. **Low Maintenance** – Requires minimal upkeep for long-term use.
   v. **Eco-Friendly** – Produces clean energy with no emissions.
   vi. **Efficient Tracking** – Accurately follows the sun for maximum energy absorption.

b) Disadvantages:

i. **Higher Initial Cost** – Requires additional components like sensors and motors.
ii. **Complex Installation** – More intricate setup compared to fixed solar panels.
iii. **Maintenance Needs** – Moving parts may require periodic servicing.
iv. **Weather Dependent** – Less effective on cloudy or rainy days.
v. **Energy Consumption** – Motors and controllers consume a small amount of power.
vi. **Space Requirement** – Needs sufficient area for panel movement.

Ⅷ. APPLICATION

i. **Concentrated Solar-Hybrid Systems** – Can be modified to maximize energy savings.
ii. **Domestic & Industrial Use** – Suitable for both small and large-scale applications.
iii. **High-Efficiency Power Generation** – Outperforms fixed solar systems in energy output.
iv. **Large PV Installations** – Ideal for solar farms and commercial projects.
v. **Emergency Lighting** – Provides reliable backup power in outages.
vi. **Highway & Roadside Lighting** – Powers streetlights in remote areas.
vii. **Public Safety** – Ensures continuous lighting in public spaces.
viii. **Smart City Integration** – Supports sustainable urban infrastructure.

Ⅸ. CONCLUSION AND FUTURE SCOPE

Conclusion

The solar tracking system developed in this project significantly enhances the efficiency of solar panels by continuously adjusting their orientation to follow the sun. This ensures maximum solar radiation absorption, optimizing energy production compared to fixed panels, which typically convert only 30-40% of incident sunlight into electricity.

Through thorough research and planning, we successfully designed a cost-effective and automated tracking system. Our focus was to develop a simple yet efficient solution that can be used in domestic, public, and large-scale applications. The trial-and-error method helped refine the system for optimal performance.

By applying engineering principles, we created a low-cost, eco-friendly alternative that promotes renewable energy use. Given the urgent need to combat global warming, adopting such sustainable energy solutions is crucial for reducing reliance on fossil fuels and building a greener future.

Future Scope

This project was developed with a realistic timeline and available resources, but there is significant potential for future improvements. The current design serves as a miniature prototype, which can be scaled up for larger applications.

To enhance performance, flexible cables can be used to reduce strain on the motor during rotation. For higher tracking precision, a photo transistor with an amplification circuit can replace LDRs. Additionally, upgrading to a dual-axis tracking system instead of a single-axis setup would further improve efficiency.

Future implementations can also integrate a microcontroller as a standalone unit within the circuit, improving automation and functionality. These advancements will make the system more efficient, accurate, and suitable for large-scale renewable energy applications.

REFERENCES

1. Paramjeet Singh Paliyal, Surajit Mondal, Samar Layek, Piyush Kuchhal, Jitendra Kumar Pandey, Automatic solar tracking system: a review pertaining to advancements and challenges in the current scenario, *Clean Energy*, Volume 8, Issue 6, December 2024, Pages 237–262, https://doi.org/10.1093/ce/zkae085.
2. A. Z. Hafez, A. M. Yousef, A. Soliman and I. M. Ismail, "A comprehensive review for solar tracking systems design in Photovoltaic cell, module, panel, array, and systems applications," *2018 IEEE 7th World Conference on Photovoltaic Energy Conversion (WCPEC) (A Joint Conference of 45th IEEE PVSC, 28th PVSEC & 34th EU PVSEC)*, Waikoloa, HI, USA, 2018.
3. Priti Debbarma, B.B. Bhowmik, "A Review on Solar Tracking System and Their Classification", IJRAR January 2019, Volume 06, Issue 1, 2018.
4. Seme, Sebastijan, Bojan Štumberger, Miralem Hadžiselimović, and Klemen Sredenšek. 2020. "Solar Photovoltaic Tracking Systems for Electricity Generation: A Review" *Energies* 13, no. 16: 4224. https://doi.org/10.3390/en13164224Siavash Esfahani et al. "Smart City Battery Operated IoT Based Indoor Air Quality Monitoring System." 2020 IEEE Sensors (2020): 1-4. https://doi.org/10.1109/SENSORS47125.2020.9278913.
5. Yang, Zihan, and Zhiquan Xiao. 2023. "A Review of the Sustainable Development of Solar Photovoltaic Tracking System Technology" *Energies* 16, no. 23: 7768. https://doi.org/10.3390/en16237768
6. A. -H. I. Mourad, H. Shareef, N. Ameen, A. H. Alhammadi, M. Iratni and A. S. Alkaabi, "A state-of-the-art review: Solar trackers," *2022 Advances in Science and Engineering Technology International Conferences (ASET)*, Dubai, United Arab Emirates, 2022, pp. 1-5, doi: 10.1109/ASET53988.2022.9735074.
7. Musa, Abdulwaheed, Emmanuel Alozie, Suleiman A. Suleiman, John Adedapo Ojo, and Agbotiname Lucky Imoize. 2023. "A Review of Time-Based Solar Photovoltaic Tracking Systems" *Information* 14, no. 4: 211. https://doi.org/10.3390/info14040211
8. M. Tahir Patel, M. Sojib Ahmed, Hassan Imran, Nauman Z. **"Optimum design of tracking bifacial solar farms -- A comprehensive global**

analysis of next-generation PV", arXiv:2011.01276 **[physics.app-ph].**
9. https://en.wikipedia.org/wiki/Photovoltaic_power_station.
10. US solar tracker dominance offers learnings for other markets. *Reuters*, 2024.