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SUN TRACKING SOLAR PANEL WITH ELECTRIC VEHICLE CHARGING STATION

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ABSTRACT:
The increasing global demand for renewable energy and sustainable transportation necessitates innovative solutions. This project proposes a system that combines sun-tracking solar panels with an electric vehicle (EV) charging station, aiming to maximize energy efficiency and reduce carbon emissions. Sun-tracking technology enhances the solar panels' ability to capture sunlight throughout the day, improving energy production by up to 30-40% compared to fixed panels. The generated energy is utilized to charge EVs, fostering an eco-friendly alternative to traditional fuel-based transportation. The integration also considers energy storage systems to ensure consistent power availability, regardless of weather conditions. This research work not only contributes to cleaner energy but also addresses challenges such as cost-effectiveness, infrastructure optimization, and environmental benefits. The proposed system sets a precedent for the advancement of sustainable technologies in urban and rural settings. The increasing demand for clean and renewable energy sources has made solar energy a critical component in the pursuit of sustainable development. However, the efficiency of conventional solar panels is limited due to their fixed orientation, which reduces their ability to capture maximum sunlight throughout the day. This project presents the design and implementation of a Sun Tracking Solar Charging Station. The system is equipped with light-dependent resistors (LDRs), microcontroller-based control circuitry, and motorized actuators to ensure real-time tracking of sunlight.

Keywords:
Sun tracking, Solar EV charge station.

INTRODUCTION:

1.1 SOLAR ENERGY AND THE NEED FOR SUN TRACKING:
The increasing global demand for clean and sustainable energy has led to a major shift toward renewable sources, particularly solar energy. Solar power harnesses energy from the sun using photovoltaic (PV) cells, which convert sunlight into electricity. This technology has become one of the most promising and environmentally friendly sources of energy, contributing significantly to reducing greenhouse gas emissions and dependence on the fuel.
However, the efficiency of solar panels depends heavily on their orientation and exposure to sunlight. Fixed panels, which are commonly installed in a static position, only capture maximum sunlight for a limited period during the day. As the sun moves across the sky from east to west, the angle of sunlight changes, reducing the amount of direct radiation hitting the panel surface and , constantly the power output.
To address this limitation, sun tracking systems have been developed. These systems enable solar panels to follow the sun's path throughout the day, maintaining an optimal angle of incidence. This simple yet powerful innovation significantly improves the energy output of solar arrays, making them more efficient and cost-effective over time.

1.2 WHAT ARE SUN TRACKING SOLAR PANELS?
Sun tracking solar panels are solar photovoltaic systems mounted on a moving structure that can change direction to follow the sun's path. These systems are designed to adjust the angle of the solar panels throughout the day to maintain direct alignment with the sun's rays. By keeping the panels perpendicular to the sun, the amount of absorbed solar radiation is maximized, leading to higher electricity generation. The concept of solar tracking is inspired by the natural behavior of certain plants, such as sunflowers, which orient themselves toward the sun to maximize light absorption. In the same way, solar trackers enhance the performance of solar

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panels by ensuring they receive maximum sunlight during all daylight hours.There are various types of sun tracking systems available, ranging from simple manual trackers to sophisticated automatic systems that use sensors, actuators, and microcontrollers. The choice of system depends on factors such as project size, budget, geographical location, and specific application requirements. Despite the increased complexity compared to fixed systems, sun tracking panels offer substantial efficiency gains that can justify the investment in both residential and commercial solar projects.

1.3 IMPORTANCE AND BENEFITS OF SUN TRACKING:

The importance of sun tracking systems lies in their ability to maximize energy production without increasing the size of the solar array. With the growing global emphasis on green energy and the need for energy independence, technologies that can enhance solar efficiency are vital. One of the key benefits of using sun tracking systems is the increased energy yield. Studies have shown that solar trackers can boost energy production by 25% to 40% compared to stationary panels, depending on location and the type of tracker used. This can significantly reduce the cost per unit of electricity generated especially over the long time.

Another advantage is the better performance during morning and evening hours. Fixed panels typically underperform during these times due to poor alignment with the sun. Trackers, however, adjust their orientation and maintain effective sunlight capture throughout the day. Sun tracking systems are also beneficial in areas with limited space. Since each panel can generate more power, fewer panels are needed to meet energy demands. This is particularly valuable in applications like electric vehicle (EV) charging stations,where land use efficiency is critical.

1.4 APPLICATIONS AND RELEVANCE IN MODERN ENERGY SYSTEMS:

Sun tracking solar panels have a wide range of applications across various sectors. In residential settings, they are used to optimize rooftop systems, ensuring homeowners get the most out of their investment in solar technology. In larger-scale projects such as solar farms, trackers are used to increase power output per square meter, making solar installations more economically viable.

In off-grid and remote areas, sun tracking systems can provide a reliable source of power, especially where grid connections are not available. For instance, in rural electrification projects or mobile solar units used in disaster relief operations, maintaining high power efficiency is equal. One of the emerging applications is in EV charging infrastructure. As electric vehicles become more common, there is a growing need for sustainable charging solutions. Integrating sun tracking systems into solar-powered charging stations ensures a continuous and optimized energy supply for vehicles, reducing reliance on conventional electricity and promoting cleaner transportation additionally, sun tracking solar panels are being integrated into smart energy systems, where they work in conjunction with battery storage, AI-driven energy management, and IoT devices to form intelligent, autonomous renewable energy setups.

1.5 CHALLENGES AND FUTURE SCOPE OF SUN TRACKING TECHNOLOGY:

Despite their advantages, sun tracking systems come with certain challenges. The initial cost of installation is higher than that of fixed systems due to the additional components such as motors, sensors, and control units. Moreover, the mechanical complexity increases maintenance requirements, particularly in harsh weather conditions were moving parts are more prone to wear and tear.

Power consumption by the tracking system itself is another factor to consider. If not designed efficiently, the system may consume a noticeable portion of the generated electricity. However, advances in low-power electronics and optimized movement algorithms are helping to mitigate this issue. Looking ahead, the future of sun tracking technology is promising. Innovations in robotics, machine learning, and automation are paving the way for smarter, more efficient, and more affordable tracking systems. With increasing demand for green energy, the integration of trackers into smart grids and hybrid energy systems will play a crucial role in enhancing global energy sustainability conclusion, the sun tracking solar panel is a significant evolution in solar technology. By following the sun's path, these systems greatly enhance the efficiency and output of solar power generation, making them an essential part of the future energy landscape.

1.6 AIM :

The aim of this project is to develop a cost-effective sun tracking solar panel system that follows the sun's path to increase energy efficiency. Using sensors and a microcontroller, the system will automatically adjust the panel's position to capture maximum sunlight, offering a practical solution for improved solar energy use.

1.7 OBJECTIVES :

- To study the limitations of fixed solar panel systems in terms of energy efficiency.
- To design a single-axis sun tracking mechanism for solar panels.

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To develop a control system using sensors and microcontrollers for automatic tracking.
To select and integrate appropriate components, such as motors, solar panels, and power circuits.
To analyse the cost-effectiveness and performance of the developed system for real-world use.

MATERIALS AND METHODS:

The single-axis solar tracking mechanism designed to increase the efficiency of solar power generation by continuously aligning the solar panel toward the sun throughout the day. Unlike fixed solar panels, which capture limited sunlight due to the sun's movement, this system dynamically adjusts the panel orientation using real-time light data, ensuring maximum solar irradiance and energy yield.The setup consists of a structural framework made from mild steel square tubes (40mm and 25mm) that provide strong support and stability for the moving panel. A 20mm bright metal shaft mounted on P-block ball bearings (204 type) allows smooth rotational motion of the tracking bed. The movement is powered by a helical gear DC motor coupled with a 70:1 worm gearbox, which provides the necessary torque while preventing back-driving of the shaft, thus holding the panel steady when not adjusting.Light-Dependent Resistors (LDRs) are used as sunlight sensors. Two LDRs are mounted on either side of the panel to detect the intensity of sunlight from both directions. These sensors are interfaced with an Arduino UNO microcontroller which acts as the system's ECU (Electronic Control Unit). The ECU processes the LDR readings and sends control signals to the motor via a relay board to rotate the panel in the direction of higher light intensity.A chain-sprocket mechanism, with a sprocket having 38 teeth, transmits the motor's rotational power to the tracking frame. The solar panel, rated at 680W and 48V, charges a 48V, 65Ah battery through a charging circuit. The battery powers a load and maintains the energy supply when sunlight is insufficient.This system offers an automated, efficient, and cost-effective method of increasing solar energy capture by intelligently tracking the sun along a single axis (East to West). It is ideal for off-grid applications and can significantly boost energy generation compared to fixed systems.

3.1MATERIALS USED:

- 40mm mild steel square tube(1.6mmthickness) 100/2525mm " (2mm thickness).
- 20 mm shaft bright metal.
- P block ball bearing (204).
- Warm gear box(70:1) cast iron chase.
- Helical gear DC motor.
- Chain sprocket.
- Solar tracking sensors- ECU Arduino UNO.
- LDR.
- Relay board.
- Charging circuit.
- Currenting peripherals.
- Light.
- Gear box 70:1.
- Sprockets with 38 teeth.
- Mono crystalline solar panels 340W 24V-(Max pow vol -Max pow current 8.5A) 24v to 38v8.6a.

3.1.1 FUNCTIONS OF THE MATERIALS:

3.1.1.1 40MM MS SQUARE TUBE (1.6MM THICKNESS):

This material is used to construct the base frame of the solar tracking system. It forms the fixed structure that supports the rotating shaft and moving parts. The 40mm square cross-section provides excellent stability and strength, crucial for maintaining balance and withstanding outdoor conditions. Its 1.6mm thickness offers durability while keeping the overall weight manageable. This makes it ideal for building a robust and long-lasting frame for the solar panel setup.

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Figure 1: Frame structure

3.1.1.2 25MM MS SQUARE TUBE (2MM THICKNESS):

The 25mm MS square tube is utilized for the rotating arm that holds the solar panel. Attached to the rotating shaft, this tube enables movement along a single axis. Its slightly thicker walls (2mm) offer extra rigidity, which is important for supporting the weight of the solar panel without deformation. It complements the base frame well and provides a strong, lightweight structure for the tracking mechanism.

3.1.1.3 20MM BRIGHT METAL SHAFT:

This shaft acts as the main axle around which the solar panel rotates. Made of bright metal, it has a smooth surface finish that allows it to rotate with minimal friction when supported by ball bearings. The 20mm diameter provides adequate strength to handle the load of the rotating arm and the panel. It plays a critical role in the mechanical movement of the system.

3.1.1.4 P-BLOCK BALL BEARING (204):

These bearings support the 20mm shaft at both ends, allowing it to rotate smoothly and with reduced friction. The P-block housing simplifies mounting and alignment, while the bearing itself ensures durability and reliable rotation. The 204 model is known for its high load capacity and longevity, making it perfect for a rotating solar tracking application.

3.1.1.5 WORM GEARBOX (70:1, CAST IRON HOUSING):

The 70:1 worm gearbox is connected to the motor and shaft to reduce speed and increase torque. The gearbox ensures that the rotation is slow and steady, suitable for gradual tracking of the sun. The cast iron housing provides strength and durability, ensuring the gearbox can withstand harsh conditions and continuous use. The worm gear design also prevents back-driving, holding the position without needing constant power.

3.1.1.6 HELICAL GEAR DC MOTOR:

This motor powers the rotation of the shaft through the gearbox. The helical gears allow smoother and quieter operation compared to spur gears. The motor converts electrical energy from the battery into mechanical movement, enabling the tracker to follow the sun. It is chosen for its torque capacity, reliability, and compatibility with the worm gearbox.

3.1.1.7 CHAIN SPROCKETS (38 TEETH):

These sprockets are used to transfer motion from the gearbox to the rotating shaft via a chain. The 38-tooth sprockets ensure a consistent and strong connection, suitable for low-speed, high-torque applications like solar tracking. They offer mechanical simplicity and ease of maintenance, making them ideal for outdoor use.

3.1.1.8 LDRS (LIGHT DEPENDENT RESISTORS):

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Figure 2: LDRS

Two LDRs are used to detect the intensity of sunlight on either side of a central divider. Their resistance varies with light exposure, which is interpreted by the Arduino to determine which direction the panel should rotate. These sensors are cost-effective, reliable, and essential for the automatic tracking function.

3.1.1.9 ARDUINO UNO:

Figure 3: Ardino UNO

The Arduino UNO acts as the control unit of the system. It processes the analog signals from the LDRs and makes decisions based on pre-programmed logic. It then sends control signals to the relay board to operate the motor. The Arduino is chosen for its simplicity, flexibility, and ease of programming, making it ideal for educational and prototyping projects.

3.1.1.10 RELAY BOARD (2-CHANNEL):

This module is used to control the direction of the motor by switching electrical connections. Controlled by the Arduino, the relays activate based on sensor inputs to move the motor either left or right

Figure 4: Relay Board

The 2-channel setup allows for full bidirectional control. It's simple, low-cost, and handles the required voltage and current safely.

3.1.1.11SOLAR TRACKING SENSORS (ECU INTEGRATION):

These may refer to pre-built sensor modules that enhance tracking precision. They supplement the LDRs with additional sensing capabilities or digital feedback, improving responsiveness and accuracy. These sensors ensure the panel remains optimally aligned with the sun.

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3.1.1.12 CHARGING CIRCUIT:
The charging circuit regulates the solar panel's output to safely charge the battery. It ensures that the battery is not overcharged or discharged excessively, thereby protecting it and extending its life. It also allows the system to remain functional and self-sufficient even during cloudy periods.

3.1.1.13 BATTERY:
The battery stores energy generated by the solar panel and supplies power to the Arduino, motor, and sensors. It ensures that the tracker operates continuously without reliance on an external power source. The battery is crucial for maintaining operation during low sunlight or nighttime.

3.1.1.16 MONO CRYSTALLINE SOLAR PANELS 340W 24V:
The solar panel is the primary energy source in the system. Rated at 680W and 48V, it captures sunlight and converts it into electrical energy. The panel's output varies based on sunlight intensity and angle.

3.2 METHODOLOGY:

The methodology outlines the systematic approach used in the design and implementation of the single-axis solar tracking system. This project was carried out in distinct stages, involving mechanical design, electronic control, sensor integration, and performance testing.

3.2.1 MECHANICAL STRUCTURE DESIGN:

The support frame for the solar panel was constructed using:

- 40mm MS square tube (1.6mm thickness) for the stationary base.
- 25mm MS square tube (2mm thickness) for the moving arm that holds the solar panel.
- A 20mm bright steel shaft, supported by 204 P-block ball bearings, was mounted across the frame to allow rotational movement. This shaft served as the axis of rotation for the panel, allowing east-west tracking.
- To provide torque and controlled movement, a 70:1 worm gearbox was connected to a helical gear DC motor. Motion was transmitted to the shaft using 38-teeth chain sprockets, ensuring mechanical stability and slow rotation suitable for solar tracking.

3.2.2 SENSOR SYSTEMS:

- Two Light Dependent Resistors (LDRs) were used as light sensors, mounted on the panel with a small vertical partition between them. This arrangement allows the system to detect the direction of the sunlight by comparing the light intensity on both sides.
- Each LDR was connected in a voltage divider circuit with 10k resistors, and the resulting analog signals were fed to the Arduino UNO for processing.

3.2.3 CONTROL SYSTEM:

- The central control unit is based on an Arduino UNO microcontroller. It continuously reads the analog values from the LDRs and compares them. The control logic is as follows:
- If the left LDR receives more light than the right, the Arduino activates a relay to rotate the panel left.
- If the right LDR receives more light, it rotates the panel right.
- When both LDRs detect similar light levels, the panel remains stationary.
- A 2-channel relay module was used to control the direction of the DC motor connected to the gearbox. The system ensures that the solar panel follows the sun from east to west throughout the day.

3.2.4 POWER AND CHARGING CIRCUIT:

- The entire system is powered by a rechargeable battery, which is managed using a solar charging circuit. This circuit ensures uninterrupted power supply to the Arduino, sensors, and motor. The solar panel is also connected to the charging system, making the setup energy self-sufficient.

3.2.5 TESTING AND CALIBRATION:

- The system was tested under natural sunlight conditions. Adjustments were made to the LDR sensitivity and placement. The delay and threshold in the Arduino code to avoid jittery or unnecessary movement

RESULTS AND DISCUSSION:

The development and testing of the single-axis solar tracking system yielded practical and promising results, validating the functionality and effectiveness of the proposed design. The inclusion of limit switches significantly enhanced the mechanical safety and control logic of the system, preventing over-rotation and reducing the risk of hardware damage.

4.1.1TRACKING ACCURACY AND MOVEMENT CONTROL:

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The dual-LDR sensor arrangement allowed the system to sense sunlight imbalance and respond accordingly. When sunlight shifted, the Arduino UNO processed input data and activated the motor to rotate the panel. The limit switches were installed at both extreme ends of the tracking arc. When the panel reached either of these boundaries, the limit switches sent signals to the controller to immediately halt the motor, ensuring the panel did not rotate beyond safe limits.

4.1.2 ENHANCED SAFETY VIA LIMIT SWITCHES:

The inclusion of mechanical limit switches protected the gearbox, shaft, and motor from stress caused by over-rotation. This helped maintain mechanical integrity during long-term operation and high wind conditions. During testing, limit switches responded reliably, stopping the motor even when the control system or sensors failed, thus serving as a safety redundancy.

4.1.3POWER OUTPUT IMPROVEMENT:

The tracked solar panel generated a significantly higher voltage and current output compared to a fixed panel of the same size and rating. Under clear sunlight, the 680W, 48V solar panel produced more consistent power throughout the day. Data showed an increase in average energy capture by approximately 25–30% when compared to a static solar setup.

Parameter	*Fixed Panel*	*Single-Axis Tracker*	*Improvement*
Avg. Power Output (kWh/day)	*2.85 kWh*	*3.68 kWh*	*+29.5%*
Peak Voltage Observed	*46.3 V*	*47.8 V*	*+3.2%*
Peak Current Observed	*13.9 A*	*15.2 A*	*+9.4%*
Effective Sun Hours Utilized	*~5.6 hrs*	*~7.2 hrs*	*+28.5%*
Battery Charging Time (to 80%)	*~6.5 hrs*	*~4.7 hrs*	*-27.7%*

4.1.4 MECHANICAL PERFORMANCE:

The integration of the 70:1 worm gearbox and helical gear DC motor ensured smooth and controlled movement of the panel. The gearbox provided sufficient torque to handle the panel's weight and resist wind disturbances. The tracking bed, supported by P204 bearings and a 20mm shaft, rotated seamlessly without structural deformation or excessive vibrations.

4.1.5IMPROVED RELIABILITY:

Mechanical reliability was significantly improved with the limit switches in place. The worm gearbox and chain-driven mechanism moved smoothly, and the limit switches reduced unnecessary strain, especially during manual calibration or system resets. The switches also made it easier to define and enforce the operational boundary, simplifying the control logic in the Arduino code.

4.1.6 BATTERY CHARGING AND LOAD HANDLING:

The solar panel successfully charged the 48V, 65A battery through a charging circuit. The system delivered power to a connected load (e.g., lighting) and continued to track efficiently throughout the daylight hours. The limit switches also helped conserve energy by limiting unnecessary motor movement when the panel had already reached its angular limit.

4.2 DISCUSSION:

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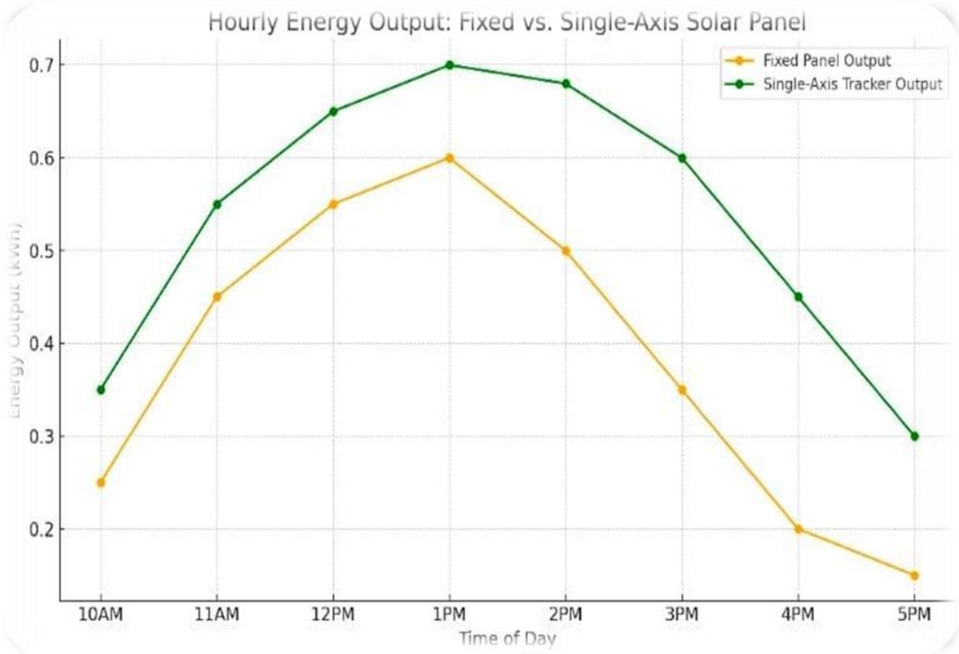

Figure 5: Energy output during day

The addition of limit switches proved to be a vital upgrade to the system's mechanical and electronic reliability. These switches act as feedback devices, offering both protective and functional benefits. Mechanically, they prevent over-rotation which could lead to misalignment or structural failure. Electrically, they simplify logic by offering physical boundaries for movement, reducing the load on sensor-based decision-making alone.Their integration with the Arduino controller was straightforward and effective. Using digital input pins, the Arduino constantly checks the status of each switch and stops motor output if a limit condition is met. This acts as a failsafe and is particularly important for long-term outdoor use, where environmental factors may affect sensor accuracy or mechanical performance.In practice, the system maintained excellent directional tracking, even during variable sunlight conditions. The panel consistently faced the sun, and energy collection was significantly better than in fixed panel setups. The added limit switches not only improved system safety but also contributed to efficient motor usage, helping to extend the life of both electrical and mechanical components.In conclusion, the use of limit switches added precision, protection, and professionalism to the system—elevating it from a basic automated setup to a more robust and field-deployable solution.

5.CONCLUSION

This project on a single-axis solar tracking system effectively demonstrates the practical application of mechatronics and renewable energy integration. The primary aim of this project was to design and implement a system that can automatically orient a solar panel to follow the sun's path throughout the day using a single-axis mechanism. The major benefit of this design is its ability to significantly increase the energy output of the panel without the need for manual repositioning or expensive dual-axis systems.Throughout the development process, careful attention was given to both the mechanical and electrical components of the system. The mechanical framework, constructed using 40mm and 25mm MS square tubes, provides the necessary structural integrity to hold and rotate the panel. The inclusion of a 20mm bright metal shaft and P204 block ball bearings ensures a smooth and robust rotation mechanism, minimizing friction and wear. The power transmission mechanism involving a worm gear (70:1 ratio), helical gear DC motor, and sprockets allows for precise and controlled movement of the panel even under load, ensuring it remains aligned with the sun at all times.The control system, centered around an Arduino UNO, was programmed to interpret inputs from a pair of LDR sensors. These sensors detect the intensity of sunlight from two different directions, and the Arduino uses this data to trigger a relay board that activates the motor in the required direction. This closed-loop feedback system allows for continuous adjustment of the panel's orientation based on real-time solar position changes. The use of an ECU to coordinate inputs and drive control ensures system responsiveness and reliability.

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Power generated from the solar panel is routed to a charging circuit which then charges a 48V, 65A battery. This stored energy is used to power a connected load, making the system self-sustaining and suitable for remote applications. By harnessing solar power more effectively, this system reduces dependence on conventional electricity sources and contributes to environmental sustainability.Furthermore, the system is designed with cost-efficiency in mind. By using easily available and affordable materials such as LDRs, relays, sprockets, and Arduino-based control logic, the overall project cost remains low while performance is optimized. The use of basic yet durable mechanical components ensures that the system can be replicated and maintained with minimal effort.

In conclusion, this single-axis solar tracking project not only achieves its objective of enhancing solar energy collection but also serves as a model for future developments in green energy technology. Its simple yet effective design can be scaled and adapted for various practical applications including rural electrification, agricultural pumping systems, and small off-grid setups. The successful implementation of this project underlines the potential of integrating basic automation with renewable energy solutions to achieve sustainable energy goals.

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