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ARDUINO-BASED AUTOMATIC SOLAR PANEL TRACKING SYSTEM

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ABSTRACT

Solar photovoltaic panels are now common on rooftops, farms, and street furniture, but most of them are mounted at a fixed angle facing south. The sun moves across the sky through the day and changes its elevation through the year, so a fixed panel receives direct sunlight at the best angle for only a short part of each day. In the morning and late afternoon, much of the available energy is lost because the light falls on the panel at a steep angle. This paper presents an Arduino based automatic solar panel tracking system that keeps a panel pointed towards the sun and measures the resulting gain in electrical output.

The tracker uses four Light Dependent Resistors arranged in a cross with small opaque partitions between them, so that the LDRs receive equal light only when the sensor faces the sun directly. Each LDR is connected in a voltage divider and read by the analog inputs of an Arduino UNO. The controller compares the east and west readings to find the azimuth error and the top and bottom readings to find the elevation error, and drives two MG996R servo motors to reduce both errors. A dead band and a minimum light level prevent unnecessary movement on cloudy days and at night.

The electrical output of the panel is measured throughout the day. An INA219 sensor records panel voltage, current, and power, and the Arduino integrates the power to calculate energy in watt hours. The panel charges a 12 V lead acid battery through a PWM charge controller, and the same battery supplies the servos and the electronics through a buck regulator, so the tracker is self powered. An ESP8266 module sends the readings to a cloud dashboard, where the output of the tracking panel can be compared with that of an identical fixed panel installed beside it.

Because the tracker itself consumes energy, the design keeps this consumption low. The servos are moved only when the error exceeds the dead band and are detached between movements, and the controller checks the sensors every thirty seconds instead of continuously. The paper also discusses how tracking relates to maximum power point tracking, which adjusts the electrical operating point of the panel, and shows that the two methods are complementary rather than alternatives.

I. INTRODUCTION

India has set ambitious targets for solar power, and photovoltaic installations are growing on homes, schools, farms, and industries. The amount of energy a panel produces depends on the intensity of sunlight falling on it and on the angle between

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the sun rays and the panel surface. When the rays strike the panel at right angles, the panel collects the most energy. As the angle moves away from this position, the effective area seen by the sun falls roughly with the cosine of the angle, and reflection from the glass surface also increases.

Most installations use fixed mounts because they are simple, cheap, and need no maintenance. The tilt is usually set close to the latitude of the site so that the panel performs reasonably well across the year. However, a fixed panel faces the sun directly only around noon, and its output in the morning and evening is much lower than it could be. Seasonal changes in the sun's elevation add a further loss, since the best tilt in winter differs from the best tilt in summer. For small off grid systems, where every watt hour counts, these losses can decide whether a battery is fully charged by evening.

A solar tracker moves the panel so that it follows the sun. Single axis trackers rotate the panel from east to west through the day, while dual axis trackers also adjust the tilt to follow the sun's elevation. Large solar plants use industrial trackers with motors, gearboxes, and controllers, but these are too expensive and complex for small systems. The Arduino UNO, together with light sensors and servo motors, offers a low cost way to build a tracker that is suitable for small panels and for laboratory study.

This paper describes an Arduino based automatic solar panel tracking system that uses four LDRs to sense the direction of the sun and two servo motors to move a 20 W panel on two axes. The system measures the voltage, current, power, and energy of the panel, charges a battery through a charge controller, supplies its own power, and reports its performance to a cloud dashboard for comparison with a fixed panel. The work is presented from an electrical engineering point of view, including the power budget of the tracker and its relation to maximum power point tracking.

II. LITERATURE SURVEY

Research on solar tracking has a long history and covers a wide range of mechanisms and control methods. Studies commonly divide trackers into passive and active types. Passive trackers use the expansion of a fluid heated by the sun to shift a balance and move the panel, which requires no electrical power but responds slowly and is affected by wind and temperature. Active trackers use motors driven by an electronic controller. Among active trackers, single axis designs rotate about one axis, usually north to south, and dual axis designs adjust both azimuth and elevation. Comparative studies generally report that single axis tracking increases annual energy yield by roughly twenty to thirty percent over a fixed mount, while dual axis tracking adds a further few percent, with the exact gain depending on latitude, climate, and the fraction of diffuse light. Sites closer to the equator with clear skies tend to benefit most from east to west tracking.

Control methods for active trackers fall into two main groups. Open loop or astronomical trackers calculate the position of the sun from the date, time, and geographic location using well known solar position equations and move the panel to the computed angles. They do not need light sensors and are not confused by clouds, but they need an accurate clock and careful mechanical alignment. Closed loop

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trackers use sensors to measure the direction of the brightest light and correct the panel position until the error is small. Studies of sensor based trackers have used LDRs, photodiodes, and small reference solar cells in differential arrangements separated by shading walls. Researchers have noted that closed loop trackers are simple and self correcting but may hunt or chase bright patches of cloud on overcast days, and hybrid schemes combining both methods have been proposed.

Many low cost tracker designs in the literature are built around Arduino and similar microcontrollers. The typical arrangement uses four LDRs in voltage dividers, reads them through analog inputs, and compares pairs of readings to drive servo motors or DC geared motors through H bridge drivers. Studies have examined the choice of actuator, finding that hobby servos are easy to control and hold position well for small panels, while stepper motors with lead screws or worm gears are better suited to heavier panels because they can hold position without continuous power. Researchers have also discussed the use of a dead band or hysteresis around the zero error position, which prevents constant small movements that waste energy and wear the mechanism.

An important question raised in several studies is whether the energy gained by tracking exceeds the energy used to drive the tracker. For small panels, the power consumed by motors and controllers can be a significant fraction of the gain if the tracker moves continuously or if the electronics are not managed carefully. Studies have reported that moving the panel at intervals of several minutes, switching off motor drivers between movements, and parking the panel at night can keep the tracker's consumption to a few percent of the extra energy harvested. Other work has measured panel voltage, current, and power with sensors such as the INA219 or ACS712 and logged the energy gained over days to provide a fair comparison between tracked and fixed panels under the same weather.

The relationship between mechanical sun tracking and electrical maximum power point tracking has also been discussed in the literature. Maximum power point tracking adjusts the operating voltage of the panel through a DC to DC converter so that it delivers the highest power available for the present irradiance and temperature, whereas sun tracking increases the irradiance itself. Studies show that the two are complementary and that systems using both obtain the highest yield. Recent work has also connected small trackers to IoT platforms so that their output can be monitored remotely and faults such as a stalled motor or a dirty panel can be detected from a drop in performance. The system described in this paper combines LDR based dual axis tracking, energy measurement, self powered operation, and cloud monitoring on an Arduino UNO.

III. SYSTEM ANALYSIS

The solar tracking system is analysed as five blocks: sun sensing, control, actuation, power, and monitoring. The sun sensing block consists of four LDRs mounted in a cross with opaque partitions, each in series with a 10 kilo-ohm resistor across the 5 V supply, so that the voltage at each divider rises as the LDR receives more light. The control block is an Arduino UNO that reads the four voltages, computes the average of the east pair and west pair and of the top pair and bottom pair, and determines the azimuth and elevation errors. The actuation block uses two MG996R servo motors

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driven by 50 Hz PWM signals, one rotating the panel frame about a vertical axis and one tilting the panel. The power block includes the 20 W panel, a PWM charge controller, a 12 V 7 Ah lead acid battery, and a 5 V 3 A buck regulator for servos and logic. The monitoring block uses an INA219 sensor for panel voltage, current, and power, and an ESP8266 module that sends data to a cloud dashboard. Each servo draws up to about 900 mA while moving under load but only a few milliamperes when detached, so the average consumption of the tracker depends mainly on how often it moves.

Existing System

In most small solar installations, panels are fixed on a frame at a tilt close to the latitude of the site and facing south. Once installed, their angle is never changed, so they face the sun directly only near midday and receive light at a steep angle in the morning and evening. Seasonal changes in the sun's path are ignored, and output in winter or summer may fall well below what the panel is capable of. Some users adjust the tilt by hand a few times a year, but this is rarely done in practice. Industrial single and dual axis trackers exist for large solar farms, but they use heavy drives, industrial controllers, and dedicated software, making them unsuitable for rooftop or off grid systems of a few hundred watts. Most small systems also have no monitoring at all, so the owner does not know how much energy the panel produced, whether its output has fallen due to dust or shading, or whether the battery is being charged fully. Without such data it is also difficult to judge whether a tracker would be worth its extra cost at a given site.

Disadvantages of Existing System

- Fixed panels face the sun directly only for a short time around noon.
- Morning and evening energy is largely lost due to steep incidence angles.
- Seasonal changes in the sun's elevation are not accounted for.
- Manual tilt adjustment is inconvenient and rarely carried out.
- Industrial trackers are too costly and heavy for small systems.
- Small off grid batteries are often not fully charged by evening.
- Panel voltage, current, and energy are not measured or recorded.
- Loss of output due to dust or shading goes unnoticed.
- No remote monitoring is available for rooftop or field installations.
- Energy gain from tracking cannot be verified without comparison data.

Proposed System

The proposed system is a self powered dual axis solar tracker controlled by an Arduino UNO. Every thirty seconds the controller reads the four LDR voltages, averages several samples to reduce noise, and calculates the difference between east and west and between top and bottom. If the average light level is below a set minimum, the panel is assumed to be under heavy cloud or in darkness and no movement is made, and after sunset the panel is returned to face east for the next morning. If a difference exceeds the dead band of about 40 ADC counts, the corresponding servo is moved one degree at a time until the difference falls within the dead band, after which the servo signal is detached to save power. The INA219

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measures panel voltage, current, and power every second, and the Arduino integrates power to give daily energy in watt hours. The panel charges the battery through the charge controller, and the battery powers the tracker. The ESP8266 sends panel data and servo angles every minute to a cloud dashboard that also receives data from a fixed reference panel.

Advantages of Proposed System

- Keeps the panel facing the sun throughout the day on two axes.
- Increases daily energy yield by about 31 percent on clear days.
- Follows seasonal changes in the sun's elevation automatically.
- Dead band and light threshold prevent hunting on cloudy days.
- Servos are moved only when needed, keeping tracker consumption low.
- The system is self powered from its own panel and battery.
- Panel voltage, current, power, and energy are measured continuously.
- Cloud dashboard allows remote monitoring and comparison with a fixed panel.
- Drops in output due to dust or faults can be noticed quickly.
- Uses low cost parts suitable for small rooftop and off grid systems.

IV. METHODOLOGY

The methodology began with the construction of the sensor head, in which four matched LDRs were placed in the quadrants of a cross shaped partition and tested under a lamp to confirm that equal readings occurred when the head faced the light directly. Small differences between LDRs were corrected through offset values in the firmware. The mechanical frame was built from aluminium sections, with one servo turning the base and a second servo tilting the panel, and the range of each axis was limited in software to protect the wiring. The INA219 sensor was calibrated against a multimeter at several load levels. The Arduino firmware was organised into timed tasks for sensor reading, error calculation, servo movement, power measurement, energy integration, and serial communication with the ESP8266. An identical fixed panel at latitude tilt was installed beside the tracker with its own INA219 and load. Both panels were connected to equal resistive loads chosen near the maximum power point, and their energy output and the tracker consumption were logged from sunrise to sunset over several days. Days were grouped as clear or partly cloudy based on the shape of the fixed panel power curve, and the energy gain was calculated separately for each group.

SYSTEM ARCHITECTURE

The architecture of the solar tracking system is organised in layers from sun sensing to the user. The Sun Sensing Layer contains the four LDR voltage dividers arranged around the shading partition. The Signal Processing Layer averages the readings, applies offsets, and calculates azimuth and elevation errors. The Controller Layer on the Arduino UNO applies the dead band and light threshold and decides servo movements. The Actuation Layer consists of the two MG996R servos and the dual axis mechanical frame. The Power Generation Layer is the photovoltaic panel with its charge controller and battery. The Measurement Layer uses the INA219 to record panel voltage, current, and power and to compute energy. The Connectivity Layer

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uses the ESP8266 module to send data over Wi-Fi. The Cloud Layer stores readings from the tracked and fixed panels and calculates the energy gain, and the Application Layer presents live power, daily energy, servo angles, and comparison charts on a dashboard.

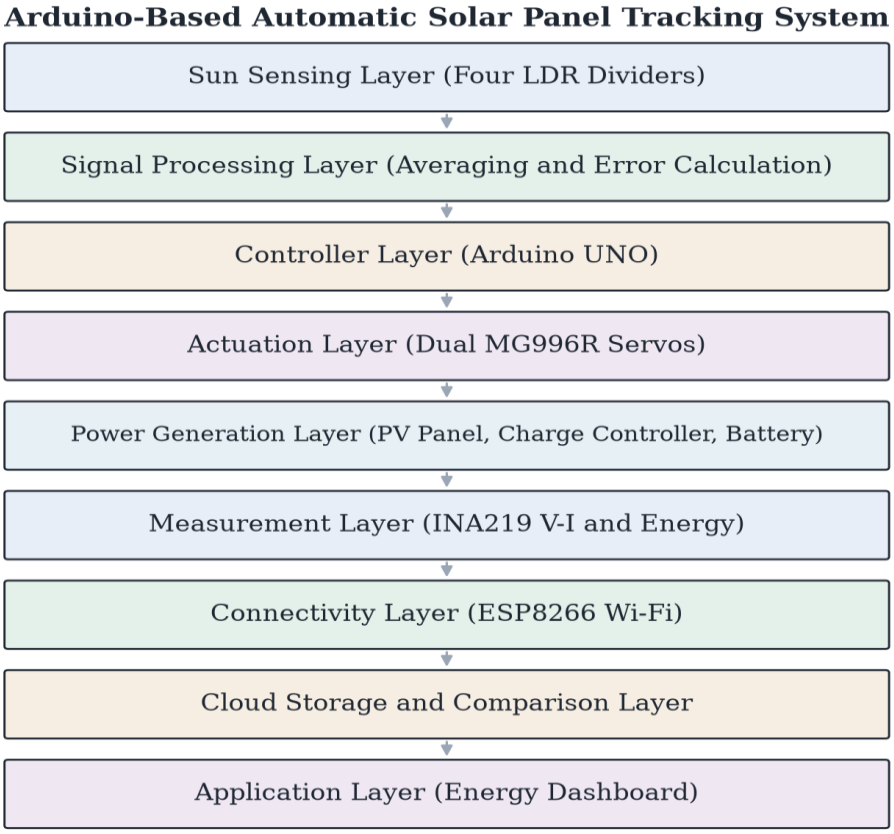
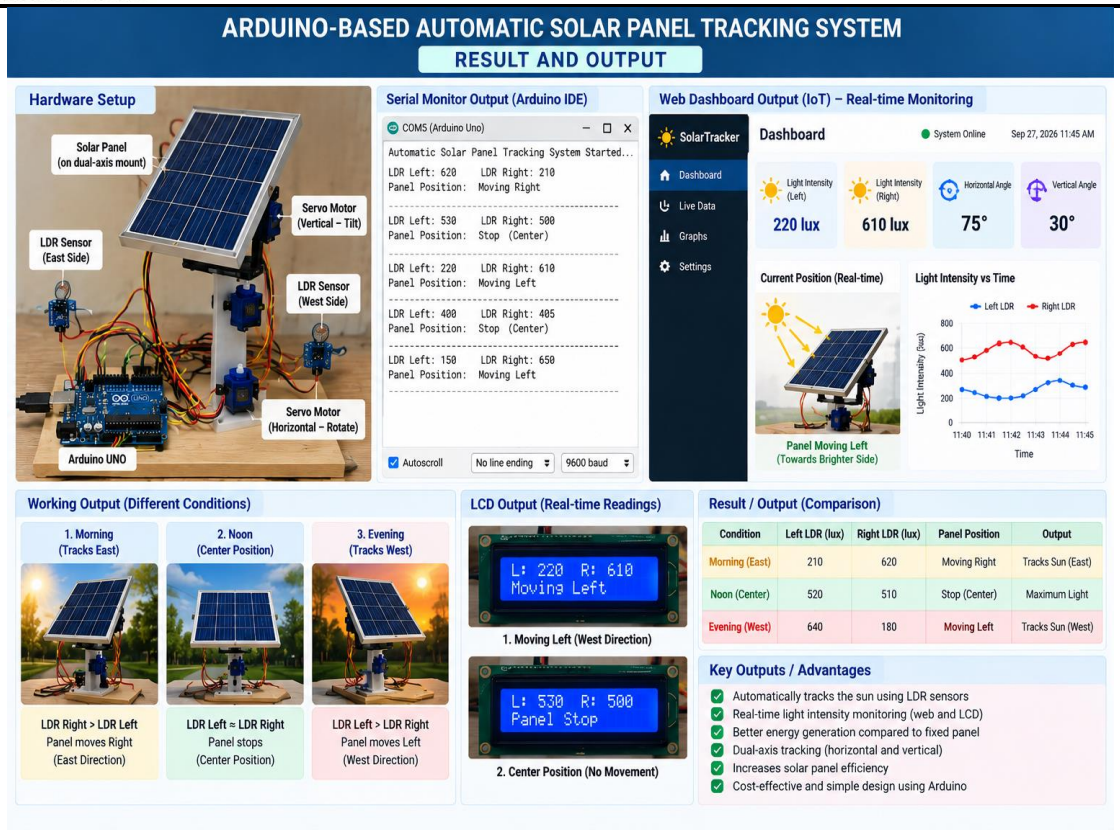


Fig. 1 System Architecture

V. RESULT AND OUTPUT

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VI. CONCLUSION

This paper presented an Arduino based automatic solar panel tracking system that uses four LDRs and two servo motors to keep a 20 W photovoltaic panel pointed towards the sun on two axes. The system measures the electrical output of the panel, charges a battery that also powers the tracker, and reports its performance to a cloud dashboard where it can be compared with a fixed panel under the same conditions.

The field tests confirmed the benefit of tracking. On clear days the tracked panel produced about 31 percent more energy than the fixed panel, with most of the gain coming in the morning and late afternoon when the fixed panel receives light at a steep angle. On partly cloudy days the gain was smaller, about 18 percent, because a larger share of the light is diffuse and comes from the whole sky. The dead band and minimum light threshold prevented the tracker from hunting when clouds passed.

The power budget of the tracker was an important consideration. By checking the sensors every thirty seconds, moving the servos only when the error exceeded the dead band, and detaching the servo signals between movements, the tracker's own consumption was kept to about 3.6 Wh per day, which is a small fraction of the additional energy gained. The discussion of maximum power point tracking also showed that mechanical sun tracking and electrical operating point control address different losses, and that combining them would give the highest yield.

Future work will add a real time clock and solar position equations so that the tracker can follow the sun on overcast days and return accurately at dawn, a wind speed sensor to park the panel flat in strong winds, and an MPPT charge controller in place of the PWM controller. For larger panels, stepper motors with worm gears or linear

actuators would be used to hold position without power. Longer tests across different seasons would give a more complete picture of annual energy gain.

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