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SMART ARDUINO-BASED SOLAR TRACKING SYSTEM FOR ENHANCED PV EFFICIENCY AND SUSTAINABLE POWER GENERATION

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Abstract

With rising global energy demands and heightened environmental concerns, renewable energy has emerged as crucially significant alternative energy sources in contrast to the conventional power plants. The sector of renewable energy is one of the key industries of growth for most countries due to its eco-friendly and financial benefits. Out of all renewable resources, solar power is perhaps the most valuable resource, particularly for rural areas where access to the conventional sources of power could be weak.

The aim of this project is to create a real-time solar tracking system using an Arduino Uno for the purpose of attaining the highest energy harvesting. The system tries to make efficiency optimal by managing the position of the solar panel, which moves dynamically according to the movement of the sun. The project has two broad stages: hardware development and software development. In the hardware component, two light-dependent resistors (LDRs) are used to detect maximum light intensity and position the solar panel to receive maximum energy. A servo motor, as instructed by the Arduino, places the panel according to LDR input. The system efficiency has been tested and compared with a stationary solar panel to find out its performance.

This project provides a cost-effective way of solar tracking, which assists in improving energy efficiency and sustainability in solar power generation.

Keywords – Solar Tracking System, Arduino Uno, Renewable Energy, Energy Efficiency

Introduction

Single Axis and Dual Axis trackers are two broad categories of trackers. Since single axis trackers are tilted approximately once a month to account for seasonal changes in the position of the sun, the single axis is utilized in tracking the day-to-day traversal of the sky by the sun. Dual axis trackers employ one axis to trace the daily sun movement and the other to track the seasonal movement, eliminating the need for monthly adjustment. Based on studies, a single axis solar tracker boosts solar production by approximately 25%, while a twin axis tracker boosts it by approximately 40% [7][8][9].

Since the need for power and the limitations of traditional sources of power, renewable energy has become the focal point. Power is a driver of nation-building globally, but almost all power generation comes from fossil fuels, which are finite and declining [6]. This has given rise to great demand for clean alternative sources of power like solar, geothermal, and ocean tidal power. Among them, photovoltaic (PV) systems stand out as capable of replacing conventional sources since they are easily available and efficient [10][12] Maximizing the amount of sunlight that hits a solar panel is the most important factor for its optimal performance.

Lessons from **wireless sensor networks (WSNs)** in agriculture and environmental monitoring highlight the value of automated, low-cost, and real-time solutions [1][2][3]. Similar approaches used in **flood detection and disaster monitoring systems** [4][5][6]can be adapted into solar tracking to enhance robustness and reliability. These studies collectively emphasize the importance of smart sensing and control technologies in sustainable energy and environmental applications.

One of the best ways to make solar panels more efficient is solar tracking technology, where panels are positioned towards the sun [7][9]. Solar power's versatility makes it a renewable source for energy generation at small scales since it can be harnessed in nearly any location.

This project presents an auto solar tracking system that is not only simple to operate but also simple to program using a microcontroller [11]. The system optimizes sunlight absorption by using light-dependent resistors (LDRs) to measure sunlight. The central control unit is an Arduino Uno that instructs a stepper motor to align the solar panel in the direction of maximum illumination. Stepper motors are chosen since they offer precise control, energy efficiency, stability, and minimal environmental footprint [8].

The research focuses on five important elements of the control system for observing the output power, current, and voltage (P=IV). It also compares and tests the effectiveness of fixed solar panel systems and solar tracking systems. By incorporating this monitoring system, the solar tracker positions the solar panel with respect to light intensity, thus maximizing overall energy efficiency [9][10].

Solar power is an important source of renewable energy praised for its sustainability and environmental advantages. However, to maximize its usage, sunlight must be utilized effectively—and that is where solar tracking systems come in [7][12]. These systems maximize energy generation by positioning solar panels at right angles to the sun's rays throughout the day. Though the benefits are evident, the initial installation cost of solar tracking devices may be too expensive for some. To address this, researchers and engineers have explored new ways of maximizing efficiency at lower costs [11][12].

The Arduino control circuit acts as the core processing unit of the prototype system and regulates its performance [11]. With accurate programming, the system incorporates an LDR sensor to measure sunlight intensity and direction. Once detected, the sensor triggers the control circuit to switch on a Servo Motor mechanism, allowing the solar panel to dynamically adjust its orientation in real-time [8].

This ongoing monitoring of the sun's position during the day enables the solar panel to efficiently capture and utilize the maximum possible solar energy available. In this way, the system optimizes energy yield and overall efficiency, rendering solar power more economically feasible and eco-friendly [9][12].

Methodology

Hardware Components Used

The following hardware components were used in the construction of the solar tracking system [11]:

- **Arduino UNO** – Acts as the main microcontroller for signal processing of input signals and motor movement control.
- **Voltage Regulator (7805) –** Provides a stable 5V power supply to the circuit.

- **Infrared (IR) Sensors with Light-Dependent Resistors (LDRs)** – Senses sunlight intensity to identify the best position for the solar panel [7][8].
- **Solar Panels** – Transforms sunlight into electrical energy.
- **10 RPM Gear Motor** – Offers controlled motion for tilting the solar panel.
- **L298N Motor Driver** – Enables bidirectional control of the gear motor.
- **9V Battery** – Supplies power to system components.

This hardware configuration allows the solar tracker to adjust the panel position dynamically for maximum light intake, thus enhancing efficiency [9][10].

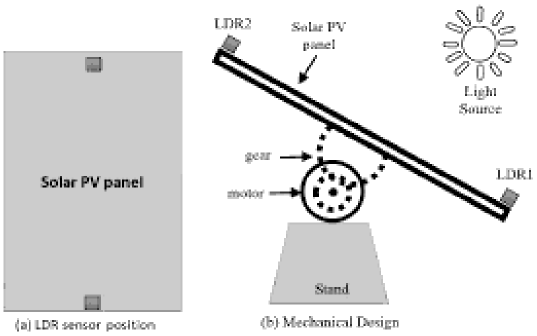
Light-Dependent Resistors (LDRs) Solar tracking systems can be made simple by incorporating low-cost control methods [7]. The simplified systems, however, may not always ensure constantly high efficiency. Different tracking approaches can be employed, such as placing the solar panels at three preselected locations depending on the path of the Sun—daily, yearly, or hourly [8].

The present research proposes a cost-effective approach that uses low-accuracy control mechanisms while keeping photovoltaic (PV) modules within an optimal range of efficiency. This concept is called **Efficiency as a Function of Orientation (EFO)** [9]. It balances cost and performance, ensuring affordability without compromising sufficient energy output [10] [11].

Furthermore, insights from **agriculture automation systems** [1][2][3] and **flood monitoring solutions** [4][5][6] prove that similar low-cost, sensor-driven approaches can be effectively scaled to renewable energy applications, making solar tracking systems more robust and practical for real-world deployment.

A Light Dependent Resistor (LDR) is otherwise called a Cadmium Sulphide (CdS) cell or a photoresistor. It is sometimes called a photoconductor. Basically, an LDR is a photocell which operates according to the law of photoconductivity, with its resistance dropping with increasing incident light intensity.

Essentially, the passive element is a resistor in which resistance value decreases as that of light. The optoelectronic component is used chiefly in circuits for light-varying sensors and light- and dark-activated switching. Camera light meters and street lights are some of its applications. LDR Organization and Functioning: The basic construction of an LDR is illustrated below.



The Cadmium Sulphide (CdS) film along the sides is depicted by the snake track underneath. Metal films are mounted to the terminal leads at the bottom and top such that there is maximum contact area between the two metal layers to facilitate efficient conduction.

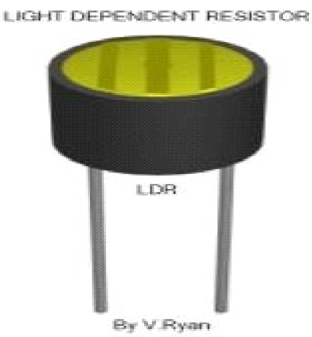
To permit unbroken exposure to outdoor light, the whole device is covered in a transparent plastic or resin housing. As previously stated, cadmium sulphide (CdS) is the major material used in the development of light-dependent resistors

(LDRs). Cadmium sulphide is a photoconductor that shows very high resistance—it is usually in the megaohm order—when it is in darkness because the free electrons are rarely present.

With increasing light exposure, the conductivity of CdS becomes higher since photons impart enough energy to facilitate electrons' move from the valence band to the conduction band. As the light intensity exceeds a critical value, free electrons are emitted by the material, with a considerable decrease in resistance, usually below 1 kilo-ohm.

A resistor that has a falling resistance with greater light intensity is also referred to as a photoresistor, light-dependent resistor (LDR), or CdS cell. It can also be called a photoconductor. Built from a high-resistance semiconductor, an LDR works on the basis that absorbed photons of light give bound electrons sufficient energy to move into the conduction band. This increase in charge carriers increases conductivity, which lowers resistance as light intensity increases.

There are two categories of photoelectric devices: intrinsic and extrinsic. In contrast to an effective semiconductor such as silicon, an intrinsic semiconductor possesses its own charge carriers. As there are only electrons present in the valence band in intrinsic devices, the energy of the photon should be strong enough to excite an electron across the entire band gap. Dopants, or impurities, are introduced into extrinsic devices such that their ground state energy is nearer to the conduction band. This is to say that lower energy photons, or longer wavelengths and lower frequencies, are sufficient to trigger the device as the electrons have less distance to hop. Additional electrons are provided for conduction if impurities like phosphorus atoms substitute some of the atoms in a sample of silicon. This is an example of an extrinsic semiconductor A Light Dependent Resistor (LDR, photo conductor, or photocell) is a component that possesses a resistance which changes based on the amount of light that falls on its surface.



GEAR MOTOR:
The range of output of most synchronous AC electric motors is 1,200–3,600 revolutions per minute. They also have torque parameters for stall speed and normal speed. Gear motors use reduction gear trains, which are designed to provide more torque and lower output speed. The proportion of the increase in torque and the reduction in speed is reciprocal. Mini electric motors can shift large driven loads with reduction gearing, but less quickly than giant electric motors. A smaller gear drives a large gear in a reduction gear. A reduction gear box can include several sets of these reduction gear sets. A gear-driven wheel that transmits a shaft's rotating motion to another shaft.

If the two shafts must turn in the same direction, gear wheels may be employed in pairs or in threes. The ratio of torque, or the difference between the input and output shafts' turning forces, is established by the gear ratio, or the ratio of teeth on the two wheels. The inverse of the gear ratio is the ratio of the angular velocities of the shafts. The most common parallel shaft gear is the spur gear, with teeth straight and in parallel to the shaft axis. The double helical gear with teeth cut in segments of corkscrew or helix form transfers energy most efficiently. Bevel gears are used to connect intersecting shafts since they possess taper teeth on the base of a cone.

ALGORITHM

Step 1: Analyse every analog voltage found on any channel.

Step 2: In the event that all voltages are equal, the gear motor will be stopped.

Step 3 The servo motor will rotate in a clockwise direction if LDR1>LDR2

Step 4:If LDR2>LDR1 Then the down motor will rotate anticlockwise.

L293D :

The L293D is a very common motor driver integrated circuit (IC) meant to drive DC motors in the forward and backward directions. This 16-pin IC is implemented with a dual H-bridge structure so it can power two DC motors in parallel, both of which have bidirectional capability.

The L293D functions on logic inputs to drive the motor's rotation direction:

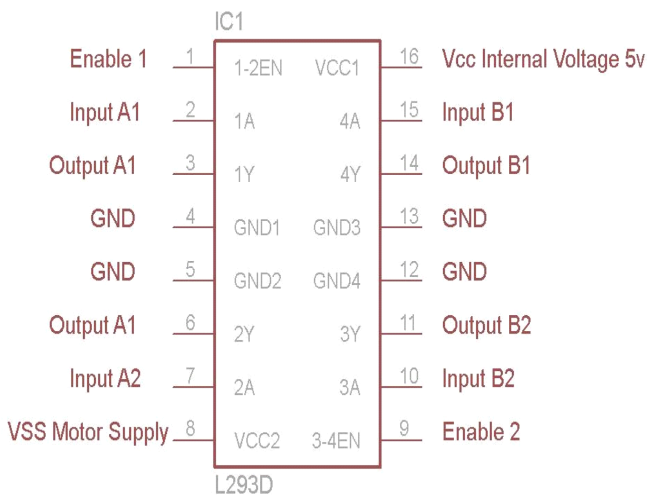
Pin 2 = Logic 1, Pin 7 = Logic 0 → Motor turns in the clockwise direction

Pin 2 = Logic 0, Pin 7 = Logic 1 → Motor spins in the clockwise direction

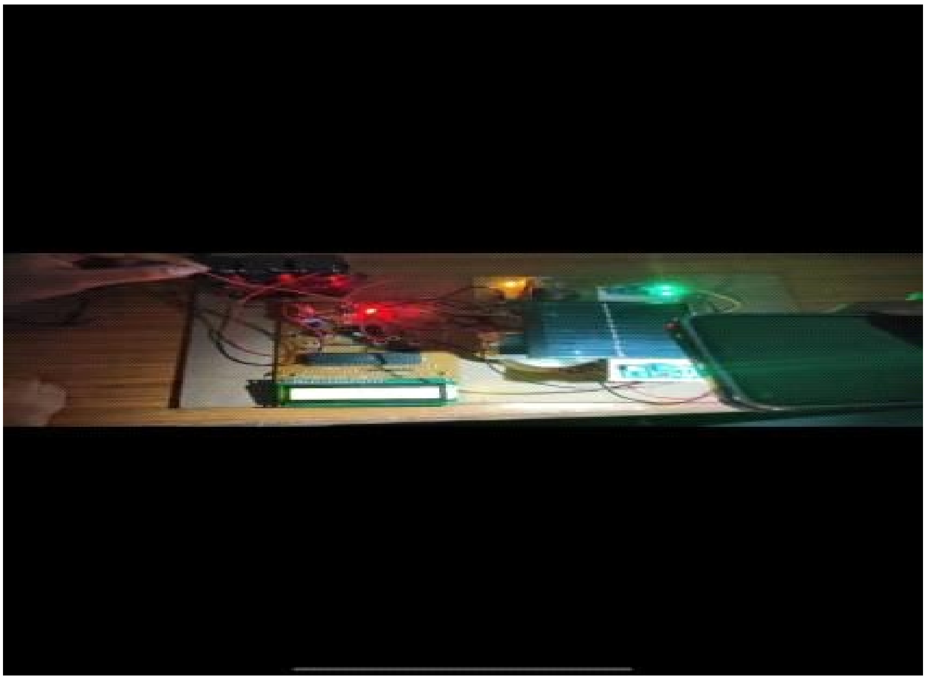
Pin 2 = Logic 0, Pin 7 = Logic 0 → Motor does not move (high-impedance state)

Pin 2 = Logic 1, Pin 7 = Logic 1 → Motor does not move (no spin)

This motor driver IC is largely employed in automation and robotics projects to drive motors in an effective manner.



Results



Conclusion

Since solar trackers get more direct sunlight than their fixed mounts, they generate more electricity. Solar trackers also exist in several forms, ranging from single- to dual-axis models, which may help us choose the perfect one for our specific task location. The perfect solar tracker for us may vary depending on various factors such as installation size, latitude, electrical needs, and local climate. Solar trackers are very efficient when it comes to maximizing land use since they produce more electricity in the same space than fixed-tilt systems do. Their drawback lies in the fact that they are somewhat more costly than stationary systems because they incorporate advanced electronics and also moving parts. Although their performance advantage is remarkable, constant maintenance is normally necessary to guarantee proper functioning. The frequency and degree of maintenance also vary with the quality of the solar tracker, with better quality systems requiring less maintenance.

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