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Designing of Dual-Axis Solar Tracking with Weather Monitoring

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ABSTRACT

This project presents a performance analysis of the dual axis solar tracking using Arduino, LDR and servo motors. It incorporates mainly with the 3 sensors namely DHT11, LDR and Rain drop sensor. Initially the 4 LDR sensors are placed at the edges of the solar panel as a tracking mechanism for the sun radiations and DC motors are connected vertically and horizontally to direct the position of the solar panel such that the panel will maintain perpendicular to the sunlight. The voltage from the panel is calculated from time to time in an interval of 1hr and this voltage is used to sense the weather conditions and climatic temperatures. Initially DHT11 and Rain drop sensors will collaborate to find out the environment conditions based on temperature, humidity and moisture content respectively and it displays on the LCD screen also it includes anti-thefting and energy storing features.

On the other half, the software part is written by using embedded C programming language which head towards the Arduino UNO controller.

Keywords- DHT 11, LDR, Rain drop sensor, Arduino UNO, Servo motors, motor driver, Lithium Battery, Buzzer.

INTRODUCTION

With the unavoidable shortage of fossil fuel sources in the future, renewable types of energy have become a topic of interest for researchers, technicians, investors and decision makers all around the world. New types of energy that are getting attention include hydroelectricity, bio-energy, solar, wind and geothermal energy, tidal power and wave power. Because of their renewability, they are considered as favourable replacements for fossil fuel sources. Among those types of energy, solar photovoltaic (PV) energy is one of the most available resources. This technology has been adopted more widely for residential use nowadays, thanks to research and development activities to improve solar cells performance and lower the cost. According to International Energy Agency (IEA), worldwide PV capacity has grown at 49% per year on average since early 2000s. Solar PV energy is highly expected to become a major source of power in the future.

While the modern tracker tracks east west and north south movement of the sun. In this project we are integrating dual axis solar tracking system with weather sensor. It detects temperature, raindrop and humidity by using sensors and the output of these sensors can be seen in liquid crystal display(LCD). Light detecting resistors(LDR's) which can sense the maximum intensity of light and the Arduino which guides the rotation of servomotors towards the maximum intensity of light is used. Servomotors are used to rotate the solar panel. Sensors are used to sense the weather conditions. From the past million years man has needed and used Energy at an increasing rate for his existence and well-being. Solar energy promises of becoming reliable energy source without any polluting effects. Hence obtaining of maximum energy with this method is more efficient and beneficial.

LITERATURE SURVEY

S. Jain, V. Agarwal [57] presented a new fast tracking algorithm for tracking maximum power point in photovoltaic systems. An initial approximation of maximum power point was quickly achieved using a variable step size. Subsequently, the exact maximum power point was targeted using a conventional method. The strength of the algorithm came from the fact that instead of tracking power, which does not have one to one relationship with duty cycle, it tracked an intermediate variable which had a monotonically increasing one to one relationship. The algorithm was verified on a photovoltaic system modeled in Matlab software.

Weidong Xiao, William G Dunford [59] developed an experimental evaluation method to test the performance of tracking using photovoltaic modules and low cost artificial lights.

D. Shmilovitz [63] proposed that photovoltaic maximum power point tracking can be accomplished by monitoring the readings of the load parameters instead of the photovoltaic panel output parameters.

N. Othman, M. I. A. Manan, Z. Othman, S. A. M. Al Junid have designed a two-axis sun tracking system with the use of five LDRs and an Arduino UNO controller. The objective of this research is to design and construct the automatic dual axis solar tracker for maximum sun energy utilization.

Saravanan., Panneerselvam, M.A.; Christopher, I.W. A novel low cost automatic solar tracking system. *Int. J. Computer Appl.***2011**. A PV system uses a PV module/panel/array to convert solar energy into electric energy. To extract the maximum output power from the PV module, a sun tracker can be used to track the sun direction. In fact about 20%–50% more solar energy can be captured depending on the geographic position by adding a sun tracker to a PV system.

ACCOMPLISHMENT

Smart Embedded System Design:

Developed an intelligent, solar-powered embedded system using the Arduino UNO as the central processing unit for environmental monitoring and automated responses.

LDR-Based Solar Tracking Mechanism:

Integrated **LDR (Light Dependent Resistor)** sensors to detect the intensity and direction of sunlight. This data was used to control DC motors that adjusted the position of the solar panel, ensuring maximum sunlight exposure and energy efficiency.

Efficient Power Management with Charging Circuit:

A charging circuit was implemented between the solar panel and the battery to regulate voltage and current. This ensured safe and stable charging of the battery, which serves as a backup power source for the system.

Environmental Sensing with DHT11 Sensor:

The DHT11 sensor was used to measure temperature and humidity levels in real-time. These values can be used for environmental data logging or triggering further actions based on climatic conditions.

Rain Detection and Protection:

A raindrop sensor was included to detect rainfall. On sensing rain, the system can initiate protective actions such as halting panel movement or issuing visual alerts, improving system durability and performance.

Obstacle and Motion Detection Using IR Sensor:

An IR sensor was employed to detect the presence of nearby objects or movement. This functionality helps in automation safety—for example, pausing a moving mechanism if an obstacle is detected.

Motor Control Using Motor Driver:

A motor driver circuit was connected to the Arduino UNO to manage the operation of DC motors. This allowed for bi-directional control and speed regulation based on sensor inputs, mainly for panel alignment or automated tasks.

User Interface with LCD Display:

An LCD screen was connected to show real-time data such as temperature, humidity, and system status. This provides a user-friendly way to monitor system performance without external devices.

Reliable and Green Power Supply:

The entire system was designed to operate using solar energy, with battery backup to ensure uninterrupted operation. This makes the system energy-efficient, eco-friendly, and suitable for remote or off-grid locations.

FUNCTIONALLY

The operation of the solar-powered embedded automation system is divided into key functional phases, all controlled by the Arduino UNO. The system integrates multiple sensors and modules to perform environmental monitoring and automatic solar tracking. The main functionalities are as follows:

1.System Initialization

On powering the system, the Arduino UNO initializes all connected components including the DHT11 sensor, IR sensor, raindrop sensor, LDRs, motor driver, LCD display, and the power regulation circuit. This ensures all peripherals are active and ready for operation.

2.Environmental Monitoring

DHT11 measures temperature and humidity. Raindrop sensor checks for rainfall conditions.IR sensor detects obstacles near the system. These values are processed by the Arduino in real-time to assess the surroundings.

3.Solar Tracking and Power Management

Using LDR sensors, the system detects sunlight direction and adjusts the orientation of the solar panel via DC motors to capture maximum solar energy. The solar power is then regulated through a charging circuit to safely charge the battery, ensuring uninterrupted power supply.

4. Threshold-Based Response System

If rain is detected or if an obstacle is sensed, the Arduino automatically halts solar panel movement by disabling the motor. This enhances both system safety and durability.

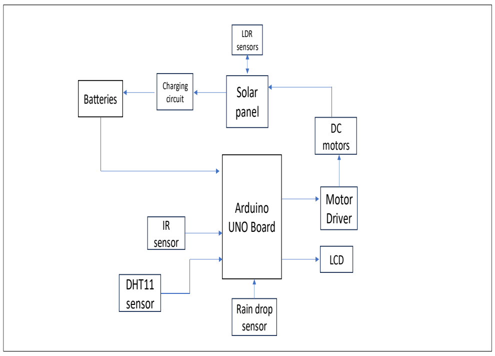
5. User Interface and Feedback

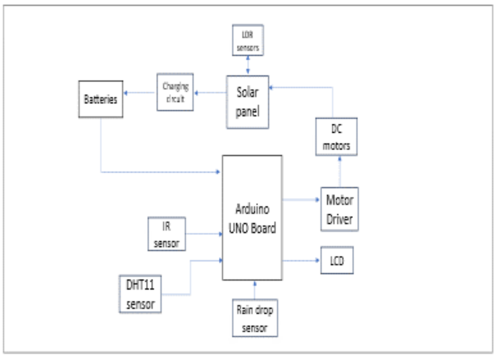
A 16x2 LCD display continuously shows sensor data like temperature, humidity, and system status. This provides the user with immediate and clear feedback on system performance**.**

6. Autonomous Operation and Energy Efficiency

The system functions fully on renewable solar energy, storing excess power in a battery for night-time or low-light use. The setup operates without any external grid dependency, making it ideal for remote or off-grid locations.

METHODOLOGY





1.Power Generation and Storage

A solar panel is used as the primary energy source. It captures solar energy and converts it into electrical energy.The generated power is passed through a charging circuit, which conditions the voltage and current before charging the rechargeable batteries.

The batteries serve as the main power supply for all system components, ensuring continuous operation even during low sunlight conditions.

2.Sensor Integration and Data Acquisition

LDR (Light Dependent Resistor) sensors are placed on the solar panel to detect sunlight intensity from different directions.

DHT11 sensor monitors temperature and humidity in real-time.

A raindrop sensor detects the presence of rain, which is critical for deciding whether to move or retract the panel.An IR sensor is used to detect obstacles or human presence around the device to enhance safety.All sensor outputs are sent to the Arduino UNO for processing.

3. Data Processing and Decision Making (Arduino UNO)

The Arduino UNO microcontroller receives analog and digital signals from the sensors. It evaluates sensor data against pre-set threshold values to make decisions:

If the rain sensor is triggered, the Arduino halts motor activity to protect the solar panel. If the LDRs detect a directional change in sunlight, Arduino adjusts the panel orientation. If the IR sensor detects an object, movement is paused to avoid collision. The Arduino also reads environmental data from the DHT11 sensor to be displayed on the output interface**.**

4. Actuation and Control

Based on the LDR values, the Arduino sends control signals to a motor driver, which then drives DC motors.

These motors adjust the orientation of the solar panel towards the direction of maximum light, ensuring optimal energy harvesting.The motor driver provides the necessary voltage and current amplification to run the motors effectively.

5. Output Display

A 16x2 LCD display is connected to the Arduino to show real-time values of temperature, humidity, and system status (e.g., motor movement, rain detection).This provides the user with continuous feedback on the system's performance.

6. System Autonomy and Efficiency

The entire system is designed to be self-sustaining, using only solar energy and battery backup.

It operates in real-time, requiring no human intervention, and is ideal for remote applications**.**

COMPONENT DESCRIPTION

1.Solar Panel

In this project the solar panel plays a central and multifunctional role. Its primary function is to convert sunlight into electrical energy through photovoltaic cells, serving as the main power source for the entire system. This electrical energy is used to run the Arduino UNO board, sensors (LDR, IR, raindrop, DHT11), LCD display, and to charge the battery via a regulated charging circuit. Unlike conventional static solar setups, this project employs a dual-axis tracking mechanism in which the solar panel is mounted on a frame that can move in both horizontal and vertical directions. Guided by LDR sensors, the Arduino continuously adjusts the panel's orientation to face the direction of maximum sunlight intensity throughout the day, significantly improving power generation efficiency.

2.LDR Sensor

In this project the LDR (Light Dependent Resistor) sensors play a vital role in enabling the dual-axis solar tracking mechanism. These sensors are used to detect the intensity of sunlight from different directions. Typically, four LDRs are positioned at the corners of the solar panel—facing north, south, east, and west. Each LDR varies its resistance depending on the amount of light it receives: the higher the light intensity, the lower the resistance, and vice versa. These varying resistance values are converted into voltage readings and fed into the Arduino UNO. The microcontroller compares these readings to determine where the sunlight is strongest and then sends signals to the motor driver, which adjusts the DC motors to reposition the solar panel accordingly.

3.DC Motors

In this project DC motors are essential components that drive the mechanical movement of the solar panel. These motors are responsible for adjusting the panel's position along two axes horizontal and vertical to ensure it constantly faces the sun for maximum sunlight absorption. The DC motors receive control signals from the Arduino UNO, which processes data from LDR sensors that detect the direction of the strongest sunlight. Based on this input, the Arduino commands the motors, via a motor driver circuit to rotate the panel precisely to the optimal angle.

4.Motor Driver

In this project the motor driver serves as a crucial interface between the low-power control signals from the Arduino UNO and the higher-power DC motors used to move the solar panel. Commonly, an L298N motor driver module is used for this purpose. The Arduino cannot directly power the motors because it can only output small currents, which are insufficient to drive motors. The motor driver solves this issue by receiving low-voltage control signals from the Arduino and using them to control the higher voltage and current required to operate the DC motors.

5.Arduino UNO Board

In the project the Arduino UNO board functions as the central control unit, coordinating all components and executing the system's logic. It processes data from various input sensors including LDRs for sunlight detection, DHT11 for temperature and humidity, raindrop sensor for rainfall detection, and IR sensors for anti-theft monitoring. Based on the real-time data received, the Arduino makes intelligent decisions, such as adjusting the solar panel's orientation via motor driver-controlled DC motors, or triggering safety responses during bad weather conditions.

6.Batteries

In this project lithium-ion batteries play a crucial role in energy storage and power continuity. These rechargeable batteries store the electrical energy generated by the solar panel during daylight hours and supply power to the system when solar energy is not available, such as during the night or on cloudy days. The stored energy ensures that critical components—including the Arduino UNO, sensors, DC motors, and LCD display—continue to function without interruption. Lithium-ion batteries are particularly suitable for this application due to their high energy density, long life cycle, compact size, and low self-discharge rate, making them more efficient and durable compared to traditional lead-acid batteries.

7.IR Sensor

In this project the IR (Infrared) sensor is primarily used as part of the anti-theft system, detecting unauthorized movement or presence near the solar panel setup. The IR sensor works by emitting and detecting infrared light when solar panel is theft, the infrared radiation is reflected back, triggering a change in the sensor's output signal. This signal is sent to the Arduino UNO, which can then activate a response such as sounding a buzzer and displaying on LCD to alert the user locally.

8.Raindrop Sensor

In this project the raindrop sensor is used to detect rainfall and help the system respond appropriately to protect the solar panel. When rain is detected, the sensor sends a signal to the Arduino UNO, which can then stop the movement of the panel or tilt it to a safer angle to prevent water damage to sensitive components. This adds an important weather-responsive feature, allowing the system to adapt to changing environmental conditions and improving its durability and reliability in outdoor installations.

9.LCD (Display)

In this project the LCD (Liquid Crystal Display) is used to visually display real-time system information. It shows key data such as temperature, humidity, rain detection status, and system activity (like panel theft or sensor alerts). Connected to the Arduino UNO, the LCD allows users to monitor the performance and environmental conditions of the system directly on-site, without needing a computer or external device. This enhances user interaction and helps with troubleshooting and system status verification in real time.

Working Principle

This project is an intelligent and autonomous solar energy system designed to optimize energy harvesting while ensuring protection against environmental hazards and unauthorized access. It integrates four core functionalities: dual-axis solar tracking, weather monitoring, anti-theft detection, and energy storage all orchestrated by an Arduino-based control unit.

1. Dual Axis Solar Tracking

The primary goal of the system is to maximize solar energy generation by ensuring the solar panel remains perpendicular to the sun's rays throughout the day. This is achieved using four Light Dependent Resistors (LDRs) strategically placed at the edges of the panel to sense sunlight intensity from different directions. The LDRs output signals to the Arduino UNO, which processes the differences in light levels.

Based on these readings, the Arduino generates control signals for a motor driver module (L298N) that operates two DC motors one controlling horizontal rotation and the other vertical.This dual-axis movement continuously adjusts the solar panel's orientation, improving energy efficiency significantly compared to fixed systems.

2. Weather Monitoring

To safeguard the system against adverse weather, a raindrop sensor is integrated to detect rainfall. When rain is detected, the Arduino halts panel movement and may adjust the panel to a safe position to minimize water impact. Additionally, a DHT11 sensor measures ambient temperature and humidity. These readings help monitor environmental conditions that may affect system performance or component life. The collected data is displayed in real time on an LCD display, providing users with easy access to key environmental parameters.

3. Anti-Theft Mechanism

For physical security, the system incorporates an Infrared (IR) sensor to detect solar panel theft. If solar panel is theft, the IR sensor sends a signal to the Arduino. The controller can then trigger an alert mechanism, such as activating a buzzer and displaying the message on LCD, to detect theft or unauthorized access. This feature is particularly valuable in remote or unattended locations where security is a concern.

4. Energy Storing System

Energy generated by the solar panel is not only used to power the system in real time but is also stored in a lithium-ion battery. A charging circuit ensures safe and regulated charging, protecting the battery from overcharging or deep discharge. The stored energy is used during non-sunny periods (e.g., night or cloudy weather) to keep the system operational, ensuring 24/7

functionality without reliance on external power sources.

5. Control and Display

At the core of the system is the Arduino UNO microcontroller, which integrates all sensor data, performs decision-making, and controls output devices such as motors and alarms. A LCD module is used to display real-time data including temperature, humidity, rain detection status, and system activity. This interface helps users monitor and troubleshoot the system locally.

RESULT

The result of implementing a dual-axis solar tracking system with weather monitoring, anti-theft, and energy storage features is a highly efficient, secure, and reliable solar power solution. The dual-axis tracker increases energy generation by up to 30–40% compared to fixed panels by maintaining optimal panel orientation throughout the day. Weather monitoring allows for automated adjustments and protective actions during harsh conditions, enhancing system longevity. Anti-theft mechanisms reduce the risk of equipment loss and associated downtime. Meanwhile, energy storage ensures continuous power supply during low-sunlight periods or at night, improving the system's usability and effectiveness in remote or off-grid areas. Overall, these integrated features result in better performance, increased energy independence, and reduced maintenance costs.

OBSERVATIONS OF WEATHER SENSOR

Time(hrs)	Temperature (℃)	Humidity (%)
16:00	34	60
19:00	30	80

OBSERVATION OF SOLAR TRACKER

Time(hrs)	Single axis	Dual axis
08:00	04.52	07.88
09:00	06.62	10.51
10:00`	07.15	13.98
11:00	09.33	15.82
12:00	10..42	19.36
13:00	13.77	19.78
14:00	14.79	17.95
15:00	15.56	16.79
16:00	15.22	16.51
17:00	13.55	12.57
18:00	05.83	6.96

The table which is shown above indicates the output values at different time intervals. As we know dual axis solar tracker is more productive than single axis solar tracker, comparison of output voltages of both the tracking methods is done.

CONCLUSION

The implementation of a dual-axis solar tracking system integrated with weather monitoring, anti-theft, and energy storage features significantly enhances the overall efficiency, security, and reliability of solar energy solutions. The dual-axis tracking mechanism ensures maximum sunlight capture throughout the day, increasing energy yield compared to fixed systems. The weather monitoring component provides real-time data to optimize energy generation and protect the system from adverse conditions, while the anti-theft measures safeguard valuable equipment, ensuring uninterrupted operation. Additionally, the inclusion of energy storage allows for consistent power supply during periods of low sunlight or at night, making the system more dependable and suitable for off-grid applications. Altogether, this comprehensive approach contributes to a smarter, more sustainable, and secure renewable energy system.

FUTURE SCOPE

Here is the **future scope** of a dual-axis solar tracking system integrated with weather monitoring, anti-theft, and energy storage features:

- **Integration with Smart Grids**: Future systems can be connected to smart grids, allowing automated energy distribution, demand-response functionality, and enhanced grid stability.
- **AI and IoT Enhancements**: Incorporating artificial intelligence and Internet of Things (IoT) technologies can enable predictive tracking, fault detection, and remote diagnostics, further improving efficiency and reliability.
- **Scalability for Urban and Rural Deployment**: As costs decrease, such systems can be widely deployed in both urban rooftops and rural off-grid locations, increasing energy access and sustainability.
- **Advanced Weather Prediction Models**: More accurate weather forecasting can allow prevent system adjustments, protecting hardware and optimizing power output.
- **Enhanced Energy Storage Solutions**: Future developments in battery technologies (e.g., solid-state batteries or green hydrogen) can increase storage capacity and lifespan, improving power reliability.

- **Blockchain for Energy Transactions**: Blockchain could be used for secure, transparent energy trading between users in a decentralized grid setup.
- **Modular and Portable Designs**: Future systems may feature modular, lightweight designs for easier transport, installation, and maintenance, especially in remote or disaster-prone areas.
- **Environmental Impact Monitoring**: Integration of sensors to monitor environmental parameters can support sustainability assessments and regulatory compliance.

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