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Design of Sun Tracking Solar Rover Control with Mobile Application

Parvateesam Kunda[1a], Veera Venkata Durga Sai Ram Pavan Mutyala[2b], Durga Srinivas Medidi[3c], Manikanta Natte[4d], Kumar Swami Kurmapu[5e]

[1] *Assistant Professor, Dept of Electronics and Communication Engineering, Godavari Institute of Engineering and Technology, Rajahmundry, India*

[2345] *UG Student, Dept of Electronics and Communication Engineering, Godavari Institute of Engineering and Technology, Rajahmundry, India*

Author emails

[a]kundaparvateesam@ggu.edu.in, [b]mutyalarampavan@gmail.com, [c]durgasrinivasmedidi@gmail.com, [d]manikantanatte95@gmail.com , [e]kurmapukumarananl@gmail.com

Abstract. The fast-growing renewable energy demand has increased the necessity for advanced systems that can solar electricity capturing efficiently. Conventional fixed solar panels suffer from lower productivity because they cannot follow the sun's incessant movement. The project, Design of Sun Tracking sun Rover Control with Mobile Application, introduces a creative Internet of Things (IoT) solution that merges dual-axis sun tracking with a mobile robot platform. The system uses Light Dependent Resistors (LDRs) to measure the intensity of the sunlight and rotates the solar panel along both the azimuth and elevation axes automatically for optimal exposure to sunlight during the day. The energy collection is significantly boosted by an Arduino-based control unit that processes the information from the sensors and controls the servo motors for exact and instantaneous solar tracking as compared to the static systems. The proposed rover not only comes with solar tracking but also mobility, obstacle avoidance, and IoT-enabled monitoring to enhance functionality and ease of use. The solar panel that has been tracked is responsible for charging the lithium battery that can be recycled, which in turn, supplies power to the DC motors that are controlled by a motor driver. The real-time monitoring of battery status, GPS location, and system performance is actually being done through a NodeMCU (ESP8266) module that enables wireless connection with the Blynk mobile app. The system's ability to be remotely controlled and monitored through the mobile interface has resulted in increased operational flexibility that can be tapped by applications in agriculture, remote monitoring, off-grid power generation, and educational research.

INTRODUCTION

The global demand for clean and sustainable energy has been the main reason behind the rapid acceleration of research and development in renewable energy technology, and among the various sources of energy, solar power has been occupying the most reliable and eco-friendly position. Besides, solar energy can be rightly considered a powerful alternative to fossil fuels in the carbon emission reduction and climate change perpetuation process because, in essence, it is inexhaustible, non-polluting, and universally accessible [1], [2]. On the contrary, the solar energy systems performance is greatly impacted by the orientation of the photovoltaic panels to the sun. A considerable amount of energy is lost when the sun is not at its peak because of the conventional fixed solar panels that cannot adjust to optimal alignment throughout the day [3]. Therefore, the necessity of keeping solar power converting devices in the best position has resulted in the advent of smart solar tracking technologies as one of the ways to enhance power generating efficiency [4].

Solar tracking devices are designed to dynamically alter the orientation of solar panels so that the sun's path from east to west is followed. According to research [5], energy output can be up to three times higher for single-axis and dual-axis tracking systems as compared to fixed installations. Dual-axis solar tracking systems can change the azimuth and altitude angles, thus exposing the panels to the sun for the whole day and the whole year [6]. Sensor-based tracking methods that make use of Light Dependent Resistors (LDRs) and microcontroller-based control units have become popular due to their simplicity, low cost, and real-time adaptability [7].

The merging of solar monitoring with mobile robotic platforms has opened up new avenues for energy harvesting that is flexible and adaptable. Solar rovers, which are the result of the union of mobility and cognitive tracking, allow systems to relocate themselves to escape barriers, shadows, or rough ground [8]. Such technologies are of great value in secluded research areas where there is no possibility of erecting fixed installations, places without electricity, farming areas, and regions affected by natural disasters. Furthermore, the operational and robust characteristics of solar rover systems are enhanced through the integration of autonomous navigation, obstacle detection, and smart power management [9].

Moreover, the combination of mobile applications and IoT technology has transformed traditional solar systems into smart and engaging platforms. Mobile applications provide remote control and data logging, while IoT monitoring allows for the real-time observation of system parameters such as battery status, energy output, and location [10]. The Mobile Application-based Sun Tracking Solar Rover Control, as proposed, provides a complete and intelligent solution that not only observes solar energy use and guarantees the major factors of flexibility, independence, and user-friendliness by overlapping dual-axis solar tracking, rover mobility, and IoT-based mobile monitoring.

LITERATURE SURVEY

Numerous studies have revealed that fixed solar panel systems suffer from limitations that significantly decrease their capacity to gather solar energy. Research reports indicate that the static panels are not able to produce as much energy as the sun's movement during the day and thus are less efficient in the morning and evening [1], [2]. The development of solar tracking systems was one way of counteracting this problem as it made the sun's movement easier for the panels to follow.

Monotype trackers were the focus of early research which indicated small efficiency improvements but they still could not escape the limitation of not being able to change with the sun's elevation during the seasons [3]. Hence, the researchers were motivated by these findings to experiment with and try out more advanced tracking systems.

Due to the capability of changing both the azimuth and elevation angles for capturing the maximum solar irradiance, the dual-axis solar tracking systems have been the subject of extensive research. The results of the studies published indicated that dual-axis trackers could raise the efficiency of energy usage by 30–45% in relation to fixed panels [4], [5]. A lot of research works were done using Arduino platforms and microcontroller-based setups with LDR sensors for measuring sunlight intensity and controlling servo motors for precise alignment of the panels [6]. The systems were found to be reliable, inexpensive, and suitable for educational and small scale use.

The recent developments are mainly around the coupling of solar tracking with robotic mobility. The study of solar-powered rovers shows that the tracking and mobility merging is a great support for the systems to orient themselves in a way that they will not be obstructed or covered by the shadow of [7]. Mobile solar platforms have been proposed for the applications like remote power generation, environmental data collection, and agricultural monitoring. In their research, to make such rovers more independent and safer, they have also considered ways of managing energy by means of battery monitoring systems [8].

The rise of Internet of Things (IoT) technologies has led to the incorporation of mobile applications and cloud-based monitoring in a few instances of the solar tracking system by the different researchers. The IoT-enabled platforms allow the metrics like voltage, current, battery level, and GPS location to be viewed in real-time [9]. Mobile apps made using the Blynk platform feature data logging, remote access, and manual control. On the other hand, comprehensive systems with dual-axis tracking, rover mobility, obstacle avoidance, and IoT-based mobile control are still infrequent despite earlier studies confirming the effectiveness of each individual component [10]. The proposed Sun Tracking Solar Rover with Mobile Application is thus a result of this void.

Recent research has underlined the importance of not only energy management but also energy storage in solar tracking and mobile solar systems. Studies have investigated the possibility of using rechargeable lithium-ion batteries along with charge controllers in storing excess solar energy and supplying power during the night or low light [11]. The available literature has amply discussed the various Maximum Power Point Tracking (MPPT) techniques as a very effective means of extracting the maximum power from the system under different irradiance conditions [12]. It has been proved that the integration of MPPT with solar tracking systems leads to an improvement in the entire system’s performance.

On top of that, the innovations in wireless communication and embedded technologies have paved the way for smarter and more autonomous solar platforms. The real-time data transmission to cloud servers and mobile apps using Wi-Fi-enabled microcontrollers such as ESP8266 and ESP32 has been investigated in several studies [13]. These technologies offer data analytics-based performance enhancement, predictive maintenance, and remote fault finding [14]. In addition, a combination of AI and adaptive control algorithms is already being investigated in research to increase tracking accuracy and reduce mechanical wear [15]. Furthermore, the integrated sun-tracking solar rover architectures are progressively being pointed out as an important area for research/industrial application and are embodying a trend of intelligent, self-optimizing solar systems.

PROPOSED METHODOLOGY

The proposed method centers on the creation and installation of a smart Sun Tracking Solar Rover that incorporates all the features of robotic movement, dual-axis solar tracking, and IoT-based mobile monitoring. The system is designed around a microcontroller-based control architecture that keeps on monitoring system and environmental parameters in order to optimize solar energy harvesting. Light Dependent Resistors (LDRs) are placed around the solar panel in such a way that they can sense changes in sunlight intensity. The control unit finds out the sun’s perfect position and then rotates the solar panels according to the changes in the sensor readings. By making sure the solar panel is always in the sun’s track during the day, this feedback mechanism in real time significantly enhances the power collecting efficiency.

The vertical (tilt) and horizontal (azimuth) movements of the solar panel in a dual-axis solar tracking system are controlled by two servo motors. To rotate the servo motors smoothly and accurately, the microcontroller processes the data from the LDRs and generates very exact control signals. Thus, the system is equipped to handle both the variations in solar elevation due to seasonal changes and daily movements of the sun. Through the continuous monitoring of sensor values, the tracking algorithm is able to reduce the tracking error and conserve energy by limiting unnecessary motor rotations, thus softly adjusting the angles of the panel.

A platform designed as a rover with DC motors as the driving force and a motor driver as the controller carries out the motion of the system. The rover can reposition itself to get optimal sunlight or can cross different grounds to keep out of the shades. An ultrasonic sensor detects obstacles in the vicinity, the rover can either stop or change direction to prevent collisions. Moreover, the rover can be manually controlled whenever needed by an RF-based remote control system that provides the flexibility between autonomous and user-controlled operational modes.

The system is enhanced with IoT functionalities which are made possible by a Wi-Fi-enabled microcontroller connected to a cloud-based mobile application. The mobile interface gets live broadcasts of essential parameters such as battery voltage, GPS position, and system state. Through the mobile app, users are allowed to access data, check performance from afar, and even take charge of the system’s workings if required. The solar panel captures the energy, which is then stored in the rechargeable battery from which the tracking system, rover motors, and communication modules draw power, thus ensuring that the system operates reliably and non-stop.

Methodology

A Framework for Real-Time Monitoring and Multi-Sensor Data Acquisition is Described

The proposed system is built upon a multi-sensor concept, which helps in collecting real-time operational and environmental data, so that rover control and solar tracking can be performed efficiently. The position of the sun can be correctly pointed out thanks to the use of Light Dependent Resistors (LDRs), which measure sunlight intensity from different directions. The control unit receives continuous feedback from these sensors, which are the main input for the sun tracking system.

Apart from light sensing, the technology uses a GPS module to determine the rover's exact geographic coordinates. Consequently, the mobile application can keep track of the location remotely, and the monitoring based on the location is made better. To make sure that the power usage during operation is both safe and effective, a voltage sensor is integrated to check the battery condition as well.

The IoT technology is utilized by the embedded controller to first process all sensor data, after which the data is sent to a mobile application based in the cloud. The platform for monitoring in real-time which is provided by this technology improves the transparency of operations and the reliability of systems by making it possible to tell remotely the battery health, and the location of the rover, as well as the performance of the system.

Embedded Logic and IoT Platform Architecture

The selection of Arduino microcontrollers was for the purpose of developing the embedded processing logic of the system which enabled proper coordination of sensing, decision-making, and actuation. The main controller, by means of the LDR sensors, figures out the best solar panel position and, additionally, calculates the differential light intensity values. The output of this logic is then turned into control signals that move the servo motors for dual-axis solar tracking.

The secondary controller, which gets its commands through an RF module, is dedicated to Rover mobility. This splitting of control tasks not only prevents processing overload but also improves system stability. The motor driver is responsible for providing an interface between the controller and the DC motors to ensure accurate and smooth vehicle movement.

The NodeMCU (ESP8266) module provides wireless communication to a cloud-based mobile app for IoT integration. The live transfer of sensor data and system parameters allows the user to monitor the system remotely, visualize the data, and interact more with the mobile interface.

Autonomous Actuation and Safety Mechanisms for Vehicles

The rover's self-actuation system is responsible for making the adjustments of solar panel orientation and vehicle speed without any human interaction. The system's ability to constantly optimize the solar panel position made possible by the high-precision servo motors controlling its rotation in the horizontal and vertical directions is another great asset for energy harvesting. This independent actuation results in much higher energy harvesting efficiency.

Motor driver controlled DC motors allow the rover to move in all directions, forward and backward. Such versatility in the technology leads to a variety of practical applications as it works in both autonomous and manual control modes. If needed, the rover can move on its own to a more suitable place with the help of the sun for better energy absorption.

An ultrasonic sensor is used for safety enhancement through collision avoidance and obstacle detection. The technology automatically performs a halt or even a course reversal whenever it senses an obstacle within a pre-defined range. Moreover, the monitoring of battery voltage prevents deep discharge, thus ensuring the system's reliable and safe operation.

System Architecture

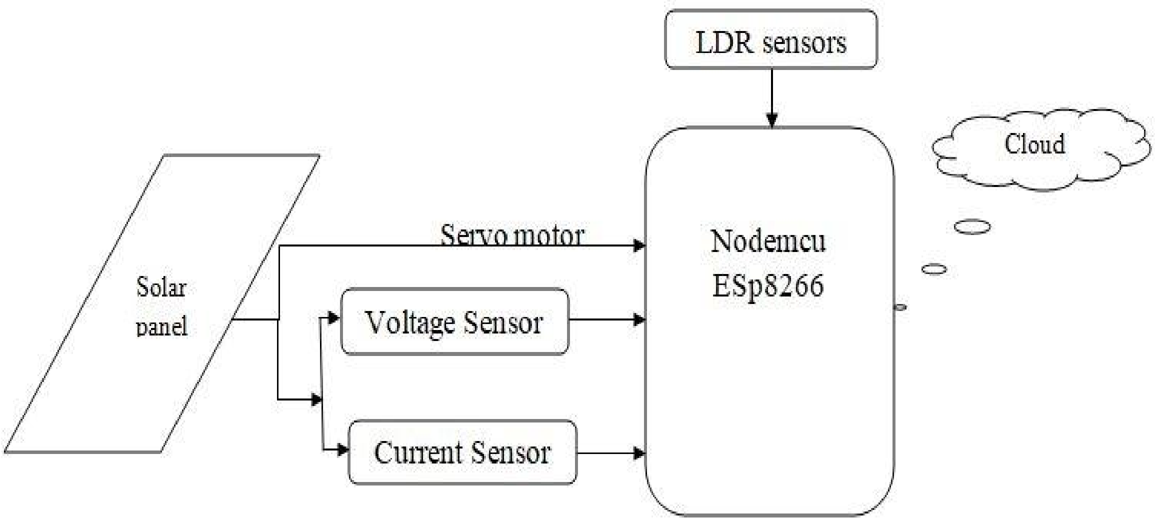

Figure 1 Architecture Diagram

RESULT

The solar-powered rover prototype that has been made demonstrates the possibility of physically integrating the sun tracking, mobility, and control systems into one working platform. The picture depicts the rover on a four-wheel chassis with DC motors ensuring its mobility is smooth on flat lab surfaces. A dual-axis mechanical system, supported by a solar panel, which is capable of rotating both horizontally and vertically, is powered by servo motors. The surrounding area of the solar panel is equipped with Light Dependent Resistors (LDRs), which detect the changes in the intensity of sunlight, thereby enabling real-time sun tracking. The small size of the electronic modules draws attention to the modular hardware design and the efficient use of the space available.

The preliminary model proves that it is possible to merge robotic movement with solar energy collection. The microcontrollers, motor drivers, and sensors on the robot collaborate to perform the tasks independently. The components' structural alignment ensures that there will be no mechanical instability while the motion takes place and the panel is being rotated. The rover's experimental observation confirms its capability of remaining steady even when the solar panel orientation changes. This photograph shows the complete working hardware model that proves the proposed design can work intelligently, being a solar tracking system with self-sufficiency that is suitable for off-grid and outdoor environments.

The image shows the effectiveness of the dual-axis solar tracking system of the rover. In the top view, the solar panel placed on a rotating platform with several LDR sensor units around it is easily seen. The controller built into the system gets the information from these sensors, which are always measuring light intensity from different angles. The system adjusts the panel's position along the azimuth and elevation axes according to the light readings that vary from one side to the other. This setup ensures that the solar irradiance is captured to the maximum throughout the day.

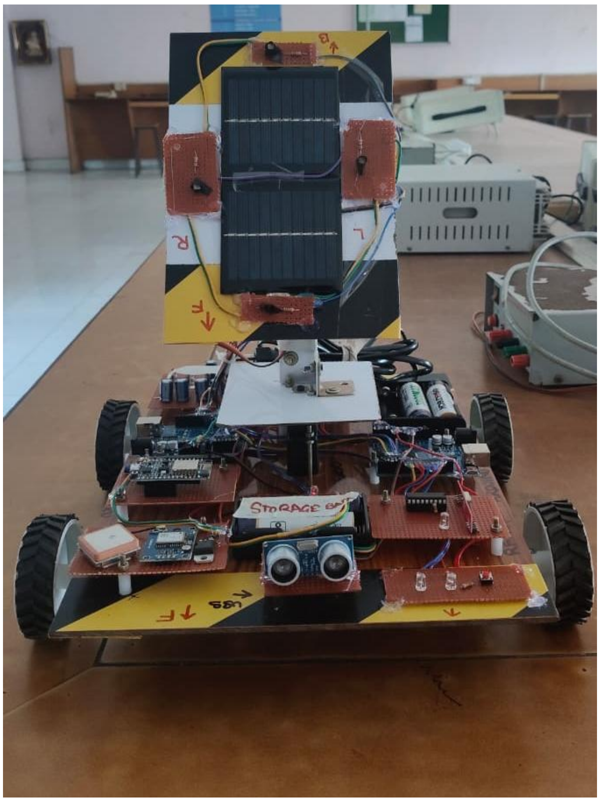

Figure 2 Solar Rover Prototype

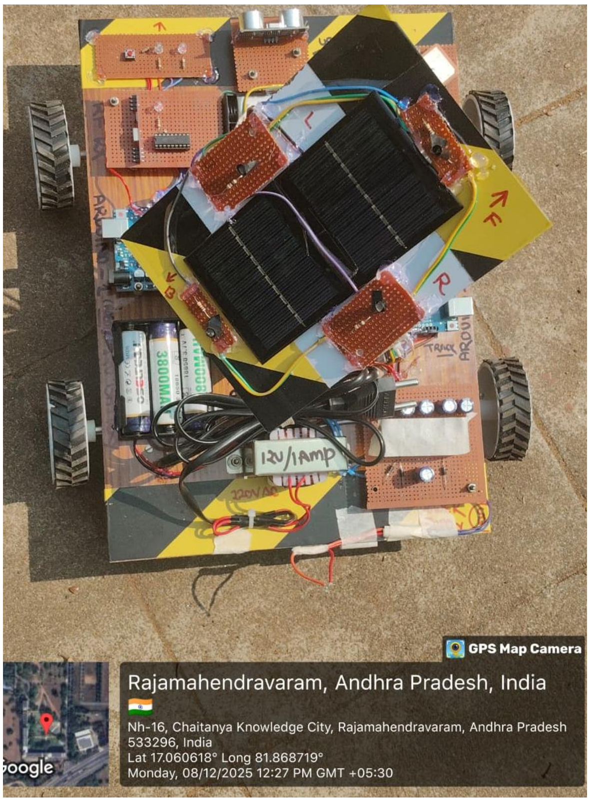

Figure 3 Dual-Axis Tracking

The results of the experiment suggest that the panel is able to find its way toward the most brilliant light all by itself. The motion of the servo motors, which was very precise and smooth, is an evidence of the rightness of the control algorithm. The rotating solar panel guarantees perfect absorption of light even when the sun's position changes, while stationary solar panel suffers loss of light. It is through this result that one could deduce the efficiency of dual-axis tracking which ultimately translates to an increase in energy production and a faster battery charge for uninterrupted rover operation. Real-time system monitoring and successful IoT integration are confirmed by the mobile application interface seen in this picture. The application shows crucial information including the rover's latitude, longitude, battery percentage, and distance traveled. A Wi-Fi-capable microcontroller linked to a cloud-based IoT platform facilitates data transfer from the rover to the mobile application. Stable connectivity between the embedded system and the mobile interface is indicated by the real-time updates.

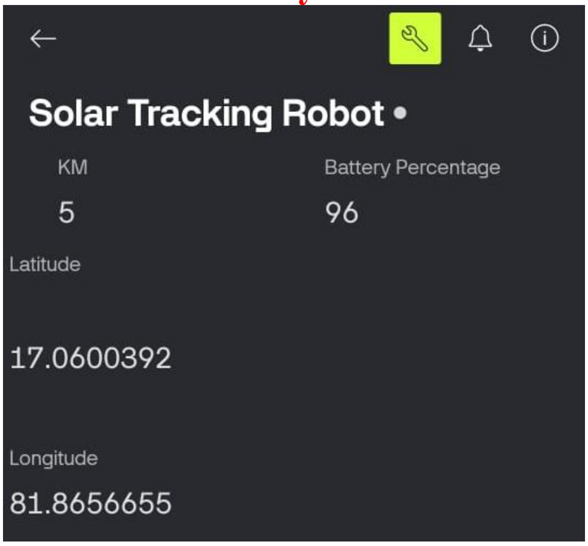

Figure 4 Mobile App Monitoring

This result demonstrates that it is not necessary for users to be physically present at the solar rover site for them to be able to check remotely how the solar rover is working. The display of battery % allows for proactive energy management, and GPS coordinates allow for exact location tracking during the outdoor deployment. The application's simple, fast, and easy-to-use design can be utilized by both tech-savvy and non-tech-savvy users. This is a proof of the system's capability of achieving better operational control, data visualization, and remote supervision.

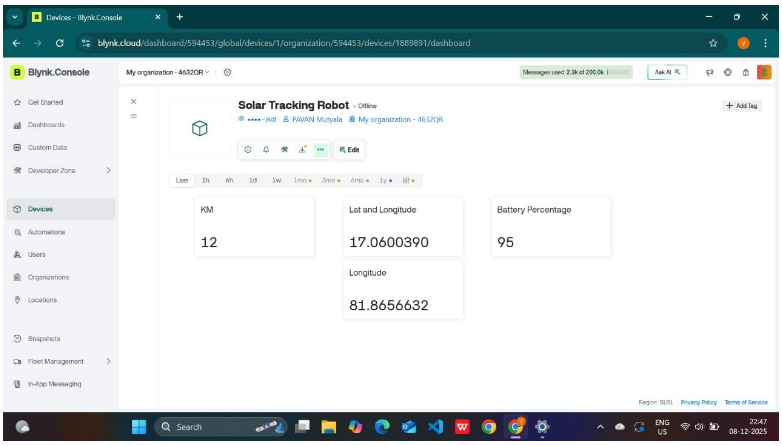

Figure 5 Cloud Dashboard Output

The confirmation of the successful long-term data logging and performance visualization of the solar rover comes from the cloud-based dashboard output. The dashboard is displaying the data that is obtained from the rover such as GPS locations, battery status, and distance measurements. These readings are stored on the cloud server and are being regularly updated, which allows to examine the historical data and evaluate the performance. The dashboard proves that the system has maintained connection and functionality for a long time. The reliability of the project's IoT communication architecture is shown by this result. By cloud monitoring, users are able to see remotely the movement patterns, battery health, and system behavior trends. Such data is an asset to predictive maintenance, defect detection, and system optimization, among others. The recommended solar rover system is versatile and suitable for real-life applications like remote monitoring, smart farming, and energy systems that work independently, as proven by the successful implementation of cloud-based monitoring.

The experimental results confirm the effectiveness of the combined hardware and software architecture, indicating the proposed Sun Tracking Solar Rover works reliably in real-time. The solar tracking system that moved in two directions helped double power production by always keeping the solar panel facing the spot where the light was the strongest, in contrast to the fixed panels. The mobile unit's successfully operating features, which include movement and obstacle detection, allowed for solar tracking without affecting the rover's stable navigation. Through the IoT-based monitoring system via the cloud dashboard and mobile app, a strong wireless link was established, providing accurate real-time updates about the battery status, GPS location, and operating conditions. The whole system by making use of proper energy consumption, delivering self-sufficient operation, and providing reliable remote monitoring has proved its worth in off-grid and smart renewable energy applications.

CONCLUSION

The Sun Tracking Solar Rover Control with Mobile Application has superbly showcased an intelligent, self-sufficient, and power-efficient solar energy usage method. By integrating a mobile rover platform with a dual-axis solar tracking system, the device brilliantly overcomes the limitations of stationary solar panels. The binary approach of LDR-based sensing and embedded control continuously optimizes the solar panel's position for maximum sunlight, leading to improved energy harvesting efficiency. The integration of sensors, controllers, actuators, and power management units during testing was a reliable hardware demonstration. In the end, the prototype developed clearly shows that the combination of robotics and embedded technology with renewable energy systems is indeed a way for effective, self-sustaining operation even in dynamic conditions.

The results from the experiments confirm that the rover performs excellently using solar tracking, smooth motion, and effective obstacle detection. The dual-axis tracking mechanism that ensured accurate panel orientation in different sunlight conditions allowed for consistent battery charge and longer operating times. The solar tracking and rover movement control logic separation significantly enhanced system reliability and reduced processing overhead. Besides, the ultrasonic sensors-based protective mechanism successfully avoided collisions, thereby securing safe navigation. These results strengthen the proposed method's reliability and demonstrate that the system can function autonomously with minimal human intervention in both indoor and outdoor environments.

Furthermore, the integration of IoT and mobile app control had a significant impact on the overall improvement of system usability and monitoring features. The mobile app together with the cloud dashboard performed real-time visualization of battery percentage, GPS location, and operational metrics, and thus, the whole process was turned into effective remote monitoring. This interconnection means that users can track rover movement, manage energy usage, and study performance trends from anywhere. The whole system architecture which considers scalability, flexibility, and sustainability is a great point for diverse applications like smart farming, remote monitoring, off-grid energy production, and educational research. Thus, the proposed solar rover is an effective and clever solution for both intelligent automation systems and renewable energy.

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