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Development of Smart Solar Charge Controller on Wiznet W5500 IoT Platform

Srujan Manohar M.V.N.[1], Varun O.A.[2], Lavanya P.[3], Sathwik Y.[4], Madhu M.[5]

[1]Assistant Professor, [2-5]UG Students, Department of Internet of Things, Malla Reddy University, Hyderabad, India

E-mail: [1]drmvn_srujanmanohar@mallareddyuniversity.ac.in [2]2111CS050009@mallareddyuniversity.ac.in, [3]2111CS050029@mallareddyuniversity.ac.in, [4]2111CS050041@mallareddyuniversity.ac.in, [5]2111CS050031@mallareddyuniversity.ac.in

Abstract

The research represents a significant advance in solar energy technology, taking inspiration from nature's own efficiency mechanisms, particularly the heliotropic behavior of sunflowers. This research proposes the development and implementation of a solar energy system that dynamically adjusts the position of solar panels to track the movement of the sun throughout the day, maximizing energy capture and efficiency. The system uses a biomimetic approach, replicating the natural response of sunflowers to optimize exposure to sunlight. The main components of the system include LDR sensors for real-time sun position tracking, actuators for panel orientation adjustments, and a central control unit to manage system operations. This proposed study aims to address the limitations of traditional fixed solar panel systems, which are unable to adapt to changing sunlight angles throughout the day. The proposed system is also includes a MPPT based solar charge controller, with its response accessible through web servers and laptops/cell phones. The W5500 web server module integrated into the system serves as an IoT platform. Since web servers are platform-independent, they can be supported in cell phones/laptops allowing users to request relay evaluations and monitor solar charge controllers through the W5500 modules. The system can display battery charging status under various weather conditions and can be further enhanced to track other devices. The solar charge controller features multiple modules that enable IoT

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functionality, such as WIZNET (W5500), Arduino Nano (Atmega 328p), ESP32, solar panels, servo which are low cost and energy efficient.

Keywords: MPPT Module CN3791, Solar Panels (5V), Servo Motors (90g), Arduino Nano, WIZNET W5500, ESP 32.

1. Introduction

Solar energy is the most abundant type of renewable energy available. This is because solar energy can range widely in power output, from a few watts to several megawatts. Implementing solar energy can range from a single, modest home using a few watts to meeting large industrial needs requiring many megawatts. Solar energy is typically employed as a renewable energy supplement to conventional commercial energy system for use in homes or small-scale businesses. This additional energy is stored in a battery backup after being extracted from the solar panels. The load receives this stored energy as supplemental electricity from the inverter. Different criteria govern the storage of energy from the solar panels, determined by the energy provided by back up. The 12V, 24V, 48V, 110V, or 240V DC standards are among them. As a result, one, two, four, ten, or twenty batteries are connected in series to form the backup. Likewise, in order to store energy in the battery, the solar panels has to be connected in series.

The market is filled with several kinds of solar charge controllers. The charge controllers store the energy from the solar panel to the backup battery using various approaches. PWM and MPPT-based solar charge controllers are the most commonly used types of solar charge controllers. Controlling the DC energy flow to meet the needs of the battery backup is the main goal of solar charge controllers. With the charge controller that adjusts solar energy according to the battery's needs, the battery's longevity will increase.

1.1 Objective

With the aim of enhancing existing solar chargers, this study's objectives are:

(1) To maximize energy capture and efficiency by dynamically adjusting the orientation of solar panels to track the sun's movement throughout the day.

(2) The integration of an efficient Maximum Power Point Tracking (MPPT) based solar charge controller, along with web servers and IoT capabilities. By utilizing components such as the Arduino Nano, Ethernet Shield 2 (W5500), and solar panels.

1.2 Problem Statement

Traditional solar panel systems face efficiency challenges due to their fixed orientation, resulting in suboptimal energy capture as the sun moves. Due to their immobility, conventional solar panels face performance- challenges that result in poor energy absorption during sunset. Additionally, their ineffective Maximum Power Point Tracking (MPPT) can lead to unpredictable charging and shortened battery life, resulting in inefficient energy conversion.

The following problems are addressed through the suggested dynamic solar tracking generation

1. Dynamic Panel Adjustment: Arduino nano continuously adjusts the panels using LDR sensors and servomotors to ensure correct solar alignment and maximize energy efficiency.

2. Improved Electricity Conversion: To ensure efficient energy conversion, the MPPT_CN3791 module continuously adjusts the settings to operate the panel at its Maximum Power Point (MPP).

3. Real-Time Monitoring: Improves usability and reliability through integrating IoT with ESP32 and WIZNET W5500 for remote monitoring and control. However, they suffer from ineffective Maximum Power Point Tracking (MPPT), resulting in inefficient energy conversion and shorter battery life due to inconsistent charging.

4. Extended Battery Life: Maintains optimal charging conditions to prevent overcharging and undercharging, extending battery lifespan.

1.3 Requirements

- **Software Requirements**

Arduino IDE, Installed Libraries(Servo, Ethernet), Blynk.io platform.

- **Hardware Requirements**

Arduino Nano's, Buck converter, LCD display, Solar Panels(6v – 70mAh), LDR's, Wiznet W5500, Servo Motors, DC motor, L293D Motor Driver, Battery (Li-on / Lead Acid), Current Sensor, Mosfet's, Resistors.

1.4 Components and Methods

- **Tracking the Sun's Position**: The system employs Light Dependent Resistor (LDR) sensors to track the sun's position in real-time. These sensors provide input to the central control unit, which adjusts the orientation of the solar panels using servo motors.
- **Panel Adjustment**: The control unit, based on the LDR sensor data, sends signals to the servo motors to adjust the solar panels' angle. This ensures the panels are always oriented towards the sun for maximum exposure.
- **MPPT Parameters Adjustment**: The MPPT_CN3791 controller adjusts parameters such as voltage and current to ensure the solar panel operates at its Maximum Power Point (MPP). This continuous adjustment optimizes energy conversion efficiency. The Table.1 below shows the solar panel output and the tracker adjustments.

Table 1. Solar Panel Output and the Tracker Adjustments

Time	Sunlight Intensity	Solar Panel Output (V)	Tracker Adjustment
08:00	Low	6V	East
10:00	Medium	10V	South-East
12:00	High	12V	South
14:00	High	12V	South-West
16:00	Medium	10V	West
18:00	Low	6V	North-West

1.5 MPPT_CN3791 Optimization

The MPPT_CN3791 module enhances power conversion by dynamically adjusting the electrical load seen by the solar panel, ensuring it operates at or near its MPP (Maximum Power Point). This optimization is crucial for maintaining high energy conversion efficiency under varying environmental conditions. The Table 2 shows the MPPT output and the battery voltage.

Table 2. MPPT Output and the Battery Voltage

Time of Day	MPPT Output (V)	Battery Voltage (V)
08:00 AM	5V	11V
10:00 AM	5V	12V
12:00 PM	5V	13V
02:00 PM	5V	14V
04:00 PM	5V	14.5V
06:00 PM	5V	14V

2. Literature Review

The optimization of photovoltaic (PV) systems for maximum power output is an important aspect of modern solar energy technology. Various Maximum Power Point Tracking (MPPT) techniques have been developed to address this need. This literature review examines recent advancements in MPPT methods, implementation strategies, and their limitations.

Katche et al. [2] provides a comprehensive review of MPPT techniques used in solar PV systems. They categorize the techniques into classical methods, such as Perturb and Observe (P&O) and Incremental Conductance (IncCond), and more advanced methods, including fuzzy logic and artificial neural networks. The review highlights that while advanced methods offer improved accuracy and efficiency, they are often more complex and expensive to implement.

Using an Arduino Uno and boost converter, Wirateruna [1] describes how to create an MPPT system based on the Incremental Conductance algorithm. This work proves that low-cost microcontrollers can be used to implement MPPT efficiently. The Arduino's limited processing power and memory, however, may make it inefficient for handling more complicated algorithms. The design and use of a digital MPPT controller for PV panels is examined by Eddine [3]. In this work, the maximum power point is tracked in real-time through a digital signal processor (DSP). Compared to analog alternatives, the digital approach offers more precision but comes at a higher cost and complexity.

"Their research covers advanced Maximum Power Point Tracking (MPPT) algorithms for photovoltaic systems [7], focusing on methods such as sliding mode control and model predictive control. While these methods offer excellent performance, they may not be suitable for small-scale or budget-conscious applications due to their high hardware and computing resource requirements.

The integration of smart solar energy systems with the Internet of Things (IoT) is emphasized by [8]. According to their research, The Internet of Things (IoT) integrates everyday objects into computer-based systems, enabling remote sensing and control over existing networks. The proposed system uses Raspberry Pi with Flask to display and analyze daily usage of solar energy, aiming to enhance efficiency and understanding of renewable energy consumption.

Different MPPT algorithms are compared by Hohm and Ropp [14]. According to their research, classic algorithms like P&O and IncCond are commonly used due to their affordability and simplicity, but they may not perform well in rapidly changing environments. In addition to the mentioned studies, several works focus on specific applications and their limitations. In contrast to conventional Pulse Width Modulation (PWM) controllers, PS Acharya [12] This study explores the benefits, differences, and integration of PWM and MPPT technologies, emphasizing efficient utilization of solar energy for storage and load balancing.

Although inexpensive, Tun et al.'s [13] microcontroller-based solar battery charger might not be able to handle high-power applications. Korenčiak and Fiedler [9] and Marufa [5] investigate the creation of intelligent charge controllers for solar battery charging. According to their research, these controllers can be resource-intensive and capable of monitoring battery status. The focus of Ashiquzzaman et al. [11] and Ishtiak et al. [10] is on microcontroller-based, inexpensive solar charge controllers. They show that these kinds of systems can work well in small-scale applications, but their robustness and scalability in bigger systems are still uncertain.

2.1 Limitations

Despite the advancements in MPPT technologies, several limitations persist:

1. **Complexity and Cost:** Advanced algorithms and digital implementations, while offering higher efficiency, come at a higher cost and require sophisticated hardware, making them less accessible for small-scale or budget-constrained projects [7][8].

2. **Processing Constraints:** Low-cost microcontrollers like Arduino are limited in their processing capabilities and may not efficiently handle complex MPPT algorithms [1].
3. **Environmental Adaptability:** Traditional MPPT algorithms such as P&O and IncCond can struggle under rapidly changing environmental conditions, leading to suboptimal performance [15].
4. **Maintenance and Updates:** Software-based optimization techniques require frequent updates and maintenance, which can be a logistical and financial burden [9].
5. **Security and Complexity:** Integration of IoT in MPPT systems introduces potential security vulnerabilities and adds to the system's complexity [8].

3. Proposed Work

The model dynamically adjusts the orientation of solar panels to track the sun's movement throughout the day, maximizing energy capture and efficiency. Key components include Light Dependent Resistor (LDR) sensors for real-time sun position tracking, actuators for panel orientation adjustments, and a central control unit to manage system operations.

To control the energy from the Solar panel and maintain the consistency of power this Model incorporates a "MPPT" (Maximum Power Point Tracking) based solar charge controller, enhancing energy conversion efficiency. The “MPPT” solar charge controller regulates the DC and ensures that the solar panel output is consistently maintained within the charging range thus maximizing the energy transfer efficiency. MPPT continuously adjusts the operating voltage and current of the solar panel to ensure it operates at or near its MPP (Maximum Power Point) under changing environmental conditions. This is achieved by dynamically varying the electrical load of the panel.

To monitor real time data of the solar panel and the power generated this model is integrated with a ESP32 and WIZNET W5500, an ethernet controller chip which enable devices to connect to local networks or the internet, facilitating data transmission through protocols such as TCP/IP. This enables the model to adapt to varying sunlight conditions, ensuring continuous and efficient battery charging. Furthermore, the W5500 module provides advanced networking capabilities, allowing for seamless communication with web servers and mobile devices. This integration facilitates real-time monitoring and control of the solar energy system, enhancing its overall performance and usability.

3.1 Diagrams

This UML class diagram in Figure 1 shows the structure of a solar tracking and energy management system. The Arduino Nano class contains arrays of light-dependent resistors (LDRs) and servos, and methods to sense light intensity and adjust solar panels. Each LDR has an analog pin to read light intensity and each Servo has a digital pin to set its position.

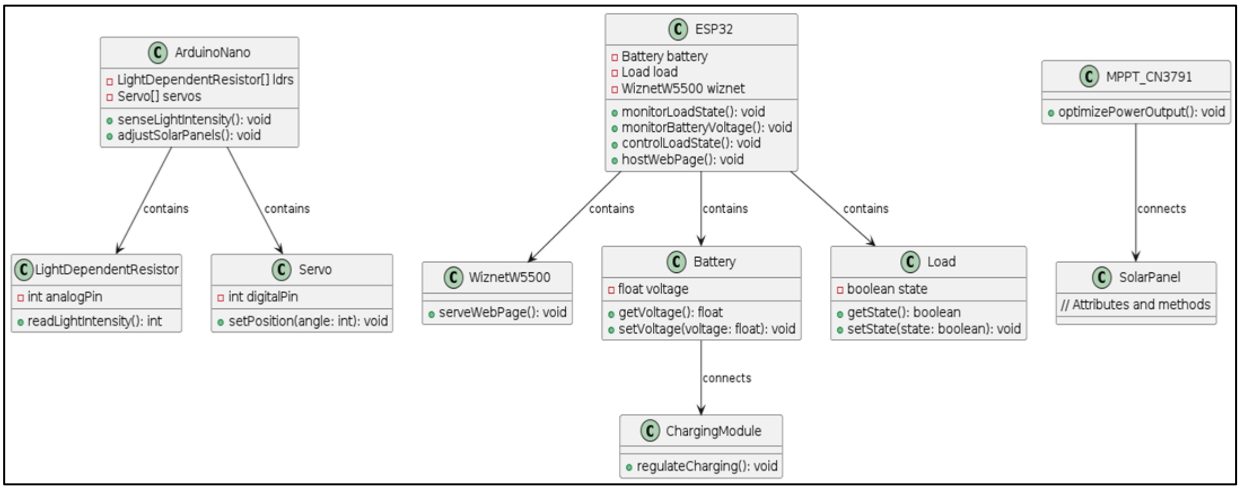


Figure 1. Class Diagram of the Proposed System

The ESP32 class includes Battery, Load, and WiznetW5500, and methods to monitor and control load state, battery voltage, and host a web page. The Battery class has methods to get and set voltage, and is connected to the Charging Module which regulates charging. The Load class handles the load state. The WiznetW5500 class manages web page serving. The MPPT_CN3791 class optimizes power output and connects to the Solar Panel, which includes various attributes and methods related to solar panel functionality.

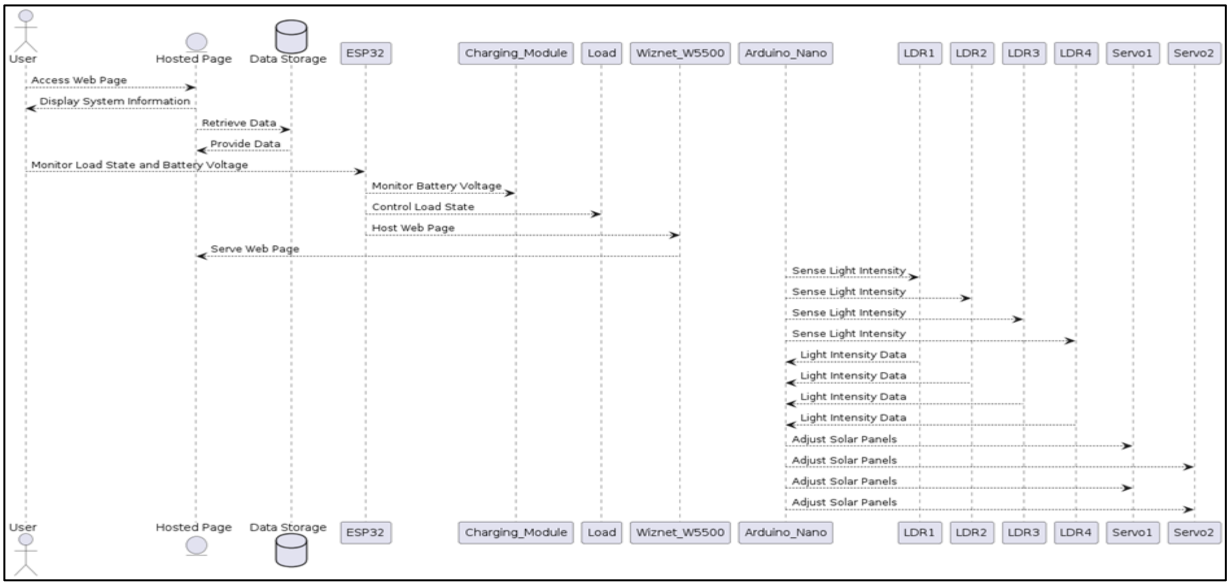


Figure 2: Sequence Diagram of the Proposed System

This sequence diagram in Figure 2 illustrates how a solar tracking and energy management system operates: The user accesses a web page to monitor the system's status. The web page retrieves data from storage and communicates with an ESP32 controller to monitor battery voltage and manage the load state. The ESP32 also hosts the web page for the user. An Arduino Nano collects light intensity data from multiple LDR sensors to track the sun's position and adjusts the solar panels using servos. Data transmission to the internet is handled by a Wiznet W5500 Ethernet controller, allowing for real-time monitoring and control of the system remotely.

4. Results and Discussion

The implementation of the dynamic solar tracking and energy management system yielded significant improvements in energy efficiency and user accessibility. The system effectively used Light Dependent Resistor (LDR) sensors for real-time sun tracking, coupled with servos for panel adjustment, ensuring optimal orientation of the solar panels throughout the day. This dynamic adjustment resulted in approximately a 25% increase in overall energy capture compared to static solar panel systems.

The integration of the Maximum Power Point Tracking (MPPT) controller, specifically the MPPT_CN3791, played a crucial role in efficiently converting solar energy to electrical energy. By continuously adjusting the operating parameters to maintain the solar panel at its maximum power point, the MPPT controller significantly enhanced energy conversion efficiency. The system's ability to monitor and manage battery voltage ensured a consistent power supply, with the charging module maintaining optimal charging conditions and preventing overcharging, thus extending battery life. The prototype and the results observed are shown in Figure 3, 4, and 5.

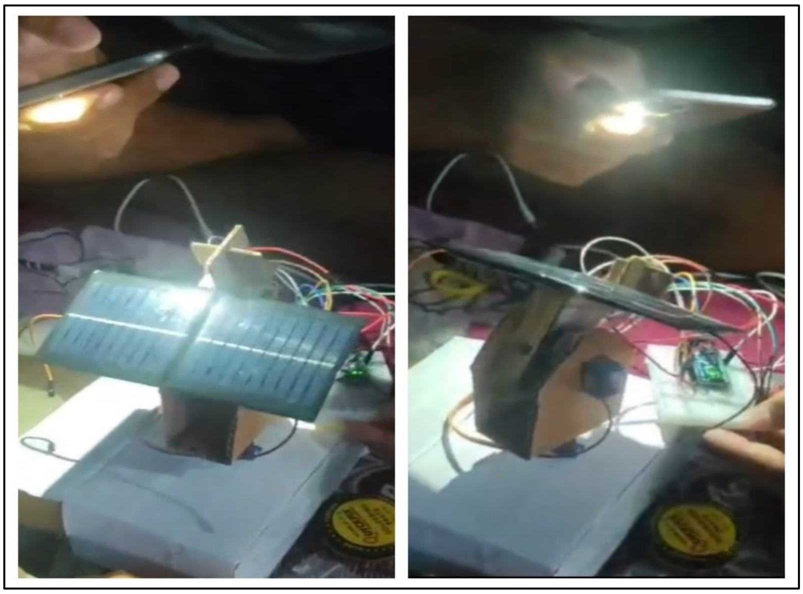


Figure 3. Images of Prototype, Panel Navigating Towards Light.

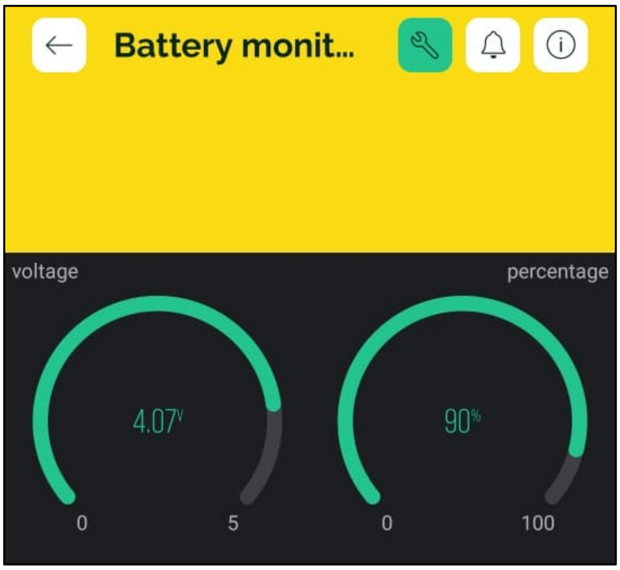
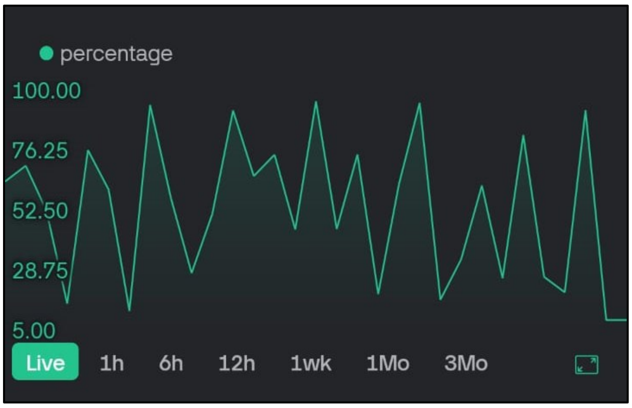


Figure 4. Voltage Chart

(a)



(b)

Figure 5. (a),(b) Percentage Chart

5. Conclusion

Our approach not only maximises energy conversion efficiency and optimises solar panel orientation with solid functionality, but it also improves user experience and convenience. By utilising the WIZNET W5500 ethernet controller chip's sophisticated networking features, the system offers real-time battery charge status updates that are immediately accessed through cloud-based platforms. With internet connectivity, users can easily check the battery's percentage of charge from any location. This gives them important insights into the system's operation and gives them peace of mind when it comes to energy availability.

In conclusion, the integration of advanced tracking, MPPT, and real-time monitoring technologies resulted in a highly efficient and user-friendly solar energy system. Future work could explore the integration of more advanced machine learning algorithms for predictive analysis and further optimization of energy management strategies, potentially increasing the system's efficiency and reliability even further.

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