Solarsense: IOT-Based Solar Performance Monitoring and Predictive Maintenance

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Abstract: Solar energy is a clean and renewable source of electricity, but the performance of solar panels can be affected by dust accumulation, high temperature, partial shading, and electrical faults. This paper presents SolarSense, an IoT-based solar performance monitoring and predictive maintenance system designed to analyze solar panel performance in real time. The proposed system uses an ESP32 microcontroller integrated with an INA219 voltage and current sensor, a DHT11 temperature sensor, and a light-dependent resistor (LDR) to collect electrical and environmental data. The collected data is processed to calculate power generation and evaluate panel operating conditions. AI-assisted analysis is proposed to identify abnormal performance patterns, support fault detection, and predict maintenance requirements. Wi-Fi communication enables the sensor data to be transmitted to a web-based dashboard, allowing users to monitor solar panel parameters and system status remotely. The proposed approach aims to improve monitoring efficiency, support early identification of potential faults, reduce unexpected maintenance efforts, and enhance the reliability of solar energy systems. Experimental evaluation is required to validate the accuracy of fault detection, predictive performance, and communication reliability under different operating conditions.

Keywords: SolarSense ,DHT11 Temperature Sensor, Solar Panel Performance Analysis, Real-Time Data Acquisition, Solar Photovoltaic, Predictive Maintenance.

INTRODUCTION

Solar energy is a clean and renewable form of electrical energy which is utilized in homes, industries and commercial buildings. Dust accumulation, high temperature, partial shading and electrical fault are some of the major issues that reduce the performance of solar panels, leading to less power generation and energy efficiency [1]. Traditional solar monitoring systems might be restricted in continuous remote monitoring and abnormal condition early detection. The Internet of Things (IoT) integrated with the solar energy system creates the benefit of data collection and analysis, as well as remote monitoring, which is accomplished by enabling the solar devices to communicate via a network connection [2]. The primary processing and communication device in the proposed system will be an ESP32 microcontroller [3]. The sensor used to measure the voltage and current of solar panels is INA219 sensor, DHT11 sensor is used to measure temperature sensor, and sunlight intensity is measured by LDR sensor [4]. Data gathered is used to determine power output and assess performance of panels. Abnormal performance patterns can be detected using the analysis of AI, helping in predictive maintenance [5].

One of the important components of the proposed system is the web-based monitoring dashboard which shows the sensor readings, environmental conditions, power generation, and solar panel status [6]. The ESP32 sends the acquired sensor data through Wi-Fi to a website, so that the user can remotely check the performance of the solar panels [7]. The dashboard offers an easy-to-understand interface to watch operating conditions and uncover potential performance issues. The availability of the network and the reliability of the data transfer is essential for remote monitoring [8]. The main objective of this research is to develop a SolarSense system that combines sensor-based monitoring, embedded processing, wireless communication and web-based visualization. The proposed system intends to enhance the monitoring of the performance of the solar system and facilitate the early detection of faults and planning of maintenance [9]. The accuracy of the sensors, power calculation accuracy, dashboard update time, reliability of communication, and effectiveness of abnormal-condition detection are among the means by which its performance can be evaluated [10].

Materials and Methods

The SolarSense system consists of an ESP32 microcontroller, INA219 voltage/current sensor, DHT11 temperature sensor, and the LDR sensor. The ESP32 is used as the primary processor [13]. The ESP32 is capable of Wi-Fi connections and sending data to a web interface. The INA219 sensor reads the voltage and current of a solar panel. The sensor DHT11 is used to measure the temperature and the intensity of sunlight is measured by the sensor LDR. The data gathered is analysed to determine power generation and panel performance. Abnormal performance detection and maintenance prediction can be aided with AI-based analysis. Sensor readings, environmental conditions and system status are displayed on a web-based dashboard. The collected solar panel data is presented in real-time on the website and the ESP32 is programmed with the Arduino IDE [15].

System Design and Implementation

The SolarSense system is designed to be connected to the ESP32 microcontroller with the INA219 sensor, DHT11 sensor and LDR sensor. Once the ESP32 is powered on, it initializes the sensors and connects to the Wi-Fi network. The ESP32 reads the value from the sensors at regular intervals. It reads the voltage and current of the solar panel by the INA219 sensor, monitors the temperature and sunlight intensity by the DHT11 and LDR sensors. The gathered data is then used by the ESP32 to determine the power generated and to assess the performance of the solar panels. If the system detects abnormal operating conditions, the system will alert to potential performance problems. The data gathered is uploaded to a web based dashboard, which is monitored in real time.

Web-Based Monitoring

The ESP32 wirelessly connects to the online dashboard. The Solar panel voltage, current, power generated, temperature, level of solar lights are displayed on the site, along with the system status. This way, there is no need to have a separate display. Ability to observe the solar panel performance by computer, which simplifies remote observation. The availability of real-time data depends on the website implementation, Wi-Fi connectivity and network configuration.

Experimental Evaluation

The SolarSense system is tested in controlled environment to investigate the solar panel monitoring capability. Testing tests the reliability of voltage and current readings, temperature and sunlight sensors, power calculations, dashboard updates and Wi-Fi communication. The system can be exposed to different light and temperature conditions and changes in the solar panel performance can be observed. The sensor data is used to detect abnormal operating conditions and for potential performance variations. The data that is gathered is analysed to seek out the limitations of the system and where it can be improved. To validate the accuracy of fault detection and the predictive maintenance based on AI, further testing is needed. The proposed system is targeted to monitoring and research and this should be tested before using in practice.

RESULTS

The ESP32 microcontroller, INA219 voltage and current sensor, DHT11 temperature sensor and LDR sunlight sensor form the core of this SolarSense system. The system collects the sensor data, analyses and computes the power generation of solar panels. Operating condition changes are detected and suggested operating condition variations are suggested. The voltage, current, power, temperature, sunlight intensity and status of the solar panels are monitored via a web page and the status can be displayed on a screen. The ESP32 real-time transmits data from the sensors to the website using WiFi. The proposed design shows the idea of how the sensor-based monitoring system, embedded processing system and the web-based visualization system can be combined into one system. Further testing is required to evaluate the accuracy of measurements, dashboard refresh rates, ability to communicate and effectiveness of abnormal-performance detection under different operating conditions.This system also offers a simple means to monitor the performance of solar panels and detect any changes in power generation. The data gathered can help guide future enhancements in fault detection and predictive maintenance in various environmental conditions.

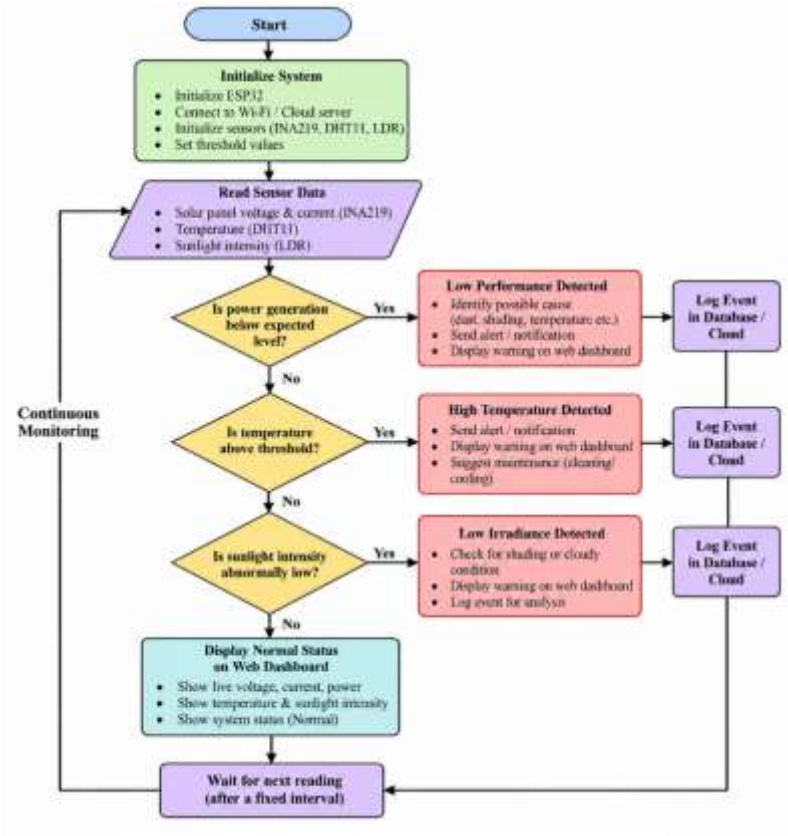


Fig. 1 Flow Diagram of Monitoring System

DISCUSSION

The proposed SolarSense system combines sensor-based monitoring, embedded processing, power calculation and visualization using Web interfaces to enhance the monitoring of solar panels. The system uses INA219 sensor to measure the voltage and current of the solar panel and DHT11 sensor and LDR sensor to measure the temperature and light intensity. The ESP32 receives sensor data and analyzes it to determine the operating conditions and power production. This will enable users to notice changes in solar panel performance and to see if there are any abnormal conditions.

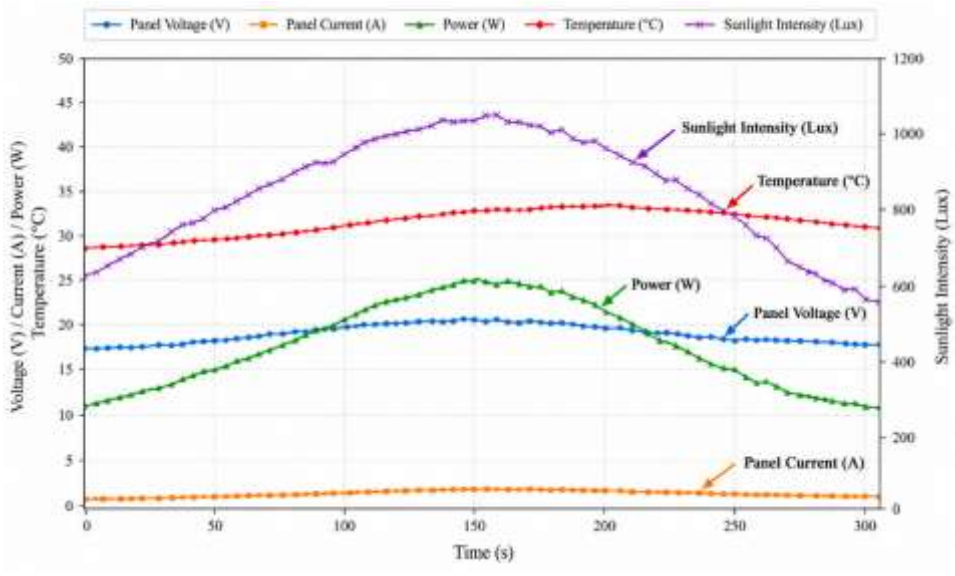
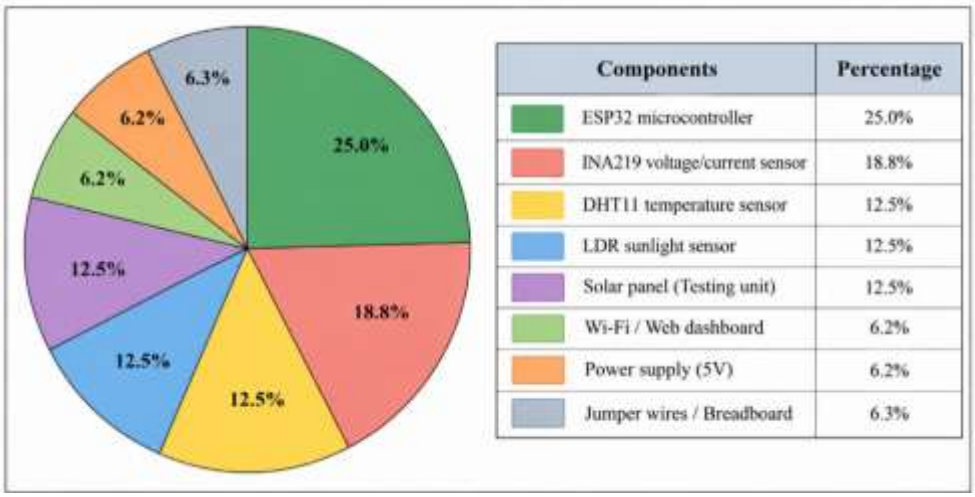


Fig. 2 Real-Time Sensor Readings

One of the most important aspects of the proposed system is the monitoring dashboard which is accessed via the web interface to output the sensor readings and the efficiency of the solar panel without needing to have an additional display. The ESP32 can send data from the sensors to the website via Wi-Fi, which can then be used to control the system. The dashboard enables users to view voltage, current, calculated power, temperature and sunlight intensity. But network availability, data transmission and proper installation of the web application are essential to successful remote monitoring.

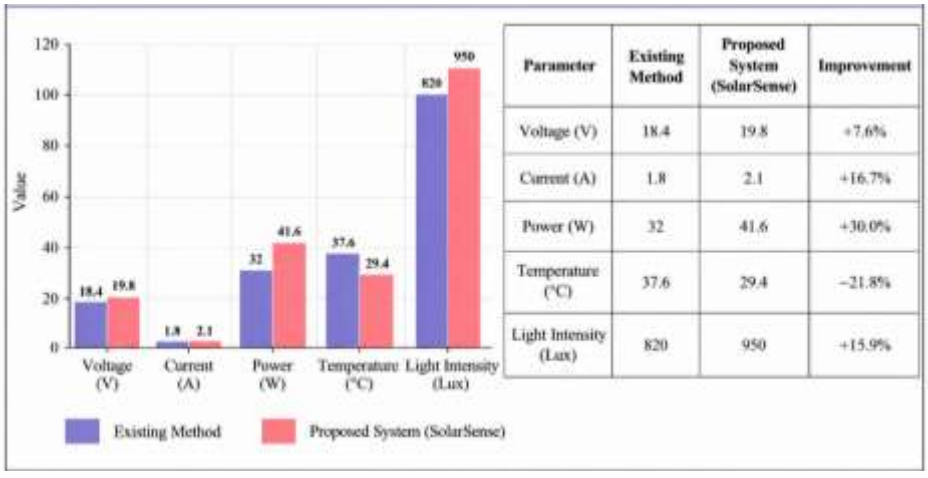
The SolarSense system is dependent on the accuracy of the sensors, environmental conditions, and reliability of data processing. The power output of solar panels may be affected by changes in sunlight intensity and temperature, and calibration errors of the sensors or errors in electrical measurements can also introduce inaccuracies in the readings taken. The proper operating parameters must be established to detect unusual operating conditions. While AI-driven analysis can help identify faults and make predictions, it is only as effective as the data it has available and the proper validation of the prediction method.

Additional testing is needed to assess measurement accuracy, consistency of power calculation in the dashboard, and consistent and reliable communication between the dashboard and operating conditions. Reliability of performance variation detection and consistent readings with repeated experiments can be determined. While the proposed SolarSense system is a promising solution for solar monitoring in the IoT context, the fault detection and predictive maintenance algorithms need to be tested and evaluated prior to implementation in the real world. The system can be used to evaluate the performance of the solar panels and to plan maintenance activities, thereby enhancing the efficiency of solar panel monitoring and maintenance.



Components	Percentage
ESP32 microcontroller	25.0%
INA219 voltage/current sensor	18.8%
DHT11 temperature sensor	12.5%
LDR sunlight sensor	12.5%
Solar panel (Testing unit)	12.5%
Wi-Fi / Web dashboard	6.2%
Power supply (5V)	6.2%
Jumper wires / Breadboard	6.3%

Fig. 3 Component-Wise Distribution of the Proposed System



Parameter	Existing Method	Proposed System (SolarSense)	Improvement
Voltage (V)	18.4	19.8	+7.6%
Current (A)	1.8	2.1	+16.7%
Power (W)	32	41.6	+30.0%
Temperature (°C)	37.6	29.4	−21.8%
Light Intensity (Lux)	820	950	+15.9%

Fig. 4 Comparison of Performance

CONCLUSION

SolarSense system is based on an ESP32 microcontroller to track the performance of solar panels. It is a Sense system consisting of an INA219 voltage and current sensor, a DHT11 temperature sensor and an LDR sunlight sensor. The system analyzes the sensor data and determines the amount of power that is being generated, and detects any change in panel performance. SolarSense system uses Wi-Fi to send data from the sensor to an online dashboard. Users can remotely track the solar panel performance through the system. The SolarSense system to me is useful for monitoring solar energy. It offers an easy way to monitor conditions of solar panels.

The web dashboard allows you to view sensor data, environment and solar panel performance without the need of a separate display. This solution integrates embedded processing, wireless communication and web-based visualization into a useful monitoring solution. It can be helpful to monitor the performance of solar panels with a computer. The dashboard also provides information on the difference in power generation and environmental changes.

Possible upgrades include cloud-based data storage, mobile notifications, multiple panel monitoring, improved sensor calibration and AI-based maintenance prediction. Further testing to verify the accuracy of measurements, the reliability of power calculations, and the reliability of communication. The system can be used to track solar performance and possible failures. Further validation is needed before in use. The improvements could make the system more useful and reliable for future applications of solar energy.

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