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IOT and ML Based Multitasking Drone System for Solar Panel Fault Detection

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Abstract

As per the increasing demand for solar energy has highlighted the need for efficient and automated maintenance solutions for large-scale solar farms, where manual inspection is time-consuming, labor-intensive, and prone to errors. To overcome limitations of traditional methods using fixed sensors and thermal cameras, this research proposes an IoT and ML-based drone system equipped with RGB and thermal cameras to autonomously survey solar panels and capture image data. The images are uploaded to cloud storage in real time and combined with an existing dataset to train a CNN model for accurate detection and classification of faults such as dust accumulation, cracks, hotspots, shading, and diode failure. A cloud-based model comparison identifies faults and provides their GPS location along with severity levels via a user-friendly dashboard, enabling timely maintenance and improved efficiency. This system reduces operational costs, enhances fault detection accuracy, supports predictive maintenance, and significantly improves the lifespan and performance of solar installations, with potential scalability to other sectors such as wind turbine inspection, agriculture, and infrastructure monitoring.

Introduction

Solar energy has been a leading source of clean and renewable power, contributing significantly to global sustainability goals. the efficiency of solar farms mainly depends on the regular monitoring and maintenance of solar panels. In large installations, thousands of panels are spread across vast areas, making manual inspection difficult, time-consuming, and prone to human error. Faults such as dust accumulation, cracks, hotspots, shading, diode failure, and temperature irregularities can drastically reduce power generation if not detected in time. Therefore, there is an urgent need for a fast, accurate, and automated solution that can identify and classify faults in real time.

To overcome this challenge,we make an intelligent drone-based solar panel fault detection system integrated with IoT and Machine Learning (ML). The drone is uses RGB and thermal cameras to capture detailed images of solar panels during surveys. These images are uploaded to cloud storage and processed using a (CNN) model, which detects faults with higher accuracy. The system captures the exact GPS location.

This technology significantly reduces inspection time, minimizes labour dependency, improves fault detection accuracy, and enhances the overall efficiency and lifespan of solar installations. Moreover, the system is scalable and can be adapted for other industrial applications, including wind turbine monitoring, agricultural analysis, and infrastructure inspection. Hence, the proposed drone-based solar panel fault detection system offers a modern, sustainable, and cost-effective approach to renewable energy management.

Literature Review

[1]Bhatt, Shah, and Patel highlighted that thermal imaging combined with machine learning is highly effective for detecting hotspots and internal defects such as micro-cracks and diode failures in PV modules, proving better fault identification accuracy than conventional electrical testing methods .[2] Kumar and Singh demonstrated the benefits of IoT-enabled drone-based inspection in large solar farms by enabling real-time remote monitoring, reducing manual involvement, and increasing operational efficiency .[3] Tsai and Chang established that CNN-based classification significantly improves detection of dust, cracks, and hotspots compared to traditional image-processing methods, offering superior computational performance for real-time PV diagnostics .[4] Hernandez et al. showed that integrating RGB and thermal imaging enhances monitoring accuracy through complementary temperature and visual defect information, supporting multi-sensor approaches for PV inspection.[5] Zhao and Li emphasized that IoT-based predictive maintenance reduces system downtime and improves reliability through cloud analytics, remote computing, and automated data handling .[6] Al-Turjman and Alturjman demonstrated that UAV-based inspection minimizes labor and time requirements while improving coverage across large installations, validating drone platforms as efficient monitoring tools for renewable infrastructures .[7] Patel and Mehta confirmed that CNN-based image processing reliably classifies different PV faults and improves dataset labeling and preprocessing strategies, increasing overall detection accuracy.[8] Sharma and Verma highlighted the role of cloud dashboards in automated scheduling, visual fault reporting, and maintenance decision-making .[9] Li and Wang discussed drone inspection challenges including flight stability and data synchronization, guiding real-world drone deployment strategies for solar fields.[10] Hamid and Khalid conducted a comparison between manual and drone-based inspection and concluded that drone technology is significantly faster, more accurate, and cost-efficient, making traditional inspection methods less effective for large solar farms.

Identified Research Gap

1. **Lack of an integrated system** combining RGB + thermal imaging + IoT + CNN on a single autonomous drone platform.
2. **Absence of real-time GPS-based fault localization** directly linked with fault severity.
3. **Limited datasets** supporting multi-type faults (dust, cracks, hotspots, shading, diode failures) in a unified CNN model.
4. **Most studies focus on either ML or drone sensing**, not the complete workflow from aerial capture to cloud dashboard output.
5. **Scalability and automation** (waypoint missions, cloud storage integration, automated preprocessing) are rarely demonstrated.
6. **Few works provide live dashboard visualization** for actionable decision-making in solar farm maintenance.
7. Our project addresses these gaps by developing a **fully automated, end-to-end IoT + ML drone system** capable of capturing, uploading, analyzing, classifying, and mapping faults in real time with GPS tagging and dashboard visibility.

Overview Of Project

The proposed project presents an IoT & Machine Learning-based drone system for real-time fault detection in solar panels. As solar farms grow in size, manual inspection becomes inefficient, labor-intensive, and slow. Faults such as cracks, dust accumulation, hotspots, shading, and diode failures reduce energy output and require timely identification. This project introduces an automated system where a drone equipped with RGB and thermal cameras captures images of solar panels and sends them to a cloud-based platform via IoT connectivity. Model processes these images, identifies faulty panels, classifies the types of fault, and provides GPS-based fault locations along with severity levels on a dashboard. This reduces maintenance time, improves accuracy, supports predictive maintenance, and increases the lifespan and performance of solar farms. The system is scalable and can also be applied to wind turbine inspection, agriculture, and infrastructure monitoring.

Major Components and Their Working

1. Drone System
Role: Autonomous aerial inspection of solar farms.
Work: Flies over solar panels following a pre-defined path, capturing images from different angles.
Importance: Covers large areas quickly and efficiently compared to manual inspection.
2. RGB Camera
Role: Captures normal visual images of solar panels.
Work: Detects visible defects such as cracks, dust, broken cells, or shading.
Importance: Provides clear image data for visual fault analysis.
3. Thermal Camera
Role: Captures the hotspots on panels.
Work: Identifies hotspots, temperature variations, and diode failures.
Importance: Crucial for detecting faults not visible to the naked eye or normal cameras.
4. IoT Connectivity (Wi-Fi / LTE / LoRa)
Role: Enables wireless data transfer.
Work: Sends captured images to cloud storage in real time.
Importance: Supports rapid processing and remote monitoring.
5. Cloud Storage & Processing
Role: Central platform for image storage and data analysis.
Work: Stores image dataset, preprocesses data, and integrates it with the CNN model.
Importance: Enables remote access and real-time processing.
6. Machine Learning Model (CNN)
Role: Fault detection and classification.
Work: Analyzes input images to detect cracks, hotspots, dust, etc.
Importance: Provides high accuracy with automation and reduces manual decision-making.
7. GPS Module
Role: Gives the location of faulty panel.
Work: Tags coordinates with each image captured by the drone.
Importance: Helps maintenance teams locate and repair faulty panels quickly.
8. User Dashboard
Role: Displays results in an easy-to-understand format.
Work: Shows fault type, severity level, panel number, and GPS location.
Importance: Helps in quick decision-making and maintenance management.
9. Power Supply / Battery
Role: Provides energy to the drone and sensors.
Work: Li-Po battery powers flight and data collection systems.
Importance: Provides longer flight duration and stable operation.

Conclusion of Overview

This project creates a full automated, real-time, and accurate monitoring system for solar panel maintenance using drones, IoT, and machine learning. It reduces inspection time, reduces human error, and ensures efficient energy production. It holds scope for future needs and demands of industries due to its capability and can also be modified to make more useful.

System Design

The given idea makes a advanced and automated model of solar panel fault detection and inspection using Thermal and RGB cameras that flies over the solar farm using a planned flight path and captures high-resolution images of solar panels along with their GPS coordinates. RGB camera detects all the external faults like cracks, dust layer formation or shading occured on the panels. Thermal camera detects all the internal faults like hotspots, diode failures or any abnormalities in temperature. All the captured images is transferred to cloud for storing through an IoT module, which provides real-time access to data so there is no need for manual data handling.In cloud the data is processed - clearing of images , classifiyng images based on similarities , labelling of the images and training for ML. AThe processed data is used to train a CNN model to detect and classify various types of faults hotspot formation, cell damage, dust deposition, or diode failures.Once the images are analyzed, a dashboard or report is formed which specifies all the fault with their location occured on the panel. GPS helps to give the exact loaction of the fault. In this way the work of maintenance team is made easier and they can accurately detect and clear the fault without wasting much time. This way the efficiency of the solar panels is increased and overall life span of solar field increases. The system also stores inspection data in a database, which can be used in future for predictive analysis and continuous model training to increase accuracy over time. This type of working reduces human intervention, reduces operational cost, increases inspection speed.

Working Methodology

Working of the IoT & ML-based Solar Panel Fault Detection Drone System follows certain processes to complete its job which include real-time monitoring, accurate fault detection, and effective maintenance.

The workflow can be divided into following steps:

1. Drone Working & Image Acquisition
The drone consists of RGB and thermal cameras which inspects the complete solar fields as per the decided path by Mission Planner.
Images of solar panels are captured from various spots and angles.
Each image is tagged with time, GPS coordinates, and sensor data.
2. Data Transfer via IoT
Using Wi-Fi communication, the collected images are automatically transferred to cloud for storage .This gives real-time access and remote monitoring. No manual data handling is necessary.
3. Dataset Preprocessing
The images are processed and unclear or duplicate data is removed.
Images are enhanced and sorted according to similarities.
The dataset is labeled into healthy and faulty panels for training.
This dataset is merged with previously stored data to improve model accuracy.
4. Machine Learning Model (CNN) Training
A Convolutional Neural Network (CNN) model is trained using TensorFlow.
The model learns to identify faults such as:

- Dust accumulation
- Cracks or broken cells
- Hotspots (thermal abnormalities)
- Shading issues
- Diode failures

The final model classifies images into fault categories with high accuracy.
5. Fault Detection & Classification
The processed images are compared with the trained model.
The CNN model detects faults and classifies them automatically.
Fault severity level is highlighted.
The GPS location of the faulty panel is extracted from metadata.
6. Result Visualization
Results are displayed on a dashboard or web interface.
The dashboard shows:
Type of fault
Severity of fault
GPS location of affected panel
Image evidence for verification
This allows field engineers to take quick maintenance actions.

7. Continuous Learning & Model Updates
Each inspection cycle adds new data to the dataset.
The ML model is periodically retrained to improve accuracy.
This supports predictive maintenance and early fault detection.
Flow of Methodology

Drone Survey → Image Capture → Cloud Upload → Dataset Preparation → CNN Model → Fault Detection → Dashboard Output → Maintenance Action

This structured methodology ensures automation, high precision, reduced inspection time, lower labor cost, and improved solar energy efficiency.

Hardware
The system includes an autonomous quadcopter drone, thermal imaging sensor, GPS module, microcontroller for IoT data handling, and Li-Po battery. These components ensure accurate temperature measurement, stable flight, and reliable data transmission.

Main components with their specifications are :
I] BLDC MOTOR
BLDC motors are used in drones because they are lightweight, highly efficient, and provide high power with very quick speed response, which is essential for stable flight. They have no brushes, so there is no friction or wear, making them more reliable and low-maintenance. BLDC motors can spin at high RPM with smooth, low-noise operation and generate strong thrust, allowing drones to lift easily and maneuver accurately. Overall, they give maximum performance with minimum energy loss, making them ideal for drone applications.
II] ESC – FlySpark
The FlySpark F4 V1 BLS 60A Stack shown in the image is a flight-controller + 4-in-1 ESC combo used in mid- to heavy-lift drones. The board includes an F4 processor, built-in gyro, and a 60A BLHeli-S electronic speed controller for each motor, meaning it can safely drive high-power BLDC motors (up to 6S Li-Po). The markings around the edges show the input/output pads: M1–M4 for motor ESC signals, 5V / VBAT outputs for powering accessories, SBUS for receiver input, LED, VTX, and CAM pads for FPV system connections, and UART/RX/TX pins for GPS, telemetry, or external sensors. Large power pads marked B+ and B- are the main battery input. The board connects the battery to the ESC section and sends speed signals to each motor, while the flight controller takes sensor data, stabilizes the drone, and adjusts motor speed through the ESC for smooth flight. Overall, it handles power

distribution, motor control, stabilization, and signal communication in a compact stack.

III] Li-Po BATTERY

The **Orange 22.2V 5200mAh 35C 6S Li-Po battery** is a high-performance power pack commonly used in drones and RC aircraft. With six cells in series giving **22.2V**, a **5200mAh** capacity for good flight time, and a **35C discharge rate** for strong current delivery, it provides stable and reliable power even during high-load moments like takeoff or quick movements. We chose this battery because it offers the right balance of power, endurance, and weight for my drone, keeping all motors and electronics running smoothly and safely.

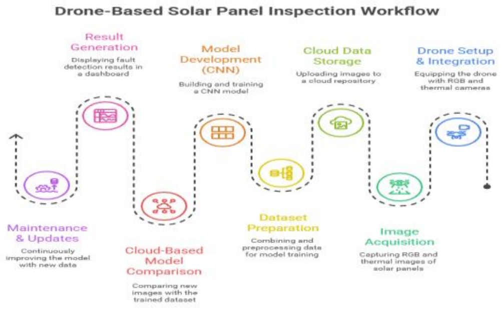
IV] GPS MODULE

The NEO-M8N GPS Module with Compass is a reliable, high-precision positioning unit commonly used in drones and autonomous systems. It combines the u-blox M8N GPS chipset with a built-in compass, giving both accurate location and orientation data. Since it supports multiple satellite systems like GPS, GLONASS, Galileo, and QZSS, it locks signals quickly and maintains strong accuracy even in challenging conditions. In my drone setup, this module provides stable real-time tracking and enables autonomous features such as waypoint missions and return-to-home through Mission Planner. Its easy integration and dependable performance make it an essential component for smooth and precise drone navigation.

V] TRANSMITTER

The **Flysky FS-i6X Transmitter with FS-iA6B Receiver** is a simple, reliable, and budget-friendly radio control system commonly used in drones and other RC models. It runs on a 2.4GHz AFHDS 2A signal, which helps maintain a strong, interference-free connection during flight. The transmitter supports up to 10 channels, giving plenty of flexibility for different flight modes and custom functions, while the FS-iA6B receiver offers stable performance and wide compatibility. Overall, it's a dependable choice for smooth, responsive control in both beginner and advanced drone setups.

Block Diagram



Conclusion

This research presents a fully automated IoT- and ML-enabled drone system designed to improve the speed, accuracy, and efficiency of solar panel fault detection in large-scale installations. By integrating RGB and thermal imaging with cloud-based processing and a CNN model, the system successfully identifies multiple types of faults—such as cracks, hotspots, dust accumulation, shading, and diode failures—while providing precise GPS-based localization. The drone-based approach significantly reduces manual inspection time, minimizes human error, and enables real-time monitoring through an interactive dashboard. The results demonstrate that this system enhances operational reliability, supports predictive maintenance, and improves the overall energy output and lifespan of solar farms. With its scalable design, the proposed solution also holds potential for wider applications in industries such as wind turbine inspection, agriculture, and infrastructure monitoring. Overall, the system provides a modern, cost-effective, and sustainable method for maintaining renewable energy assets.

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