Solar Farms Inspection Using High Resolution Thermal Imagery

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Abstract

As the demand for solar energy grows, ensuring the efficient performance of photovoltaic (PV) systems has become crucial. Traditional inspection methods for large-scale solar farms are often time-consuming and inefficient. This paper proposes an advanced approach using high-resolution thermal aerial imagery captured by drones to inspect solar farms. The methodology involves acquiring thermal data using unmanned aerial vehicles (UAVs) equipped with real-time kinematic (RTK) sensors and generating an orthomosaic by stitching together aerial images. Deep learning models are applied to segment individual solar panels, allowing for precise fault detection and performance analysis.

Anomalies such as hotspots, malfunctioning diodes, and Potential-Induced Degradation (PID) are identified through thermal imagery, enabling early intervention for maintenance. Additionally, performance efficiency is analyzed by comparing the instantaneous temperature data of solar panels against reference values. This approach enhances inspection efficiency while minimizing downtime, offering a cost-effective solution for maintaining large solar installations. Integration of thermal and RGB imagery further improves anomaly identification by reducing false positives, ensuring more reliable inspection outcomes.

Key words: Photovoltic, TIR, Solar

1 Introduction

Solar energy has become increasingly important in addressing global energy demands. The transition from fossil fuels to renewable sources is essential for sustainable development. Research indicates that solar energy can significantly reduce greenhouse gas emissions while providing reliable power. In the context of renewable energy, India possesses critical strategic significance and remarkable potential for alternative energy sources, particularly solar energy, due to its geographical attributes and conducive environment for the establishment of solar facilities. The majority of India experiences between 300 and 330 sunny days each year, which translates to an impressive solar energy potential exceeding 5000 trillion kWh annually—far surpassing the country's total energy consumption. The average solar irradiance ranges from 4 to 7 kWh per square meter per day, with the highest annual radiation levels recorded in the western region of Rajasthan. Solar PV technology is utilized to directly convert solar energy into electrical energy through the use of silicon solar cells. The generated electricity can be employed for a variety of applications, either directly or via a battery storage system. Maintaining the performance and longevity of photovoltaic (PV) systems has become essential. Ensuring optimal efficiency requires the timely detection of faults and degradation in panels, a task that is particularly challenging for large-scale installations. Traditional methods of inspecting solar panels are too time-consuming and nearly impossible for frequent surveys. However, in recent years, the use of unmanned aerial vehicles equipped with thermal imaging sensors has emerged as a promising technique for monitoring solar farms, as they provide high-resolution data. In addition, advancements in computer vision techniques, particularly deep learning, have significantly enhanced the ability to automatically detect faults in thermal imagery. Structure from Motion (SfM) allows precise 3D reconstruction or 2d mosaic of solar installations that enables geolocation of faulty panels, making inspections more efficient and actionable.

2 Methodology

2.1 Data Acquisition

For effective solar farm inspections, a drone equipped with a high-resolution thermal camera and an RTK sensor is essential. Ideally, flight planning should target a minimum altitude of 80 meters to achieve optimal ground sampling distance (GSD). Ensuring 70-80% image overlap with a slight off-nadir angle (5-10 degrees) improves both the quality of the mosaic reconstruction and the accuracy of fault detection. Additionally, images should be captured on a clear day to avoid interference from environmental conditions, ensuring the highest data quality for thermal analysis.

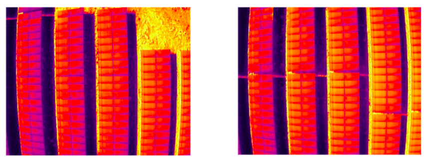

Figure 1: solar panel captured by drone

2.2 Orthomosaic

After acquiring the images, an orthomosaic is generated to facilitate accurate panel detection and tracking. This composite image, created by stitching multiple aerial images together, ensures detailed and consistent mapping of the solar farm, enabling precise fault tracking and performance analysis.

2.3 Panel Segmentation

Panel segmentation can be efficiently performed using deep learning models that are specifically fine-tuned with extensive datasets tailored for solar PV segmentation. These models enable precise identification of individual panels, enhancing the

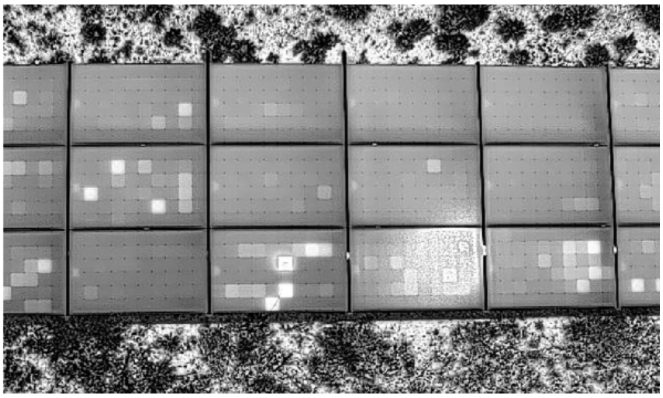

Figure 2: closer look thermal image at midday in solar farm

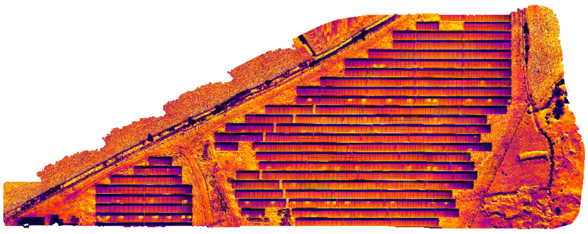

Figure 3: Mosaic image

accuracy of fault detection and further analysis of performance degradation across the solar farm.

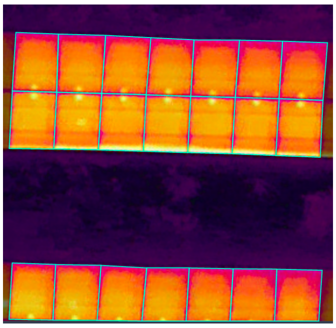

Figure 4: panel segmentation

2.4 Analysis

After segmenting the solar panels, several types of analysis can be performed to assess both the physical condition and the performance of the panels:

1. Anomaly Detection: Using high-resolution thermal imagery, various anomalies can be identified, including hotspots, malfunctioning diodes, Potential-Induced Degradation (PID), dust or vegetation accumulation, catastrophic failures, and disconnected panels. These anomalies are critical for timely maintenance, ensuring the long-term efficiency of the solar farm.

A bright spot in thermal imagery is often classified as a hotspot. Hotspots can be further categorized into two types: single-cell and multi-cell hotspots. One common cause of hotspots is overheating in the junction box. Additionally, a pattern known as String-End Heating Pattern (SEHP) can be observed across large areas or repeated throughout the site. SEHP may indicate the onset of PID, where affected cells are typically located at the negative end of a string. Heated panels and strings can be detected by comparing the temperature patterns of individual panels against surrounding units, highlighting potential underperformance or faults.

2. Performance Analysis: Efficiency analyses can be conducted for each solar panel as a result of the segmentation process. In this context, the efficiencies of the solar panels are determined using the reflectance values obtained from the average thermal data in the thermal orthomosaic images of the study area. By comparing the instantaneous temperatures of the panels to reference temperatures derived from ideal conditions, the efficiency of each panel can be calculated. This method allows for a detailed assessment of the photovoltaic performance, highlighting any deviations from expected efficiency levels and enabling targeted maintenance efforts to optimize energy production.

3 Conclusion

The use of thermal imagery for solar panel monitoring and inspection has emerged as a highly productive and cost-effective solution, significantly reducing inspection times and enabling timely maintenance interventions. However, challenges can arise in the interpretation of thermal images, potentially leading to the misclassification of anomalies. For instance, a thermal image may show a bright spot that could be interpreted as a hotspot indicating a malfunctioning solar cell. However, this bright spot could also result from reflected sunlight or an object in proximity to the panel. These issues can be mitigated by integrating thermal imagery with RGB (color) imagery.

For example, if a thermal image shows an unexpected temperature increase in a specific area of a solar panel, the corresponding RGB image can be analyzed to determine whether there are physical obstructions, such as dirt, vegetation, or debris, that might cause a false positive in the thermal data. This combined analysis helps ensure accurate identification of true anomalies, such as faulty cells or junction boxes, thereby enhancing the reliability of the inspection process.