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Automated Detection of Defective Photovoltaic Panels Using Drone Thermal Imaging

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Abstract
This project aims to provide a solution that will process the thermal dataset taken during the inspection of photovoltaic power plants by drone. The output of the dataset processing is an orthophoto of the entire power plant, from which the individual PV panels were segmented. These were then classified as to whether they contained any defect and which defect it was. The solution includes creating a multispectral orthophoto in which the temperature information is encoded, training a Mask-RCNN model for the panel segmentation task, training a Vision Transformer and a convolutional model for the panel classification task, and finally creating a web application that guides the user through the entire dataset processing pipeline and displays the results. The system was tested on a PV plant inspection dataset from the Czech Republic, manually annotated by a domain expert. The classification precision for defective panels is 73%, and the recall is 99%. The result of this project is a functional product that could greatly speed up the PV plant inspection process. It has been implemented in a way that can be easily extended in the future.

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1. Introduction

A side effect of most photovoltaic (PV) panel defects is an increased temperature in the affected area. This makes drone thermal imaging camera inspection a suitable non-invasive method to detect defective panels [1].

The thermal dataset acquired during the inspection of the PV plant consists of hundreds of images. The analysis is done manually. An expert must examine each thermal image individually and measure suspicious points using FLIR Tools[1] software. If the expert determines that the examined panel is defective, identifying the panel's location within the context of the entire solar plant becomes necessary — a task that can be challenging. Processing the dataset from a single inspection typically requires several days.

The main benefit of this work is to speed up and simplify the processing of the thermal dataset. The resulting solution should automatically detect faulty panels and display them to the user so that their location is easily identifiable. A dataset from a Czech PV power plant that was manually annotated by an expert in the field is available to determine the reliability of the implemented system.

Higuchi et al. [1] attempted PV panel segmentation using binarization, but the method lacked robustness. They generated an orthophoto to locate defective panels, though brightness variations in thermal images introduced artifacts that hindered detection. A bachelor's thesis [2] improved segmentation by training a Mask-RCNN model on a newly created dataset, achieving promising results, including hotspot detection and matching to panels. However, it still relied on orthophotos without managing their creation or using actual thermal data. Other works [3], [4] focused on training classification models for defect types but did not address the full dataset processing workflow.

The developed solution covers all steps of dataset processing, from image normalization and orthophoto creation with real temperature data, to panel segmentation and classification. The entire workflow is integrated into a web application that guides the user and enables interactive review and correction of predictions.

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[1] https://support.flir.com/SwDownload/app/RssSWDownload.aspx?ID=1247

2. Multispectral Orthophoto

Thermal images in the captured dataset may have different brightness levels, which is due to how the thermal camera maps the temperature data to the image data. Therefore, an algorithm was implemented that generates new images from the temperature data that are focused and normalized across the dataset. The comparison of images can be observed in Figure 2.

The Open Drone Map[2] software is used to create the orthophotos and has been integrated into the implemented web application. The creation of the orthophoto is done in multispectral mode, which prevents the loss of real temperature data.

3. Panels Segmentation

Panel segmentation is performed using a trained Mask R-CNN model, following the approach proposed in the referenced bachelor's thesis [2]. However, the original work included annotated images from only a single power plant, which led to reduced segmentation accuracy when applied to images from other sites. To address this limitation, the dataset was expanded and the model was retrained. The model achieved an average precision of 96,9% at an IoU threshold of 75%, with additional results presented in Table 1.

Some segmentation errors split a single panel into two. An algorithm fixes this by merging suspicious instances and checking the bounding box area, as shown in Figure 4.

4. Panels Classification

The classification models were trained on a publicly available dataset [5] containing segmented PV panels categorized into classes. Examples of panels from each selected class are shown in Figure 8.

The implemented system includes two trained models: the first is a Vision Transformer, and the second is a lightweight convolutional neural network, whose architecture is illustrated in Figure 5. The Vision Transformer uses pre-trained layers, whereas the convolutional model was trained from scratch. Both models achieved comparable performance, as presented in Table 2. The convolutional model demonstrates significantly faster inference.

Within the application, the user can select which classification model to use. Additionally, the classification categories can be reconfigured or grouped in different ways to better suit specific analysis goals.

5. User Review

Once the panels are classified, it is up to the user to check the resulting predictions. The panels are interactively rendered on an orthophoto as can be seen in Figure 1, and when the user clicks on a selected panel, its detail is displayed, as shown in Figure 7. The system automatically locates the hotspots occurring on the panel and measures their temperature. The user can take manual temperature measurements and all the data is stored in the system. The predictions of the classification model are also listed on the right and it is up to the user to decide if the predicted class is accurate and correct it if necessary.

The last step is to label panels based on the power plant naming scheme. The user can label the entire rack of panels at once and enter the coordinates for the first panel only. The positions of the other marked panels are then calculated automatically as shown in Figure 8.

6. Evaluation and Results

The implemented system was evaluated using a dataset captured during an inspection of a PV power plant in the Czech Republic. This dataset was manually annotated by a domain expert, and the annotations served as ground truth for the evaluation.

On the generated orthophoto, the system failed to detect only 4 out of 2208 panels, resulting in a segmentation success rate exceeding 99%. As not all panel classes present in the training dataset were represented in the ground truth annotations, the classification settings were adjusted accordingly. The results of both classification models are summarized in Table 3. In this evaluation, the convolutional model outperformed the Vision Transformer.

According to the confusion matrix (Figure 9), the convolutional model missed only 6 defective panels, achieving 99% recall. Precision was 73%, indicating some healthy panels were misclassified as defective.

7. Conclusions

The outcome of this work is a functional system with the potential to significantly accelerate the inspection process of PV power plants. Its modular implementation enables straightforward future extensions, such as the integration of newly trained models.

References

[1] Yuji HIGUCHI and Tadatoshi BABASAKI. Failure detection of solar panels using thermographic images captured by drone. In *2018 7th International*

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[2] `https://opendronemap.org/`

Conference on Renewable Energy Research and Applications (ICRERA), pages 391–396, 2018.

[2] Filip Haužvic. Detekce a klasifikace vad panelů fotovoltaických elektráren z termokamery dronu. Bakalářská práce, Vysoké učení technické v Brně, Fakulta informačních technologií, Brno, 2024. Vedoucí práce Ing. Daniel Bambušek.

[3] E.A. Ramadan, Nada M. Moawad, Belal A. Abouzalm, Ali A. Sakr, Wessam F. Abouzaid, and Ghada M. El-Banby. An innovative transformer neural network for fault detection and classification for photovoltaic modules. *Energy Conversion and Management*, 314:118718, 2024.

[4] Minhhuy Le, DucVu Le, and Hong Ha Thi Vu. Thermal inspection of photovoltaic modules with deep convolutional neural networks on edge devices in auv. *Measurement*, 218:113135, 2023.

[5] Matthew Millendorf, Edward Obropta, and Nikhil Vadhavkar. Infrared solar module dataset for anomaly detection. *ICLR 2020*, 2020.