Automated detection-classification of defects on photo-voltaic modules assisted by thermal drone inspection

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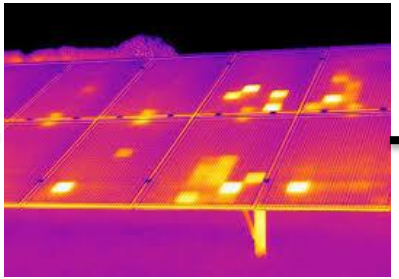
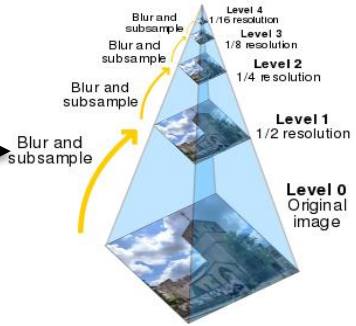
International Conference of Engineering Against Failure (ICEAF)

Objective of the study

Automated detection-classification of defects on photo-voltaic modules assisted by thermal drone inspection using thermal imaging





Detection and classification of pv modules

Computational tools

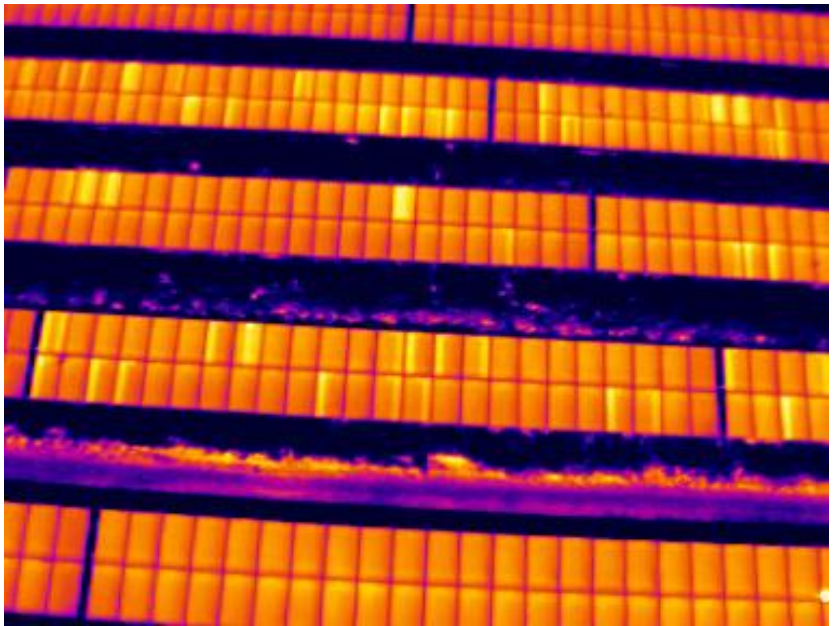
- OpenCV (Open Source Computer Vision)
  - Primary interface in C++, Python, Java MATLAB/OCTAVE
  - Application areas include
    - Facial recognition
    - Motion Tracking
    - Segmentation
- Python
  - High level programming language
  - Object oriented
  - Available for many operating systems

Thermal imaging

Thermal imaging is an important and powerful non-destructive technique for the investigation of structural or operational defects

Advantages-Capabilities

- Fast, surface inspection
- No physical contact
- Great versatility of applications
- Ease of numerical thermal modelling

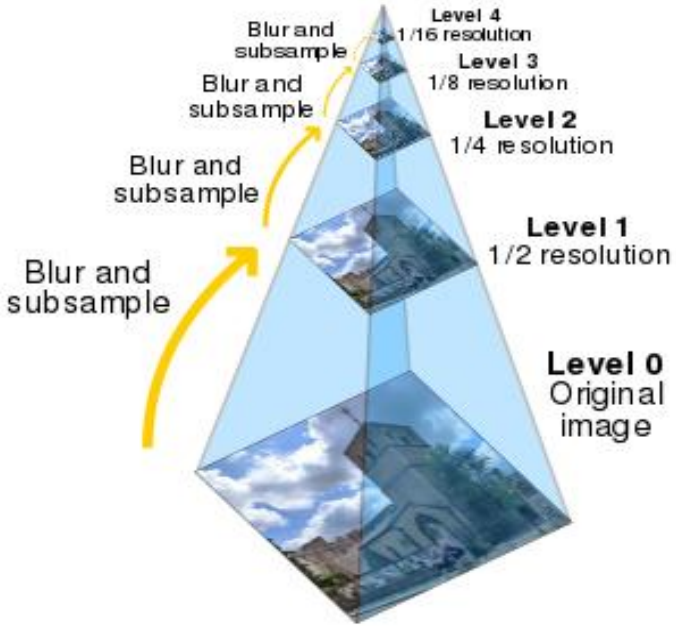


Digital Image Processing

Computational method to convert an image into digital form and perform numerical operations in order to extract useful information from the under investigation image.

Applications :

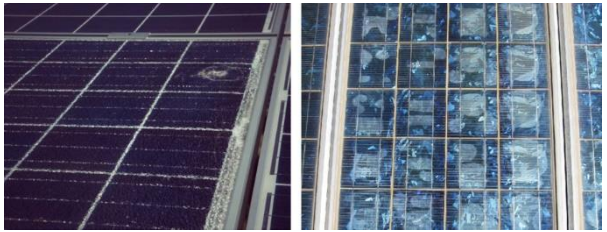
- Intelligent Transportation Systems
- Moving object tracking
- Defence surveillance
- Biomedical Imaging techniques
- IR-Thermography



Faults in PV modules

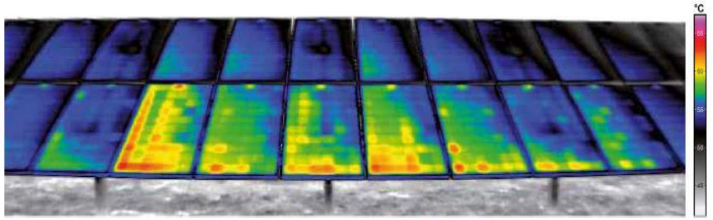
Faults in PV modules can be classified in 3 different categories:

- Optical degradation: delamination and “bubbles”, discoloration of the encapsulant glass(front-cover)breakage.



- Electrical mismatches and degradation: cell cracks/fracture and snail trails, broken interconnection ribbons, poor soldering, shunts and short-circuited cells, shading.

- Non-classified Faults: PID, defective/short-circuited bypass diode, open-circuited sub-module



Proposed Methodology

Image Collection and initialization of the image Processor

Load image, select correct images using a Neural Network

Normalization of thermal image

Perform Gaussian blurring

Image Thresholding

Morphological transformations (erosion, dilation)

Connected Component Analysis

K means (BIRCH, DBSCAN) clustering algorithms

Define region of interest (ROI region)

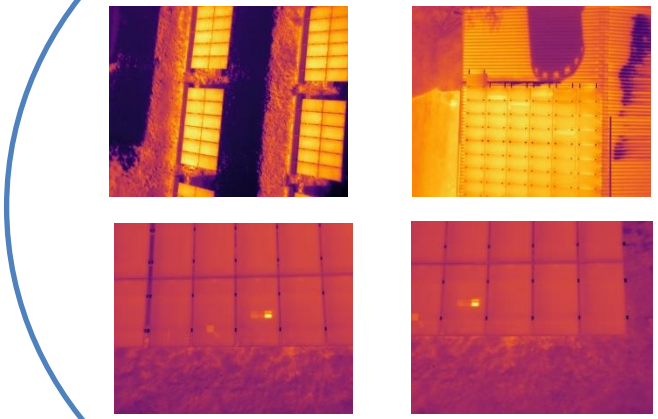
Fault characterization based on pixel intensity, temperature and the shape of the fault.

Send detailed report back to the controller of the system

Collection of thermal images

1. The system controller initiates a UAV Flight
2. Thermal images are collected from the UAV flight
3. The images are passed on to the image processor module for further processing.

System Controller: Initiate UAV Flight



IR images are passed on to the image processor module

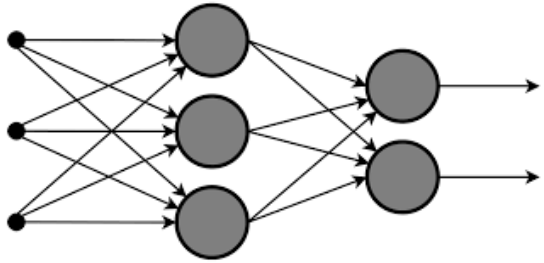
Neural Network Deployment

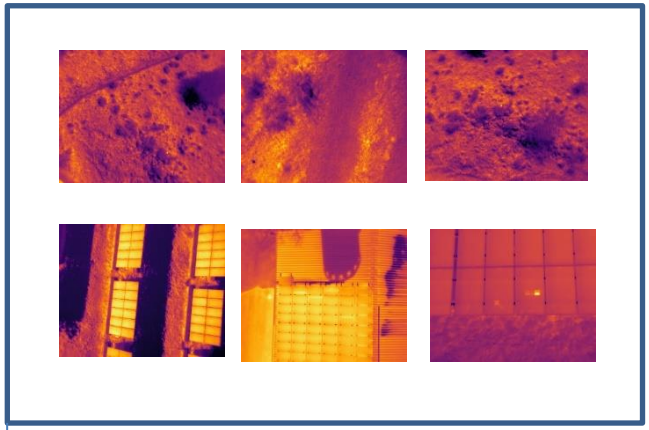
Problem:

In many cases images not containing PV modules were observed thus affecting the accuracy of the image processing methodology in terms of accuracy and computational time.

Solution:

Deployment of a Convolutional Neural Network (CNN) in order to filter out unwanted images. The CNN is trained with images containing PV modules and images not containing PV modules.





Prediction

Normalization and Conversion of images

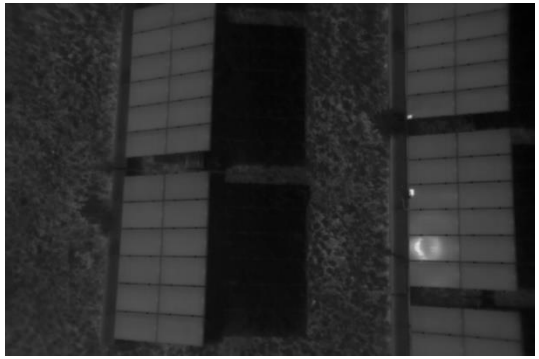
1. Images are obtained in .tiff format and need to be converted in a suitable format.
2. Normalize images for the preprocessing phase.
3. Convert pixels into temperature range.
4. Apply a Color map for better visualization

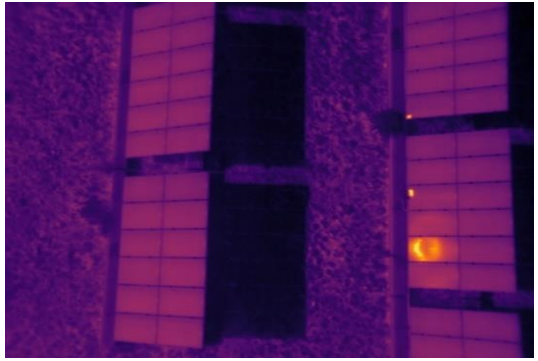
Images obtained with Flir Vue pro Thermal camera

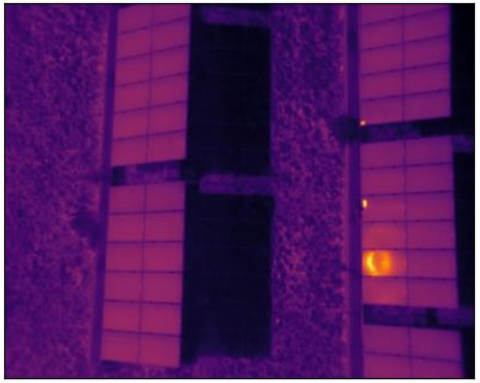
Width : 640 pixels

Height: 512 pixels

Bits per pixel : 16(unsigned)







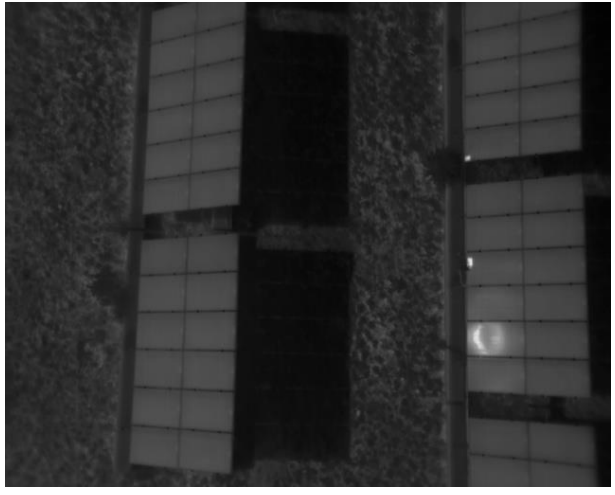
Gaussian Filter

The Gaussian blur is a type of image-blurring filter that uses a Gaussian function

$$G(x,y) = \frac{1}{\sqrt{2\pi\sigma^2}} e^{\frac{-(x-\mu_x)^2}{2\sigma_x^2}\frac{-(y-\mu_y)^2}{2\sigma_y^2}}$$

Where :
x : the distance from the origin in the horizontal axis
y : the distance from the origin in the vertical axis
σ : the standard deviation (for each of the variables x,y)
μ : is the mean

Input



Output

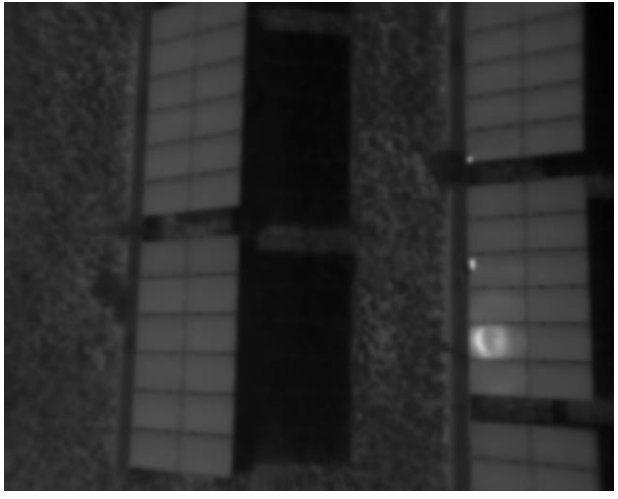


Image thresholding

Thresholding is the simplest method of image segmentation. From a grey-scale image, thresholding can be used to create binary images.

The simplest thresh-holding methods replace each pixel in an image with a black pixel if the image intensity I_{ij} is less than some fixed constant T (that is $I_{ij} < T$), or a white pixel if the image intensity is greater than that constant.

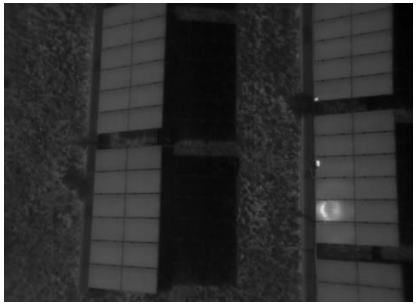
Input

Output

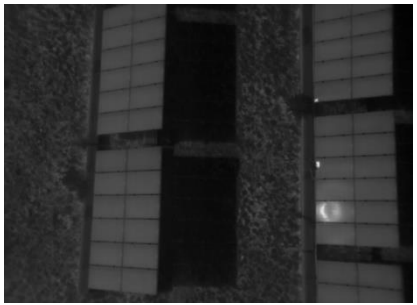
Morphological transformations

Morphological image processing is a collection of non-linear operations related to the shape or morphology of features in an image

Dilation



Erosion



Connected component analysis

1. Loop over the contours(hotspots) of the thermals image.
2. Perform a Connected component analysis in order to extract each feature individually
3. Store each feature in matrix for further processing

K means Clustering algorithm

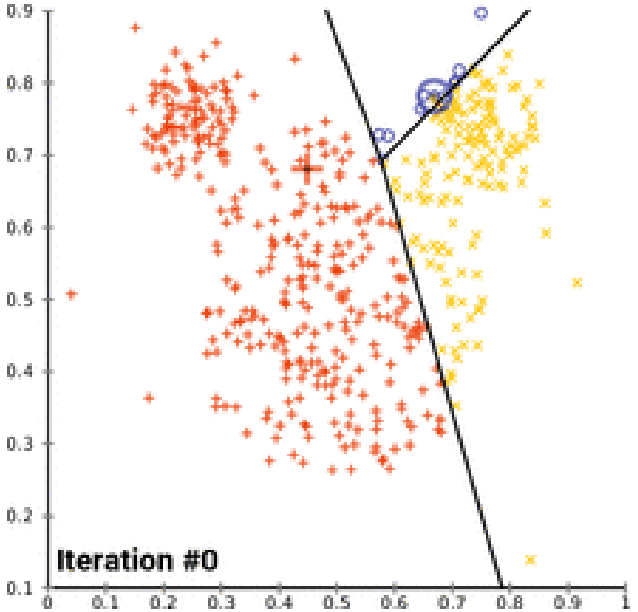
K-means is one of the simplest unsupervised learning algorithms that solve the well known clustering problem

number of clusters
number of cases
centroid for cluster *j*
case *i*
objective function

$$J = \sum_{j=1}^{k} \sum_{i=1}^{n} \left\| x_i^{(j)} - c_j \right\|^2$$

Distance function

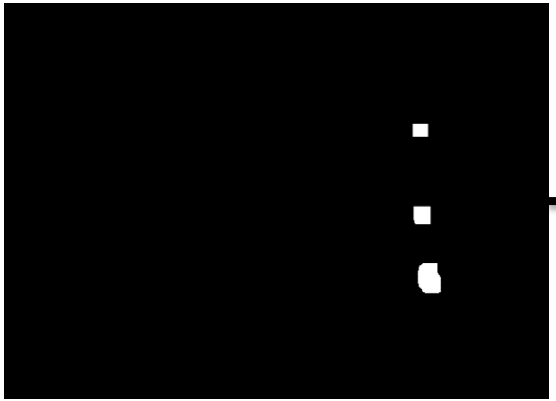
Algorithm
1. Clusters the data into *k* groups where *k* is predefined.
2. Select *k* points at random as cluster centers.
3. Assign objects to their closest cluster center
4. Calculate the centroid or mean of all objects in each cluster.
5. Repeat steps 2, 3 and 4 until the same points are assigned to each cluster in consecutive rounds.



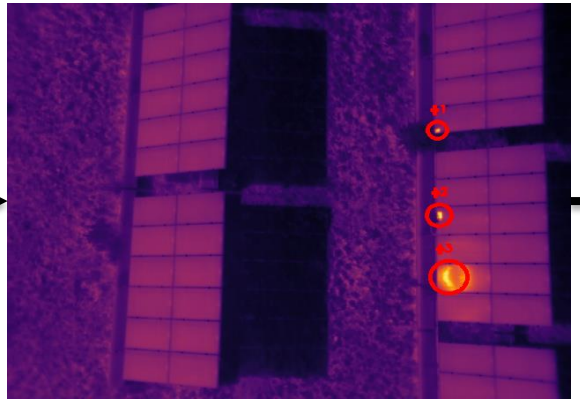
Mark region of Interests (ROI)

The last step of the pre processing phase is to mark the regions of interest we have detected and extract them for the post processing phase where the fault and characterization

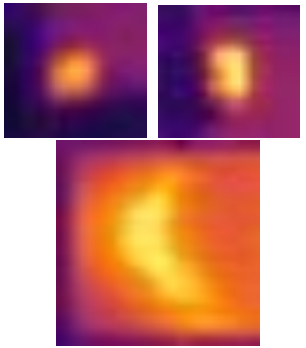
Input



ROI marking



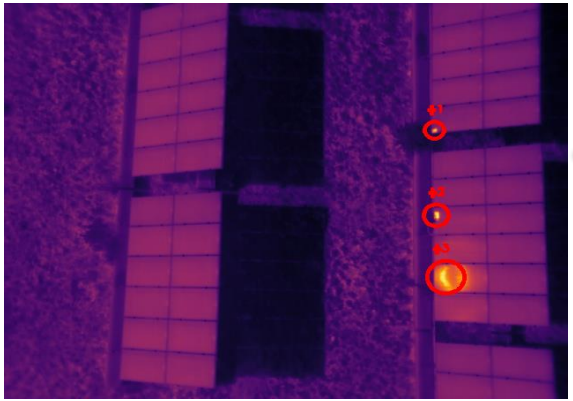
ROI extraction



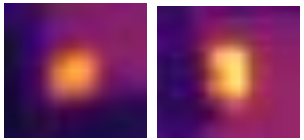
Mark region of Interests (ROI)

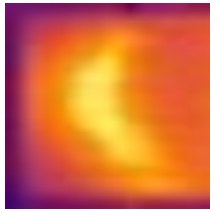
The last step of the image processor is the categorization and characterization for each hot spot (ROI) extracted from the original image.

ROI marking



ROI extraction





Hotspot categorization and characterization based on the shape detected, pixel intensity and temperature

Send detailed report to the controller

Fault categorization and characterization

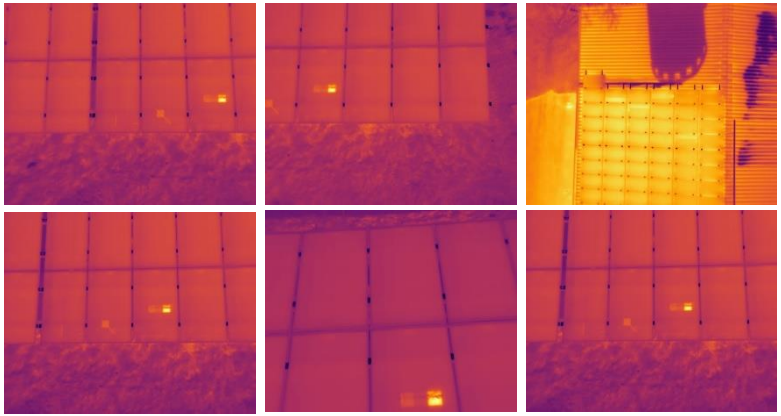
The fault categorization and characterization for each hotspot detected by the image processor uses the following criteria

Temperature (°C)	Severity stage
0-35	No fault, Minor fault
35-45	Small Fault
45-55	Medium fault
55-65	Major Fault
65-150	Critical Fault

ROI shape	Hotspot detection	Temperature range (°C)	Fault Category	Fault characterization
No shape	No hotspot detected	0-35	No Fault	Healthy panel
Small square boxes	Hotspot detected	0-35	Minor Fault	Dusting on panel
Small square boxes	Hotspot detected	35-45	Small fault	Dusting on panel, optical degradation
Medium size square boxes	Hotspot detected	45-55	Medium fault	Cell crack, physical damage
Rectangular shape	Hot spot detected	55-65	Major Fault	PID
Box shape	Hotspot detected	65-150	Critical Fault	Shading, faulty interconnections
Rectangular shape	Hot spot detected	65-150	Critical Fault	Faulty bypass diode, broken interconnection between cells

Results

A quick demonstration how the image processor unit operates



Directory where the images are stored

Detailed analysis of faulty pv modules

```
reading image 20210218_125605.tiff
reading image 20210218_125618.tiff
reading image 20210218_125621.tiff
reading image 20210218_125627.tiff
reading image 20210218_125630.tiff
reading image 20210218_125635.tiff
All images have been scaled and analysed. For a detailed analysis see report.txt
```

Terminal to run the code

report.txt

Results

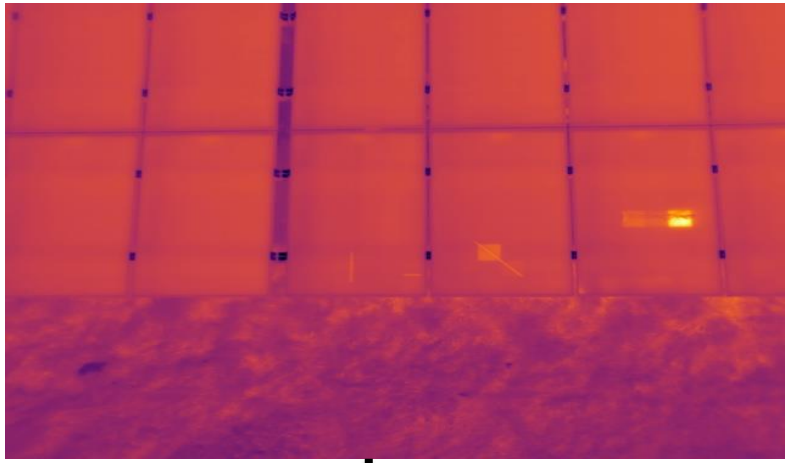
report.txt

Output generated from the image processor module

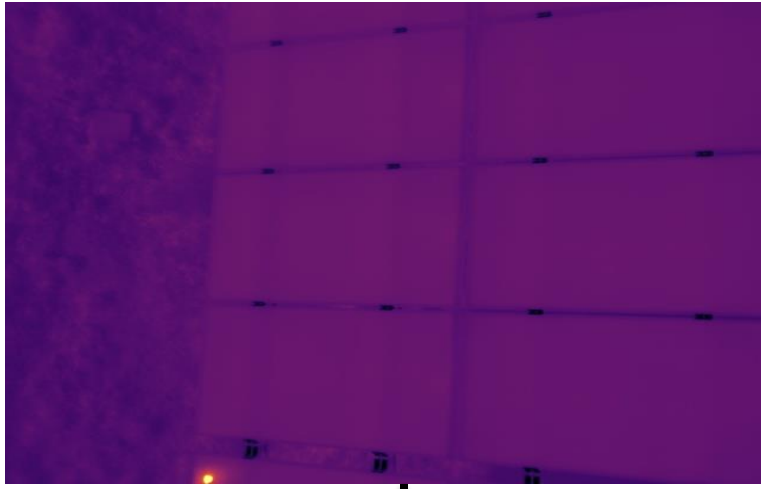
```
Results for image 0.tiff there are| 1 |hotspots detected |Severity stage |critical fault | Possible Defect | shading |
Results for image 1.tiff there are| 1 |hotspots detected |Severity stage |critical fault | Possible Defect | shading |
Results for image 3.tiff there are| 1 |hotspots detected |Severity stage |critical fault | Possible Defect | shading |
Results for image 44.tiff there are| 3 |hotspots detected |Severity stage |small fault | Possible Defect | Faulty interconnections |
Results for image 44.tiff there are| 1 |hotspots detected |Severity stage |critical fault | Possible Defect | shading |
Results for image 114.tiff there are| 0 |hotspots detected |Severity stage |-|Possible Defect | None|
Results for image 115.tiff there are| 0 |hotspots detected |Severity stage |-|Possible Defect | None|
Results for image 116.tiff there are| 0 |hotspots detected |Severity stage |-|Possible Defect | None|
```

Results

Indicative results from various flights are presented



Hotspot detected
Severity stage : Medium Fault
Possible defect : Cell crack, physical damage



Hotspot detected
Severity stage : Medium Fault
Possible defect : Burned Cell

THANK YOU FOR YOUR TIME!!

ANY QUESTIONS ?