Automatic quantitative analysis of Silicon solar panels based on statistical parameters from electro- and photo-luminescence images

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1. Introduction and Motivation

- Electro- and Photo-Luminescence imaging (EL & PL)
  - Very useful characterization techniques for the detection of fails in solar panels
  - A solar plant inspection produces a big amount of images to process
- Development of a screening method
  - To process a big amount of cells and panels
  - Allow quantitative analysis

2. EL and PL Images Analysis

- Most common method: Visually detecting of failures
- Our proposal: Automatic quantitative method based on the statistical parameters of the solar panel normalized luminescence intensity distribution (NLID)

$$p_{EL-Cell}(k,i) = \frac{n_i^k}{n^k}$$

$$0 \le i \le L\,,\, 1 \le k \le N_c$$

- N_c: Total amount of cells
- n_i^k: Number of occurrences of gray level i in cell k
- n^k: Total number of pixels in the image of cell k
- L: Maximum gray scale level

Mean Value

$$\mu_{Cell}(k) = \frac{1}{L}\sum_{i=0}^{L} p_{EL-Cell}(k,i)$$

Standard Deviation

$$\sigma_{Cell}(k) = \sqrt{\frac{1}{L}\sum_{i=0}^{L}[p_{EL-Cell}(k,i) - \mu_{Cell}(k)]^2}$$

Kurtosis

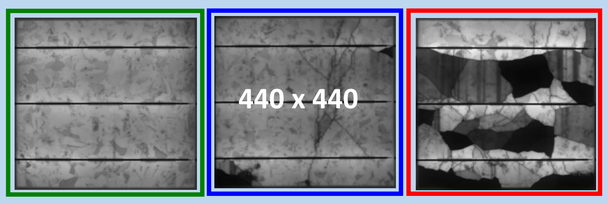
$$\kappa(k) = \frac{1}{L}\sum_{i=0}^{L}\left[\frac{p_{EL-Cell}(k,i) - \mu_{Cell}(k)}{\sigma_{Cell}(k)}\right]^4$$

Inactive Area

$$I_{Cell}(k)[\%] = 100\sum_{i=0}^{TH} p_{EL-Cell}(k,i)$$

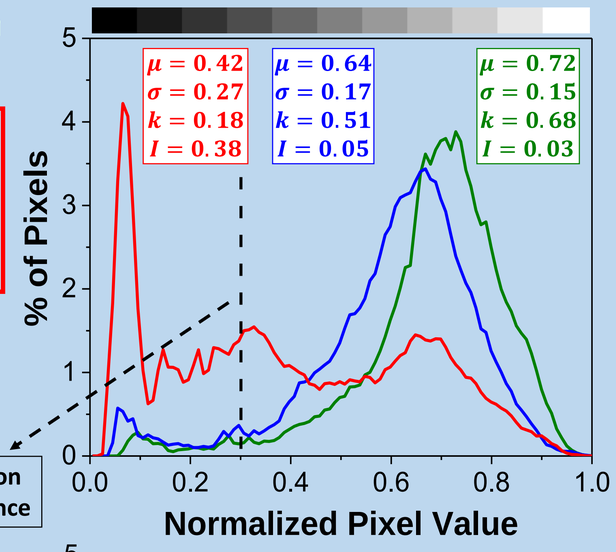
3. Resolution and cells comparison

Indoor EL High Resolution

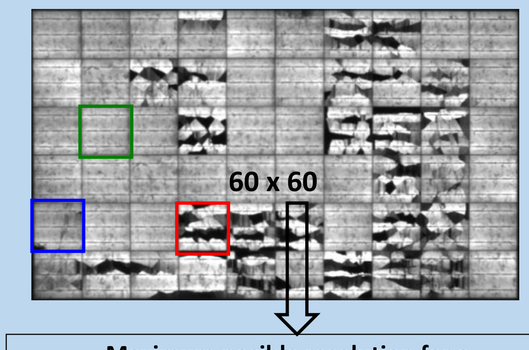


- Similar differences between low and high resolution EL images
- 640 x 512: Enough camera´s resolution to obtain good images

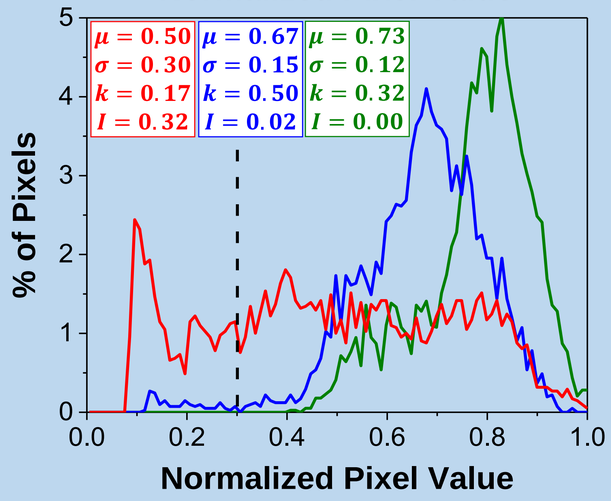
Thresholds based on our testing experience



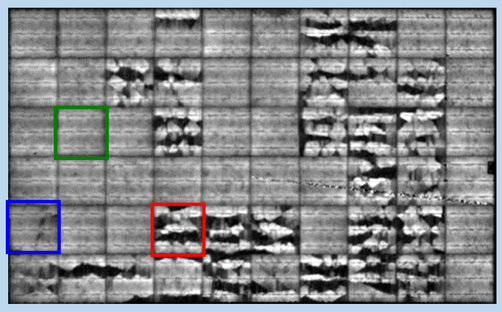
Indoor EL Low Resolution



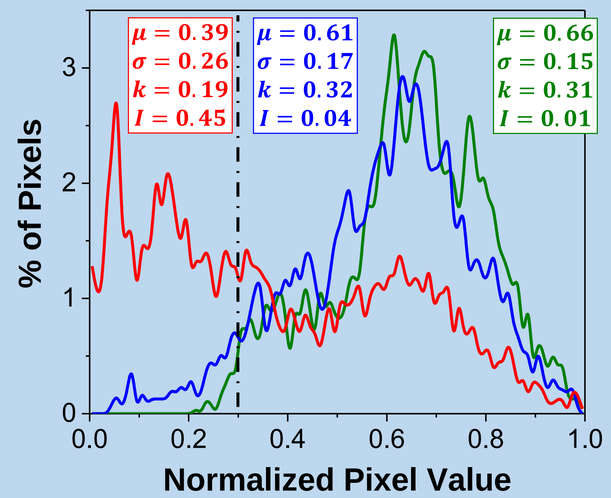
Maximum posible resolution for a (10 x 6 cells) panel allowed by a 640 x 512 camera



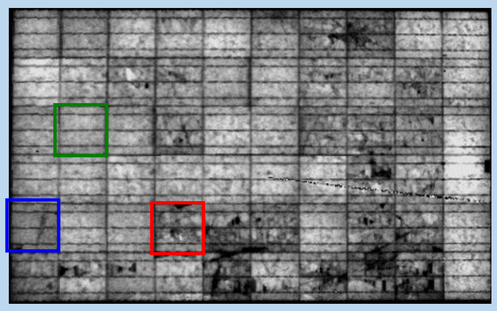
Outdoor EL (970 W/m²)



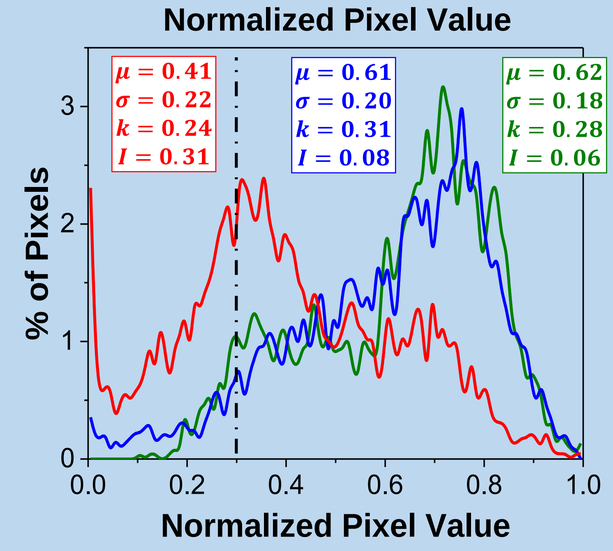
- The filtering process to obtain outdoor luminescence images allows them with a high quality



Outdoor PL (970 W/m²)

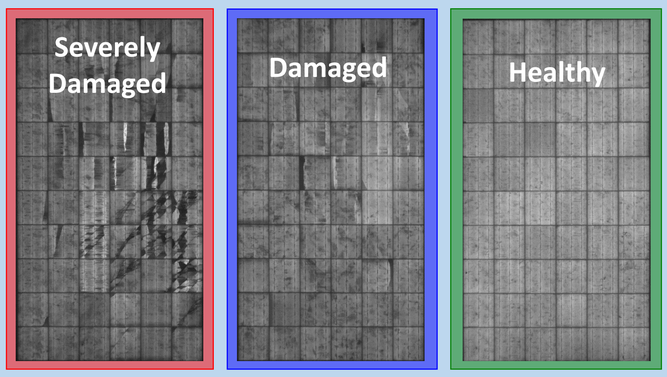


- Quality difference between the three selected cells is similar in all images

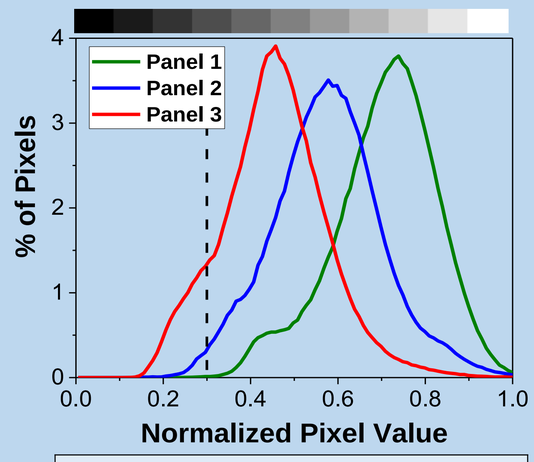


4. Comparison of entire PV panels

Indoor EL Images

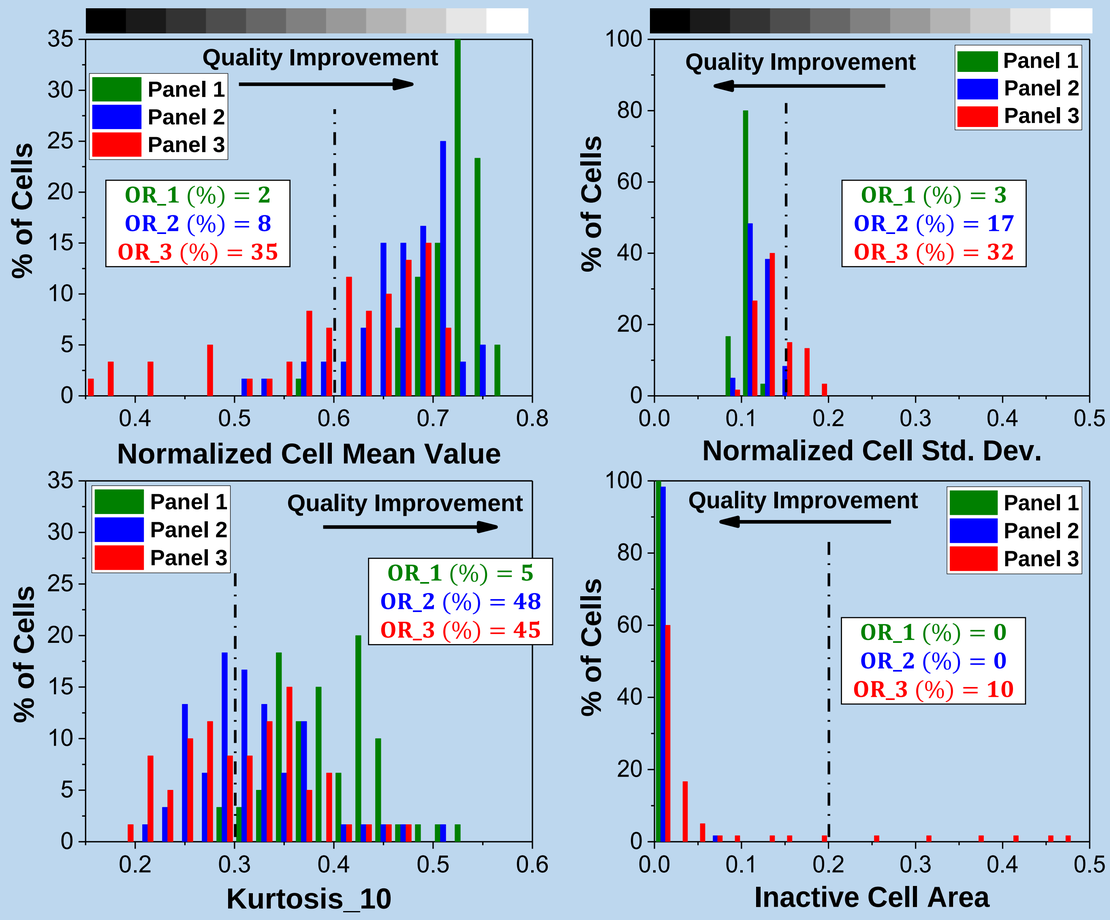


- Analysis of the entire solar panel NLID. Enough to qualify it.
- Mean Value and Inactive Area present strong variations.



	Panel 1	Panel 2	Panel 3
Mean	0.70	0.57	0.45
Std. Dev.	0.12	0.13	0.12
Kurtosis	0.35	0.32	0.34
Inactive	0.00	0.01	0.08

5. Histograms of statistical parameters from single cells

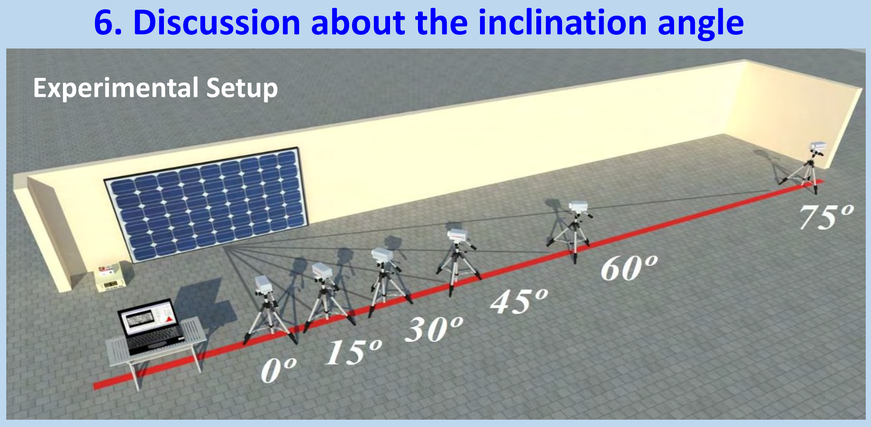


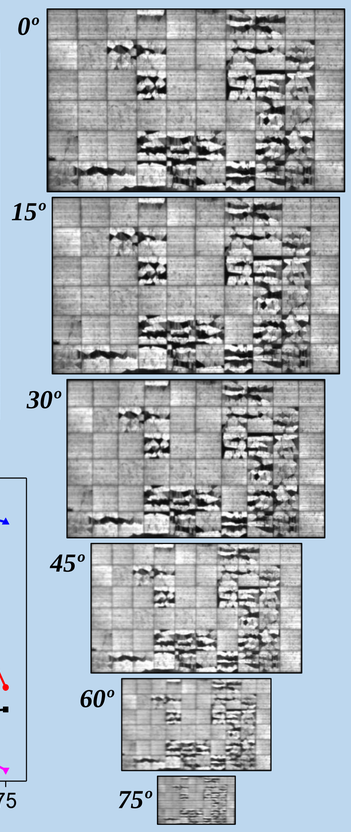
Percent of cells out of the acceptance range

$$OR\ (\%) = 100\,\frac{N_{damaged}}{N_{cells}}$$

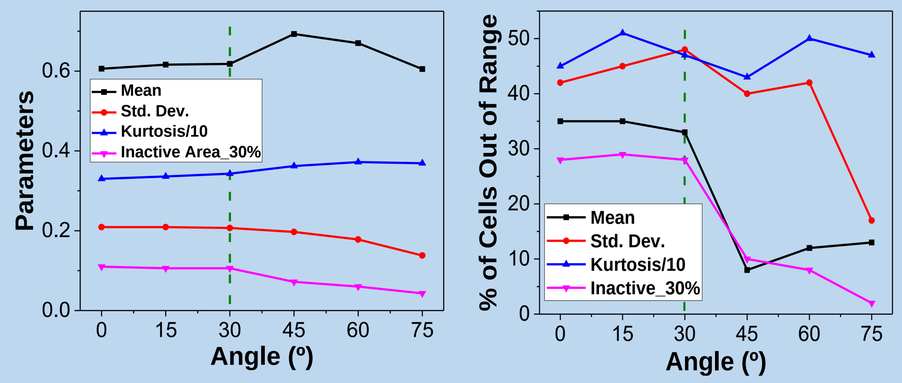
- Analysis of every single cell of the panel. More detailed than calculations for NLID of the entire panel.

6. Discussion about the inclination angle





- The limiting angle depends on the initial resolution and quality image



7. Conclusions

- High quality daylight EL/PL images in high irradiance conditions
- Screening method based on the calculation of statistical parameters
- 640 x 512 InGaAs camera. Enough resolution for the testing process
- Very similar results in EL indoor/outdoor images and PL images
- Importance of the analysis of the limiting inclination

Acknowledgments

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References

- O. Martínez, M. Guada, Á. Moretón, S. Rodríguez-Conde, M.Á. González, J. Jiménez, J. Pérez, M. Martínez, J.A. Florez, F. Domínguez, A. Velasco, L. Pérez, V. Parra, Implementation of a Friendly Daylight Electroluminescence System for the Inspection of Solar PV Panels, 33rd EUPVSEC (2017) 2021–2025
- S. Spataru, H. Parikh, P. Hacke, G.A. dos Reis Benatto, D. Sera, P.B. Poulsen, Quantification of Solar Cell Failure Signatures Based on Statistical Analysis of Electroluminescence Images, Proc. 33rd EUPVSEC (2017) 1466–1472.