Encoder-decoder networks for EL images of thin-film PV modules

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Overview

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Summary

Data

- PEARL TF-PV, 2017–2020, `http://pearltf.eu`
- Data collected by SolarTester, PI-Berlin
- Aims:
  - Catalogue of EL images of thin film failure mechanisms.
  - Improved standardised measurements and preconditioning methods.
  - Development of imaging based system for quality rating of installed modules.

This talk focuses on:

- Develop an automatic, reliable and flexible image segmentation framework, i.e. assign a label to every pixel thereby identifying locations and shapes of defects (i.e. perform image segmentation).
- Analyse a database of $\approx$ 9000 EL images of **thin-film CIGS modules**, and identify **shunts** and **droplets** on all images.

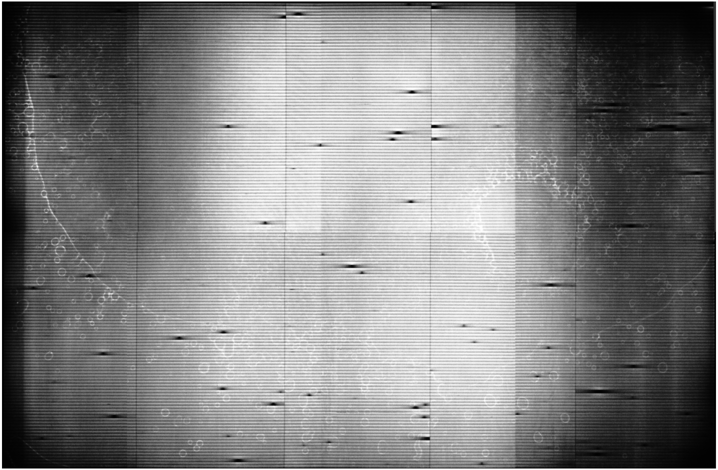


Figure: Thin-film module consists of 150 cells (positioned horizontally). The cells are separated by interconnection lines (horizontal dark lines). The module consist of several submodules separated by vertical isolation lines, which appear dark in the EL image. The EL image is stitched (there are 1 horizontal and 3 vertical stitch lines); overall intensities of different patches of images are different due to metastable changes during the measurement

Examples of defects

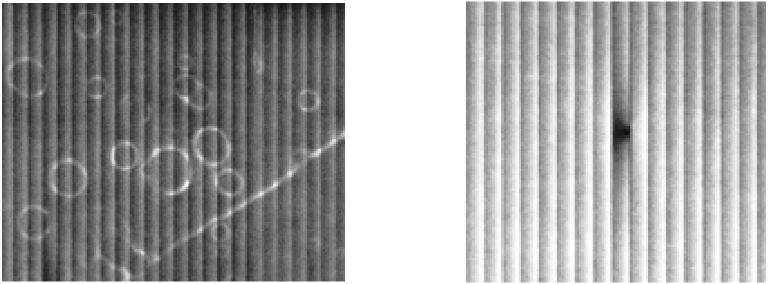
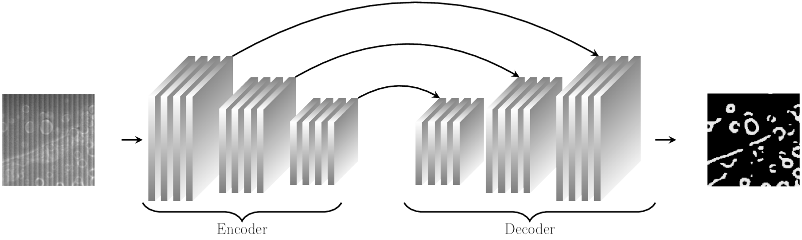


Figure: Example of droplets (left) and a shunted area (right)

Encoder-decoder models



- The encoder compresses information content of an arbitrarily high-dimensional image into a feature vector.
- The decoder gradually upscales the encoded features back to the original resolution.
- The feature vector is a small dimensional representation of data.

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Encoder-decoder combinations

- We combine different popular encoders and decoders.
- Models are pretrained on the ImageNet dataset.
- Challenge is to select the best model: there is no unique metric that measures how good a segmentation is.
- Hence, a method based on the multi-objective optimisation is proposed to select the best model.

  The targets of the optimisation are tailor metrics, that measure various characteristics of segmentation that are important for our case.

  This is the topic of:
  Evgenii Sovetkin et al. “Encoder-decoder semantic segmentation models for electroluminescence images of thin-film modules”. In: IEEE Journal of Photovoltaics (2020). accepted.

Choosing the best model

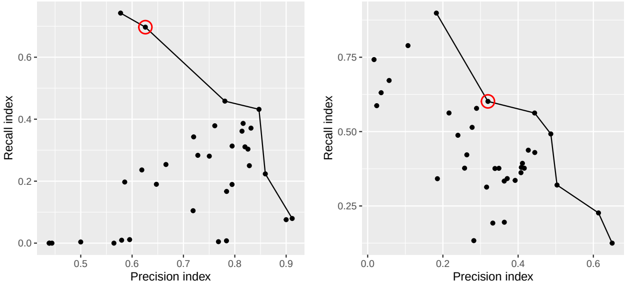


Figure: Pareto frontier for the droplets (left) and shunts (right) models

The precision is the proportion of correctly identified defects among all locations identified by a model, while the recall is the fraction of all defects that were identified by a model. Red indicates model with highest Jaccard index.

Segmentation examples

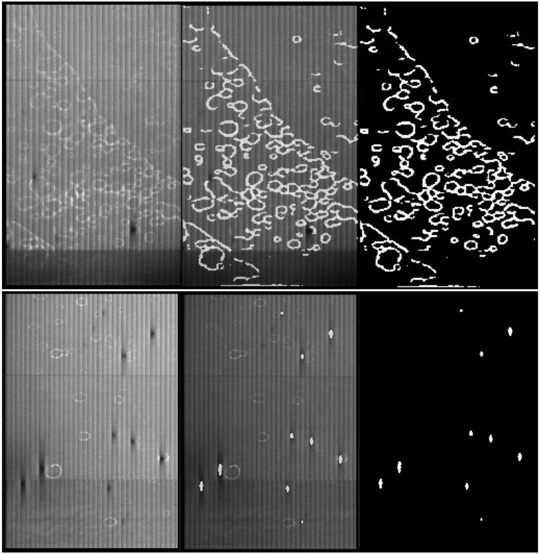


Figure: An example of droplets (top) and shunts (bottom) segmentation

Combining models together

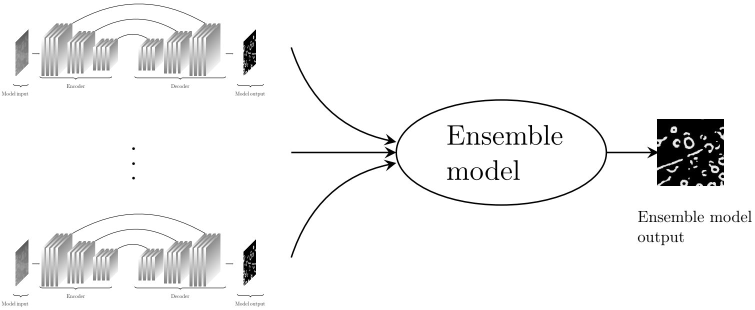


Figure: Ensemble combines several basis models together into a single encoder-decoder model

Evgenii Sovetkin et al. "PV-AIDED: Photovoltaic Artificial Intelligence Defect Identification. Multichannel encoder-decoder ensemble models for electroluminescence images of thin-film photovoltaic modules, PEARL TF-PV.". In: 37th EU PVSEC. 2020

"Bagging"-like ensemble

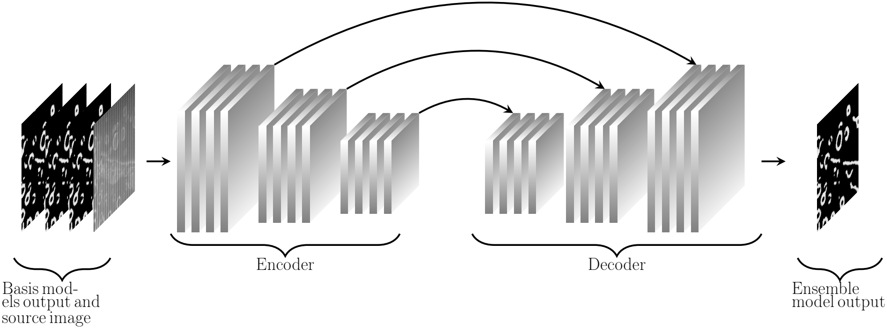


Figure: Schematic representation of ensemble encoder-decoder architecture. The left-hand side image is an input image patch together with the segmentation output of basis models that are passed to a series of the computational layers. The right-hand side image is an output binary image. The arrows are skipping connection layers, where input is being copied directly from encoder to a decoder.

Comparison of models

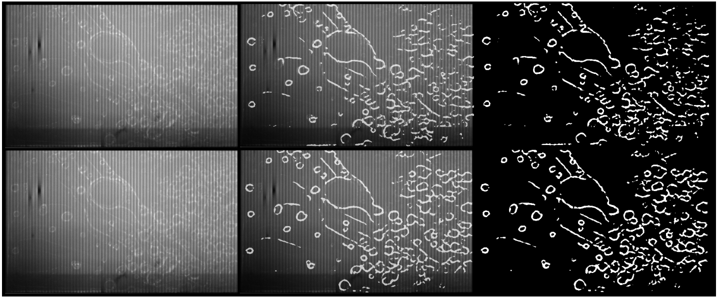


Figure: Visual comparison of the best basis model (top row), and the ensemble model (bottom row). The left column shows the original image, the right column shows the segmentation image, the middle column shows overlayed original image with the segmentation image.

Comparison of models

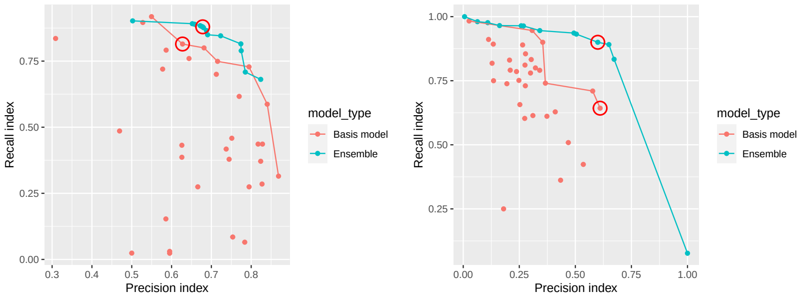


Figure: Comparison of the Pareto frontier for basis models (red line) and ensemble models (blue line) for droplets (left) and shunts (right). Individual dots correspond to individual models.

Segmentation heat-maps for droplets

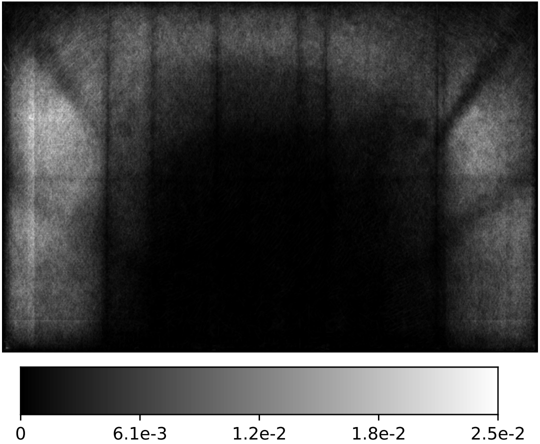


Figure: Heat map of droplets locations. The intensity scale indicates the probability a pixel is marked as a droplet. Number of images: 6000

Segmentation heat-maps for shunts

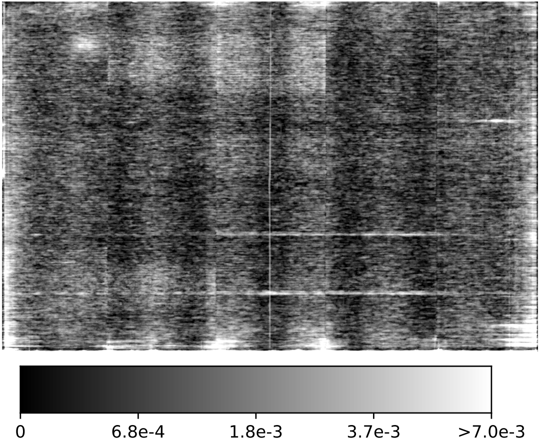


Figure: Heat map of shunts locations. The intensity scale indicates the probability a pixel is marked as a shunt. Number of images: 6000

Data

- In addition to the EL image measurements, IV measurements are performed.
  IV curve, temperature, values corrected to IEC60891 STC.

Intensity correction

Image taken at different conditions.

$$kT/q \log(\Phi/t_c),$$

where Φ pixel value intensity, t_c is the camera integration time, T temperature during the EL measurement.

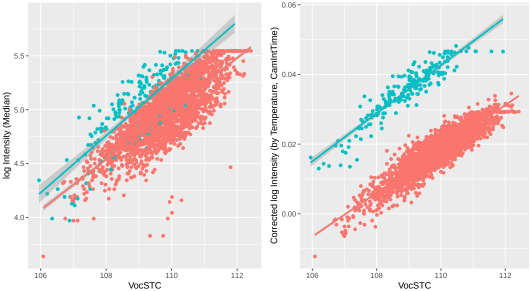
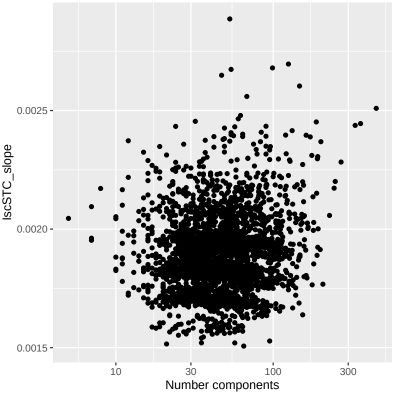


Figure: Logarithm of median intensity before and after correction. Evaluated on a selected homogeneous group of $\approx$ 2400 modules, that were measured at a constant applied current. $R^2 = 0.83$ (explained variance)

Correlation defects to performance



Linear model that includes various shunts characteristics has $R^2 \leq 0.09$.

Possible reason: modules are sorted by a manufacturer according to its performance. A module can have many shunted areas, but have a better material properties overall.

Summary

- We studied performance of the popular encoder-decoder networks, as well as ensemble models combining multiple networks architectures together.
  More complex models yield better segmentation.
- Defect segmentation in industrial thin-film PV modules: shunts, droplets.
  Defects do not occur uniformly in a module.
- Correlation defects to a module performance is a hard problem.
  A simple statistic of number of defects has little correlation with module performance.

Feel free to contact me if you have any questions:
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