AI and ML Applications for PV Reliability & System Performance

K. Perry[1], C. Deline[1], D. Jordan[1], M. Deceglie[1], M. Muller[1], M. Springer[1], R. White[1], B. Meyers[2], D. Ragsdale[2], S. Miskovich[2], G. Ogut[3]

(1) National Renewable Energy Laboratory, Golden, CO 80401, USA

(2) SLAC National Accelerator Laboratory, Menlo Park, CA 94025, USA

(3) Stanford University, Palo Alto, CA 94305, US

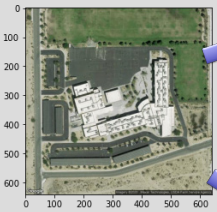
PV Fleets: Automated Data QA and Metadata Verification

Automated Metadata Satellite Analysis using Deep Learning

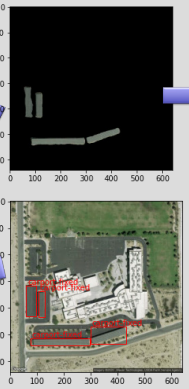
- NREL Panel-Segmentation Package
- Uses deep learning models to automatically do the following:
  - Locate solar installation in Google Maps satellite image
  - Extract solar azimuth
  - Determine the mounting configuration (rooftop, carport, ground; fixed or tracking)
- Imagery analysis great use case for deep learning
- Useful for analyzing fleets where metadata is unknown or incorrect

Panel-Segmentation package:

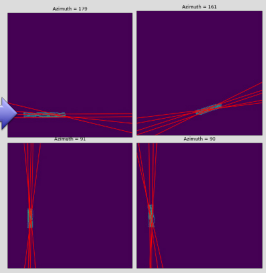
Semantic segmentation: VGG16 model. Find pixel mask of arrays



Google Maps Image



Mounting configuration detection: Resnet-50 model. All arrays determined to be carport-fixed tilt

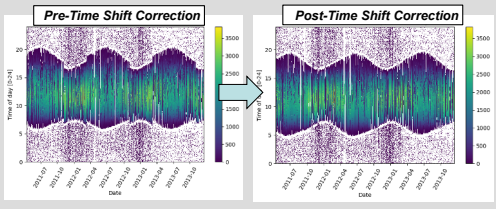


Edge Detection and Hough Line Transform: get the azimuth associated with each array

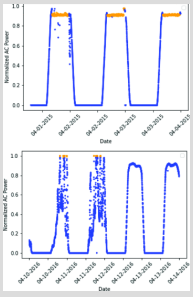
Automated QA: Clipping Detection, Time Shift Estimation, Capacity Shift Detection

- Developed supervised and unsupervised ML algorithms for finding issues/features in measured PV data
  - **Clipping/curtailment detection:** Logic-based AI method and supervised ML method (XGBoost). Creates mask of clipped/non-clipped periods
  - **Time shift detection:** Unsupervised changepoint detection (CPD) to identify time shifts between modeled and measured solar noon
  - **Capacity shift detection:** Unsupervised CPD to detect abrupt capacity shifts in measured PV data
- All functions validated with "ground-truth" labeled data and results published
- Functions publicly available in Python PVAnalytics package and Rdtools package (clipping only)

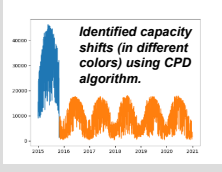
PVAnalytics package:



Daily heatmap of AC power values before automated time shift correction and after, respectively, for a data stream with daylight savings time (DST).



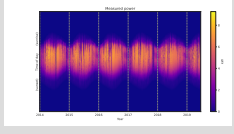
Curtailed and clipped systems, with AI-identified clipped periods in yellow

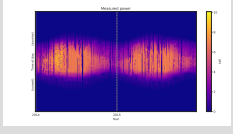


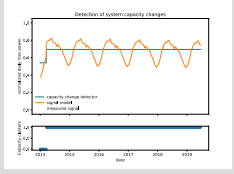
Identified capacity shifts (in different colors) using CPD algorithm.

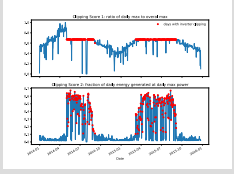
Statistical Learning in PVInsight

- Developing *white-box* machine learning models based on statistical signal processing, convex optimization, and domain expertise
- Deep neural networks are not part of our toolkit!
- **Methods:** we have a *monograph*[1] and a no-math, no-code *tutorial*[2]
- **Applications:** check out this *report*[3] and this *dissertation*[4]
- As opposed to neural networks, this flavor of machine learning is
  - interpretable (good for science *and* troubleshooting!)
  - highly data efficient (good models with 75% data loss!)
  - computationally efficient (less energy, water, cost, …)





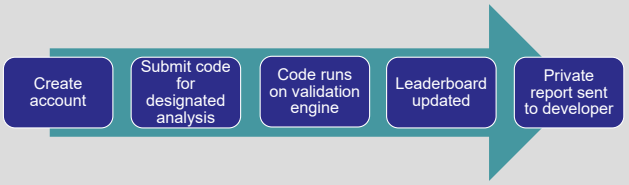


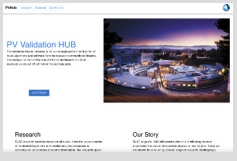


1 2 3 4

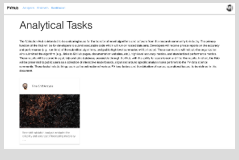
PV Validation Hub

- Allow developers to submit PV analytics algorithms for validation.
  - *Degradation, soiling, tilt/azimuth estimation, etc.*
- Well-curated validation data sets and procedures
- Consistent labeled data sets allow for side-by-side comparison of different algorithms
- Public leaderboards and documentation facilitate tech transfer
- Enables rapid development and benchmarking of solar algorithms

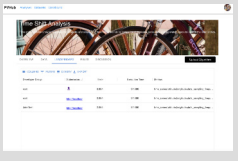




Main page of the site



List of tasks



Example leaderboard

This work was authored [in part] by the National Renewable Energy Laboratory, operated by Alliance for Sustainable Energy, LLC, for the U.S. Department of Energy (DOE) under Contract No. DE-AC36-08GO28308. Funding provided by the U.S. Department of Energy Office of Energy Efficiency and Renewable Energy Solar Energy Technologies Office. The views expressed in the article do not necessarily represent the views of the DOE or the U.S. Government. The U.S. Government retains and the publisher, by accepting the article for publication, acknowledges that the U.S. Government retains a nonexclusive, paid-up, irrevocable, worldwide license to publish or reproduce the published form of this work, or allow others to do so, for U.S. Government purposes.

SETO Workshop on Solar Applications in AI and ML, Alexandria VA, October 31, 2023
NREL/PO-5K00-87931