

6/5/16

SAND2016-5408C

Wondering what to blame?

Turn PV performance assessments into maintenance action items through the deployment of learning algorithms embedded in a Raspberry Pi device

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Introduction

Sub-System Monitoring

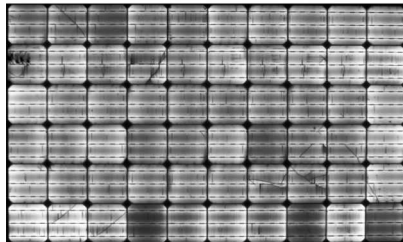
String level faults

- Bypass diode
- Hot spots
- Shading
- Other

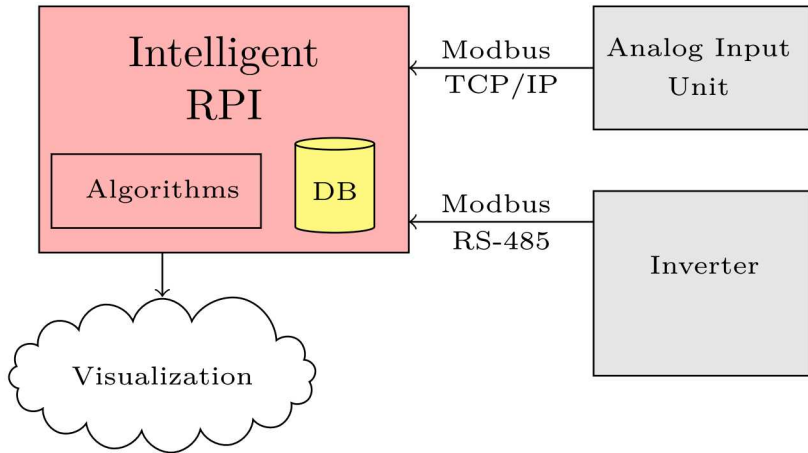
Sensor Data

- POA Irradiance
- Ambient Temperature
- Module Temperature
- Current, Voltage, Power

Fault Conditions



Proposed Device Set-Up



Intelligent Raspberry Pi

RPI Connected to Analog Input



Data Collection

- Modbus TP/IP
- Modbus Serial
- MySQL DB
- GPS Clock

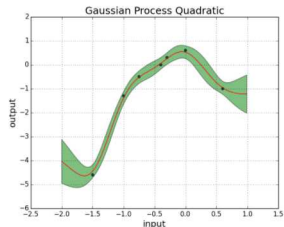
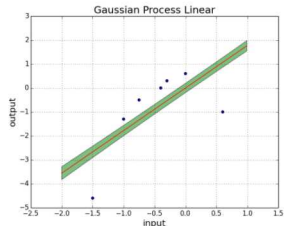
Algorithms

- Gaussian Process Regression
- Support Vector Novelty Detection

Estimate PV Performance

Gaussian Process Algorithm

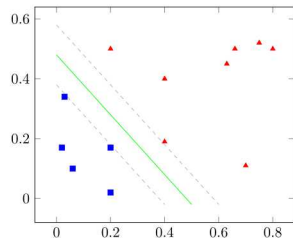
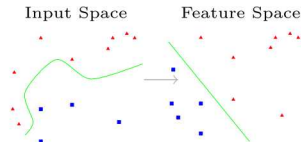
- GP is the generalization of the Gaussian probability distribution
- Parameterized by:
 - Mean function - $\mu(x)$
 - Covariance function (kernel) - $K(x,x')$
- Gaussian Process Regression
 - Predictive distribution
 - $p(y_* | x_* X, y) = \mathcal{N}(\mu_*, \sigma_*^2)$
 - where
 - $\mu_* = K_{*N}(K_N + \sigma^2 I)^{-1} y$
 - $\sigma_*^2 = K_{**} - K_{*N}(K_N + \sigma^2 I)^{-1} K_{*N} + \sigma^2$
 - $K_N = \text{Covariance}$
 $K_{*N} = \text{training covariance}$
 - $K_{**} = \text{training-testing covariance}$



Fault Detection

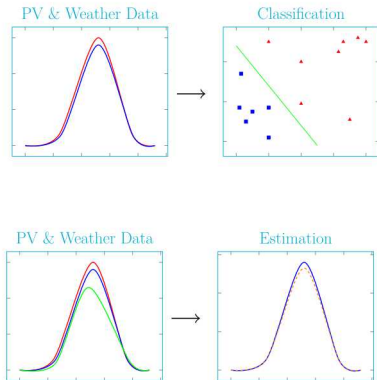
Support Vector Novelty Detection

- Unsupervised learning algorithm
- Learns a decision function without class labels
- Transform from input to feature space with radial basis kernel
 - $K(x, x') = \exp(-\gamma \|x - x'\|^2)$
- Maximum margin separation in feature space using cost function
 - $\min\{\frac{1}{2}\|w\|^2 + \frac{1}{\nu n} \sum_{i=1}^n \xi_i - \rho\}$
- Decision function
 - $f(x_*) = \text{sign}(w \cdot \phi(x_i) - \rho)$

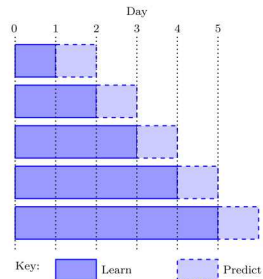


Experiment

On-board Classification & Regression



On-Line Learning

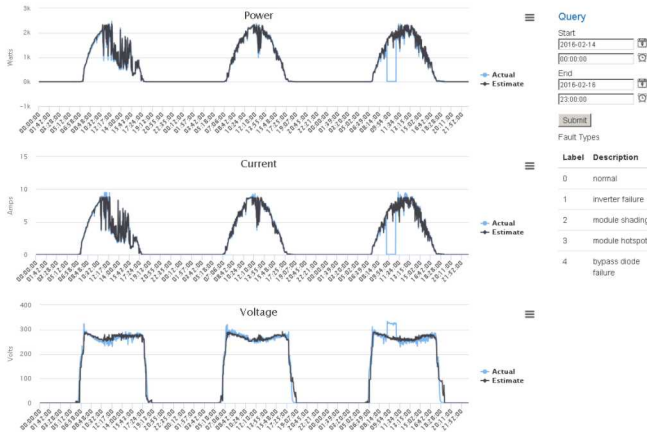


Web-based Visualization

Raspberry Pi hosted web interface

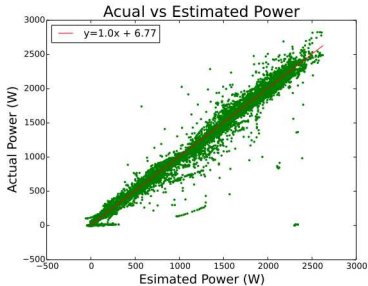
Home Weather PV Check Check All

Performance Check



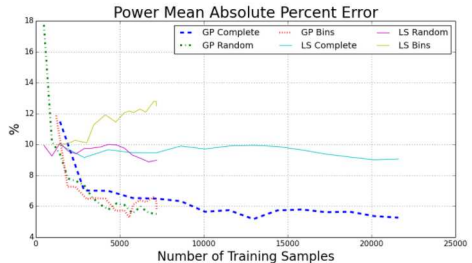
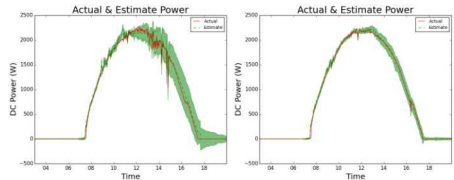
Performance Estimate Results

Power Generation Estimates



- GP Estimate had strong linear relationship with actual
- Increased training samples improved uncertainty and error
- GP converged to 5% MAPE as training data increased

On-Line Learning Impact



Fault Detection Results

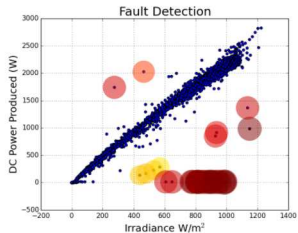
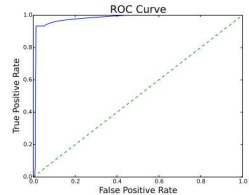
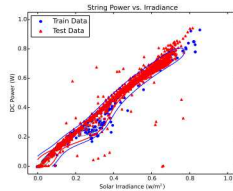
Binary decision problem

Novelty Detection

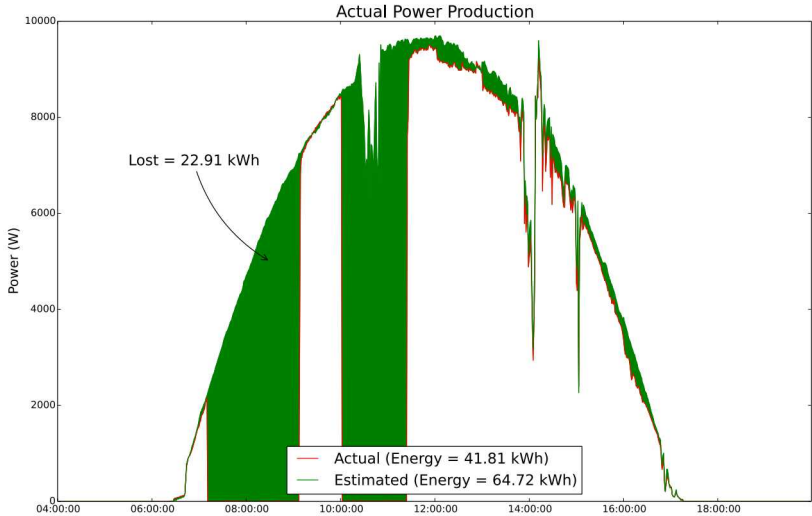
	estimate	
	p	n
p'	True Positive	False Negative
n'	False Positive	True Negative

$$TPR = \frac{TP}{TP + FN} \quad (1)$$

$$FPR = \frac{FP}{FP + TN} \quad (2)$$



Lost Production Results



Conclusions

Successful implementation of RPI

Data Collection

- PV and weather sensors
- Frequency equal to 5 seconds
- On-board storage (MySQL)

Estimation & Novelty Detection

- Reliable estimation
 - Voltage
 - Current
 - Power
- Accurate novelty detection
 - Area under ROC curve equal to 0.9
 - High TPR
 - Low FPR

Visualization/Reporting

- Web-based interface
- Easy to use