A data-driven adaptive model-identification based large-scale sensor management system: application to Self Powered Neutron Detectors (SPND)

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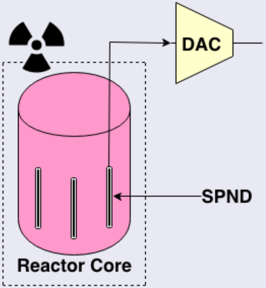
Overview

Introduction

About SPNDs

- SPNDs are widely used to measure neutron flux inside nuclear reactor.
- Flux measurement provides direct measurement of reactor output power.
- Nuclear reactor considered for this work has 144 SPNDs.
- Positioned at different location inside the reactor core.

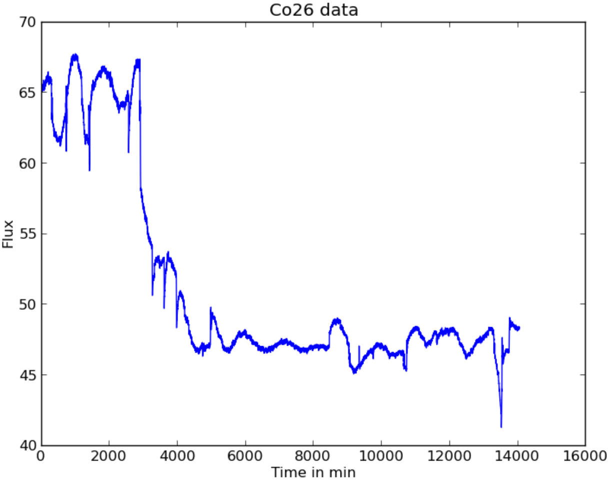
SPNDs Location



Problem:

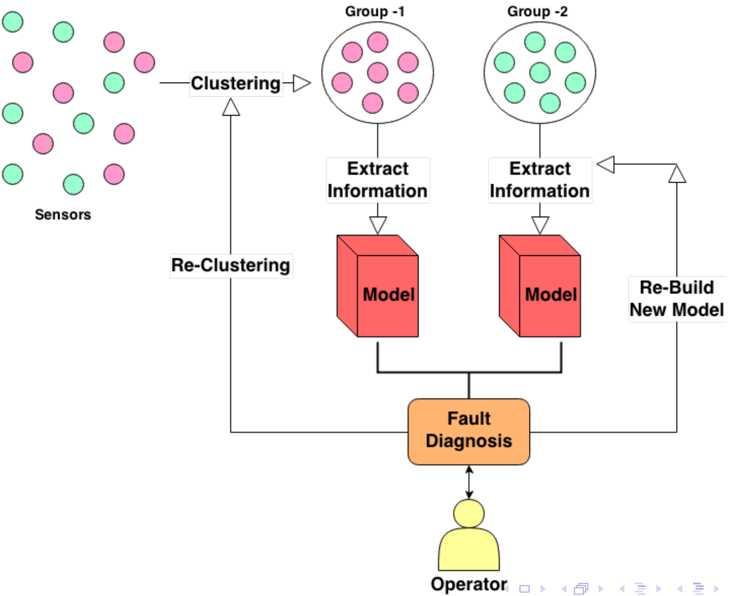
- SPNDs can become faulty due various reasons like - aging, mechanical and electrical failure.
- Results in forced shutdown of reactor to replace faulty sensor.

SPND Output



Co26 data
Flux
Time in min
70
65
60
55
50
45
40
0
2000
4000
6000
8000
10000
12000
14000
16000

Overall Proposed Solution



SQLite and Pytables

SQLite - Sensor database

- SQLite is used to maintain database of all 144 sensors data.
- It is the most widely deployed SQL database engine in the world.
- sqlite3 module provides interface for using SQLite in python.

Pytables - model and cluster database

- Pytables is a python module that is build on top of HDF5 library.
- Hierarchical Data Format (HDF5) is a set of data format and libraries designed to store large amount numerical data.

Clustering

- SPNDs with strongly correlated measurements are grouped together.
- Used k-means algorithm available in Pycluster module for python.
- High correlation is decided by - absolute Pearson correlation distance.

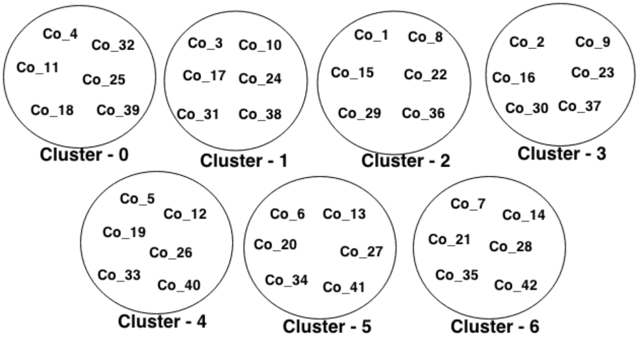
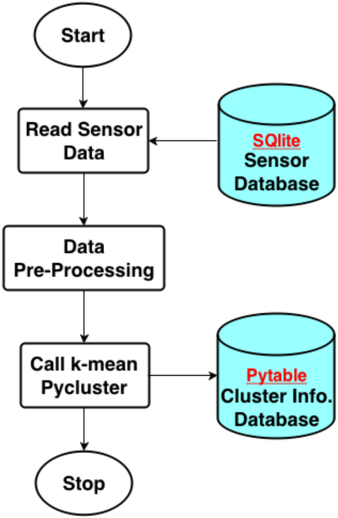
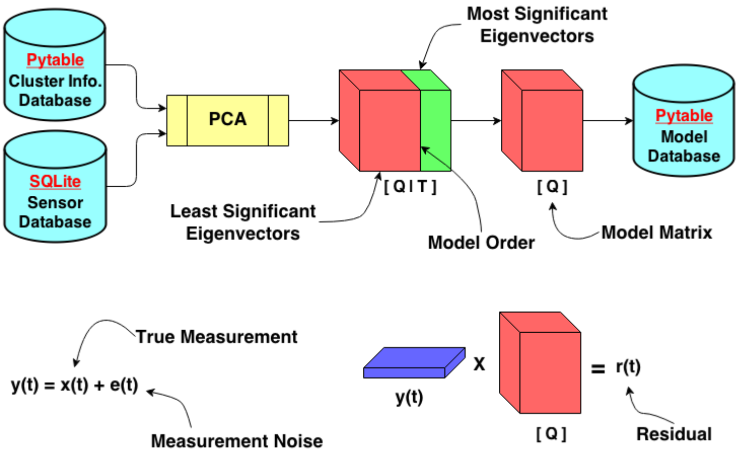


Figure : On of the cobalt SPNDs clustering solution - 7 groups each containing 6 sensors

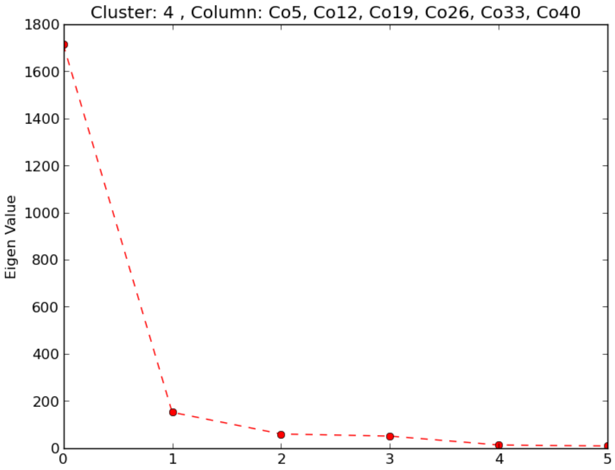
Cluster database



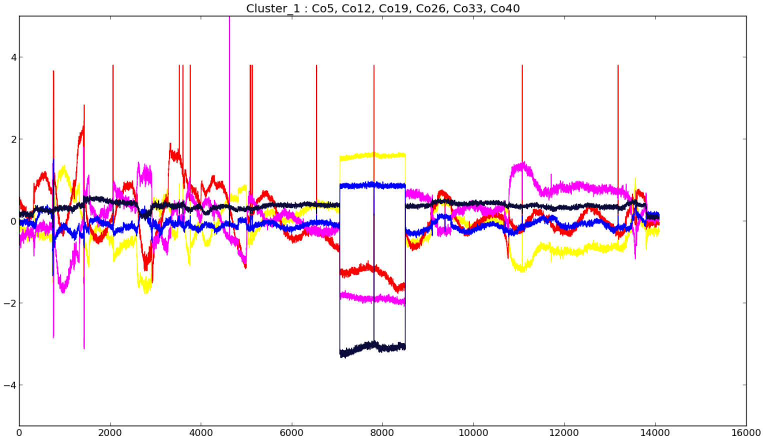
Model Identification using Principal Component Analysis (PCA)



Eigenvalue plot - Co sensors



Residuals plot - Co sensors



Fault Diagnosis - Gross Error Detection

- For each cluster the following test statistic is considered:

$$\gamma(t) = r(t)^T V^{-1} r(t) \tag{1}$$

  V is covariance matrix of residuals

- In the absence of gross error $\gamma(t)$ follows χ^2-distribution with m degrees of freedom and α as confidence level.
- A gross error is detected if $\gamma \geq \chi^2_{1-\alpha,m}$
- Used python's statistical library scipy.stats for χ^2 test.
- Once gross error is detected for a cluster, the variable(s) responsible for gross errors along with estimates of gross error is identified using Generalized Likelihood Ratio (GLR).

Fault Diagnosis - Data Reconciliation

- It is process to obtain more precise estimate of true value which would satisfy the process model.
- The estimate is given by the following weighted least square optimization problem:

$$\min_{x(t)} \; (y(t) - x(t))^T \mathbf{W} (y(t) - x(t)) \tag{2}$$

$$\text{constraint} \quad Ax(t) = 0$$

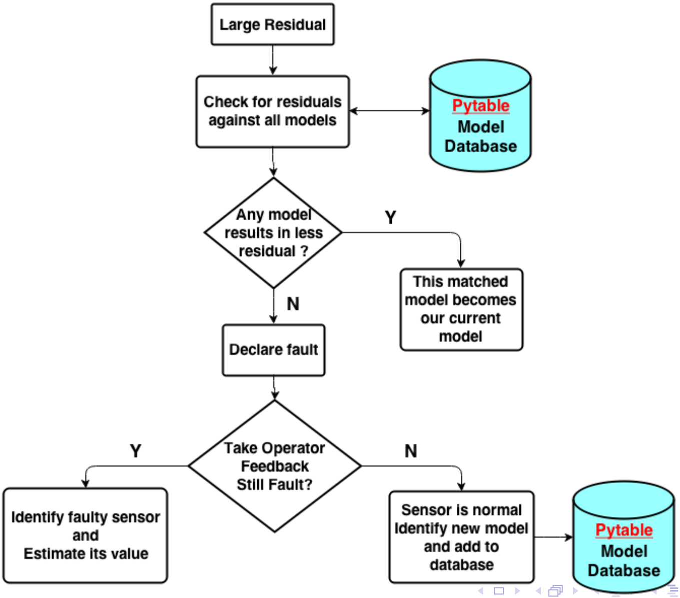
W is weighting matrix taken as inverse of noise covariance matrix.

- The solution to the above optimization problem is given by:

$$\hat{x}(t) = y(t) - W^{-1}A^T(AW^{-1}A^T)^{-1}Ay(t) \tag{3}$$

$\hat{x}(t)$ are reconciled estimate of the true values at time t.

Adaptive model updating



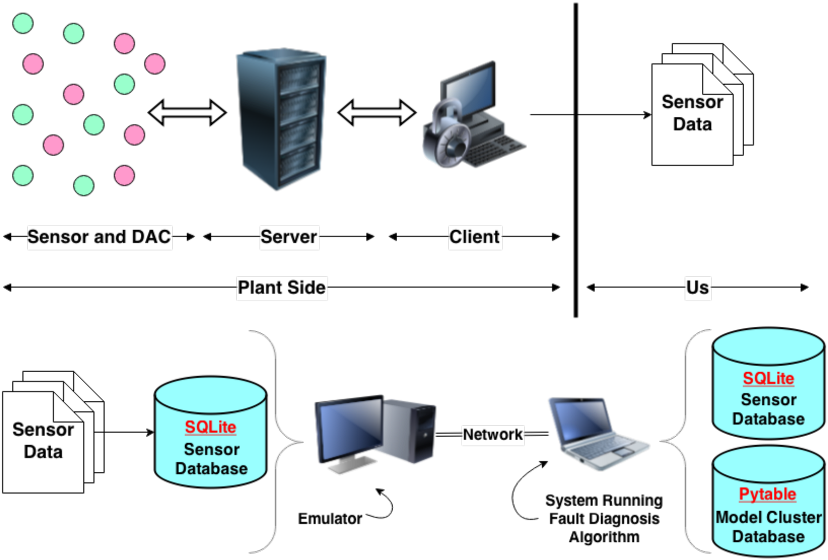
Adaptive re-clustering

- Re-clustering decision is at higher level than updating model.
- Cluster configuration may change depending on normal operating condition of plant.

Rules used for re-clustering sensors:

1. If faults are detected in multiple clusters simultaneously.
2. Once again take operator feedback before re-clustering.

Emulating server-client interaction



Results - Profiling - Cluster building

- **cProfile** module of python is used for profiling.
- **Cluster building**:
  - Data points = 7000

SPND	**No. of clusters**	**npass**	**nfound**
Cobalt	7	100	13
Vanadium	12	100	1

Table : Clustering Parameters

npass = No. of times clustering algorithm is run.
nfound = No. of times optimal solution is found.

SPND	Time(sec) - **build_cluster()**	Time(sec) - **kcluster()**
Cobalt	**4.192**	**3.292**
Vanadium	**25.278**	**23.277**

Table : Timing analysis - Cluster building

Results - Profiling - Model building and Gross error detection

- **Model Building**:
  - Data points = 7000

SPND	Time(sec) - Serial Code	Time(sec) - Parallel Code
Cobalt	**0.428**	**0.015**
Vanadium	**1.314**	**0.058**

Table : Timing analysis - Model building

- **Gross Error Detection**:
  - Data Points = 14061

SPND	Time(sec) - **error_detect()**	Time(sec) - per cluster
Cobalt	**20.055**	**2.867**

Table : Timing analysis - Gross error detection

Conclusion and Future work

Real-Time

The key challenge would be to implement the proposed techniques in real-time.

Real-Time Communication

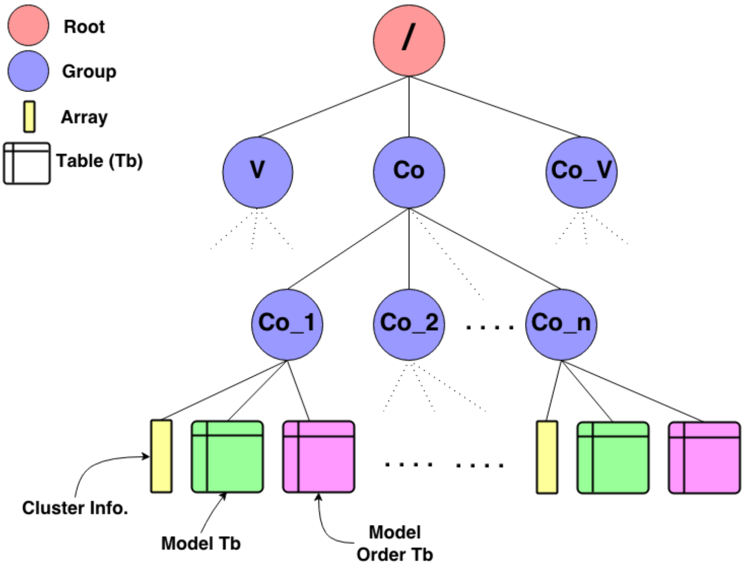
Actual interaction with the client system and remotely situated server requires knowledge of network protocol and thus establishment of real time communication.

Fully-supervised

The decisions for re-clustering and re-building of models are required to be ratified by the operating personal.

Thank you!

Pytable - cluster and model database



GLR

- S. Narasimhan and R.S.H Mah. *Generalized Likelihood Ratios for gross error identification in dynamic process.* AIChE Journal, 34:1321-1331, 1998.
- S. Narasimhan and C. Jordache. Data reconciliation and gross error detection: intelligent use of process data. Gulf Pub. Co., 2000.