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SAND2018-2040C

Open Source Software to Monitor Sensor Networks and Analyze Infrastructure Resilience

Katherine Klise, Bethany Nicholson, Michael Bynum, David Hart, Carl Laird
Sandia National Laboratories, Albuquerque, NM

Sandia National Laboratories has recently released several open source Python software packages that can be applied to a wide range of sensor network and infrastructure resilience applications. The tools are currently used by government agencies, industry, and researchers to 1) monitor sensor data and alert system operators of anomalous conditions, 2) determine optimal sensor placement to maximize monitoring effectiveness and 3) simulate and analyze resilience of water distribution networks. The software tools are built on the Python SciPy Stack, a set of powerful data analysis and graphing packages that are commonly used by the data science community.

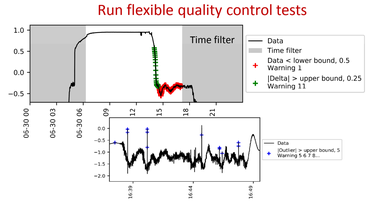
Pecos ✓ Monitor sensor data and send alerts if sensor reading indicate anomalous conditions

Pecos is built on the Pandas data analysis package and provides a general purpose performance monitoring and reporting tool.

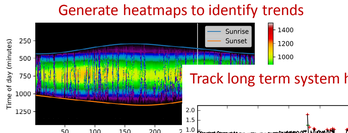
Pecos includes capabilities to:

- Monitor historical or real-time data
- Load data from files, databases, the web, or directly from sensors
- Run flexible quality control tests to identify anomalous conditions
  - Missing data
  - Duplicate/non-monotonic data
  - Corrupt data
  - Data out of expected range,
  - Stagnant readings
  - Abrupt changes
  - Outliers
- Integrate a wide range of analysis options into quality control tests
  - Filtering
  - Rolling window statistics
  - Clustering
  - Machine learning
  - System models
- Compute general and custom performance metrics to keep a running history of system health
- Run analysis on an automated schedule
- Generate HTML formatted reports, dashboards, and interactive graphics that can be sent via email or hosted on a website

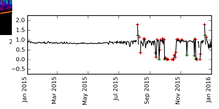
Run flexible quality control tests



Generate heatmaps to identify trends

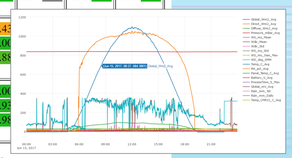


Track long term system health



Generate HTML reports, dashboards, and interactive graphics

	System 1	System 2	System 3	System 4
Location 1	DA 1.00 QCI 1.00 EPI 0.99	DA 0.13 QCI 0.78 EPI nan	DA 1.00 QCI 1.00 EPI 0.98	DA 1.00 QCI 1.00 EPI 0.98
Location 2	DA 0.42 QCI 1.00 EPI 0.88			
Location 3	DA 1.00 QCI 0.92 EPI 0.93			



DA = Data availability
QCI = Quality control index
EPI = Energy performance index

Pecos has been used to monitor solar panel performance, marine hydrokinetic experiments, and water quality in rivers.

https://github.com/sandialabs/pecos

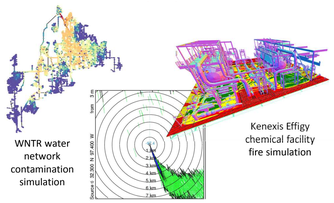
Chama Optimize sensor locations and technologies to maximize monitoring effectiveness

Chama includes a set of mixed integer programming formulations to perform sensor placement optimization using Pyomo.

Chama includes capabilities to:

- **Generate/load simulations**: Model simple Gaussian atmospheric dispersion, or load system model results from third party software. Multiple scenarios should be included to capture uncertainty in the system.
- **Define sensor technology**: Define sensors technology with the following properties:
  - Fixed or mobile
  - Point or camera detectors
  - Detection threshold
  - Sensor cost
  - Sampling times
- **Compute impact assessment**: Extract the impact (i.e. detectability, time to detection, damage, or coverage) for each simulation and sensor
- **Run sensor placement optimization**: For a given budget, optimize sensor layout with one of the following objectives:
  - Minimize time to detection
  - Minimize damage
  - Maximize scenario coverage
  - Maximize geographic coverage
- Analyze results and generate graphics

Flexible framework integrates simulations from third party software

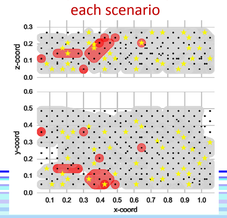


WNTR water network contamination simulation

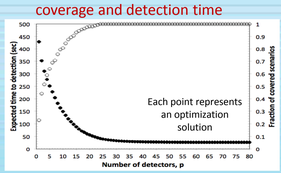
Kenexis Effigy chemical facility fire simulation

NOAA HYSPLIT air parcel trajectory simulation

Analyze detectability for each scenario



Cost benefit analysis for scenario coverage and detection time



Chama is currently being used to design sensor networks to monitor airborne pollutants and to monitor water quality in water distribution systems.

https://github.com/sandialabs/chama

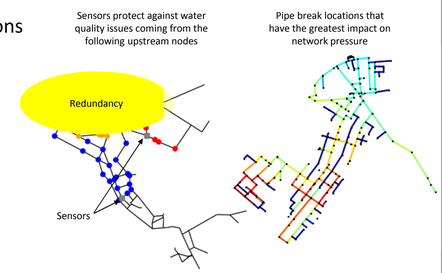
WNTR Water Network Tool for Resilience — Simulate and analyze resilience of water distribution networks

WNTR was developed in response to recent storm and contamination incidents which caused major disruptions in drinking water service.

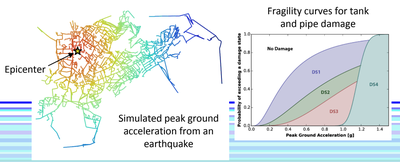
WNTR includes capability to:

- Generate water network models
- Modify network structure/operations
- Assign probabilistic fragility and survival curves to network components
- Model disruptive events such as
  - Power outages
  - Earthquakes
  - Fires
  - Floods
  - Pipe breaks
  - Contamination incidents
  - Cyber attacks
- Model response and repair strategies
- Simulate hydraulics and water quality
- Evaluate resilience using a wide range of metrics
  - Topographic metrics
  - Hydraulic and water quality metrics
  - Population and cost metrics
- Integrate dependency with other critical infrastructure and supply chains
- Analyze results and generate graphics

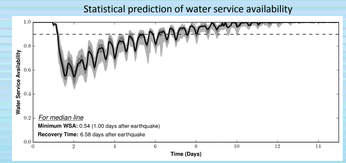
Sampling and pipe criticality analysis



System wide damage and response modeling



Statistical prediction of water service availability



WNTR is currently being used by to analyze water network resilience for several cities, including Flint, Michigan; Napa, California; and Tampa, Florida.

https://github.com/sandialabs/WNTR

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