INL/MIS-22-66441-Revision-0

Analytics-at-Scale of Sensor Data for Digital Monitoring in Nuclear Plants Powerpoint for March ASI meeting

March 2022

Cody McBroom Walker

Changing the World's Energy Future

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Prepared for the
U.S. Department of Energy
Under DOE Idaho Operations Office
Contract DE-AC07-05ID14517

U.S. DEPARTMENT OF ENERGY | Office of NUCLEAR ENERGY

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Analytics-at-Scale of Sensor Data for Digital Monitoring in Nuclear Plants

OVERVIEW

Purpose:
This project will address a unique challenge in the area of digital monitoring, i.e., the application of advanced sensor technologies (particularly wireless sensor technologies) and data science-based analytic capabilities, to advance online monitoring and predictive maintenance in nuclear plants and improve plant performance (efficiency gain and economic competitiveness).

Objectives:
- Techno-economic analysis of wireless sensor modalities
- Develop integrative algorithms for diagnostic and prognostic estimates using structured and unstructured heterogeneous data
- Develop visualization algorithms and guidelines
- Validate the developed methodologies

IMPACT

Logical Path:
Task 1: Gap analysis and development of TEA framework of wireless sensor technologies
Task 2: Implementation of a wireless vibration sensor in a nuclear plant site
Task 3: Develop integration algorithm and machine learning models for decision-making and knowledge discovery
Task 4: Develop data visualization algorithms
Task 5: Validation and verification.

Outcomes: The high-level outcomes of the project will include
1. Generalized techno-economic analysis framework for wireless sensor technologies
2. Development of models to be used in predictive maintenance of plant equipment
3. Development of a visualization technique to support presentation of right information, to the right person, in right format, and at the right time.

DETAILS

Principal Investigator: **Vivek Agarwal**

Institution: **Idaho National Laboratory**

Collaborators: Oak Ridge National Laboratory, Electric Power Research Institute (EPRI), and Exelon Generation Company

Duration: 3 years
Funding: **$1,000,000**

TPOC (Technical Point of Contact): **Richard Vilim, Argonne National Laboratory**

Federal Manager: Melissa Bates

PICS:NE Workpackage: CA-18-ID-IN__-0703-01

RESULTS

- Development of an end state vision to implement digital monitoring in nuclear plants.

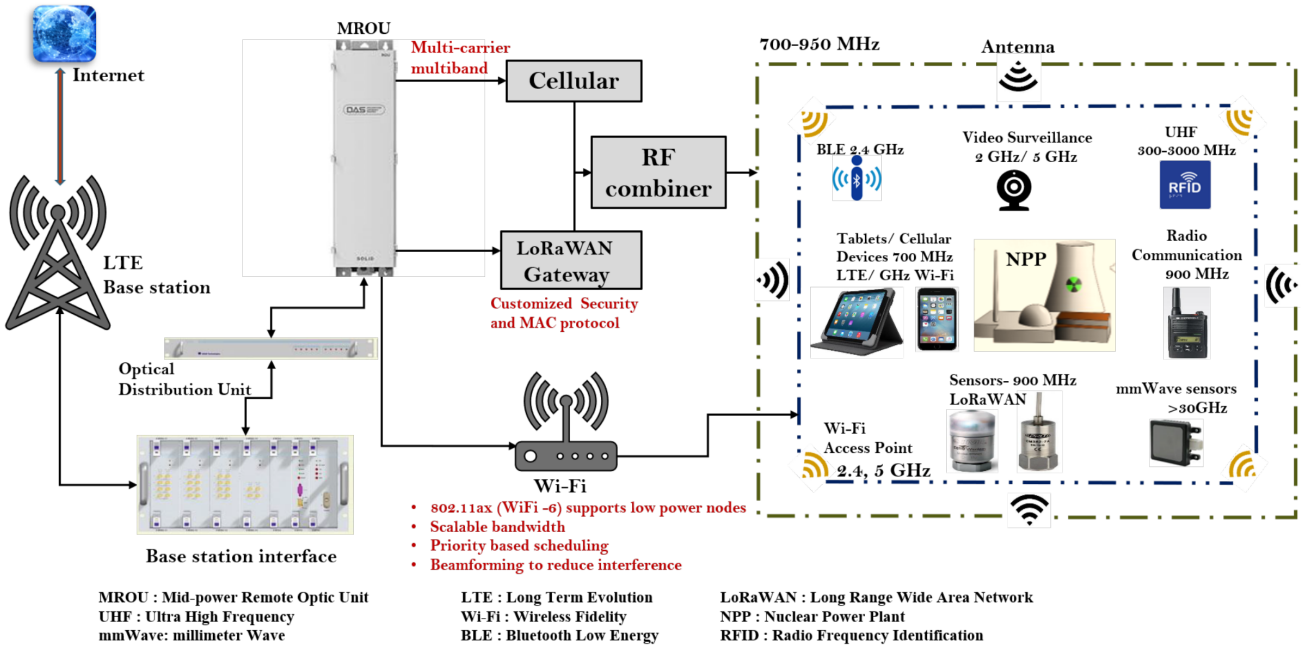
- Cloud Computing Advantages:
  - Networking & Security
  - Storage & Databases
  - Artificial Intelligence

Accomplishments:
1. Journal paper (Development of Short-term Forecasting Models Using Plant Asset Data and Feature Selection) accepted to the International Journal of Prognostics and Health Management.
2. A level 3 milestone report on development of an end state vision to implement digital monitoring in nuclear plants to be submitted, March 31, 2022.

Analytics-at-Scale of Sensor Data for Digital Monitoring in Nuclear Plants

Summary of previous updates

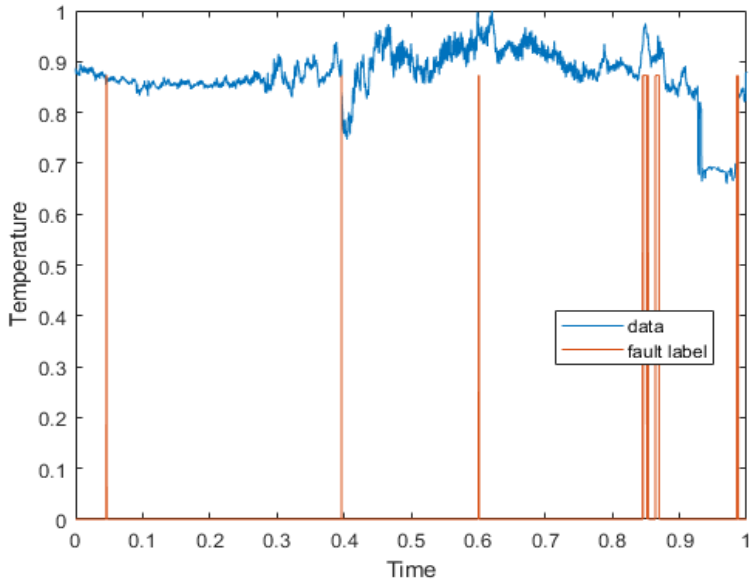
- Techno-economic analysis of wireless architecture.
- Proposed wireless network deployment strategy for nuclear power plant.
- Compared commercially available Wi-Fi based, cellular compatible, and radio frequency-based vibration sensors.

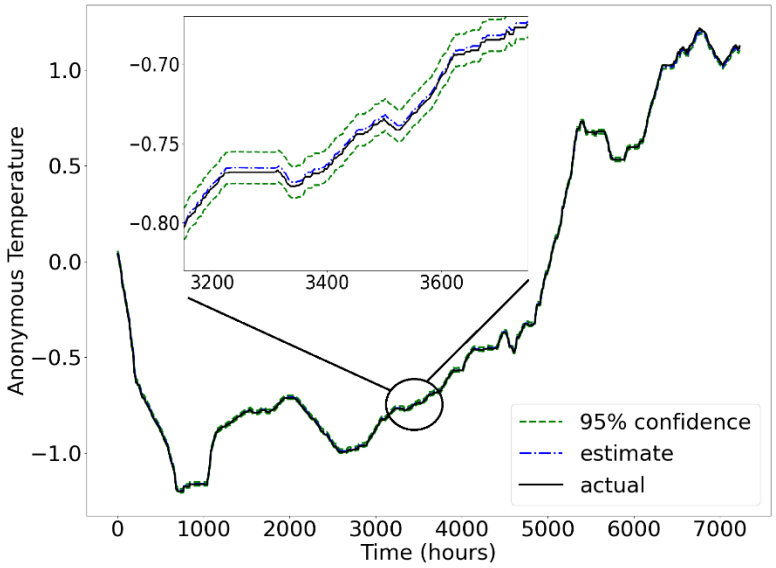


Analytics-at-Scale of Sensor Data for Digital Monitoring in Nuclear Plants

Summary of previous updates

- **Feature selection**: Shapley additive explanations (SHAP) values are being used to explain impact of a feature on the predicted outcome, and Variance Inflation Factor (VIF) to understand multicollinearity in the data.
- **Diagnostic and prognostic models**: Long Short-Term Memory (LSTM) Neural Networks, Support Vector Regression (SVR), Random Forest (RF)
- Recommendations to change preventative maintenance (PM) frequencies.





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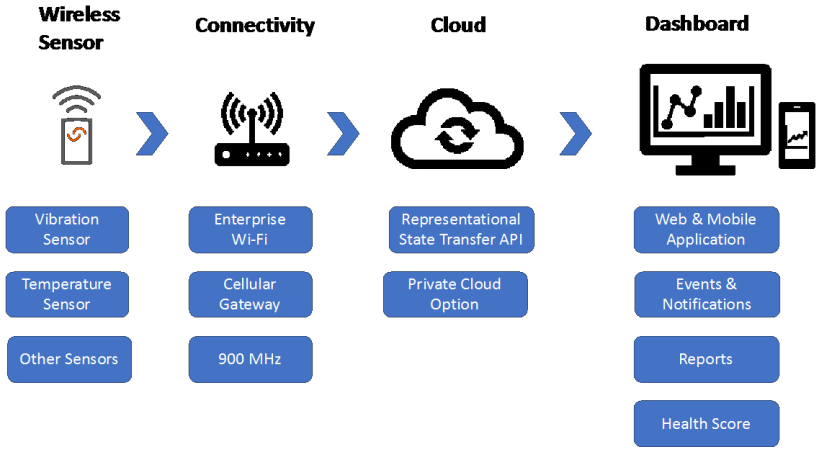
Analytics-at-Scale of Sensor Data for Digital Monitoring in Nuclear Plants

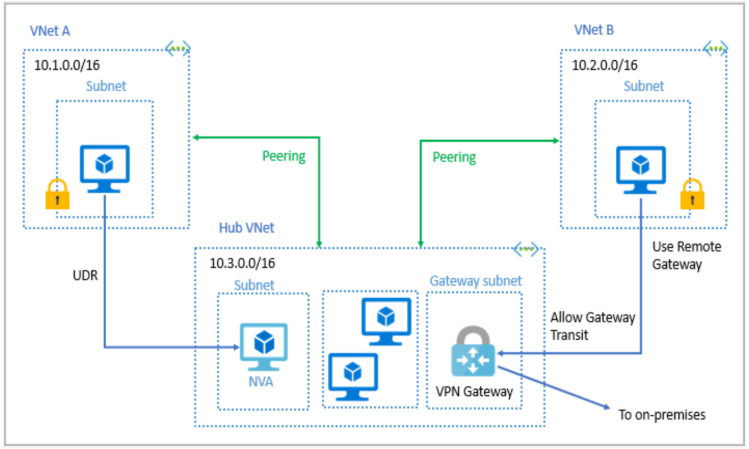
Development of end state vision to implement digital monitoring in nuclear power plants.

- End-to-end vision:
  - Wireless online monitoring
  - Feature selection
  - Cloud computing
  - Diagnostic/prognostic modeling
  - Data visualization

- Benefits of cloud computing with Microsoft Azure:
  - Networking & Security
  - Storage & Databases
  - Artificial Intelligence



Wireless transfer from sensor node to cloud for processing



Example of Azure virtual machine networking

Analytics-at-Scale of Sensor Data for Digital Monitoring in Nuclear Plants

- **30/60/90 days**
- **30 days:**
  - Finish and submit final milestone.
  - Finish edits to journal that was accepted to the International Journal of Prognostics and Health Management (IJPHM).
- **60 days:**

- **90 days:**

Analytics-at-Scale of Sensor Data for Digital Monitoring in Nuclear Plants

- **Publication List:**

1. K. Manjunatha and V. Agarwal, “Techno-economic analysis framework for wireless networks in nuclear power plants,” Idaho National Laboratory, Idaho Falls, ID, September 2019. INL/EXT-19-55830 Rev 0, 2019.

2. V. Agarwal, “Enabling predictive maintenance with wireless instrumentation in balance of plant system,” Idaho National Laboratory, Idaho Falls, July 2019. INL/EXT-21-54866 Rev 1.

3. K. Manjunatha and V. Agarwal, “Review of Wireless Communication Technologies and Techno-Economic Analysis,” 2019. Idaho National Laboratory, Idaho Falls, ID. INL/EXT-19-53966.

4. P. Ramuhalli, C. Walker, V. Agarwal, and N. J. Lybeck, *Development of Prognostic Models Using Plant Asset Data. Technical Report, ORNL/TM-2020/1697, Oak Ridge National Laboratory*, no. September. 2020.

5. C. Walker, V. Agarwal, and N. Lybeck, “Nuclear Power Fault Diagnostics and Preventative Maintenance Optimization,” Idaho National Laboratory, Idaho Falls, ID, January, 2021. INL/EXT-21-61427.

6. T. Mortenson, T. Miyake, and R. Boring, “Data Visualization to Support Decision Making at Nuclear Power Plants,” Idaho National Laboratory, Idaho Falls, ID, May 2021. INL/EXT-21-62703.

7. C. Walker, V. Agarwal, P. Ramuhalli, N. Lybeck, and M. Taylor, “Verification and Validation of Developed Short-Term Forecasting Models,” 2021. Idaho National Laboratory, Idaho Falls, ID. INL/EXT-21-65074.

8. C. Walker, V. Agarwal, P. Ramuhalli, N. Lybeck, and M. Taylor, “Development of Short-Term Forecasting Models Using Plant Asset Data and Feature Selection.” *International Journal of Prognostics and Health Management.* [accepted].

9. C. Walker, V. Agarwal, P. Ramuhalli, N. Lybeck, and M. Taylor, “Development of an end state vision to implement digital monitoring in nuclear plant.” *PHM Society Conference*. Nashville, TN. Nov 1-4. 2022

Analytics-at-Scale of Sensor Data for Digital Monitoring in Nuclear Plants

- **Publications**
  - 1 journal article accepted to the International Journal of Prognostics and Health Management (IJPHM).
  - 1 papers to be presented at the Prognostics and Health Management Society conference, November 1-4, 2022
- **Issues and Concerns:**
- **Variances**
- **Schedule variance:**
  - Due to lack of interaction with plant site and delay in additional data access,
    - the validation and verification activity of the project will be completed in fiscal year 2022 as part of no cost extension period of performance
    - Will be leveraging data made available by the Electric Power Research Institute from other plants sites to validate and verify developed prognostic models.