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Online monitoring using cloud-based applications.

November 2023

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Online Monitoring Using Cloud-Based Applications

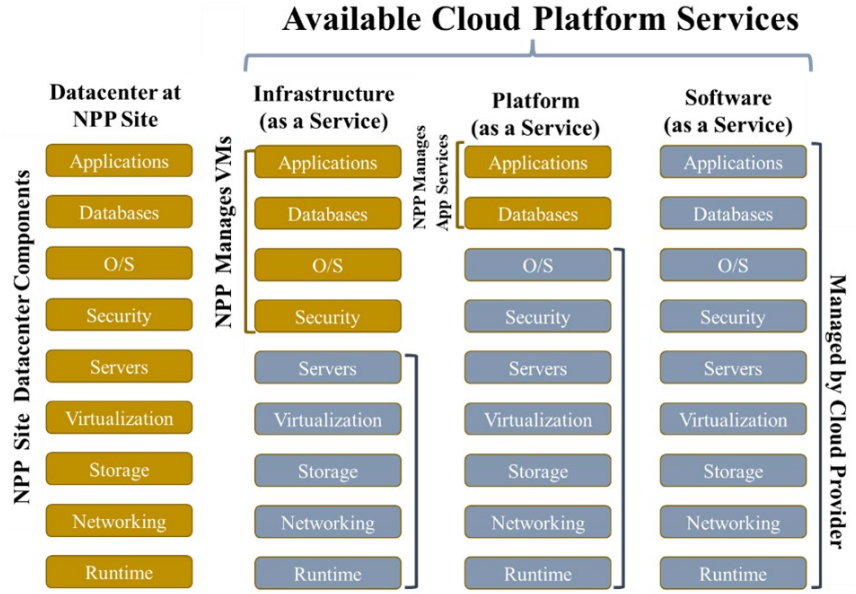
Idaho National Laboratory

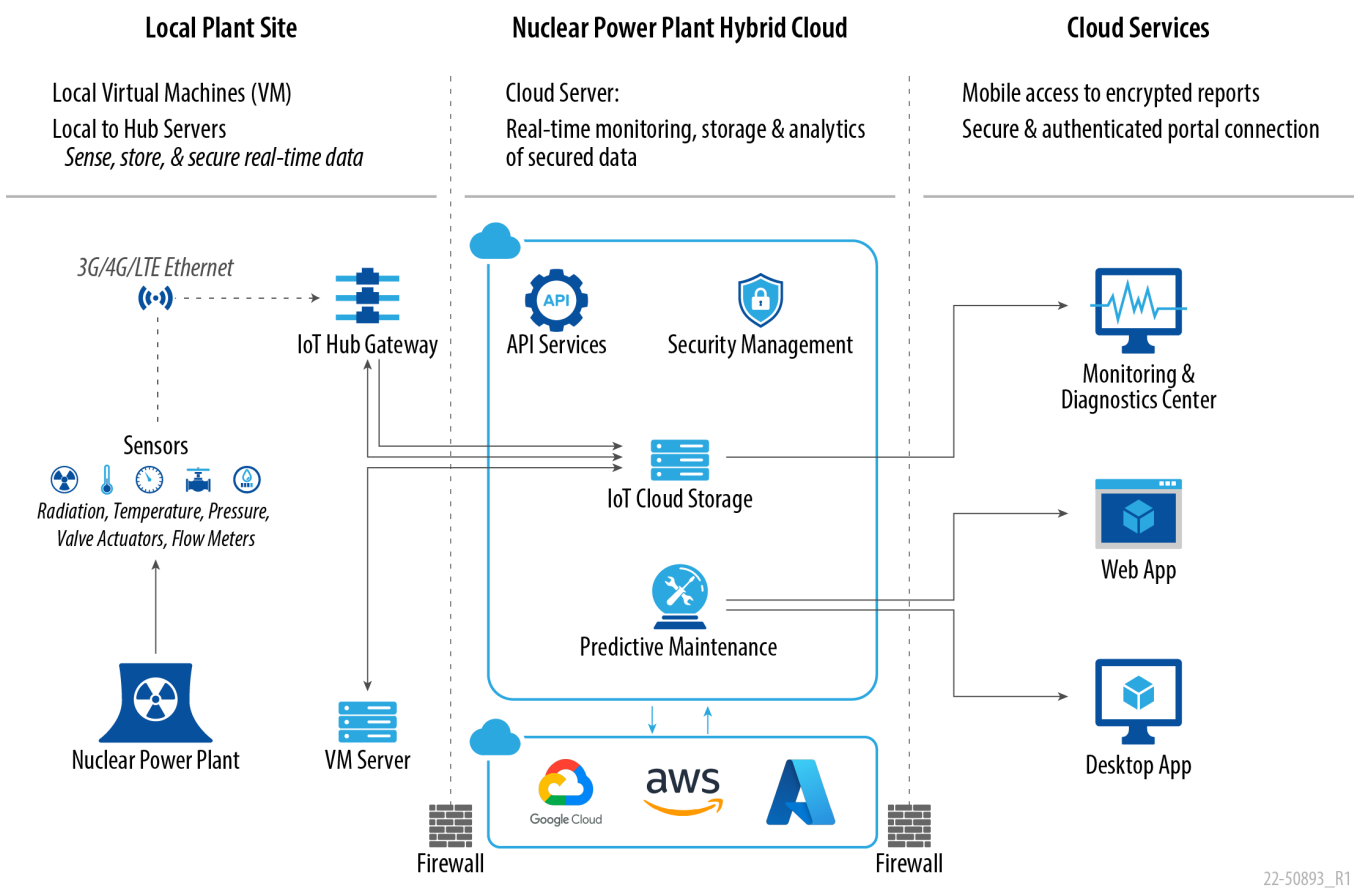
Outline

- Architecture for nuclear power plant-to-cloud computing
- Safety relief valve problem
- Online model training
- Speed testing
- Predictive capabilities
- Overall costs

Online Monitoring Using Cloud Services Will Require Additional Sensors, Systems and Choices

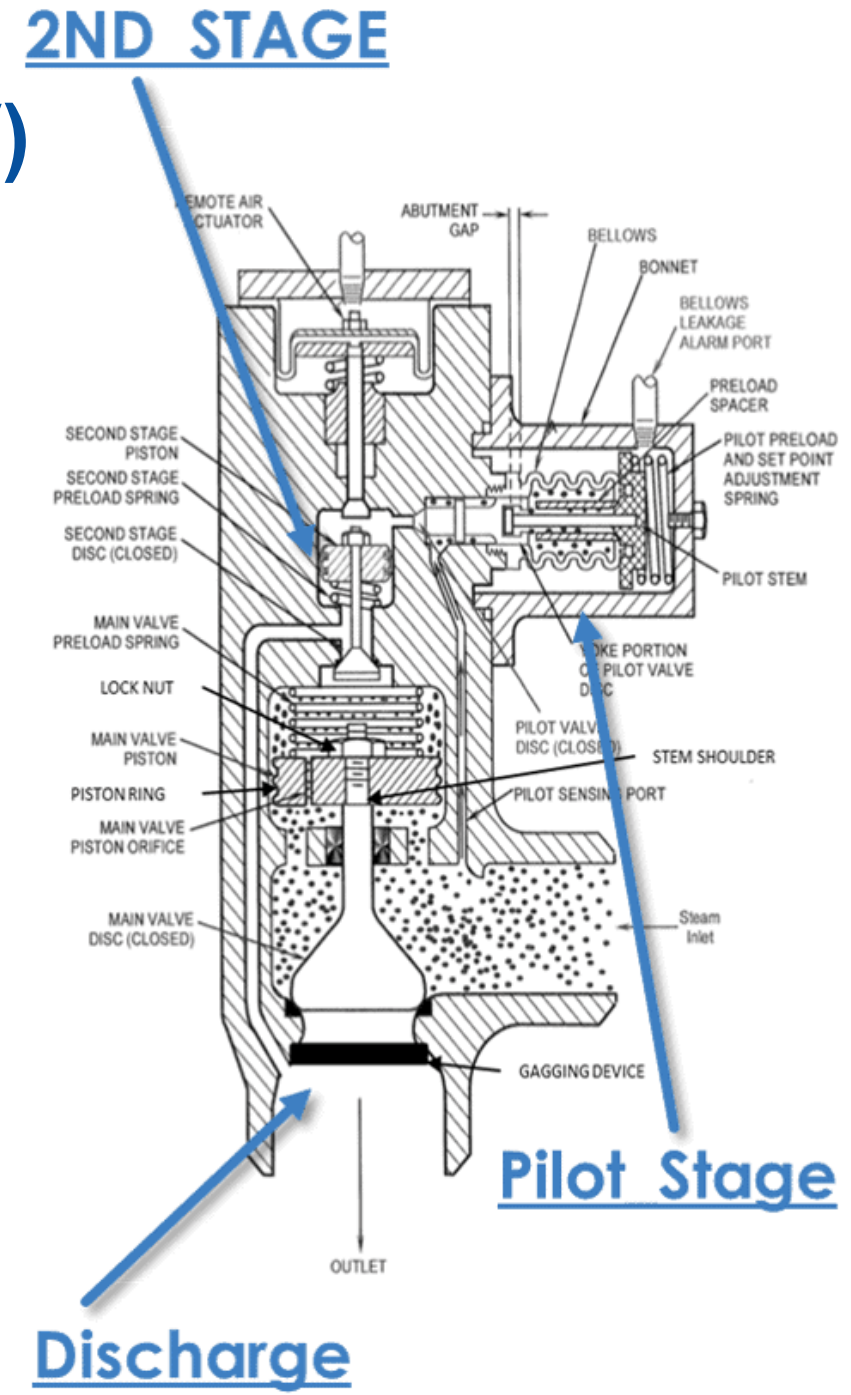
- The end-goal of online monitoring is predictive maintenance
- Cloud computing may be a cheaper way to achieve that goal





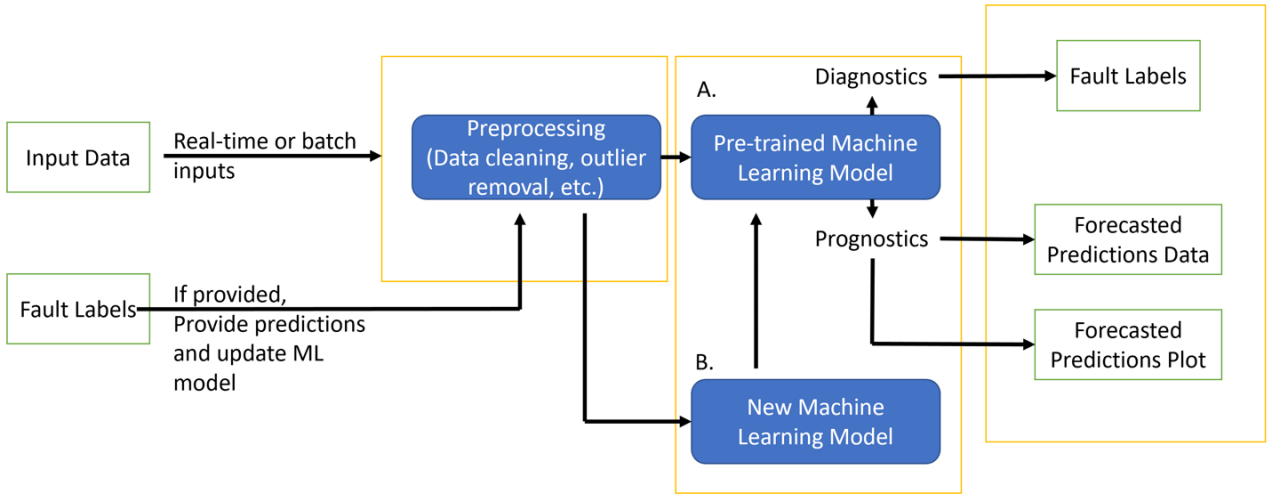
Monitoring a Safety Relief Valve (SRV) Using Multiple Thermocouples.

- SRVs (also known as a pressure relief valve) are highly reliable, nonpowered ways to relieve pressure
- Used in systems that may build up pressure under accident conditions
- Common stressors include:
  - Wear (mechanical stress, cavitation, corrosion, erosion)
  - Temperature (rate of corrosion, spring rate, etc.)
- Data were taken over 14 months
- Monitoring locations include pilot stage, second stage valve body, and downstream discharge.



A/B Model Testing Allows for Continual Updating While Maintaining a Stable Model for Use.

- Models for this research:
  - Feedforward Neural Network (FNN)
  - Long Short-Term Memory (LSTM)
- Preprocessing cleaned the data before model training or updating
- Pre-trained Model A is used to diagnose the current state of health and to predict future parameter values
- Model B is Model A but it is being continually updated with new data
- Model B eventually replaces Model A and a new model begins updating.



Cloud Computing has Elastic Resources and Can Scale Up or Down Depending on Demand

Resources Compared

	Local	HPC (CPU)	HPC (GPU)	Microsoft Azure
Processor	Intel CITM i7-9700 CPU @ 3.00 GHz	2 Intel Xeon 8268 CPUs @ 2.90 GHz 24 cores per CPU	NVidia Tesla V100 32 GPU	28–112 Gb Memory 8–32 Cores
Installed RAM	32 Gb	8 Gb RAM per core	32 GB RAM	14 Gb Memory

Resources Had Comparable Results

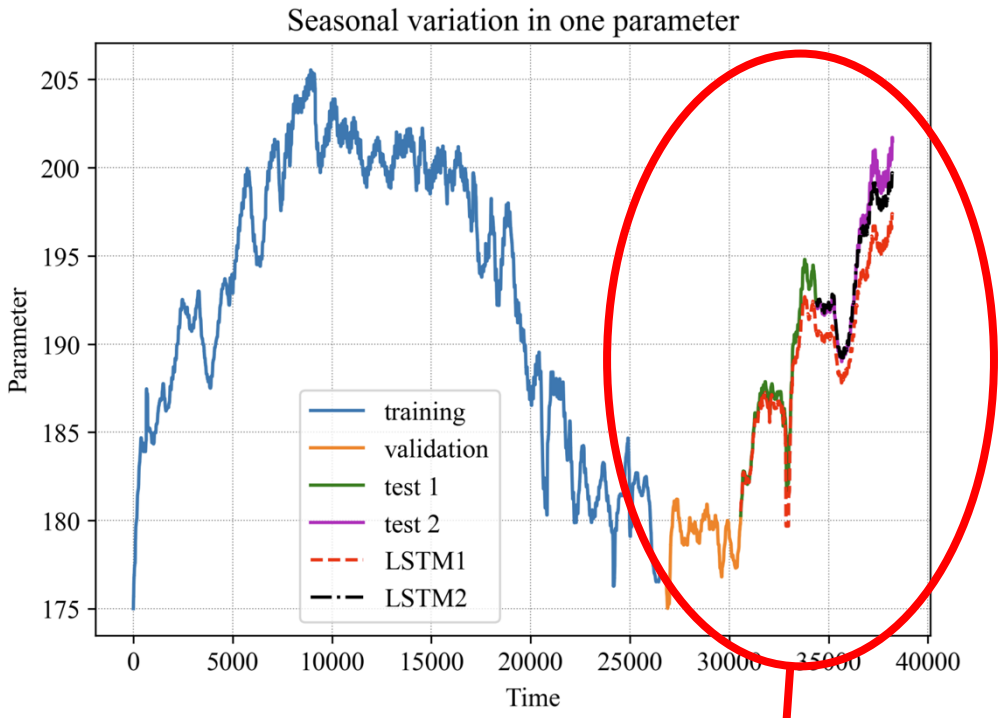
Cloud Computer Speed Testing (in seconds)					
Test	**Local**	**HPC (GPU)**	**HPC (CPU)**	**HPC (multi-CPU)**	**Azure**
Loading Data	3.26 ± 0.10	2.87 ± 0.02	N/A	N/A	14.67 ± 0.29
Preprocess	34.89 ± 0.10	37.94 ± 0.02	N/A	N/A	38.00 ± 0.29
Train FNN 1	8.09 ± 2.01	27.57 ± 5.59	7.18 ± 1.97	11.14 ± 2.51	7.12 ± 2.14
Update FNN 2	0.97 ± 0.06	2.62 ± 0.2	1.04 ± 0.027	—	1.07 ± 0.03
Train LSTM 1	103.67	89.62	126.68	162.47	96.07
Update LSTM 2	8.78	7.76	14.5	—	8.72

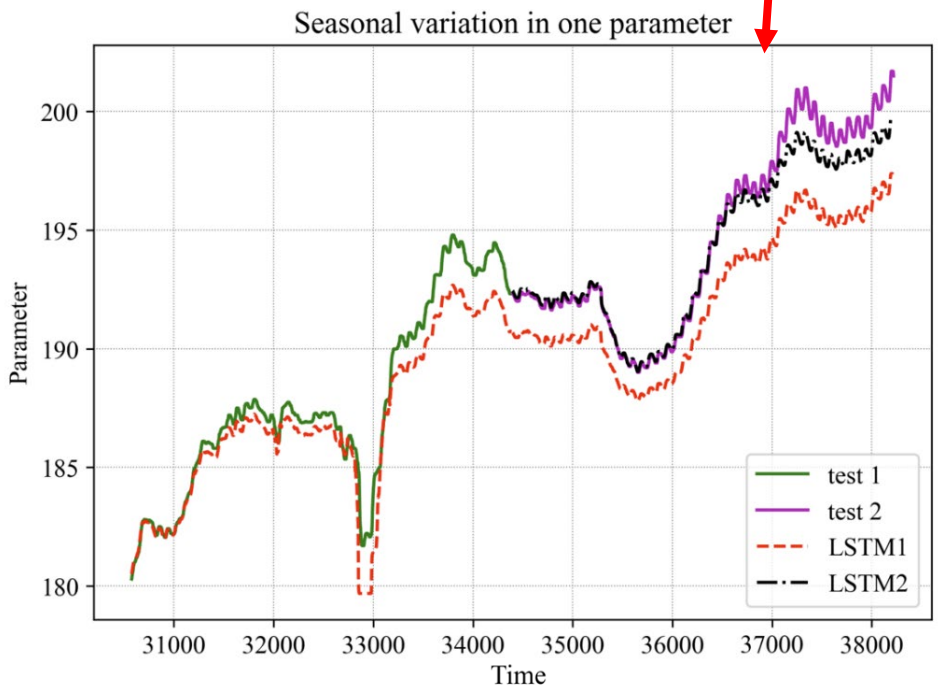
Updated Models Reduced Data Drift

A/B Model Testing		
Test	**FNN (RMSE)**	**LSTM (RMSE)**
Model 1 Test A	1.361 ± 0.679	1.411
Model 1 Test B	2.559 ± 1.264	2.792
Model 2 Test B	0.593 ± 0.300	0.504

Updating Models with Recent Data Reduces Model Drift

- A large seasonal component can be seen in the temperature measurement
- Model A was trained on the first 10 months of data, validated in 1.5 months, and tested on ~1.5 months
- Model B was also trained on Test 1 before being tested on Test 2
- Results show that updating with more recent data can reduce model drift when using time series data.





Current Prices for Cloud Computing Could Be Cost Effective for On-line Monitoring

Current Estimated Costs to Maintain On-site Diagnostics

Hardware	Number of Items Saved	Item Cost	Total Cost	Annual Costs	Monthly Costs	Assumptions
Servers	18	$4,500.00	$81,000.00	$16,200.00	$1,350.00	Replaced every 5 years
Network Elements (e.g., routers)	30	$800.00	$24,000.00	$4,800.00	$400.00	Replaced every 5 years
Software						
Commercial Software	Base Cost	$200,000.00	$200,000.00	$30,000.00	$2,500.00	Maintenance contracts
Purpose-Built Software	Base Cost	$500,000.00	$500,000.00	$75,000.00	$6,250.00	Contract programming
IT Support Staff Average Salary	17	$150,000.00	$2,550,000.00	$2,550,000.00	$212,500.00	—
Offsite Backup	—	—	—	$3,600.00	$300.00	—
Cybersecurity	—	—	—	$20,000.00	$1,666.67	—
Operational Staff	35	$150,000.00	$5,250,000.00	$262,500.00	$21,875.00	Fraction of their time
Manual Sensor Reading	8	$85,000.00	$680,000.00	$680,000.00	$56,666.67	Headcount for manual sensor reading/ recording
Facilities Costs						
Electricity	—	—	—	$300,000.00	$25,000.00	Yearly cost of electricity
Total	—	—	—	$3,942,100	$328,508	—

Estimated Installations to Enable Cloud Computing

Total Cloud Costs	Initial Costs	Annual Costs
Sensors	$300,000.00	$136.00
In-building Network	$1,131,480.00	$176,278.00
Network Aggregation Equipment	$50,000.00	$15,000.00
Installation and Cloud Set-up	$600,000.00	$60,000.00
Total	$2,081,480.00	$251,414.00

Estimated Reoccurring Costs

Direct Cloud Costs	Cost	Number of Applications	Total
Storage of 500 Gb/year	$567.00	25	$ 14,175.00
Total Model Retraining	$28,152.00	25	$703,800.00
Application Hosting	$6,000.00	25	$150,000.00
IT Personnel	$150,000.00	10	$1,500,000.00
—	—	Total	$2,367,975.00

Total Cost Comparison

Cost Comparison	Current Onsite Cost	Cloud Cost
Installation Cost	N/A	$2,081,480.00
Annualized Cost	$3,942,100.00	$2,619,389.00

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