Distance Preserving Machine Learning for Uncertainty Aware Accelerator Capacitance Predictions

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RESEARCH DESCRIPTION

- Capacitors in High-Voltage Converter Modulators (HVCMs) may degrade over time causing downtime
- Direct capacitance measurements are impractical
- Extensive simulation data based on available non-invasive sensor data is available
- Goal: Build a Machine Learning model with Uncertainty Quantification (UQ) for capacitance prediction

SNS DOWNTIME BY SYSTEM

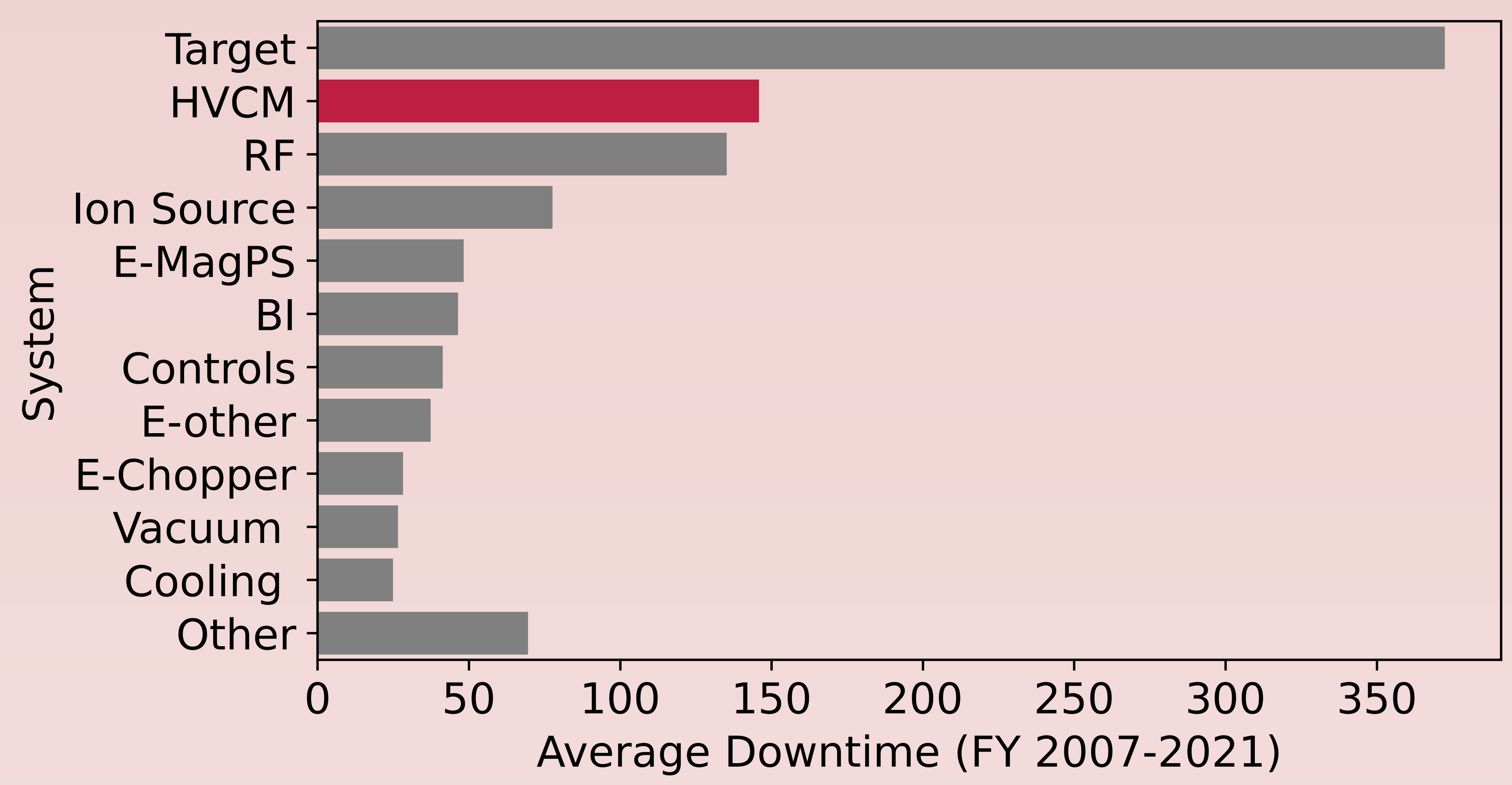

Figure 1: Average downtime by system in the Spallation Neutron Source (SNS) at the Oak Ridge National Lab.

MACHINE LEARNING MODEL

DATA CLEANING

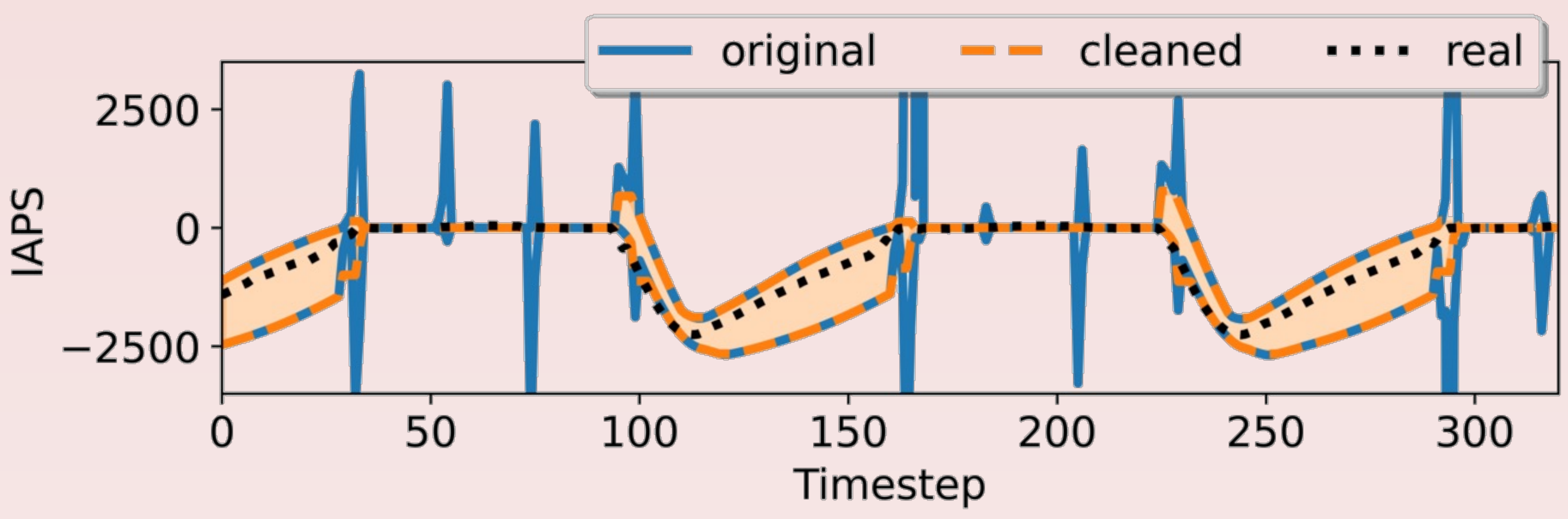

Figure 2: Range of samples (min/max) for the IAPS waveform before and after cleaning with a LULU filter. A sample real waveform from the SNS is included as a reference. This represents one of 6 current waveforms that needed cleaning and one of 7 total waveforms used for training.

MODEL ARCHITECTURE

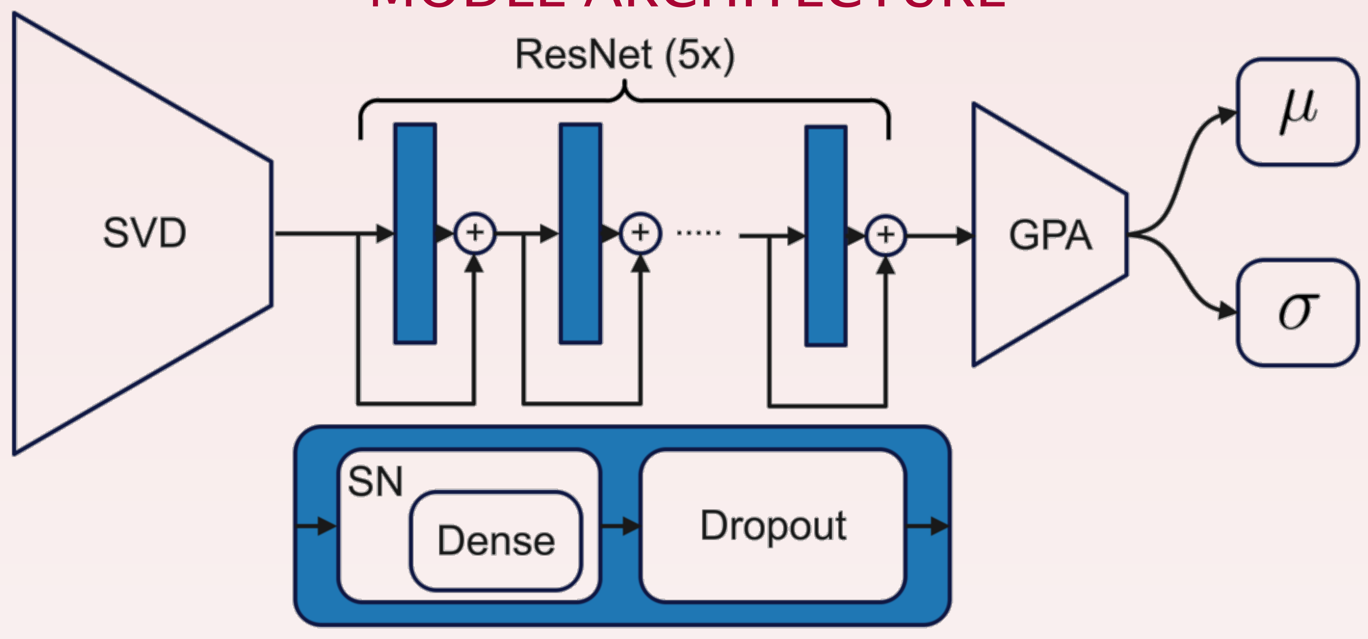

Figure 3: Model architecture. Includes the Singular Value Decomposition (SVD) on the flattened dataset, a 5-layer Spectral Normalized (SN) ResNet with Dropout, and outputs the mean (μ) and uncertainty (σ) predictions with a Gaussian Process approximation (GPA) using Random Fourier Features.

CONCLUSIONS

- Created a highly accurate ML model with UQ
  - <1% in-distribution error
  - <3.5% out-of-distribution error
- Provided proportional uncertainty estimates for changes in both output values and input data

MODEL PERFORMANCE

	Training	Validation	Testing (OOD)
Samples	1382	346	64
Capacitance (pF)	2900 to 4000	2900 to 4000	2500 to 2800

MODEL PREDICTION ERRORS

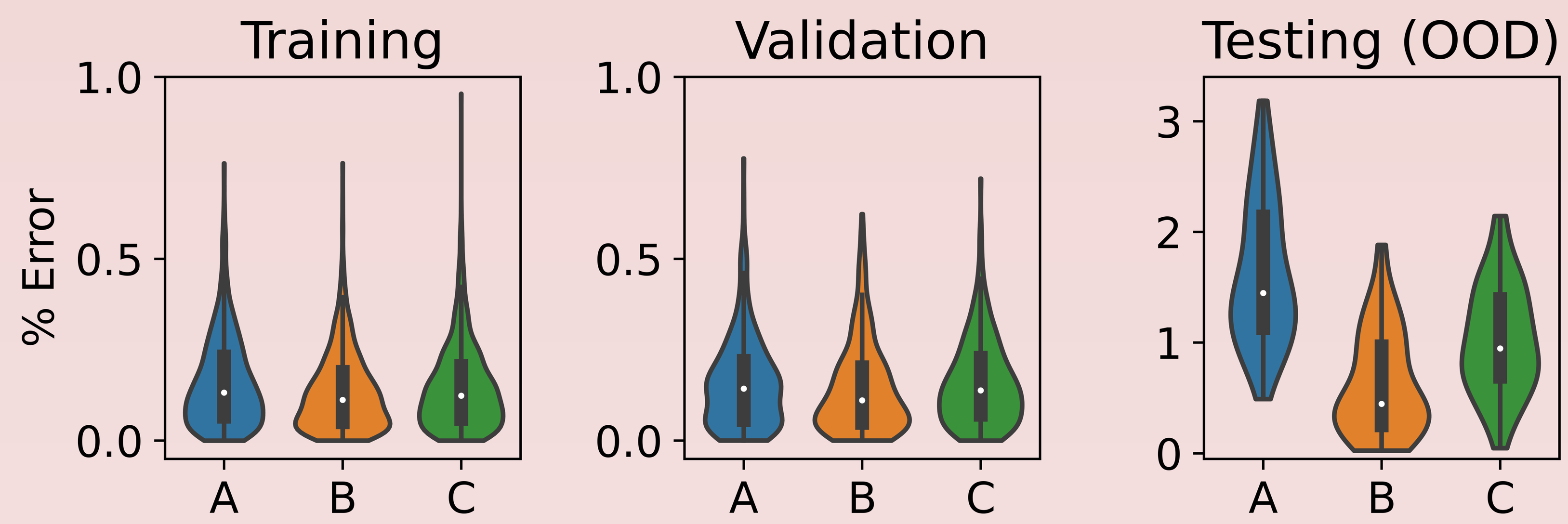

Figure 4: Violin plots of percent errors for each capacitor (A, B, C) over each of our data splits. The width of each plot denotes the density of predictions at that error level.

UNCERTAINTY FROM OUTPUT DISTANCE

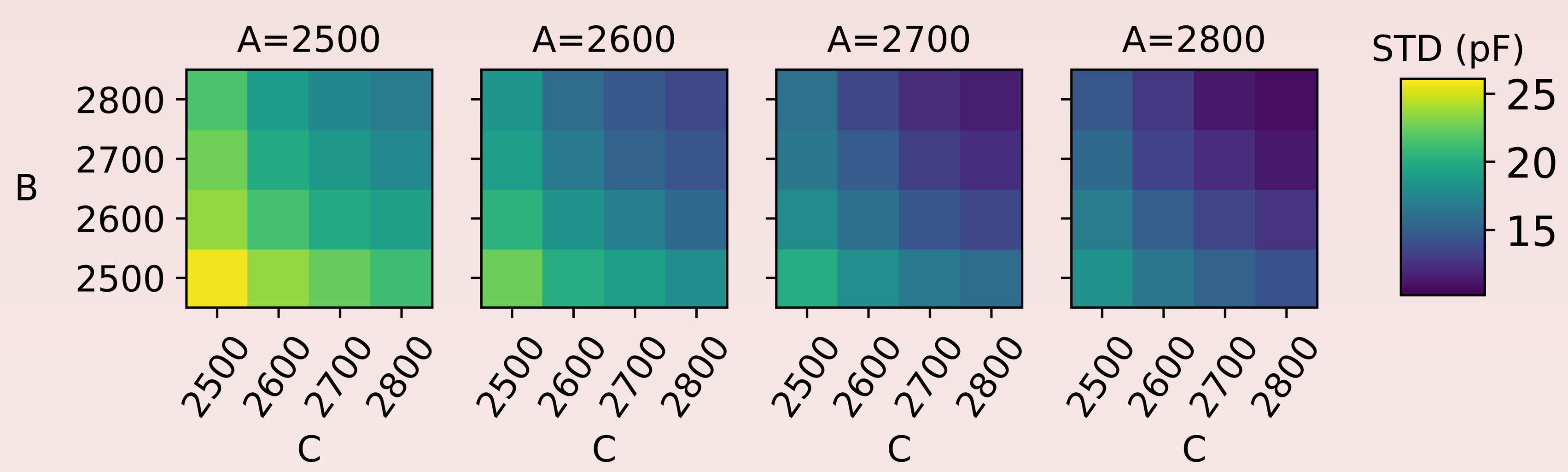

Figure 5: Uncertainty returned by our model with varying output capacitance labels from our OOD test set. As desired, capacitance values farther from our training data (i.e., smaller) have larger uncertainties.

UNCERTAINTY FROM INPUT NOISE

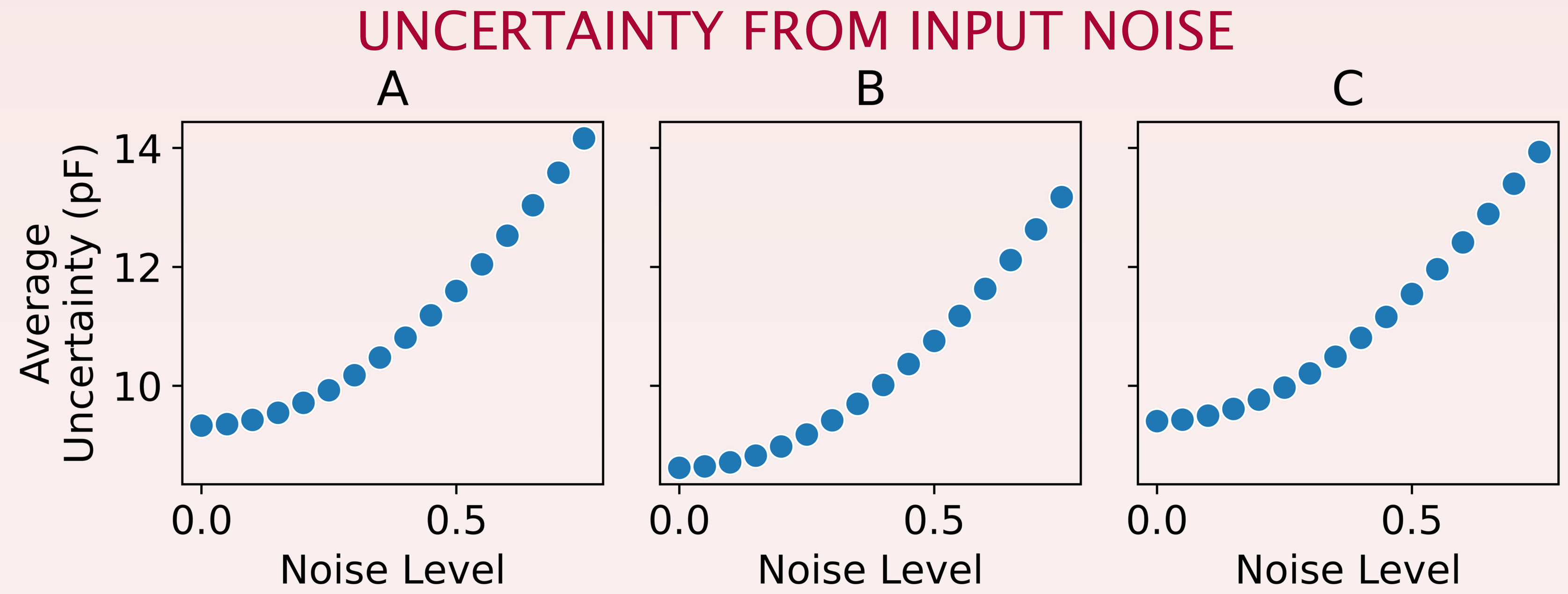

Figure 6: Average uncertainty returned by our model with increasing Gaussian noise applied to the training data.

ACKNOWLEDGEMENT

This research has been authored by UT-Battelle, LLC, under contract DE-AC05-00OR22725 with the US Department of Energy (DOE). The Thomas Jefferson Science Associates (JSA) operates the Thomas Jefferson National Accelerator Facility for the DOE under Contract No. DE-AC05-06OR23177. This research used resources at the Spallation Neutron Source, a DOE Office of Science User Facility operated by the Oak Ridge National Laboratory.

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