UPISC UNIVERSITY OF PITTSBURGH INFRASTRUCTURE SENSING COLLABORATION WORKSHOP

NATIONAL ENERGY TECHNOLOGY LABORATORY

Innovative Fusion for Pipeline Corrosion Detection: Fiber Optic Sensing, Physics-Based Modeling, and Deep Learning

Pengdi Zhang[1], Khurram Naeem[1], Enrico Sarcinelli[1], Abhishek Venketeswaran[2], Sandeep R. Bukka[2], Ruishu F. Wright[2], Nageswara Lalam[2], Paul Ohodnicki[1]

[1]Department of Mechanical Engineering and Materials Science, University of Pittsburgh

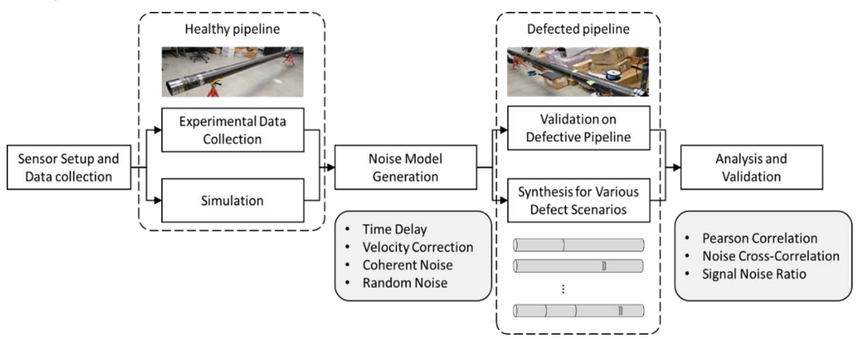
[2]National Energy Technology Laboratory, 626 Cochrans Mill Road, Pittsburgh, PA, USA 15236

Motivation:

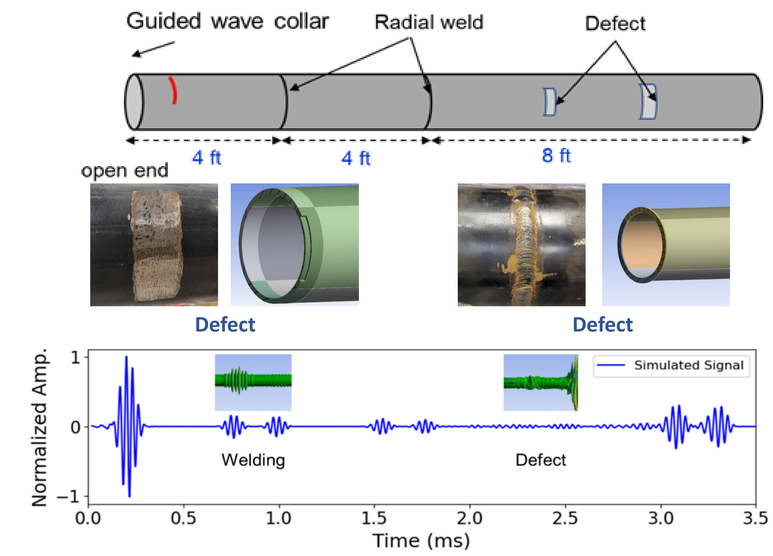
Current Status: Pipelines are prone to corrosion and structural defects, but traditional monitoring methods struggle with scalability, noise interference, and real-world variability, limiting their reliability.

Improvement: Integrate guided wave ultrasonic, distributed fiber optics, and deep learning with physics-based modeling to enhance SHM and NDE, enabling accurate, long-range monitoring with robust noise mitigation.

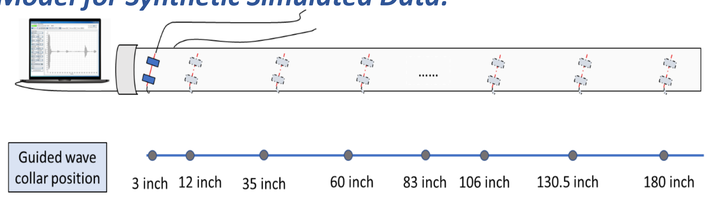
Project Outline:



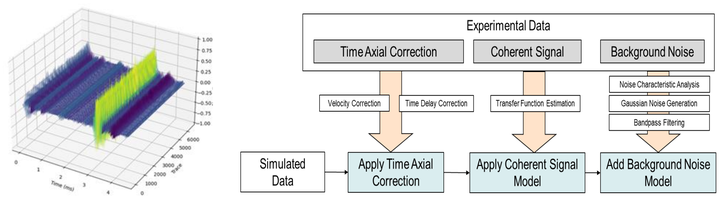
Finite Element Analysis of Guided Wave Propagation:



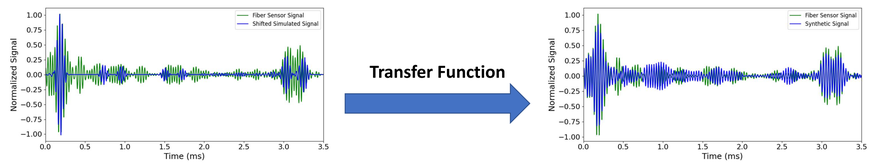
Noise Model for Synthetic Simulated Data:



Experimental Signal:

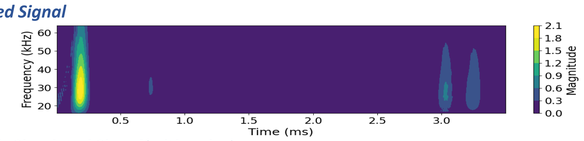


Coherent Signal Model:

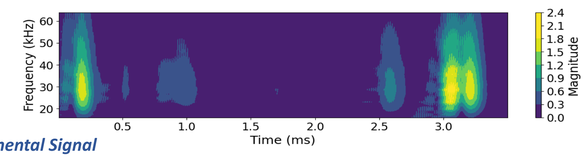


Signal comparison from fiber sensor(12 inch away from excitation):

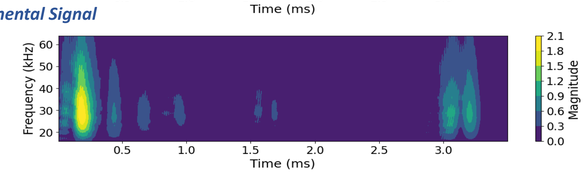
Simulated Signal



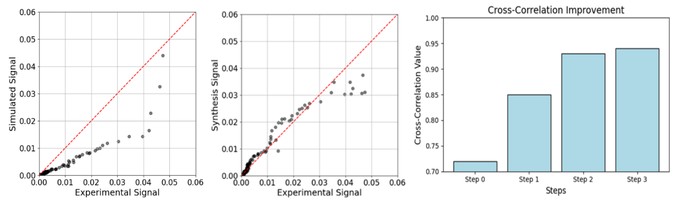
Synthesis Simulated Signal(with noise)



Experimental Signal



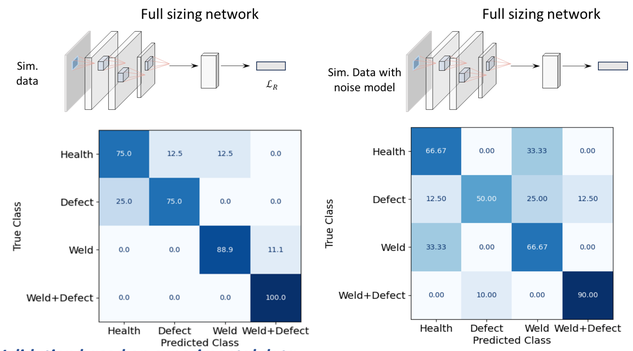
Comparative Analysis of Simulated and Synthetic Signal



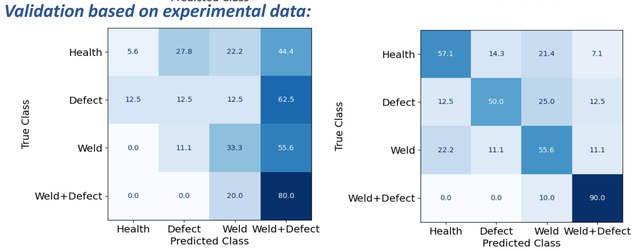
Scatter Plot of Grayscale Histograms

Improvement from Step 0 to Step 3; Steps Explained: Step 0: Pure simulated signal; Step 1: Simulated signal with time-axis correction; Step 2: Simulated signal with transfer function applied; Step 3: Synthetic signal with added background noise.

Defect defection based on different data source:



Validation based on experimental data:



Model Performance based on different data source:

Training Testing	Accuracy (%)	Precision (%)	Recall (%)	F1-Score (%)
Sim → Sim	90.00	90.63	90.00	90.31
Sim → Exp	52.94	50.00	52.94	51.43
Syn → Syn	77.50	79.17	77.50	78.32
Syn → Exp	73.68	75.00	73.68	74.34

Related Publications:

[1] Zhang, P., Venketeswaran, A., Wright, R. F., Lalam, N., Sarcinelli, E., and Ohodnicki, P. R., 2023, "Quasi-Distributed Fiber Sensor-Based Approach for Pipeline Health Monitoring: Generating and Analyzing Physics-Based Simulation Datasets for Classification," Sensors, **23**(12), p. 5410.

This work is funded by Fusion of Distributed Fiber Optics, Acoustic NDE, and Physics-Based AI for Spent Fuel Monitoring" (Award Number: DE-NE0009210) –NEUP and Natural Gas Infrastructure FWP (FWP-1022424) - DOE