This is a peer-reviewed, accepted author manuscript of the following conference abstract: Dimakos, A, Nicolson, E, Serjeant, S, Tunukovic, V, Thompson, C, MacLeod, C, Lines, D, Sweeney, N, Loukas, C, Mohseni, E & Sibson, J 2026 'High-fidelity data reduction and feature extraction for real-time robotic ultrasonic geometry estimation in nuclear manufacturing', Postdocs in Nuclear Energy (PiNE) 2026, Glasgow, United Kingdom, 13/04/26 - 14/04/26.

High-Fidelity Data Reduction and Feature Extraction for Real-Time Robotic Ultrasonic Geometry Estimation in Nuclear Manufacturing

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Nuclear manufacturing for SMRs requires right-first-time production to minimize repairs. While real-time ultrasonic sidewall fusion monitoring shows promise, with amplitude signal drop from 60% to 0% indicating proper fusion, robotic inspection introduces measurement challenges. Advanced ultrasonic data acquisition methods improve robustness but generate data volumes incompatible with real-time processing (up to 20 million data points).

This Babcock-supported research proposes the combination of automated ultrasonic inspection with machine learning to enable rapid weld geometry estimation. It extracts features from compressed data through a three-stage process: (1) identifying the most predictive hand-crafted features, (2) augmenting sparse data using oversampling and gaussian process regression, and (3) creating lightweight models (stacked support vector machine and ridge regression), suitable for real-time deployment. This achieves 90% data reduction, maintaining 1.2 mm compression fidelity and computation time below 200 ms using hybrid CPU-GPU architecture. Validated on production-relevant weld geometries (120 mm narrow gap and 15.8 mm V-groove), the approach characterises robotic positioning uncertainties by propagating positioning through linear regression for ultrasonic measurement and could enable autonomous quality control during welding. With in-process defect detection, this framework represents a step toward closed-loop quality control in nuclear manufacturing and could significantly reduce rework cost in next-generation SMRs.