**INDIAN INSTITUTE OF TECHNOLOGY GUWAHATI**
**SHORT ABSTRACT OF THESIS**

| | | |
|---|---|---|
| Name of the Student | : | Nur Mahammad Mussa Kalimullah |
| Roll Number | : | 186104113 |
| Programme of Study | : | Ph.D. |

Thesis Title:
Data-Driven and Machine Learning Frameworks for Condition Assessment of Plate Structure using Elastic Waves

| | | |
|---|---|---|
| Name of Thesis Supervisor(s) | : | Dr. Amit Shelke |
| Thesis Submitted to the Department/ Center | : | Civil Engineering |
| Date of completion of Thesis Viva-Voce Exam | : | 13/08/2024 |
| Key words for description of Thesis Work | : | Structural Health Monitoring, Elastic Waves, Scientific Machine Learning |


**SHORT ABSTRACT**

The evolving domain of structural health monitoring (SHM) is crucial for ensuring the integrity and extending the service life of engineering structures. This thesis presents a suite of data-driven and machine learning frameworks developed to enhance the condition assessment of plate structures, particularly focusing on the complexities of piezoelectric materials and anisotropic composites. In a comprehensive exploration of data-driven and machine learning frameworks for assessing the condition of plate structures, this dissertation presents a series of interconnected studies, each contributing to the advanced insights and application in SHM, particularly focusing on piezoelectric materials and anisotropic composites.

The effectiveness of piezoelectric sensors is deteriorated by the presence of defects, delamination, and corrosion, which must be identified and addressed to ensure the successful application of the SHM framework The research begins by addressing anomaly detection in piezoelectric Lead Zirconate Titanate (PZT) substrates through the development of a novel multiresolution dynamic mode decomposition (mrDMD) algorithm. This method, effective at diagnosing and localizing surface defects, utilizes the interaction of ultrasonic waves with microscale defects. It leverages sophisticated image registration techniques and Kullback Leibler divergence to enhance the precision and effectiveness of defect localization in complex material systems.

Building on these foundational insights, the work progresses to the application of a deep autoencoder neural network, specifically tailored for anomaly detection in PZT sensors. This approach is beneficial at processing complex waveform data, identifies surface defects and delamination with high accuracy. The integration of image registration and peak signal-to-noise ratio metrics further refines the anomaly quantification, demonstrating a robust solution for handling the nonlinear interaction of waves with surface anomalies.

The development of a probabilistic approach using the unscented Kalman filter, aimed at estimating the stiffness matrix of an anisotropic piezoelectric material, in particular, Lithium Niobate substrate. This segment of research presents a ground-breaking integration of experimental measurements with a physics-based mathematical model.

The implementation demonstrates the utility of Bayesian filtering in material characterization, especially under measurement uncertainties.

In an extension of these methodologies, the exploration turns to an anisotropic carbon fibre composites plate structure. Here, a probabilistic ML based on multi-output Gaussian process regression (moGPR) is employed to estimate the elastic constants of woven fabric reinforced composites. This study marks a notable advancement in interconnecting numerical simulations with experimental observations, specifically through the analysis of Lamb wave dispersion curves. The ML model correlates between theoretical predictions and practical measurements in composite laminates. Being a probabilistic framework, the implementation considers the measurement uncertainties.

The culmination of these methodologies is demonstrated in the final study, which introduces a multi-fidelity physics-informed neural network (mfPINN) for acoustic emission source localization in anisotropic composites. This innovative framework combines the strengths of data-driven and physics-informed learning. Further, this framework innovatively applies transfer learning to fuse low-fidelity physical models with sparse high-fidelity experimental data for acoustic emission source localization in composite panels. This implementation considers the uncertainties inherent in sensor measurements. This study showcasing the harmonious integration and advancement of the previously developed techniques. In other words, one can conduct this study after the diagnosis of piezoelectric transducer and characterising the composite laminates by using previous developed methods.

Collectively, these research works represent significant efforts towards the requirement of efficient, accurate, and robust SHM frameworks. Overall, this dissertation presents a holistic and sophisticated approach to structural health monitoring, setting new standards in the use of data-driven and machine learning methodologies for the detailed assessment and diagnosis of intricate systems.