Flange Bolt Looseness Prediction with Smart Touch Using Stress Wave Analysis and Machine Learning

Himansu Shaw, **PhD Student**

Department of Mechanical Engineering, Cullen College of Engineering

Problem Statement and Approach

•Manual inspection methods for ensuring the appropriate tightness of flange bolts are labor-intensive, prone to human error, and may overlook gradual loosening between checks, posing risks of equipment failure and downtime.

•Need to develop smart touch based non-destructive testing solution using PZT sensor to predict The flange bolt looseness.

•Explore the advance signal processing technique and machine learning algorithm.

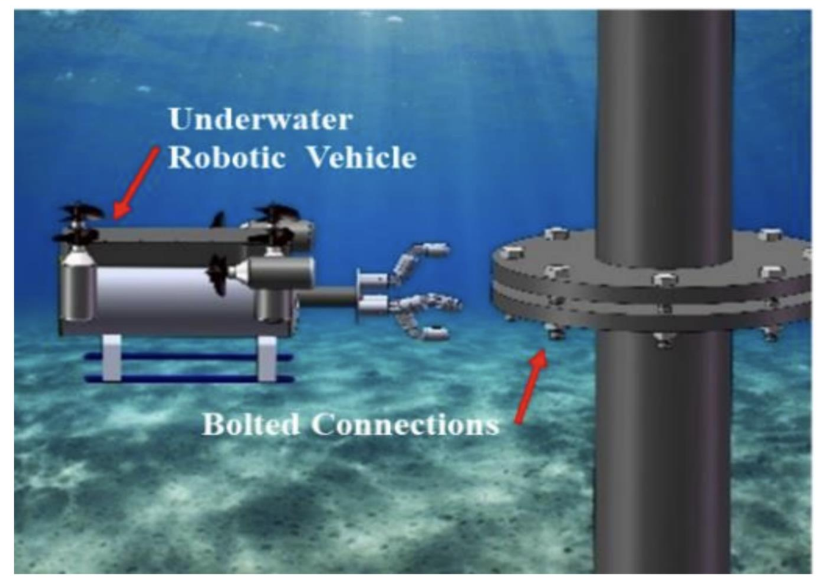

Fig.1: Proposed ROV solution
Source: Jiang and Jinwei [1]

Literature Review

- Jiang et al. [1] propose a touch-based method using PZT transducers to inspect subsea bolted connections. Spectrograms and wavelet packet transformation analysis validate the approach.
- Ning Li [2] presents a 3D electromechanical FEA approach for monitoring bolt looseness through active sensing. Confirming the efficacy of fractal contact theory, the study establishes a link between signal peak amplitude and preload
- Wang and Song [3] introduce a novel Vibro-Acoustic Modulation (VAM) method for detecting multi-bolt connection looseness, surpassing traditional single-bolt joint approaches. Their method, utilizing linear swept sine waves and the Gnome entropy (gEn).

Experimental Setup and Collection of Data

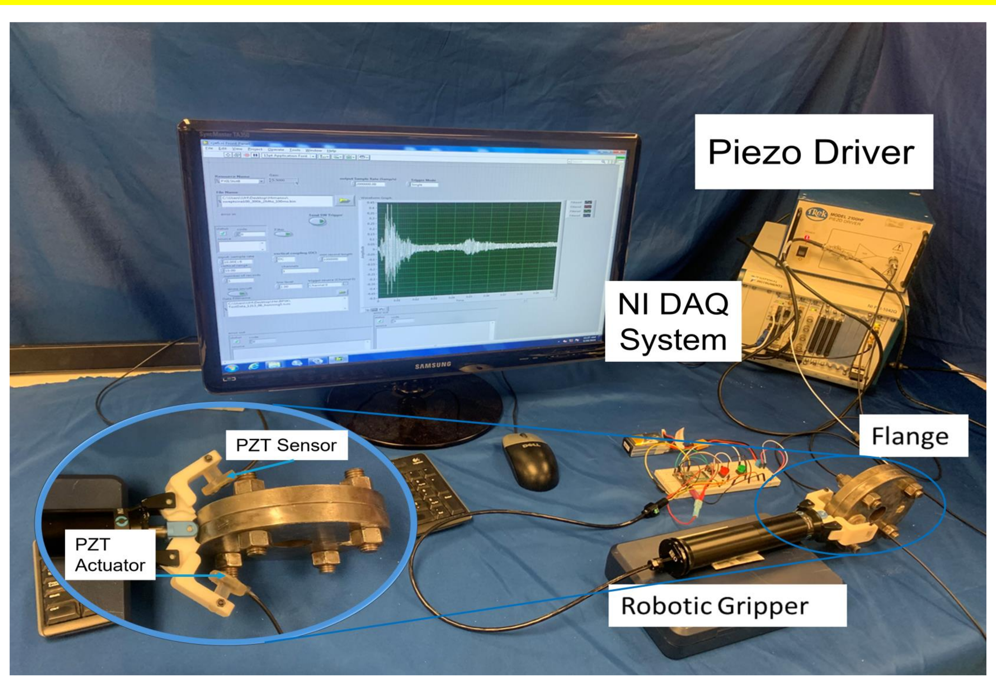

Fig.2: Experimental Setup

•Experimental setup combines PXI-1042 National Instruments (NI) hardware system with robotic gripper equipped with piezoelectric (PZT) sensors and actuators.

•LabVIEW system produces chirp signal sweeping from 100 Hz to 300 kHz over 0.1 second duration.

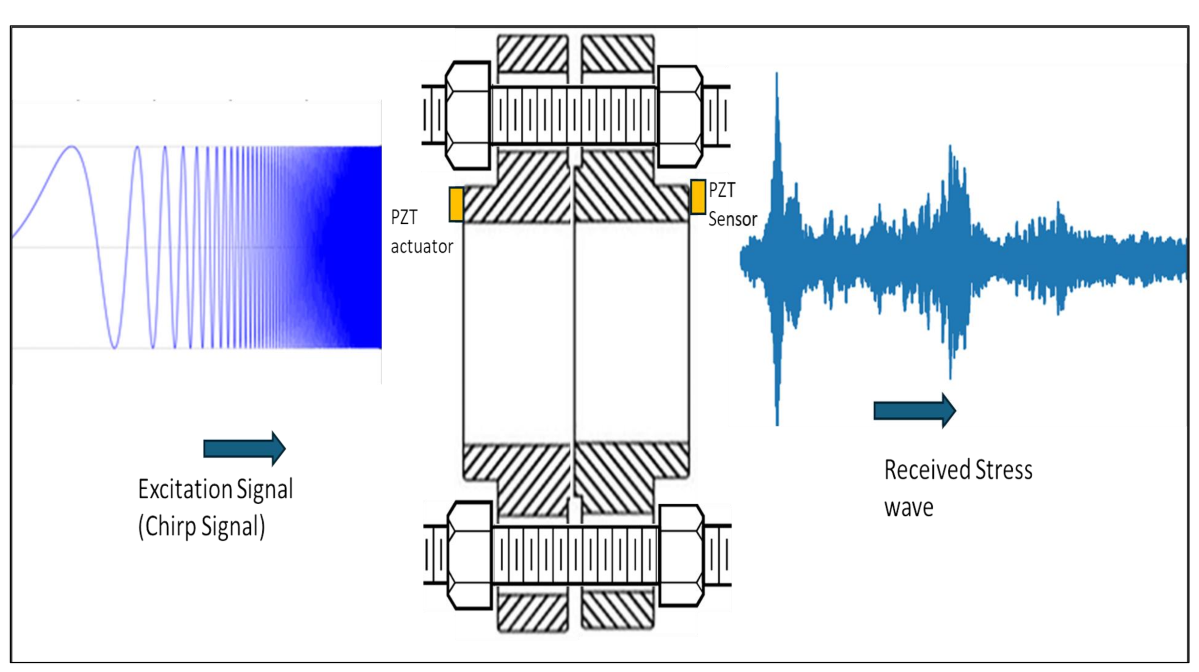

Fig.3: Schematic Diagram of Stress Wave Propagation

•A PZT sensor, located opposite the actuator on the flange plate, captures stress waves from a chirp signal. Sampling at 10 MHz ensures accurate wave recording.

•STFT plot was generated from the time series information

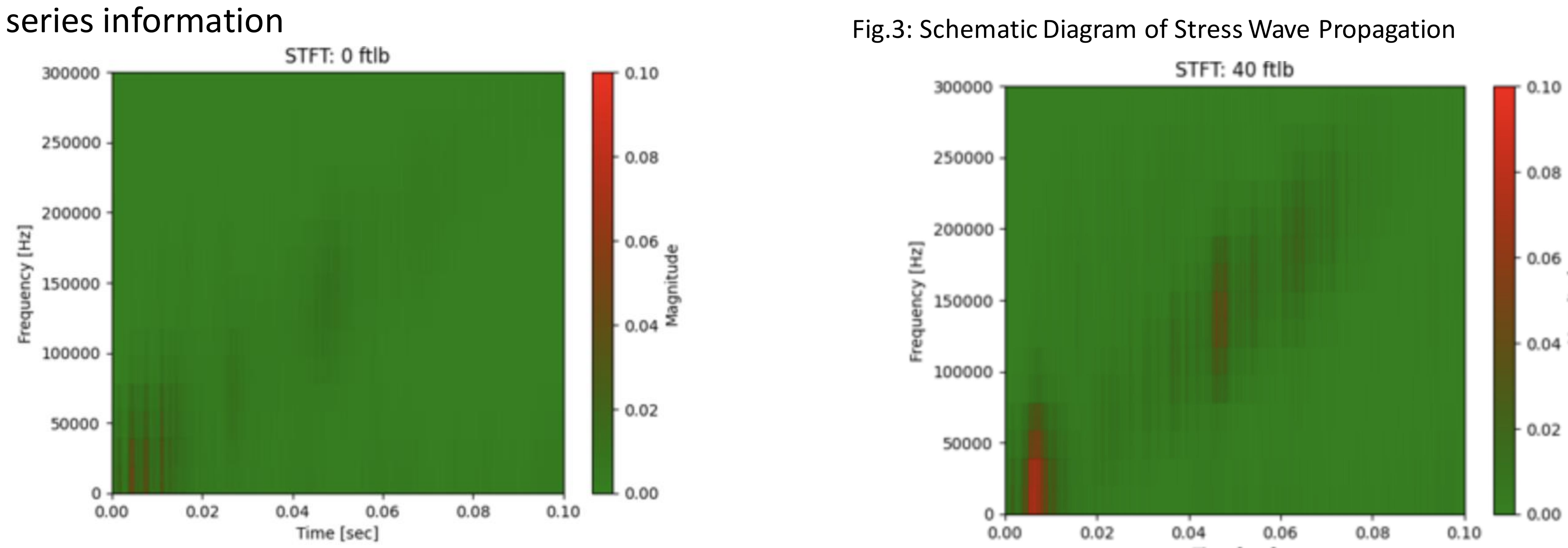

Fig.4: STFT Plot Comparison at different torque

Methods

- STFT computed with a window length of 256 points and an overlap of 128 points.
- The STFT plot was average pooled to reduced the dimension by 20 times and flatten to an 1D matrix
- Dataset comprised 500 samples with five torque labels (0,10,20,30,40 ft-lb), evenly split for training and independent verification.
- SVM model used Radial Basis Function (RBF) kernel, fine-tuned with C parameter set to 2.5 for regularization strength.
- 'Scale' option utilized for gamma parameter to adapt to dataset characteristics.

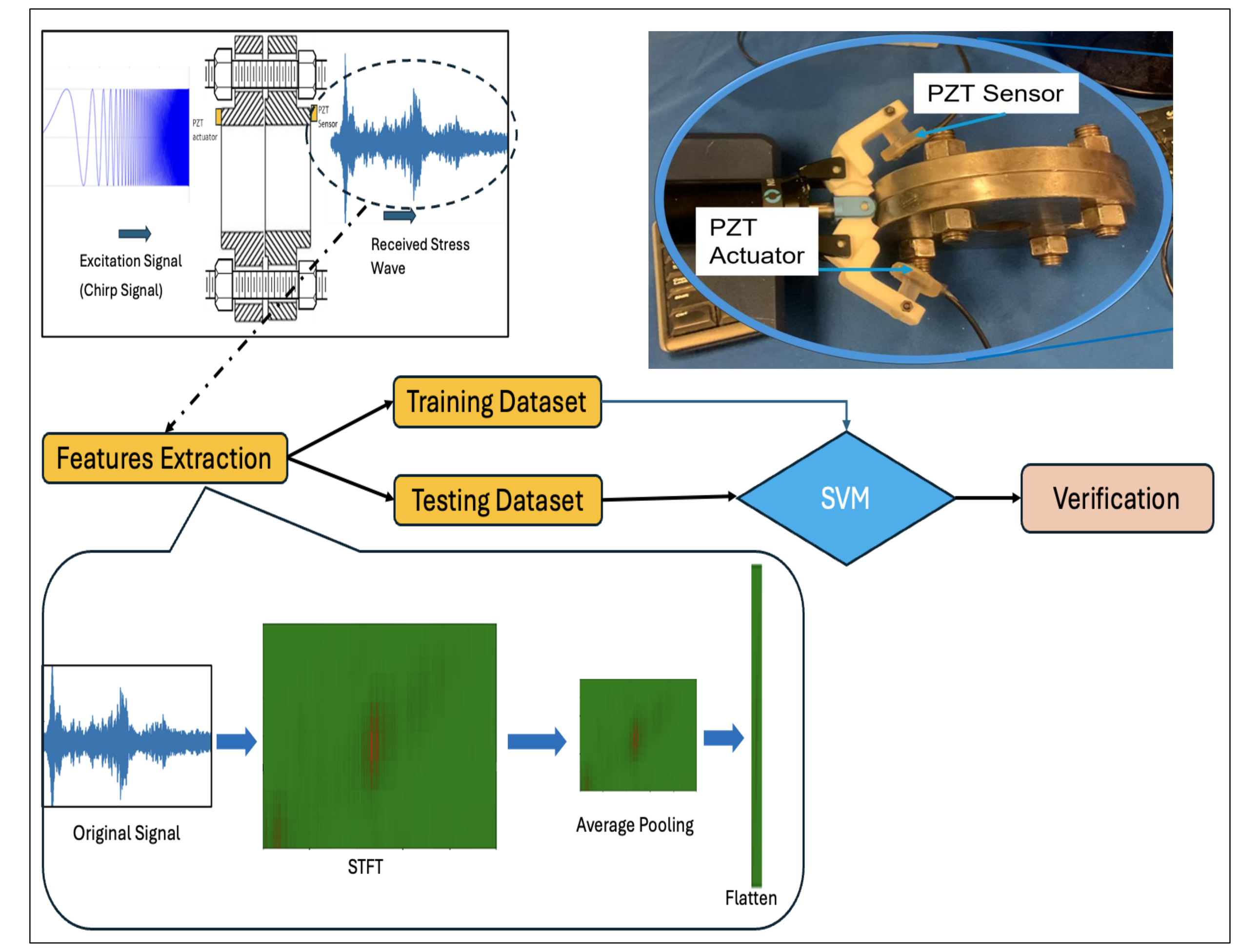

Fig.5: Flow Diagram of The Proposed Method

Results, Analysis and Discussion

- SVM model trained on 500 samples with a 50:50 split for training and testing.
- Model achieved an accuracy of 93.2% in this configuration, focusing solely on STFT data.
- Confusion matrix in Fig. 6 illustrated model performance in the independent validation test.
- Capturing subtle variations in bolt tightness levels using frequency-domain features.
- Challenges include managing computational complexity and reliance on singular feature type, suggesting room for optimization.

True Label \ Predicted labels	0 ftlb	10 ftlb	20 ftlb	30 ftlb	40 ftlb
0 ftlb	50	0	0	0	0
10 ftlb	2	47	0	1	0
20 ftlb	1	1	45	1	2
30 ftlb	3	0	0	46	1
40 ftlb	1	1	1	2	45

Fig.6: Confusion Matrix of The Independent Validation

Conclusion

- The research achieves a high accuracy of 93.2% in predicting flange bolt looseness using stress wave analysis and machine learning.
- Leveraging frequency-domain features proves effective for classification despite challenges like computational complexity and feature dependency.
- Future work in this project will focus on adopting advanced deep learning models, particularly Convolutional Neural Net-

Acknowledgements

- The financial support from Midstream Integrity Services (MIS) and technical support from Smart Materials & Structures Lab (SMSL) and Artificial Intelligence Lab for Monitoring & Inspection (AILMI) at UH.
- This research was supported by Bureau of Safety and Environmental Enforcement (BSEE).

References

[1] Jiang, Jinwei. A Comprehensive Integrity Monitoring System for Bolted Flange Connections. Diss. 2020.
[2] Li, Ning, Furui Wang, and Gangbing Song. "Monitoring of bolt looseness using piezoelectric transducers: Three-dimensional numerical modeling with experimental verification." Journal of Intelligent Material Systems and Structures 31.6 (2020): 911-918.
[3] Wang, Furui, and Gangbing Song. "Monitoring of multi-bolt connection looseness using a novel vibro-acoustic method." Nonlinear Dynamics 100.1 (2020): 243-254.