Project Title: Percussion-Based Bolted Flange Looseness Detection using Machine Learning Classification and Clustering

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Problem Statement

- Pipeline leakages can have detrimental impacts on the people and environment around it. One weak point in a pipeline is the bolted connection. Finding an effective way to monitor the health of the flange, using bolt looseness, would greatly benefit many industries using pipelines.
- I have developed a method using percussion-induced audio signals, and machine learning to determine if a bolt is loose by simply tapping next to the bolt.

Brief Literature Review

- Coelho, J.S., et. all, proposed a machine learning algorithm for pattern recognition that detects and quantifies torque loosening in bolted joints. [1]
- Chen, et. all, monitored the detection of bolt connection looseness through percussion-based method using machine learning and feature extraction method (FM-Rocket). [2]

Experimental Setup and Collection of Data

- Figure 1 shows an 8-bolt flange with a hammer used as the tapping device.
- The data collection begins by having all but one bolt fully tightened to 210[ft-lb], while the one remaining bolt stays at 0 [ft-lb]. A hammer is used to tap 25 times just to the right of the bolt as shown in a red box while an iPhone is used to record the audio. This process is repeated 7 more times with each bolt being loose once.
- Table 1 shows the data for 1 Set.

Fig. 1. 8- Bolt Flange

		Cases								
		1	2	3	4	5	6	7	8	
Bolt numbers (1 loosened at a time)	1	25	25	25	25	25	25	25	25	
	2	25	25	25	25	25	25	25	25	
	3	25	25	25	25	25	25	25	25	
	4	25	25	25	25	25	25	25	25	
	5	25	25	25	25	25	25	25	25	
	6	25	25	25	25	25	25	25	25	
	7	25	25	25	25	25	25	25	25	
	8	25	25	25	25	25	25	25	25	Total
	Total	200	200	200	200	200	200	200	200	1600

Table 1. Set 1 Data Collection

- Loosened Bolts
- Case 1
- Bolt 1
- 1600 individual audio signals per Set.

- 4 Sets were taken.
- A total of 6,400 individual percussion-induced audio signals.

Method(s)

- The collected data starts as multi-hit audio and must be separated into single-hit audio.
- MFCC is used to extract feature of the audio. [3]

Fig 2. Flowchart

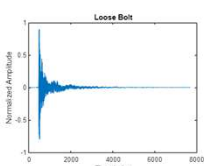

Fig 3. Loose Bolt in Time Domain

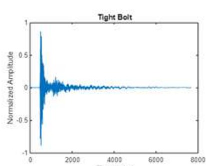

Fig.4. Tight Bolt in Time Domain

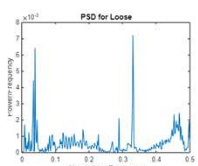

Fig. 5. PSD Plot for Loose Bolt.

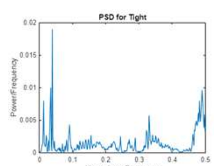

Fig. 6. PSD Plot for Tight Bolt.

- K Nearest Neighbor (KNN) will be used as my shallow learning method.
- Recurrent Neural Network (RNN) will be used as my deep learning method.
- Both Spectral Clustering and Fuzzy C-Mean will be used for clustering.

Results, Analysis and Discussion

- Shallow Learning (SVM)

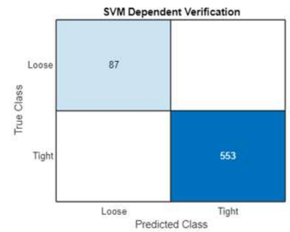

Fig. 7. SVM Dependent Verification

- 100% Accuracy

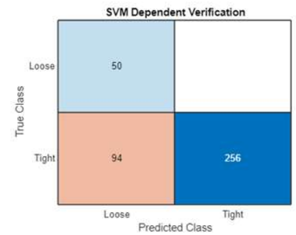

Fig. 8. SVM Independent Verification

- 76.5% Accuracy

- Deep Learning (RNN)

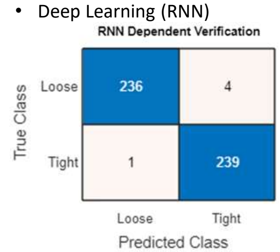

Fig. 9. RNN Dependent Verification

- 98% Accuracy

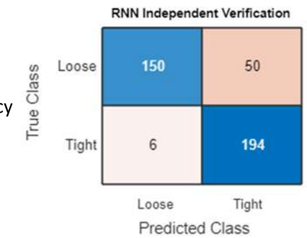

Fig. 10. RNN Independent Verification

- 86% Accuracy

- Clustering (Spectral Clustering & Fuzzy C-Mean)

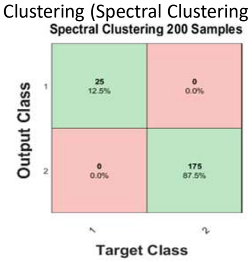

Fig. 11. Spectral Clustering

- 100% Accuracy

Fig. 12. Fuzzy C- Mean

- 72% Accuracy

Conclusion

- I have found effective ways to detect a loose bolt on a flange.
- SVM offers a good method when using dependent verification with an 80/20 split.
- RNN offers the overall best results for Classification.
- Spectral Clustering shows the best results for clustering.
- In the future, this concept can be used for underwater applications, and applying this method for more than one bolt assuming the majority are tight.

Acknowledgements

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References (brief)

1. Coelho, J.S., Machado, M.R., Dutkiewicz, M. *et al.* Data-driven machine learning for pattern recognition and detection of loosening torque in bolted joints. *J Braz. Soc. Mech. Sci. Eng.* **46**, 75 (2024). https://doi.org/10.1007/s40430-023-04628-6
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3. S. Davis and P. Mermelstein, "Comparison of parametric representations for monosyllabic word recognition in continuously spoken sentences," in IEEE Transactions on Acoustics, Speech, and Signal Processing, vol. 28, no. 4, pp. 357-366, August 1980, doi: 10.1109/TASSP.1980.1163420.