Deep Learning-based Joint Loosening Detection for Infrastructure Components

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Problem Descriptions

The goal of this research is to develop data-driven techniques for both structural damage and bolt loosening detection in infrastructure components such as railway track and bridge segment using piezoelectric transducer active interrogation.

Challenges and Motivations:

- Heterogeneous fault types, e.g., bolt joint loosening, structural damage
- First-principle modeling of fault condition is difficult
- Damage detection can be regarded as pattern recognition/ classification

Data-driven Approach

The goal is to detect the area of the structure with loosened bolt

➢ Data acquisition

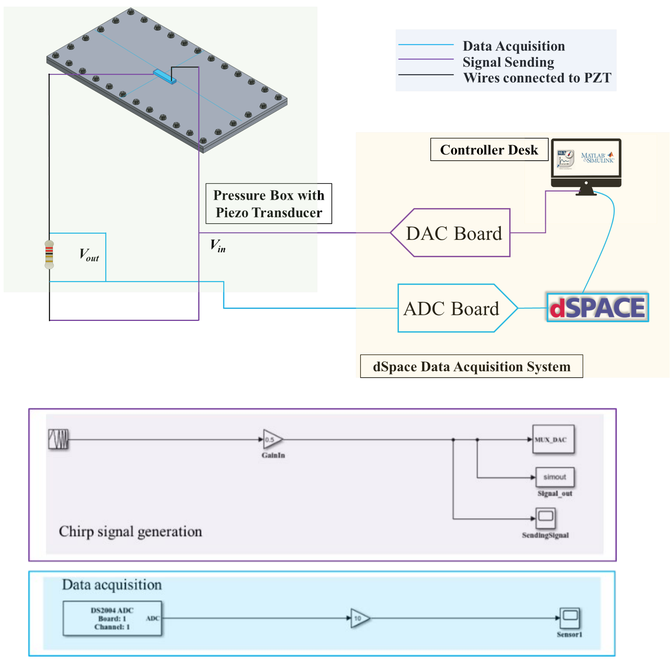


Figure 1: Data acquisition system for bolt loosening detection in jointed structure..

The chirp signal is utilized in this research to facilitate data acquisition. It has two features:

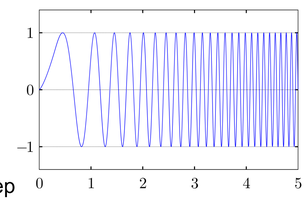
Variable frequency: frequency increases or decreases with time

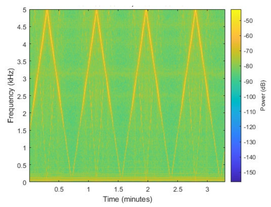
Information-rich: providing clear and distinct information about detected objects or anomalies

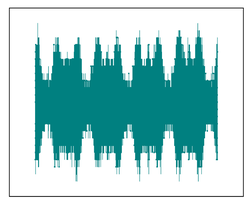
$$x(t) = A\cos\left(2\pi\alpha t^2 + 2\pi f_0 t + \phi_0\right)$$

$$f(t) = 2\alpha t + f_0 \qquad 2\alpha = \frac{f_1 - f_0}{T}$$

A is the amplitude
ϕ_0 is the initial phase
Time duration T
f_0 is the starting frequency of the sweep
f_1 is the frequency at the end of the duration T





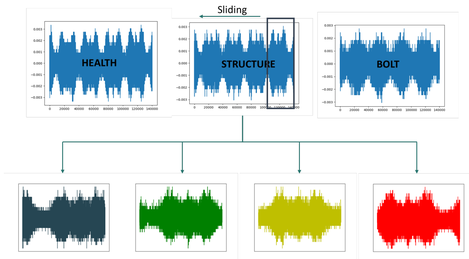


Chirp Signal
Initial Freq: 1,000 Hz
Target Time: 20s
Sampling Freq: 2,500 Hz

Final Freq: 5,000 Hz
Acquisition Time: 200s

Figure 2: Data example for chirp signal (left) and structure responses (right).

➢ Data processing



- Sliding window: Length = 35,000; Stride = 35,000
- 48 slices for each class

Figure 3: One dataset example and partition illustration.

➢ Architecture of data-driven model

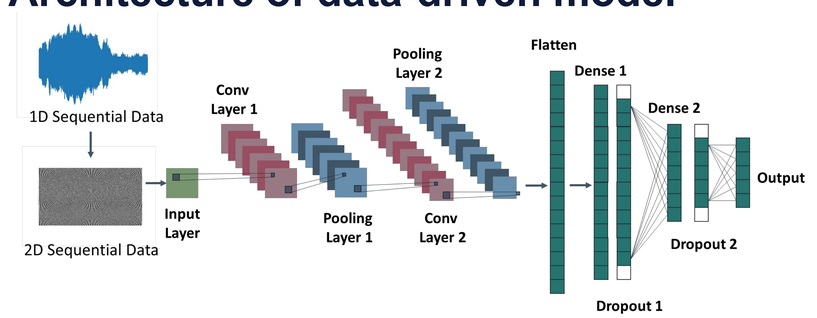
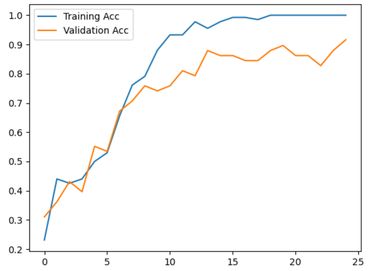


Figure 4: Architecture of proposed deep learning model.

➢ Bolt loosening detection results

- *4-Edge localization* of bolt loosening
- **S1**(short), **S2**(short), **L1**(long), **L2**(long)
- *ACC = 0.9285*



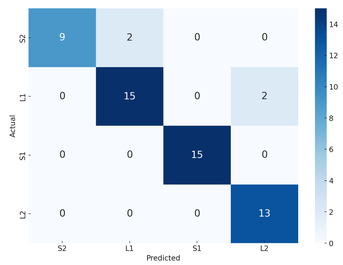


Figure 5: Training history curves (left) and confusion matrix (right)..

Conclusion

- ***Data-driven approach achieves high detection accuracy for bolt loosening detection***
- ***The different severity levels will be considered in future study***

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