Data Dirven Frameworks for

Drive by Bridge Inspection

Dr Mehri Makki Alamdari

Motivation

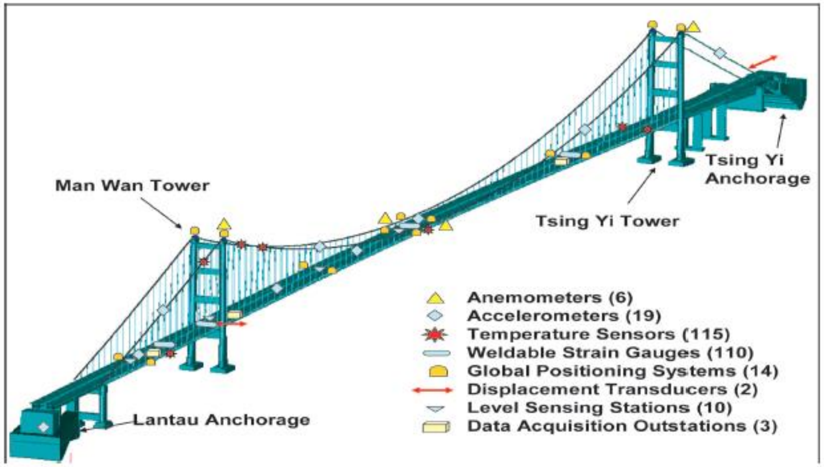
72% of bridges in Australia were built before 1976 with many of them are considered defective [1].

Types of inspection:

NDT based approaches

Taken from:
https://www.stantec.com/en/projects/canada-projects/d/detailed-visual-bridge-inspections

Conventional SHM approaches



Taken from: [2]

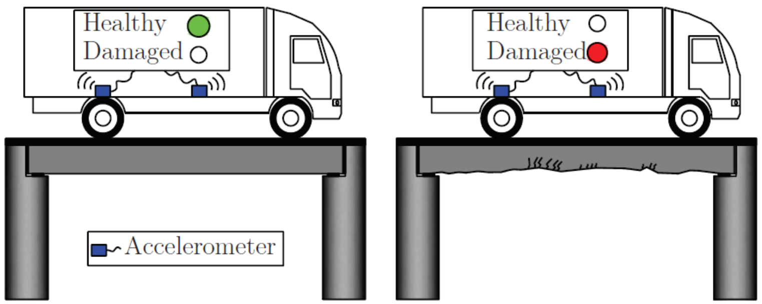
[1] Maria Rashidi1and Brett Lemass. A decision support methodology for remediation planning of concrete bridges. *Journal of Construction Engineering and Project Management*, 1:1–2011.

[2] Qipei Mei, Mustafa Gül, and Marcus Boay. Indirect health monitoring of bridges using mel-frequency cepstral coefficients and principal component analysis. *Mechanical Systems and Signal Processing*, 119:523–546, 2019.

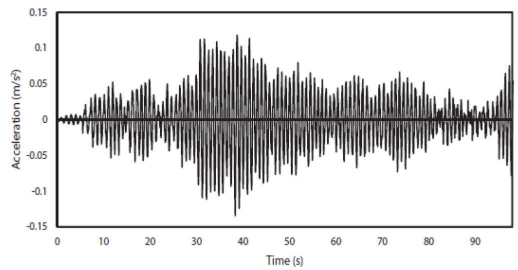
Drive by Bridge Inspection

New Alternative

Indirect Structural Health Monitoring (ISHM) based on Drive-by inspection technology



Taken from: [3]

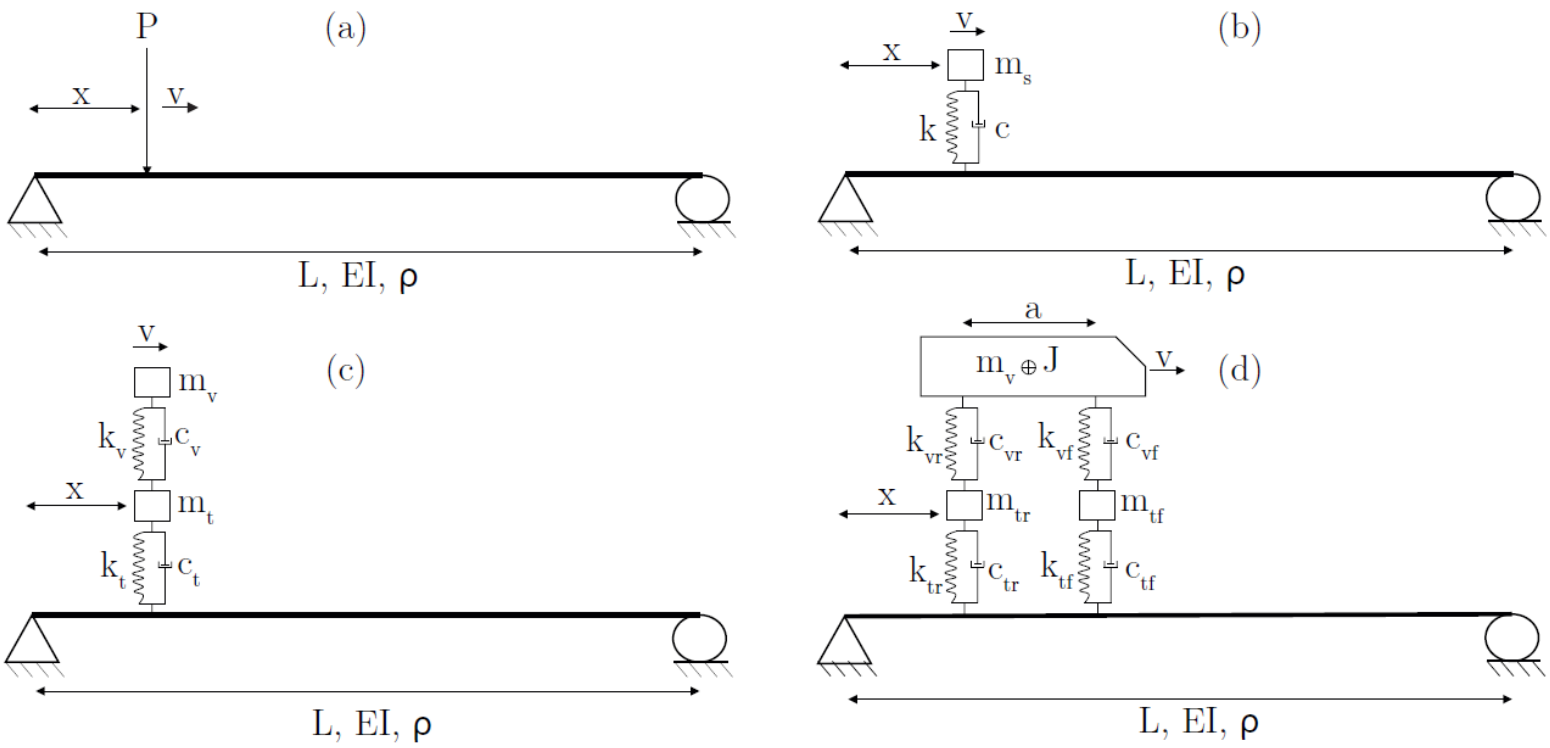


DAMAGE
- IDENTIFY
- LOCALIZE
- QUANTIFY

[3] Abdollah Malekjafarian, Patrick J. McGetrick, and Eugene J. OBrien. A review of indirect bridge monitoring using passing vehicles. Shock and Vibration, 2015:286139, Mar 2015.

Drive by Bridge Inspection

- ISHM first studied in 2004 by Y.B. Yang. [4]
- Initially used to extract bridge's natural frequencies.
- Multiple vehicle models have been used.



[4] YB Yang and CW Lin. Vehicle-bridge interaction dynamics and potential applications. *Journal of sound and vibration*, 284(1-2):205–226, 2005.

Drive by Bridge Inspection

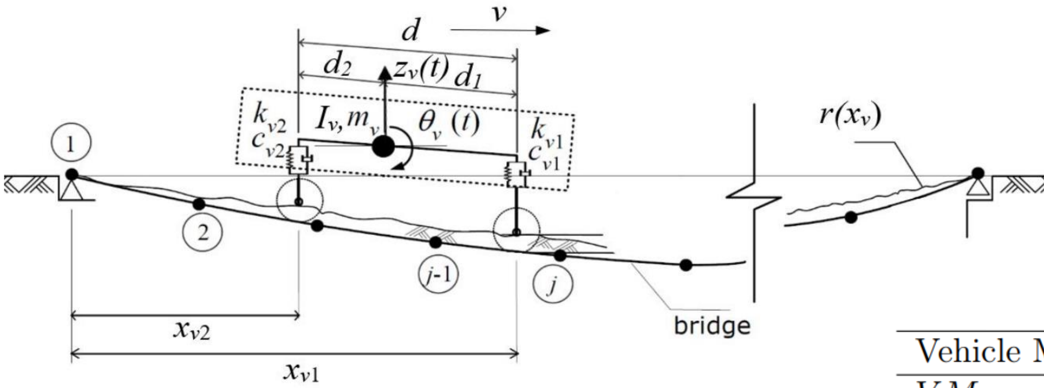
Main challenges:	Proposed Solutions:
Road roughness	Multi-axle systems Increase vehicle speed
External noise (Measurement noise, Intrinsic vehicle vibration)	Multi-axle systems
Vehicle Frequencies	External traffic excitation Highly damped vehicles Contact point response

Data-Driven Methodologies

- **Supervised learning algorithms**
  - Time consuming training,
  - Expensive,
  - Not transferable,
  - Unavailable data of damage structure.

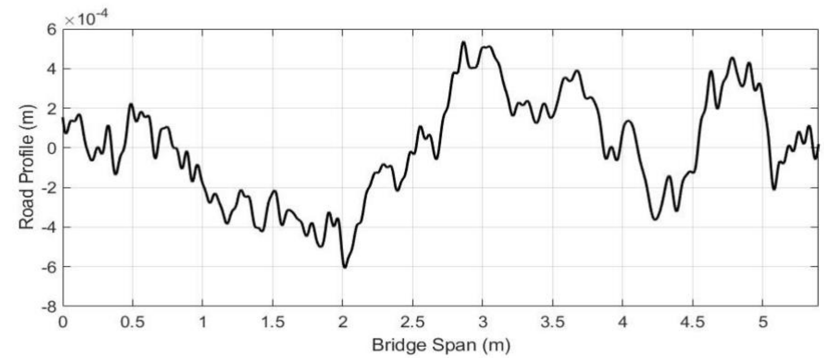
- **Unsupervised learning algorithms**
  - **Clustering-based frameworks →** Uniform Manifold Approximation and Projection (UMAP)
    - Great solution for cases when the individual clusters may have different sizes and densities.
  - **Deep learning-based methods →** Adversarial Autoencoder
    - Better representation of data in the latent sub-space with an additional prior distribution constraint
  - **Time series analysis →** Matrix Profile

Numerical Case Study



A summary of vehicle physical properties.

Vehicle Model	$m_v(kg)$	$I_v(Kg.m^2)$	$k_v(N/m)$	$c_v(Ns/m)$
VM	21.07	0.19	3,000	0



A summary of bridge's physical properties.

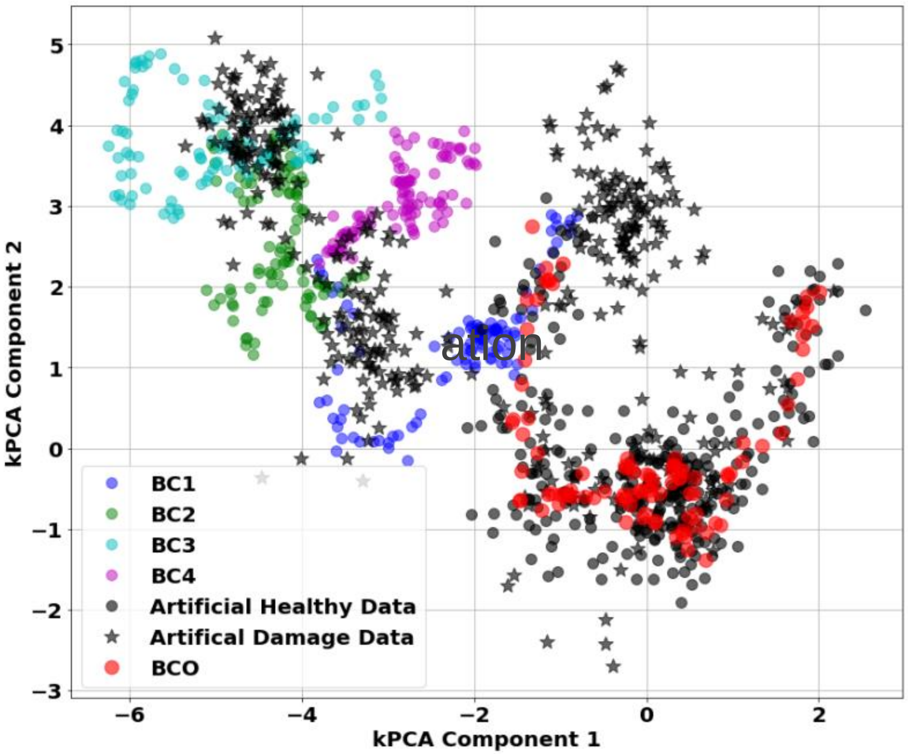
Property	Value
Span length	$5.4m$
Young's modulus	$2.1 \times 10^{11} N/m^2$
Density	$7.8 \times 10^3 kg/m^3$
Cross section area	$7.04 \times 10^{-3} m^2$
Second moment of inertia	$11.36 \times 10^{-7} m^4$

Bridge State	Mode 1	Mode 2	Mode 3
$BC0$	3.55 (—)	14.20 (—)	31.96 (—)
$BC1$	3.51 (1.22%)	14.20 (0.04%)	31.60 (1.12%)
$BC2$	3.39 (4.62%)	14.18 (0.15%)	30.67 (4.03%)
$BC3$	3.20 (9.91%)	14.15 (0.33%)	29.41 (7.97%)
$BC4$	3.00 (15.44%)	14.13 (0.52%)	28.29 (11.46%)

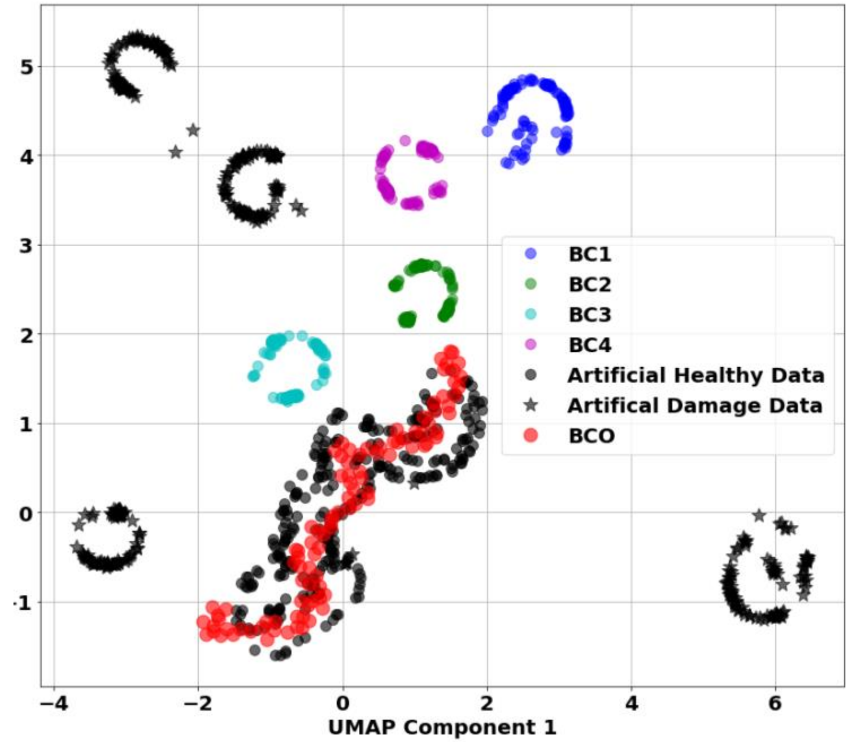
Cheema, P., Alamdari, M.M., Chang, K.C., Kim, C.W. and Sugiyama, M., 2022. A drive-by bridge inspection framework using non-parametric clusters over projected data manifolds. *Mechanical Systems and Signal Processing*, *180*, p.109401.

Numerical Results

➢ **Uniform Manifold Approximation and Projection (UMAP)**



PCA



UMAP

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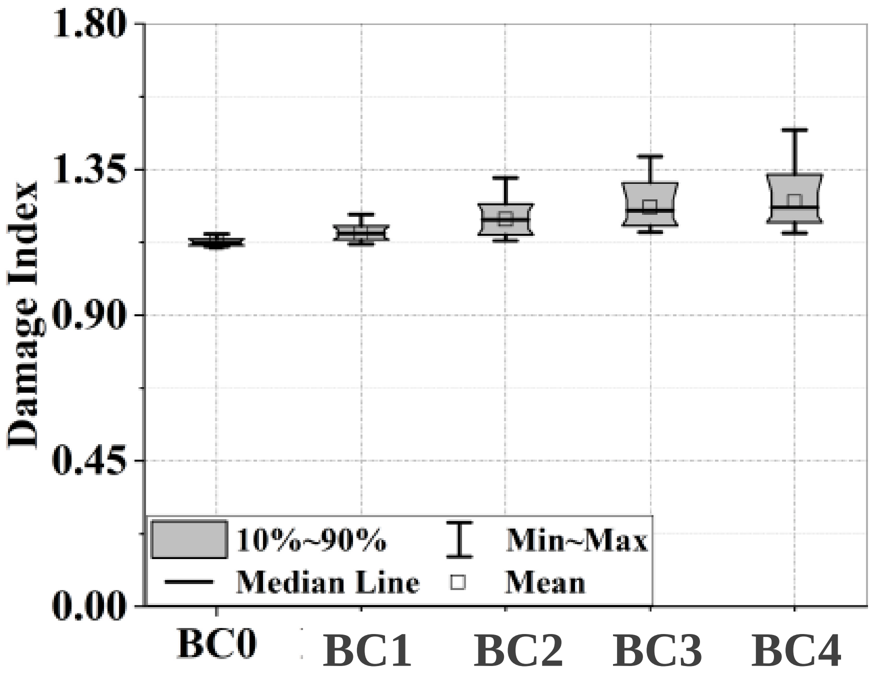
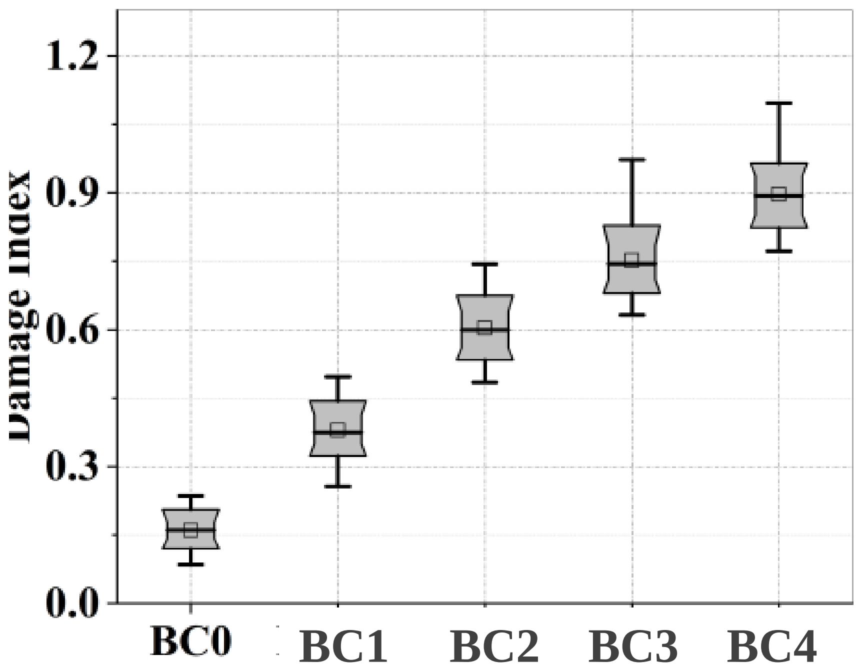
Numerical Results

➢ Adversarial Autoencoder



PCA



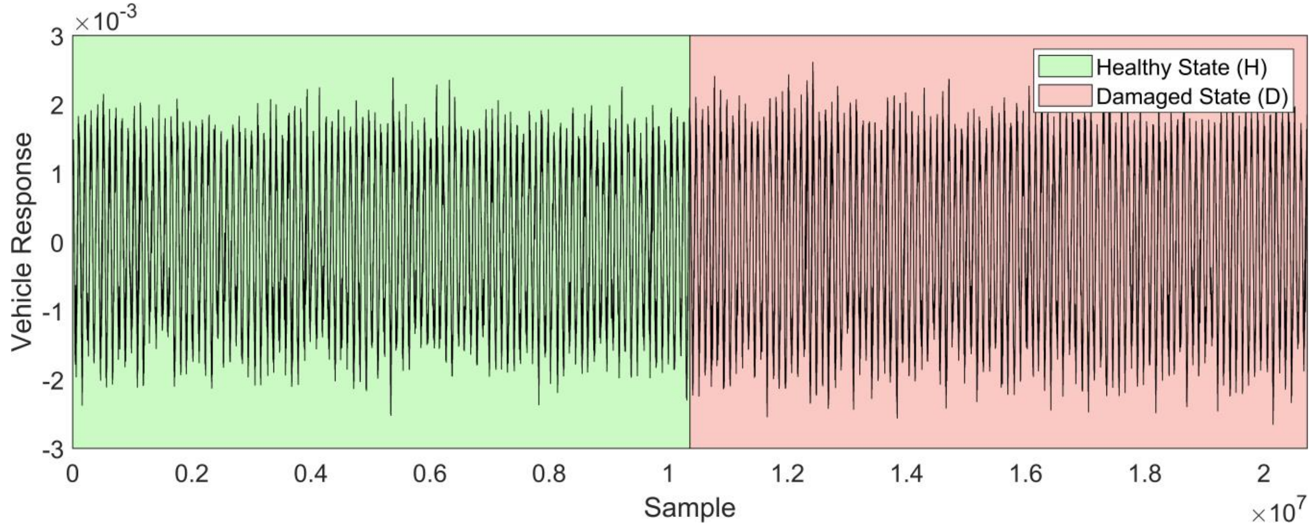
Adversarial Autoencoder

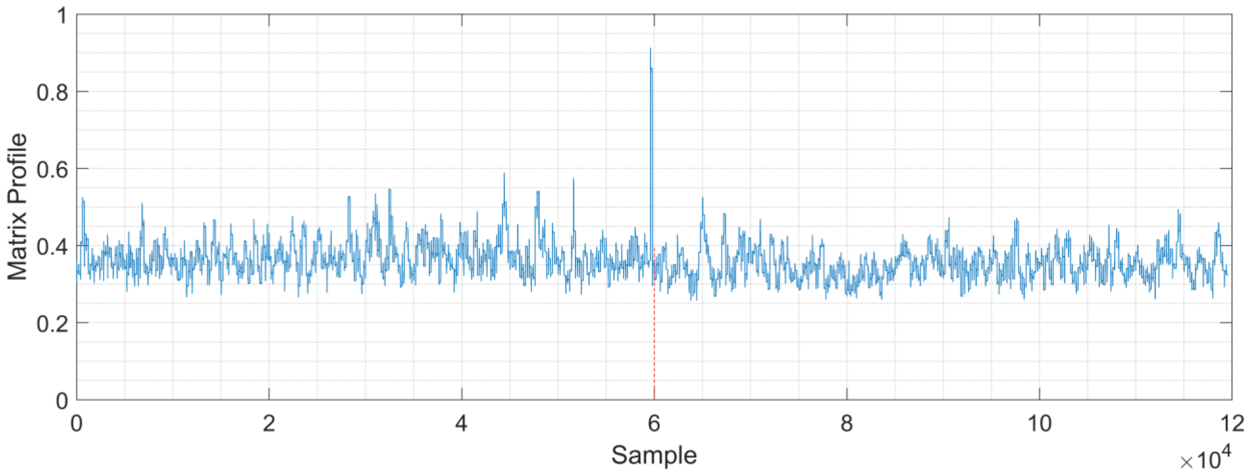
Kaur, K., Alamdari, M.M., Chang, K.C., Kim, C.W. and Atroshchenko, E., 2023. Damage Detection and Localization for Indirect Bridge Monitoring Exploiting Adversarial Autoencoder and Wavelet Transform. In *European Workshop on Structural Health Monitoring* (pp. 657-667). Springer, Cham.

Kaur, K., Alamdari, M.M., Chang, K.C., Kim, C.W. and Atroshchenko, E., 2023. Unsupervised Learning based Framework for Indirect Structural Health Monitoring using Adversarial Autoencoder, Accepted for publication in Sound and Vibration.

Numerical Results

➢ **Matrix Profile**

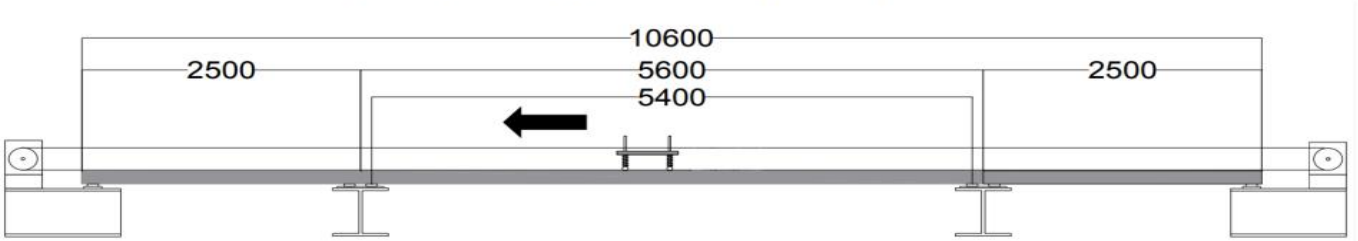




Cheema, P., Alamdari, M.M., Chang, K.C., Kim, C.W., On the use of Matrix Profile for Indirect Structural Health Monitoring. Submitted to *Mechanical Systems and Signal Processing*.

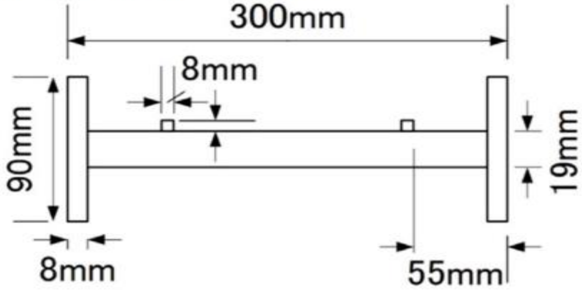
Experimental Case Study

(a) Bridge model, motor and pulley system.



(b) Schematic of the beam model (dimensions are in mm).

(c) Simply-support boundary condition.



(d) Cross section of the beam.

Experimental Case Study

Bridge State	H	$S1$	$S2$	$D1$	$D2$
First Mode (Hz)	3.66 (—)	3.69 (0.82%)	3.71(1.37 %)	3.56 (2.73%)	3.47 (5.19%)

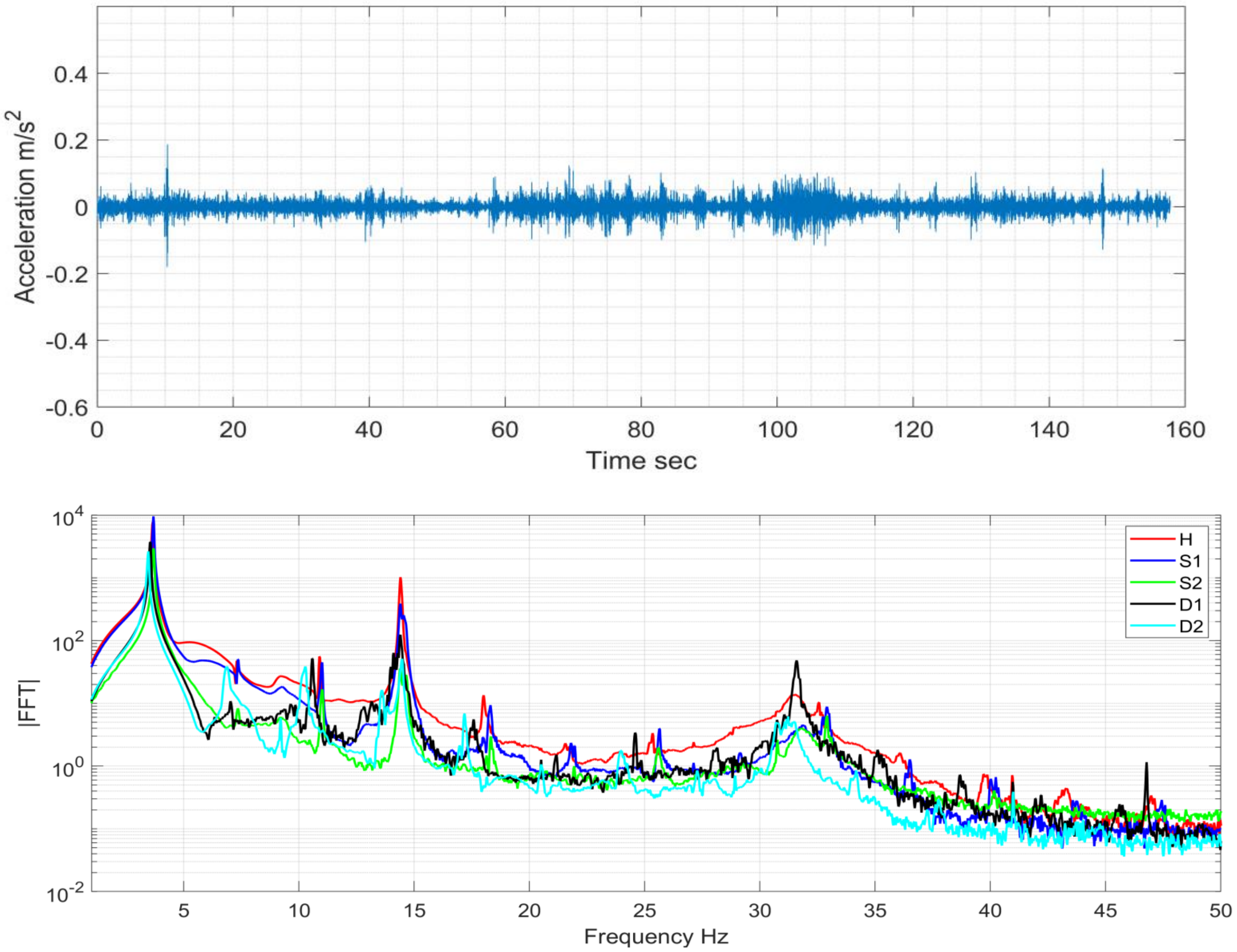
(a) Bridge condition $S1$.

(b) Bridge condition $S2$.

(c) Bridge condition $D1$.

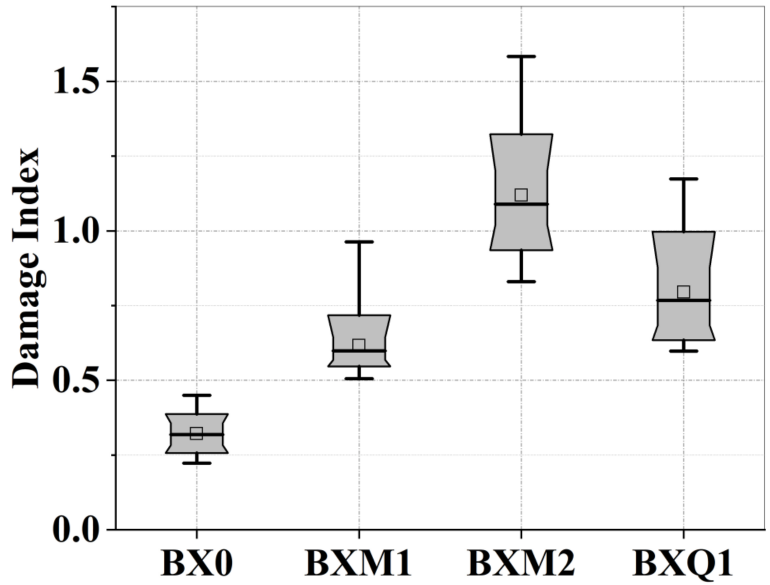
(d) Bridge condition $D2$.

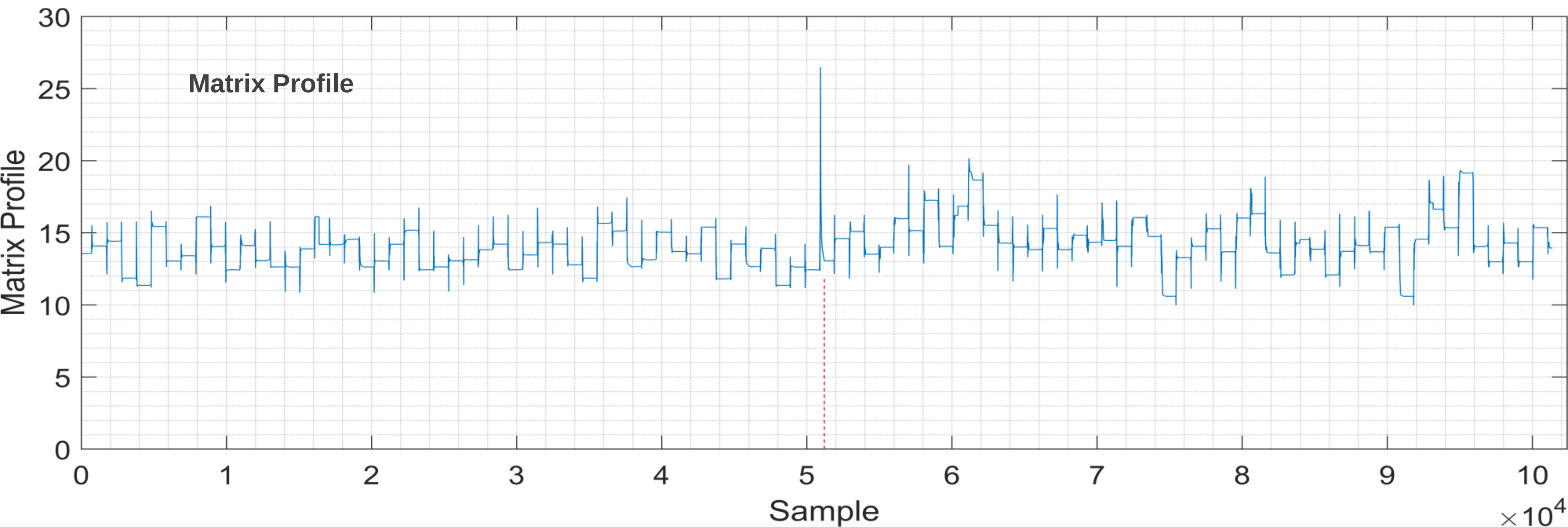
Experimental Case Study



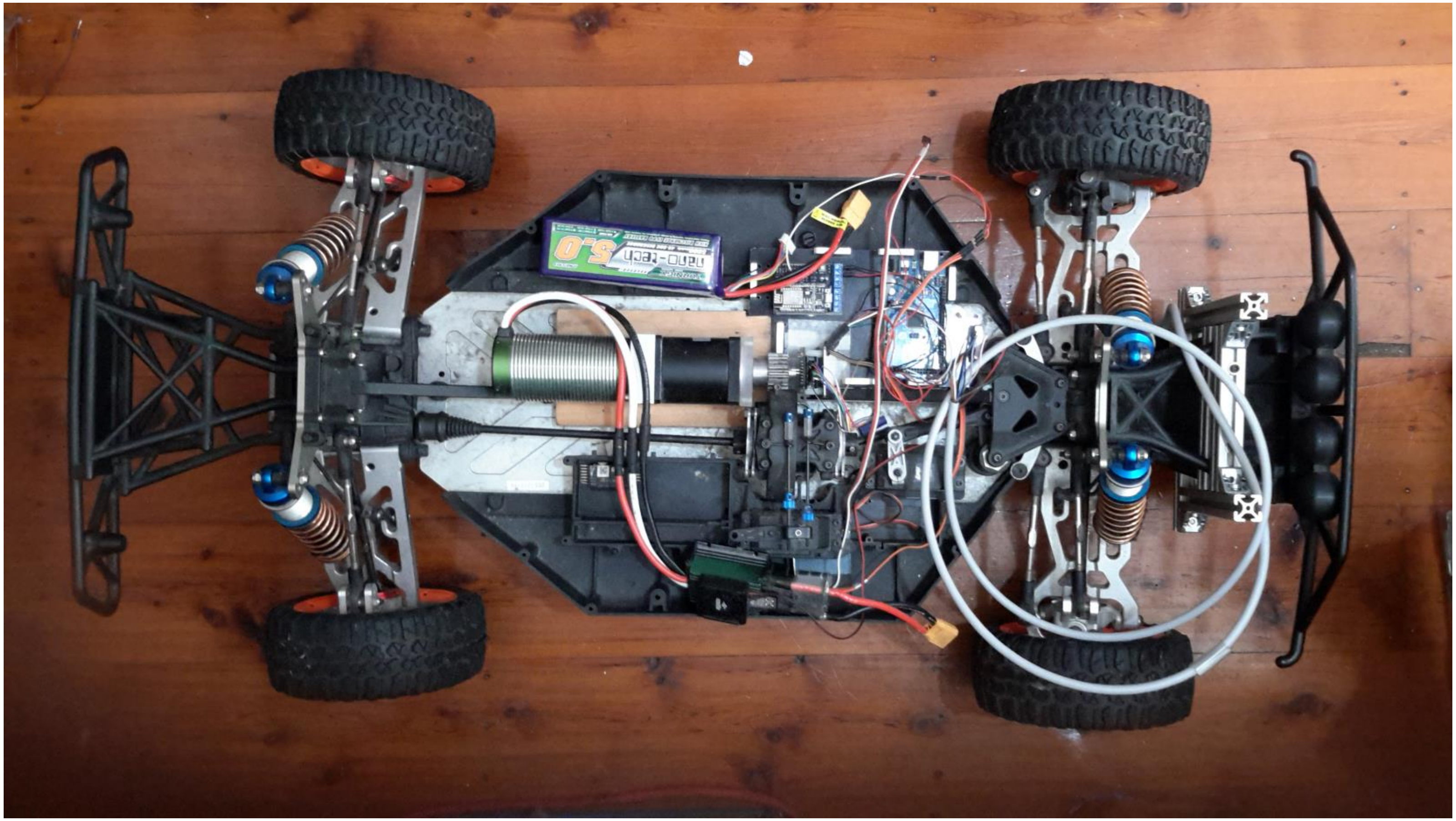
Experimental Results

Adversarial Autoencoder





Moving Forward



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Questions?