OLTC Contact Monitoring using Vibro-Acoustic Signals and Time Series Forecasting

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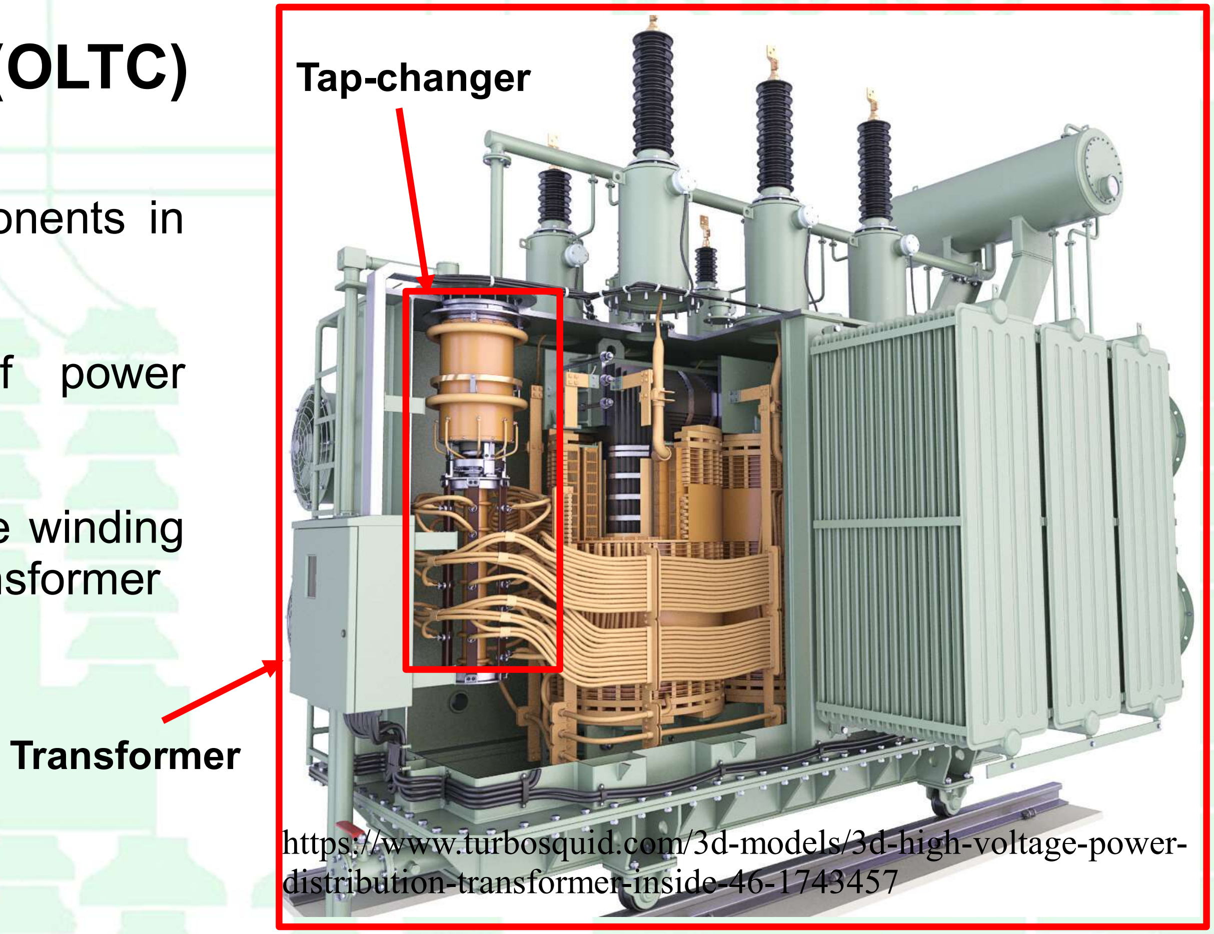
Presentation outline

- General context: OLTC contact monitoring
- Problem statement: Prognose OLTC contact degradation
- Data preparation
- Proposed algorithm
- Results and discussion
- Conclusion

What is on-load tap-changer (OLTC)

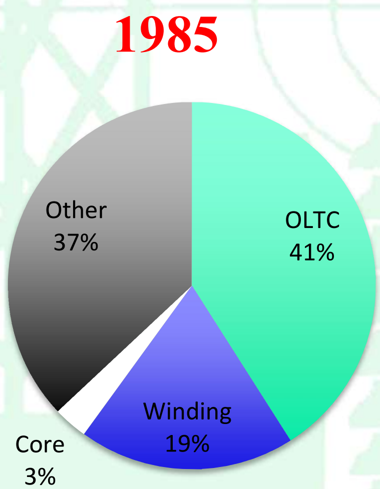
- OLTC is one of the important components in the power transformer
- It regulates the voltage level of power transformer
- It changes the number of turns in one winding and therefore the turns ratio of the transformer

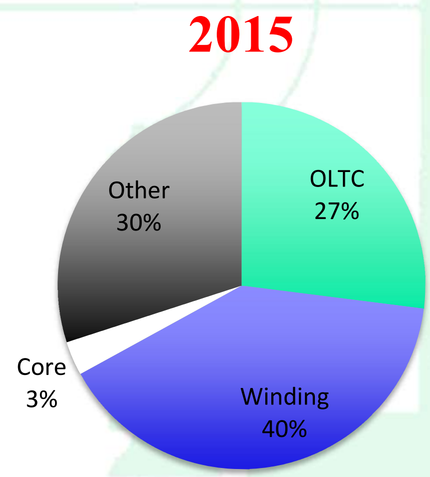


https://www.turbosquid.com/3d-models/3d-high-voltage-power-distribution-transformer-inside-46-1743457

Why does OLTC need to be monitored?

Data related to transformer failures that were collected from 13 countries





Data related to transformer failures that were collected from 22 countries

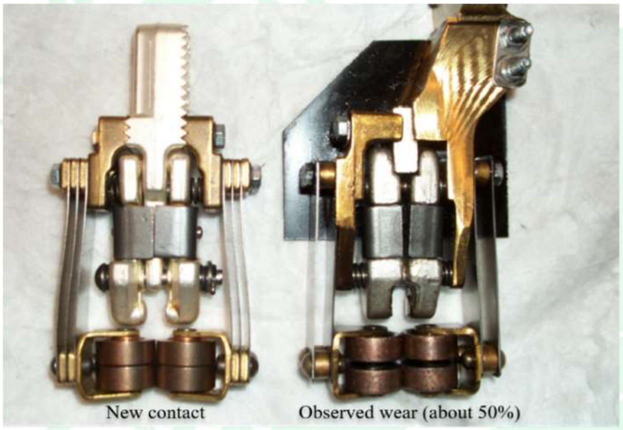
Source: CIGRE surveys from working groups 12.05 (1985) et A2.37 (2015)

Analysis of vibro-acoustic signals

- Vibro-acoustic signals analysis techniques are used to detect OLTC faults
- This technique can be used on-line/off-line
- Vibro-acoustic signals are obtained non intrusively without affecting the OLTC and transformer operations
- OLTC faults can be detected very soon in the primary stages using this technique
- This technique is expected to detect almost all types of faults in an OLTC (ref. CIGRE TB 445 – Guide for transformer maintenance)

Problem statement

- One of the key components in OLTC is the electrical contacts
- Over time, these contacts degrade gradually due to many factors including:
  - Oxidation
  - Coking
  - Mechanical wear
  - Arcing
- **The challenge is to interpret the changes to vibro-acoustic signals in relation with the failure modes**

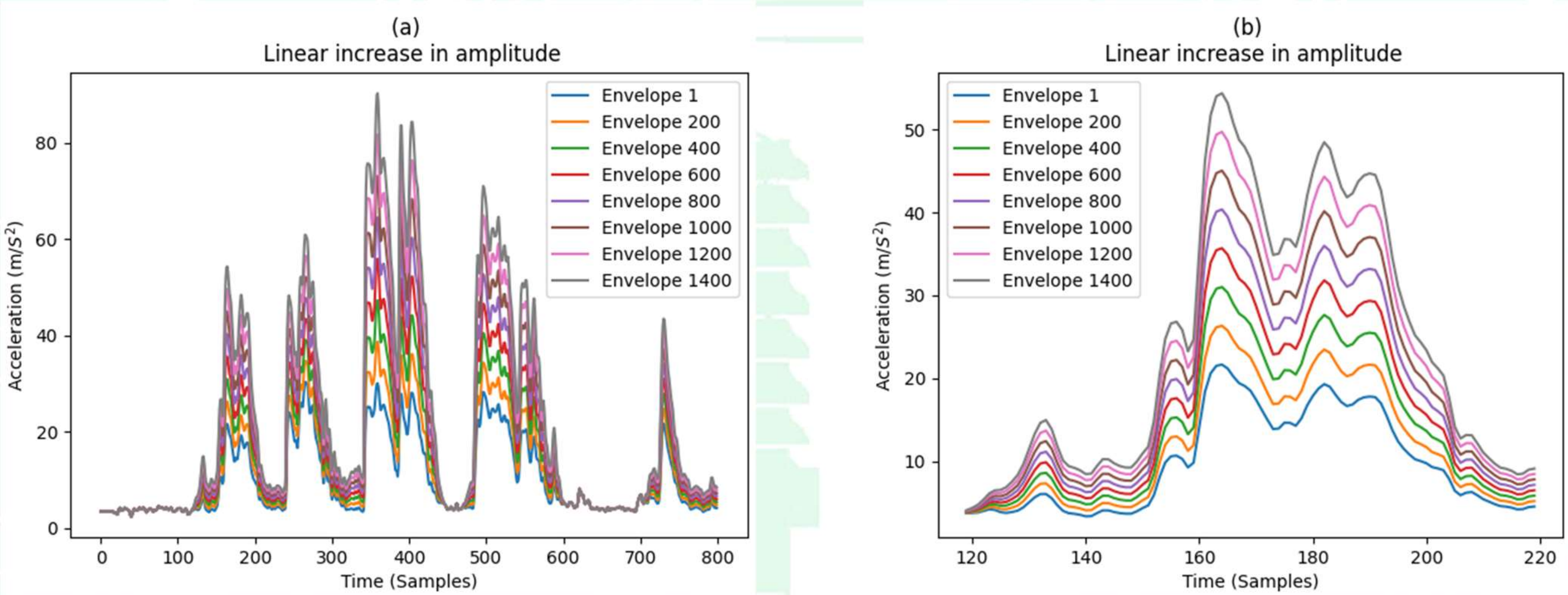


Methodology

Data preparation → Applying time-series forecasting models → Predicting the future signals generated from OLTC

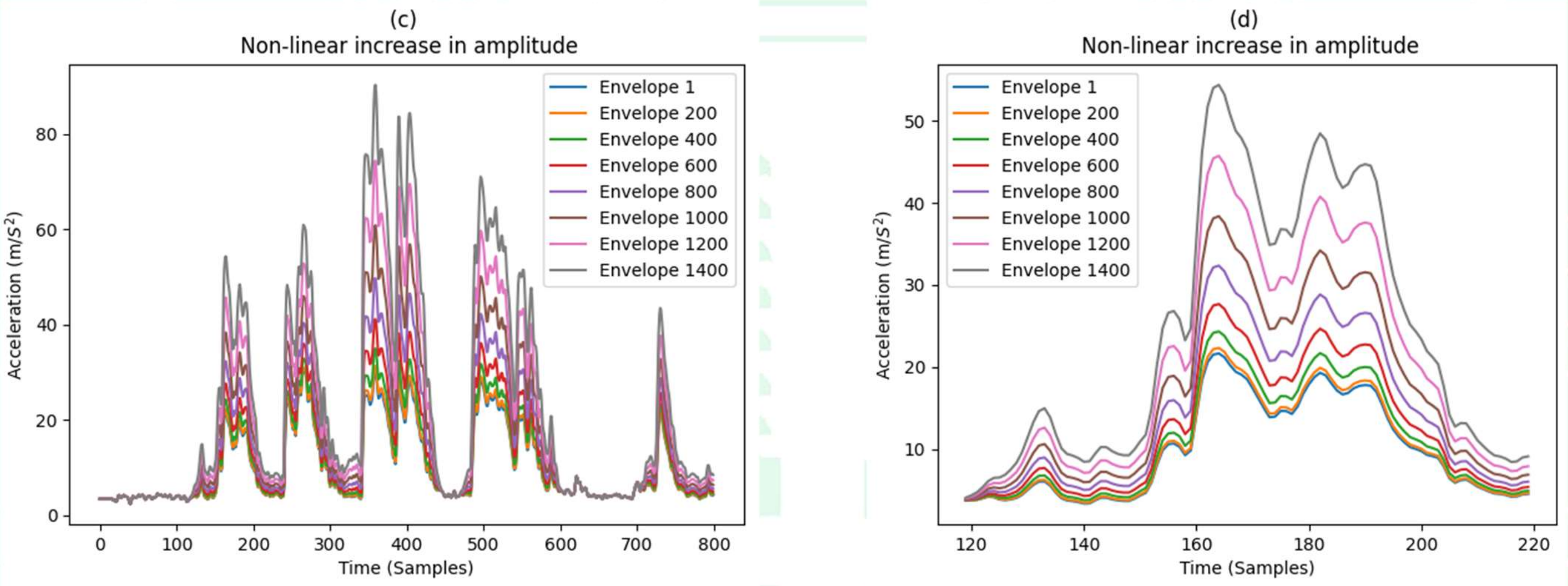
- Since no evidence of contact degradation has been observed with continuous monitoring, this work investigates simulated vibration signal envelopes to represent contact degradation
- Previous measurements before and after maintenance, using an instrument for periodic testing, allowed understanding the effects of various OLTC faults on vibro-acoustic signals, including contacts wear
- OLTC operation with a worn contact generates a vibro-acoustic signal with higher amplitude
- Simulating contact degradation can be achieved with the modification of vibro-acoustic signals in a way that mimics this failure mode

Increasing the amplitude of the envelopes linearly



This simulation was repeated by adding different levels of noise

Increasing the amplitude of the envelopes non-linearly



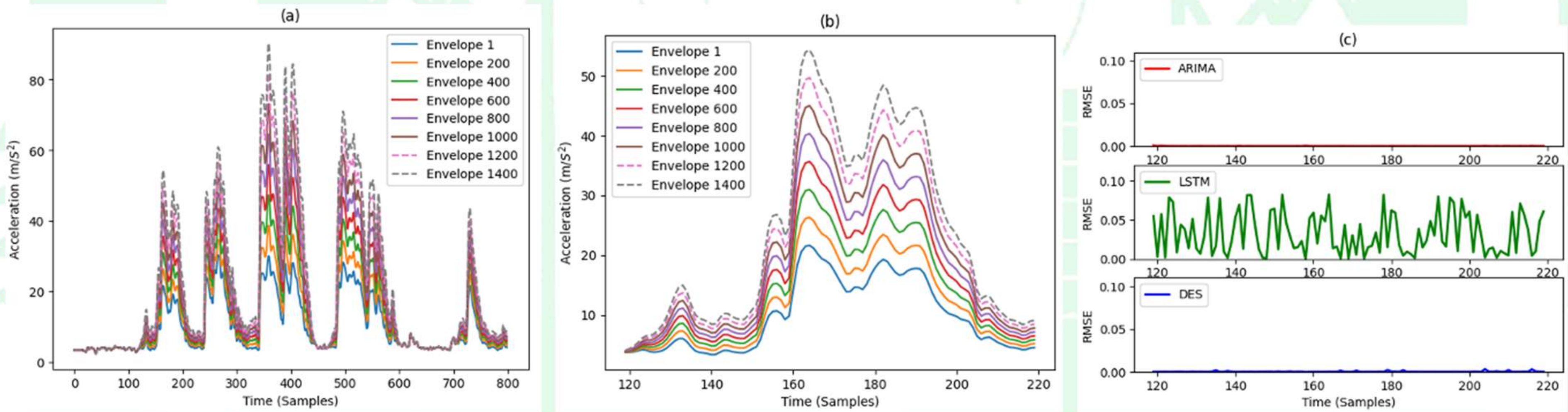
This simulation was repeated by adding different levels of noise

- Three models of time series forecasting are used to predict future signals including:
  - ARIMA (AutoRegressive Integrated Moving Average)
  - LSTM (Long Short-Term Memory)
  - DES (Double Exponential Smoothing)

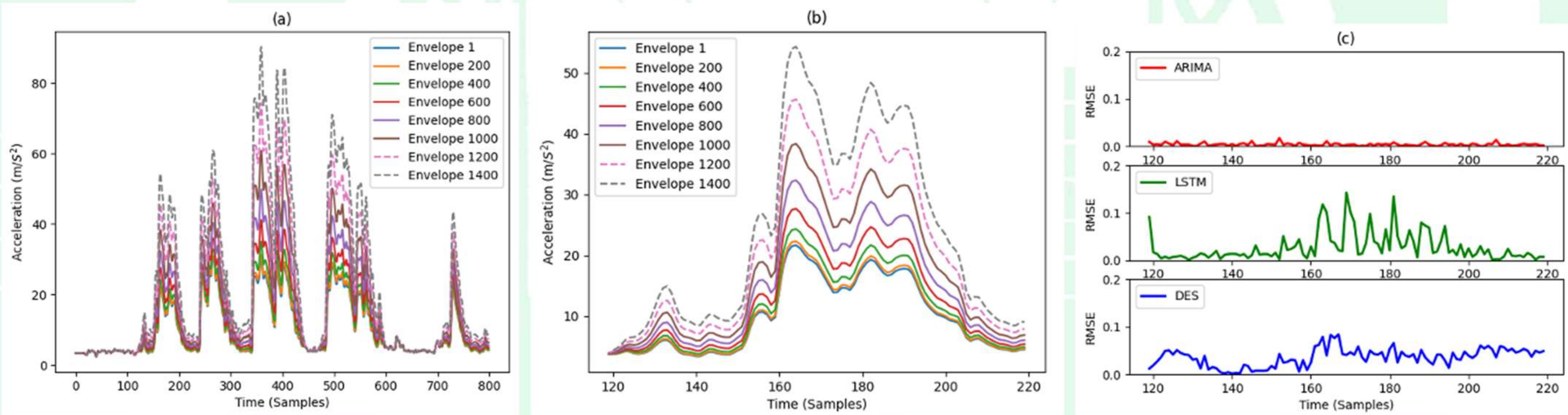
- The following algorithm is implemented

  a) The data values of the envelopes are put in a matrix (800 samples x 1,400 envelopes)
  b) Each forecasting model is trained with 1,000 envelopes, and then tested using the remaining 400 envelopes
  c) For each envelope sample, the best forecasting model (lowest prediction error) is recorded, and this forms a combined model
  d) The combined model is tested with the same 400 envelopes as in step b.

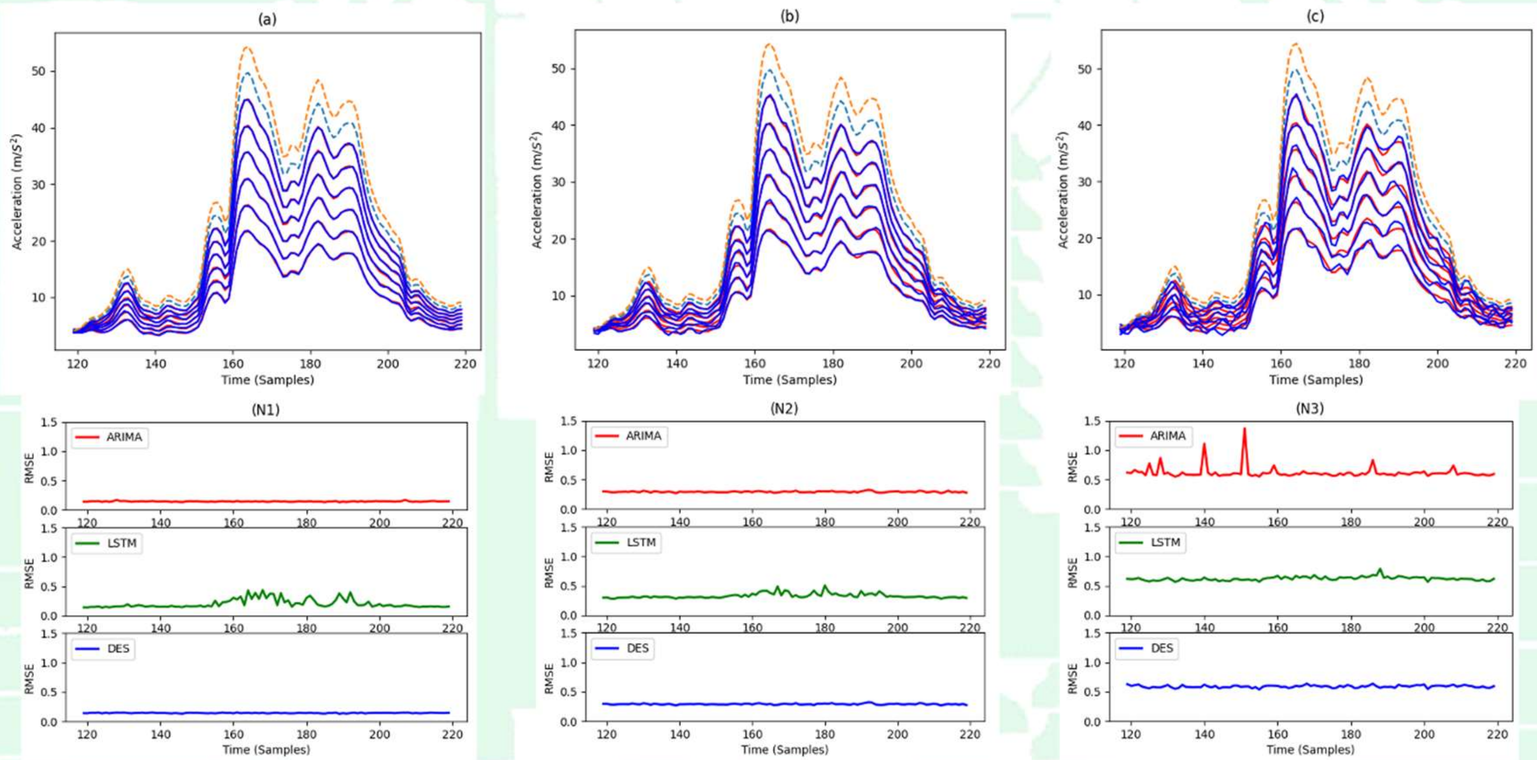
D1: Prediction results from simulated signal envelopes without noise addition (the amplitude increases linearly)



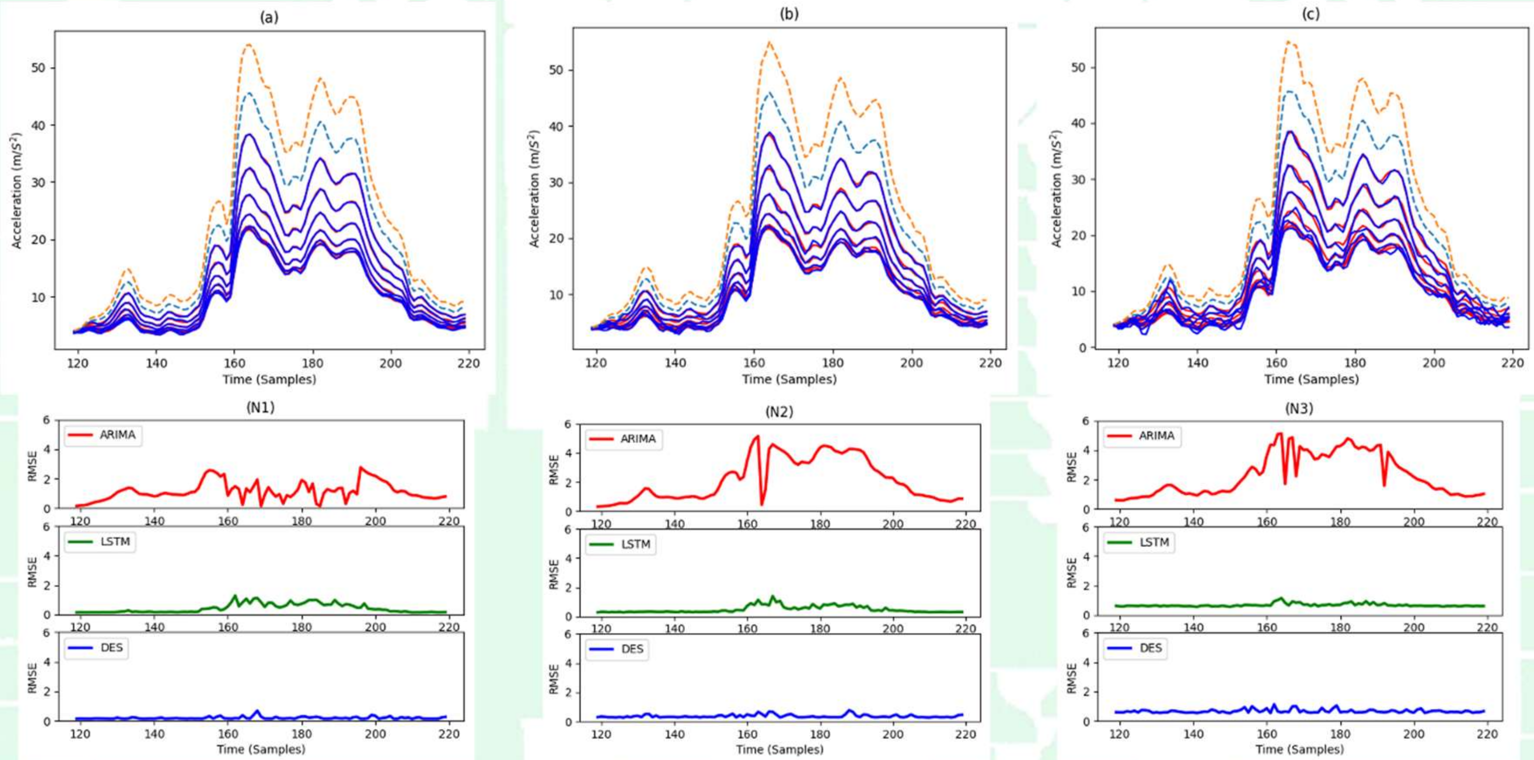
D2: Prediction results from simulated signal envelopes without noise addition (the amplitude increases non-linearly)



D1N1: Prediction results from simulated signal envelopes with noise addition (the amplitude increases linearly)



D2N2: Prediction results from simulated signal envelopes with noise addition (the amplitude increases non-linearly)



Numerical error values for different prediction models

- Error obtained from datasets without noise is close to zero which indicates the high accuracy of the proposed algorithm
- Noise causes a decrease in the accuracy of the prediction models
- As expected, the combined model is more effective than any model taken separately
- ARIMA's performance is significantly decreased when tested with nonlinear and noisy signals

#	Dataset	Description	Average RMSE Combined model	Average RMSE ARIMA/LSTM/DES
1	D1	Linear increase without noise	0.000295	0.000324/0.033172 /0.000562
2	D1N1	D1 + noise level N1	0.144955	0.146147/0.204034 /0.145089
3	D1N2	D1 + noise level N2	0.291753	0.292936/0.32787/ 0.292101
4	D1N3	D1 + noise level N3	0.590716	0.617336/0.619979 /0.591528
5	D2	Non-linear increase without noise	0.00338	0.003968/0.027673 /0.036067
6	D2N1	D2 + noise level N1	0.190707	1.144173/0.424071 /0.203751
7	D2N2	D2 + noise level N2	0.344645	2.165089/0.476722 /0.363704
8	D2N3	D2 + noise level N3	0.624953	2.291216/0.669303 /0.672139

- **Time-series forecasting models** are investigated as a prospective tool for analyzing vibro-acoustic signals for OLTC contact monitoring
- The idea is to develop an algorithm that could **prognose** the health of the contacts, to **preventively plan** their replacements as part of a condition-based maintenance program
- The proposed methodology, investigated with simulated signals, shows an **interesting potential for future applications**

Thank you for your attention

Questions?