4th IIW Young Professionals International Conference 2018

Machine learning techniques for health monitoring of pipelines under stationary and non-stationary environments

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31 August 2018

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Presentation outline

1 Introduction

2 SHM using Guided Ultrasonic Waves

3 SHM Challenges

4 SHM in stationary environment

5 SHM in non-stationary environment

6 Conclusions and perspective

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1 Introduction

- **SHM (Structural Health Monitoring) : The process of implementing a damage identification strategy for structures.**

SHM is inspired from human nervous system

- **SHM levels:**
  - **Damage detection**
  - **Damage localisation**
  - **Damage characterization**
  - **Damage prognosis**

Defects types

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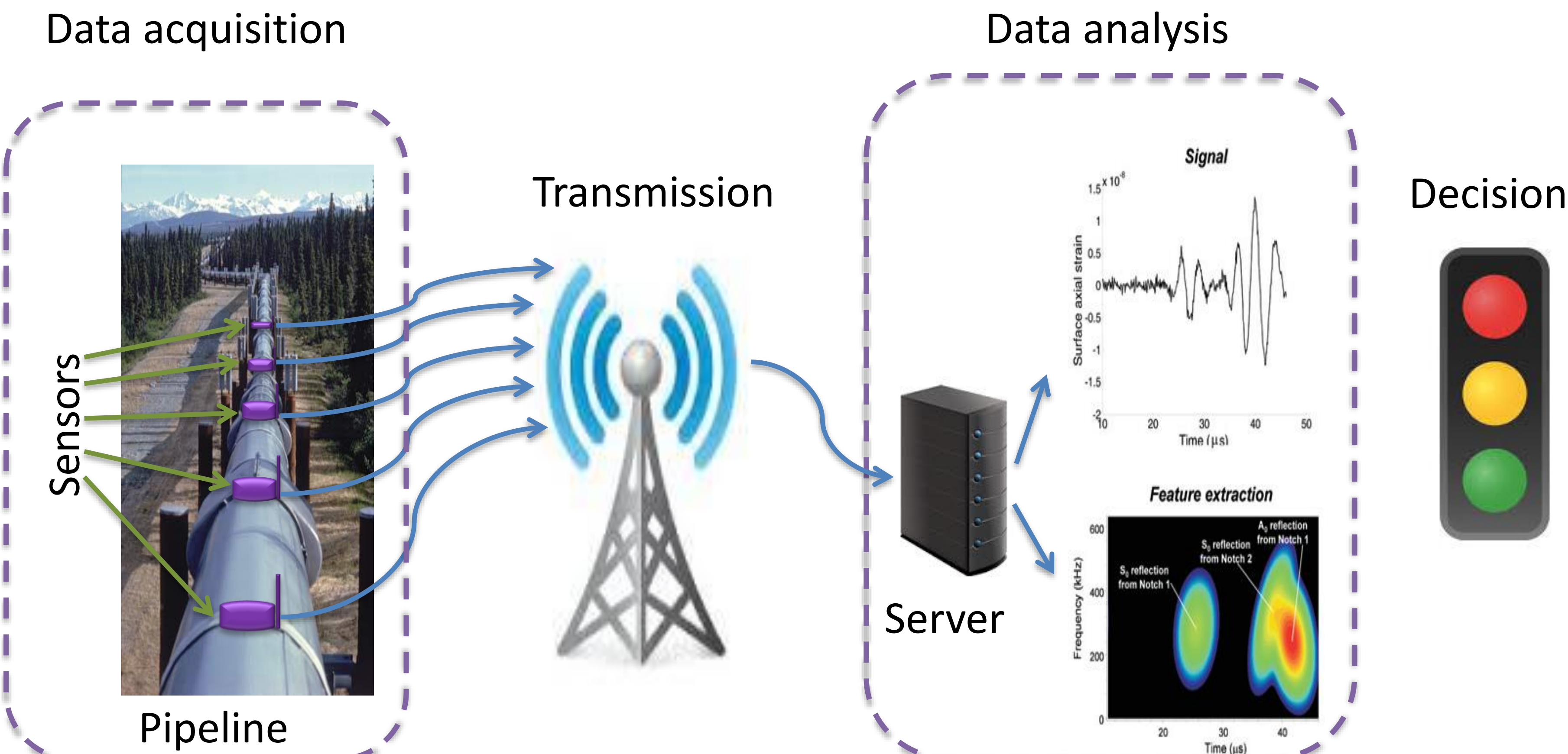
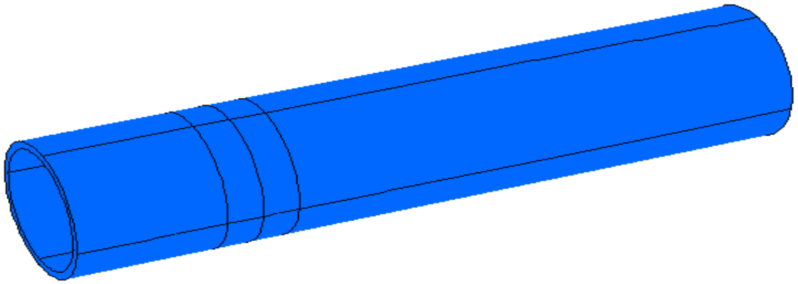
2 SHM using Ultrasonic Guided Waves

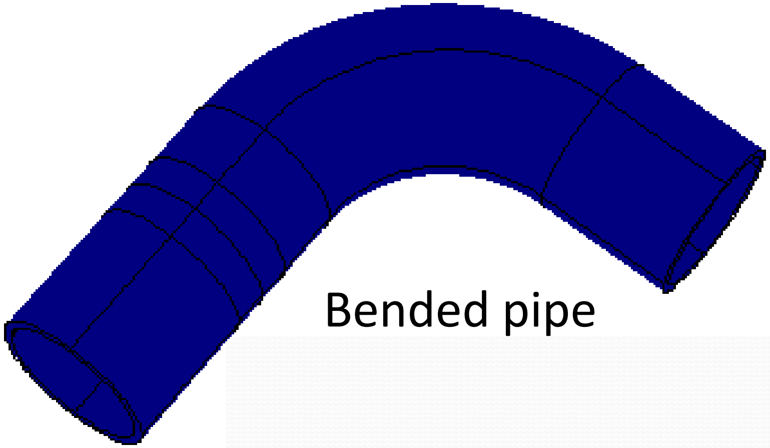
Structural Health Monitoring



Ultrasonic guided waves

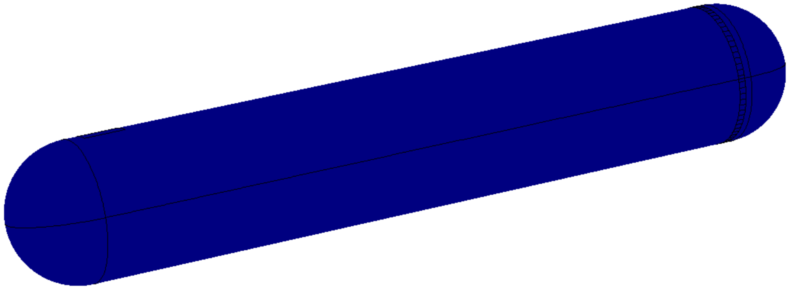
Pipe segment



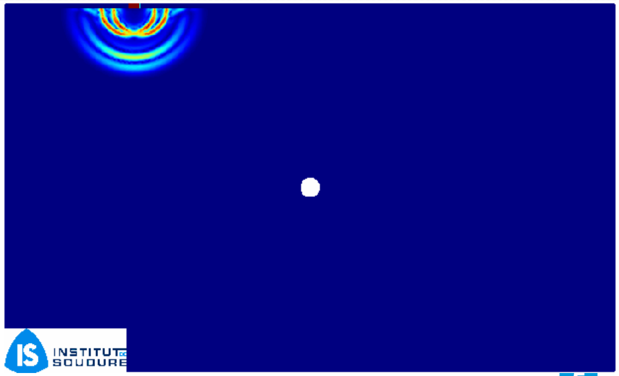


Bended pipe

Composite vessels



Interaction with defect



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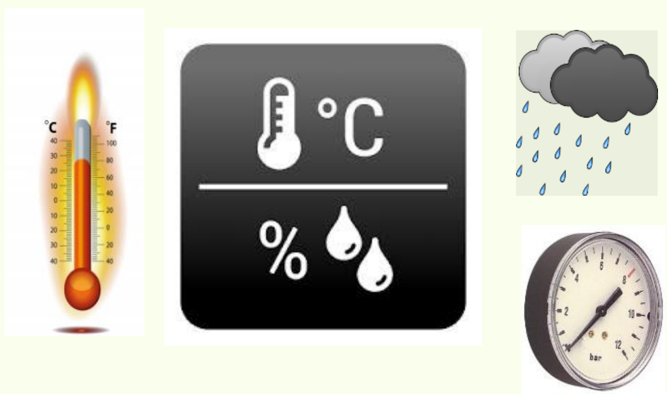
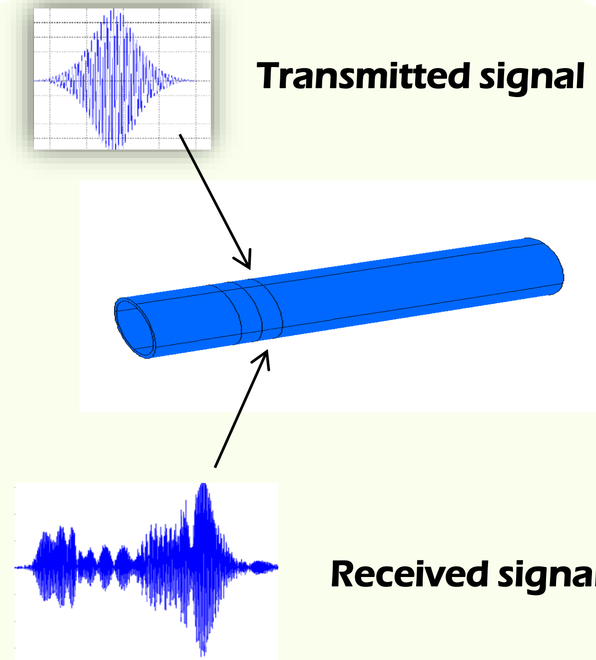
3 SHM Challenges

Variation of environmental and operational conditions (EOCs)



1. Temperature
2. Humidity
3. Pressure
4. Flow rate
5. Mechanical loading etc.

Signal interpretation



1. Dispersion
2. Multi modes
3. Multi paths

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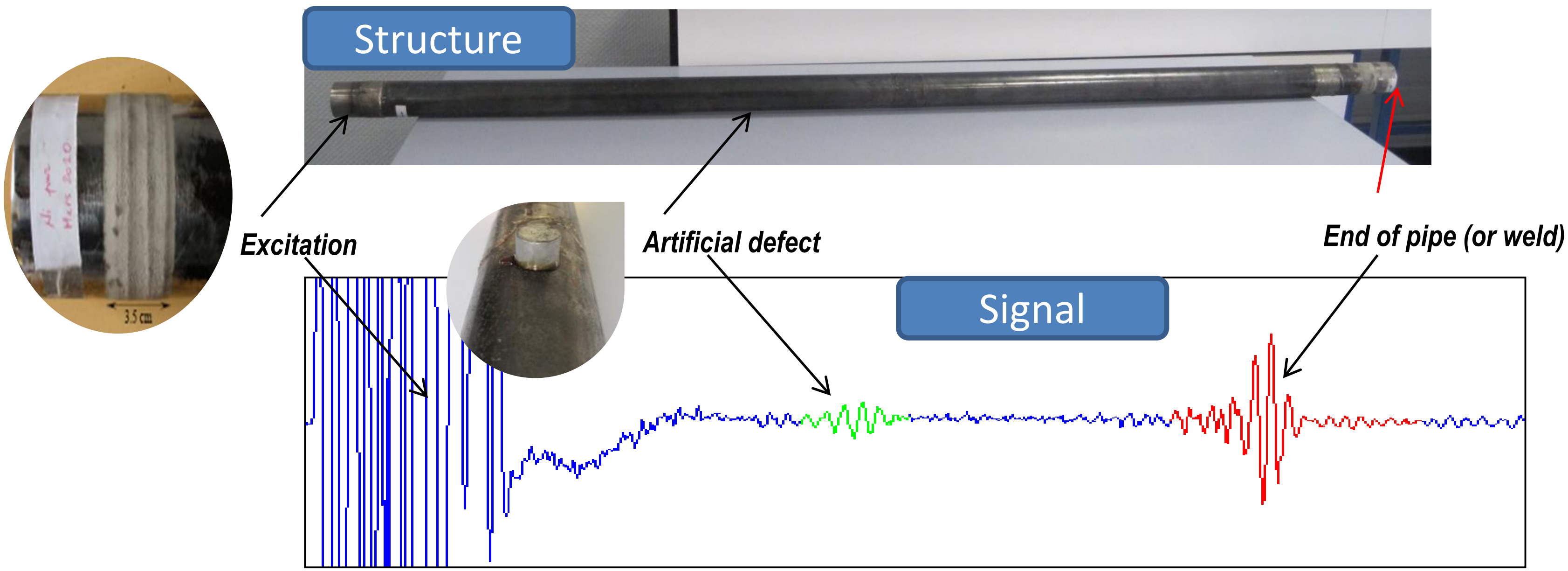
Machine Learning

4 SHM in stationary environment

4.1 Data acquisition (hypothesis: EOCs are supposed to be constant)



4 SHM in stationary environment

4.2 Machine learning scheme

Signals

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Features

How to select the most relevant features ?

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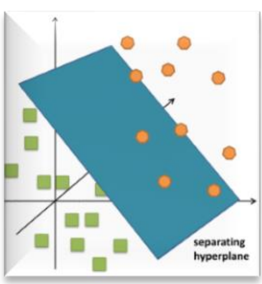
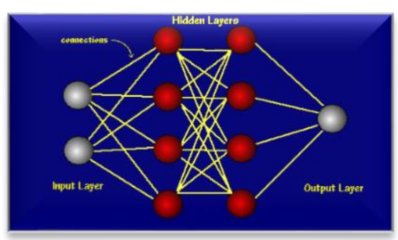
Training

↓

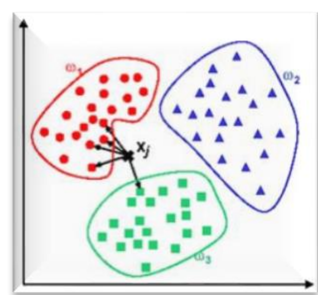
SVM



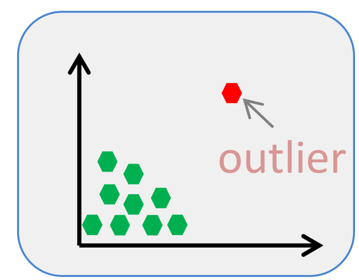
ANN



KNN



OA



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Classification

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4.3 Feature extraction/selection

Feature extraction

- **Time**
  - RMS
  - Maximum of amplitude
  - Variance
  - Correlation coefficient
- **Frequency**
  - Maximum of amplitude
  - Mean
- **Time-frequency**
  - Maximum of spectrogram

Feature selection

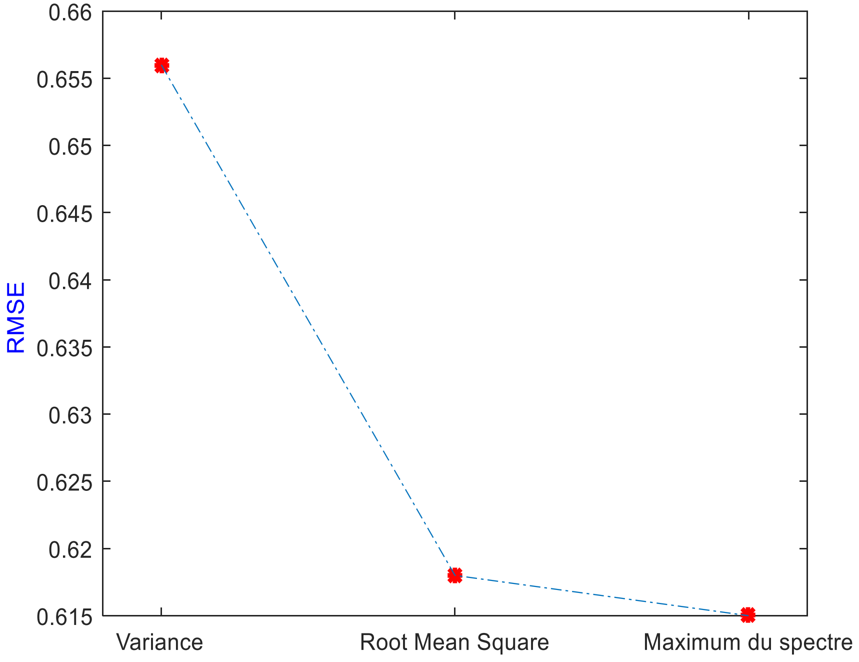
- **Filters**
  - Information gain
  - Fisher score
  - Minimum redundancy maximum information
  - RELIEF
- **Wrappers**
  - Exhaustive search
  - Genetic algorithm
  - Sequential backward
  - Sequential forward

4.3 Feature extraction/selection

RELIEF

Domain	Features	Weights	Ranking
Time	MA (maximum of amplitude)	-0.0047	7
	RMS (Root Mean Square)	-0.0004	1
	VAR (Variance)	-0.0011	2
	CR (correlation coeficient)	-0.0016	3
Frequency	MAS (Maximum of spectrogram)	-0.0019	4
	MOS (Mean of spectrogram)	-0.0042	6
Time-frequency	MS (Maximum of spectrogram)	-0.0041	5

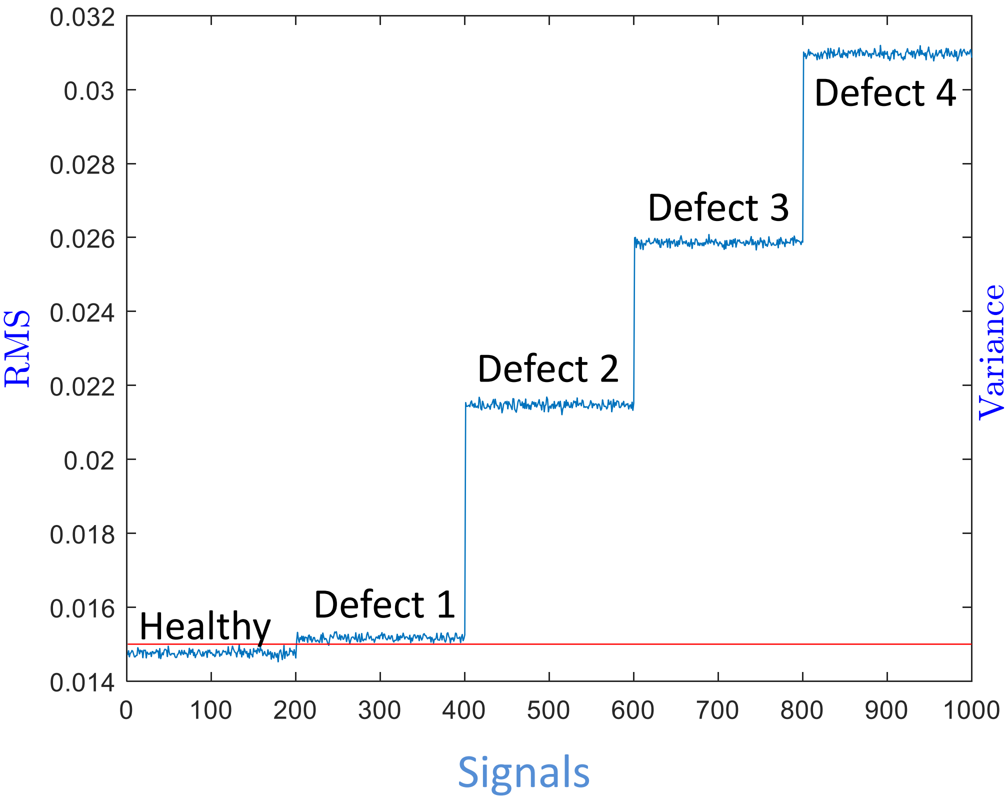
Sequential forward

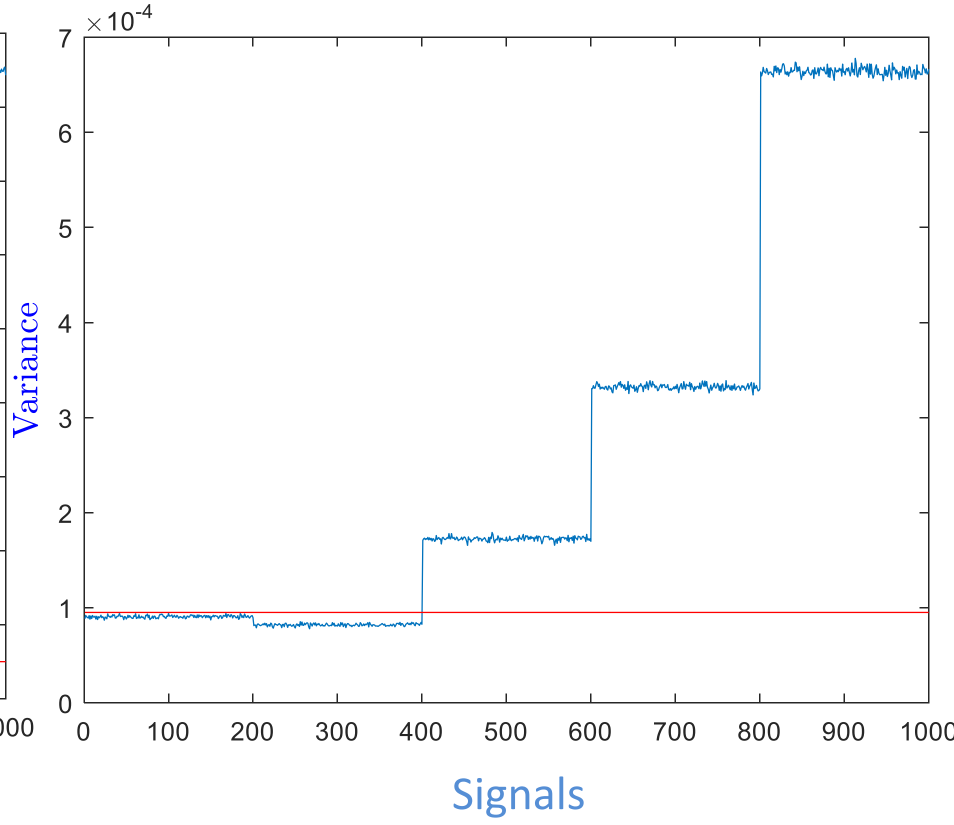


RMS and Variance are the best damage sensitive features

4 SHM in stationary environment

4.4 Damage detection

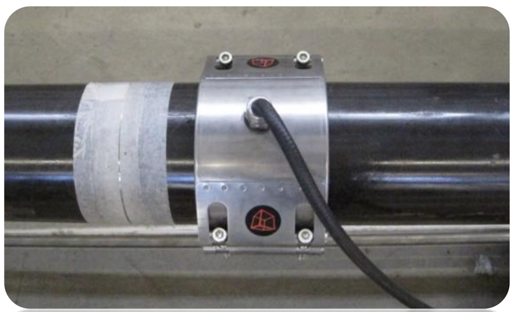




5 SHM in non-stationary environment

5.1 Data acquisition (EOCs are supposed to vary with time)

Transducer



Defect

Database	
Monitoring period	3 months
Healthy state	207 signals
Damaged state	6 defects (29 signals)
Temperature	19 °C → 26 °C

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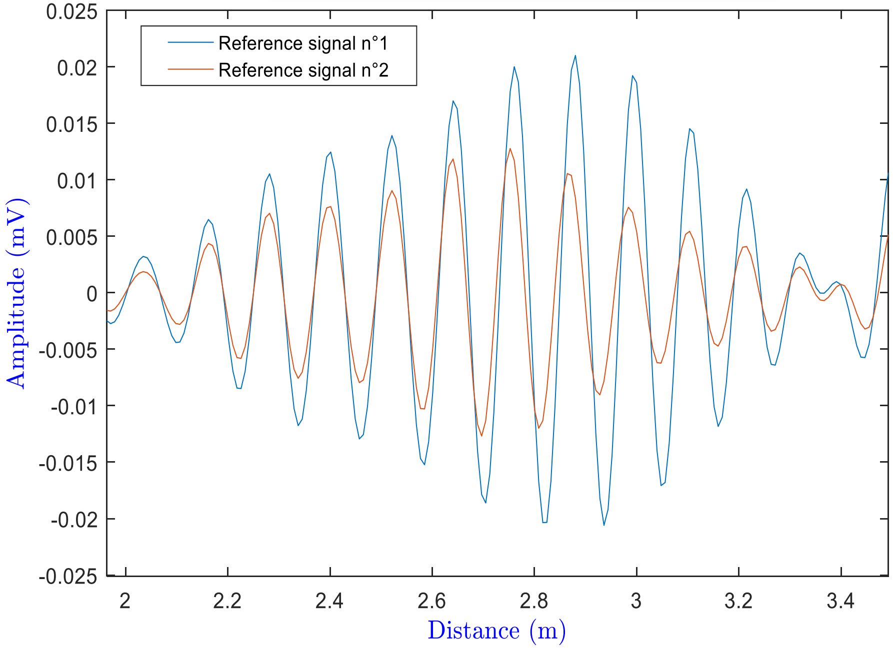
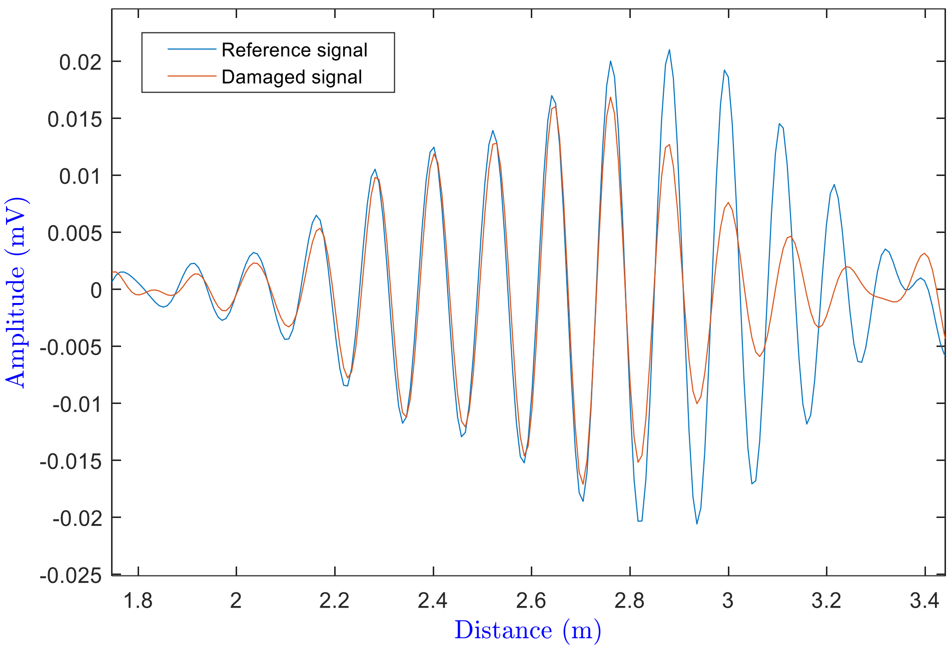
5 SHM in non-stationary environment

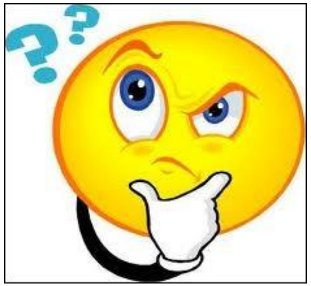
5.2 Temperature vs defect

Temperature effect



Damage effect





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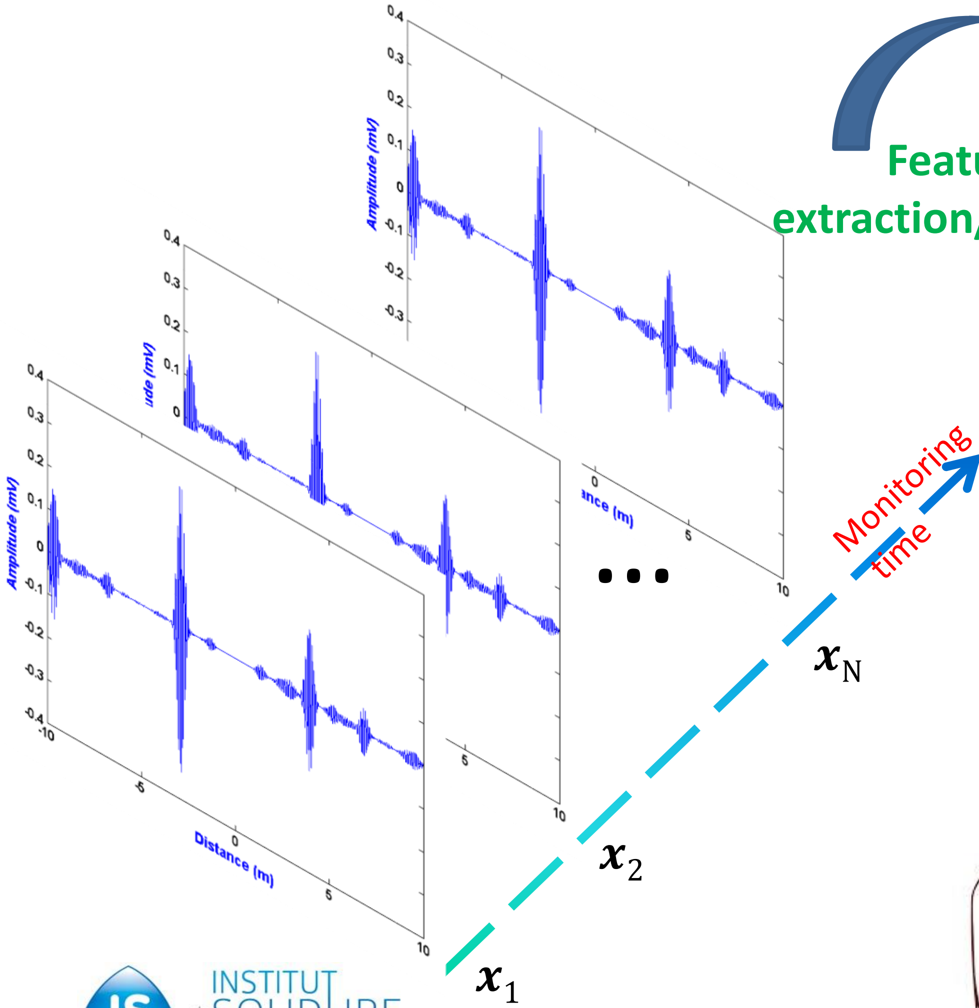
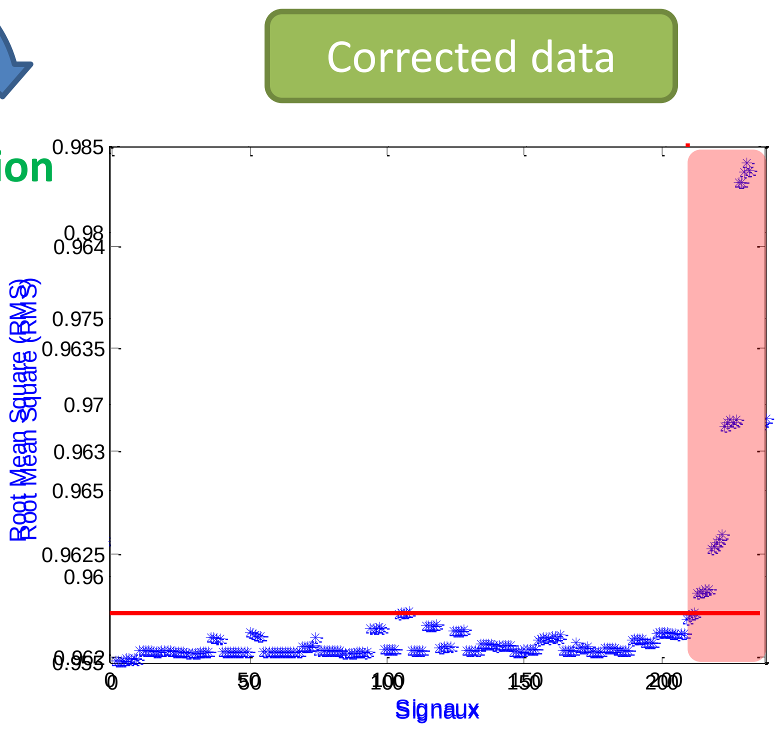
5 SHM in non-stationary environment

5.2 Method 1 : data correction



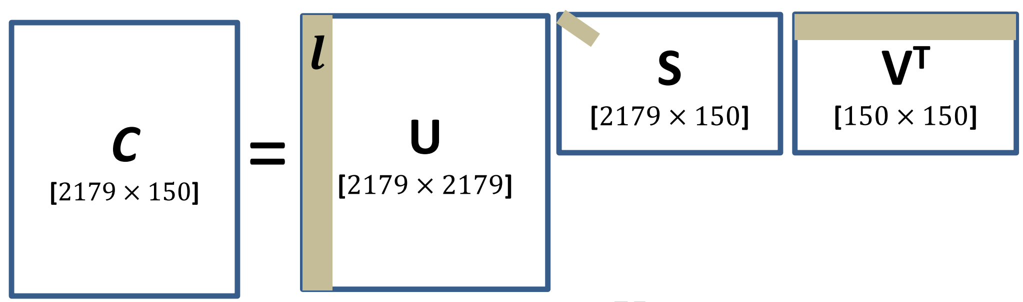


Bad damage sensitivity

5.3 Method 2 : Singular value decomposition

Singular value decomposition of matrix C of healthy state signals

$$C = U\,S\,V^T$$

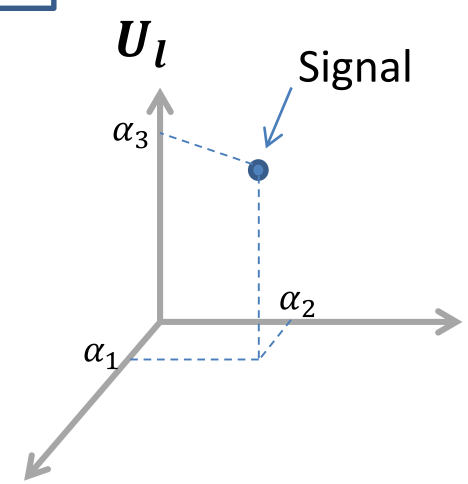


Approximation of C

$$C_l = U_l S_l V_l^T$$

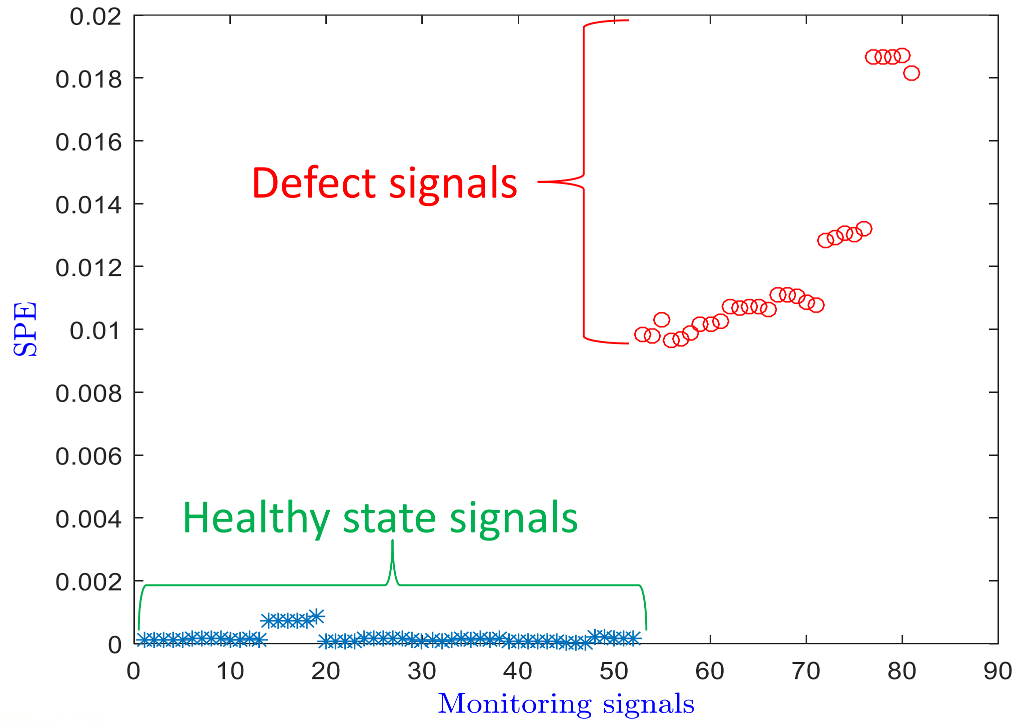
Projection of new current signal :

$$\hat{\alpha} = \underset{\alpha}{\arg\min}\ \|x_i - U_l \alpha\|^2$$



5 SHM in non-stationary environment

5.3 Method 2 : Singular value decomposition



1. Optimal number of singular vectors !!
2. Update the model is necessary to take into account new variation in EOCs

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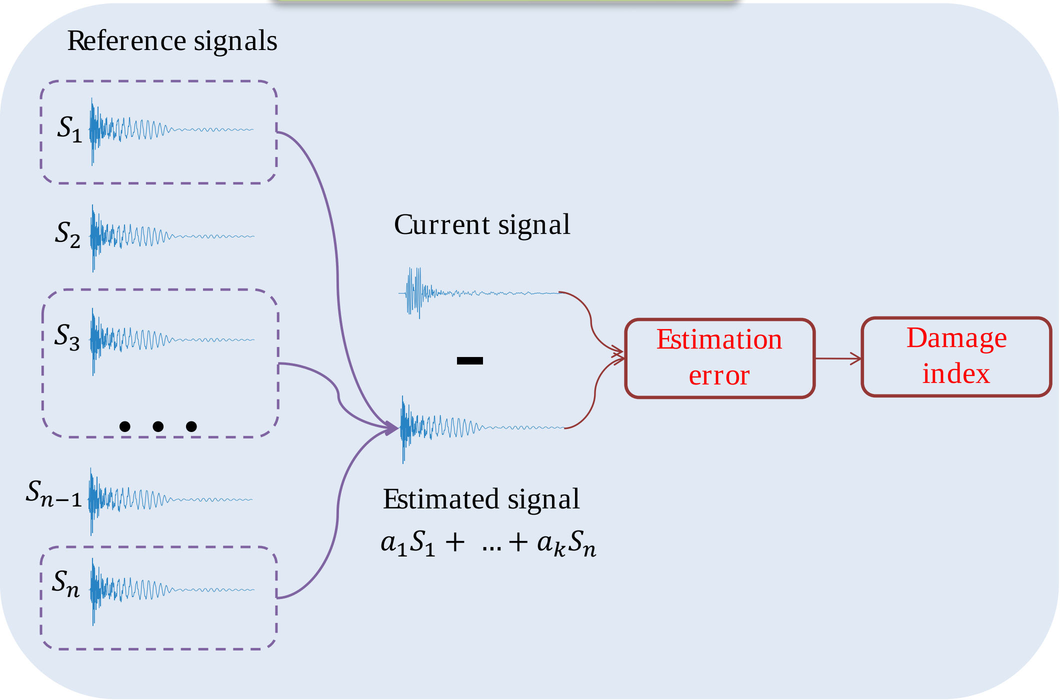
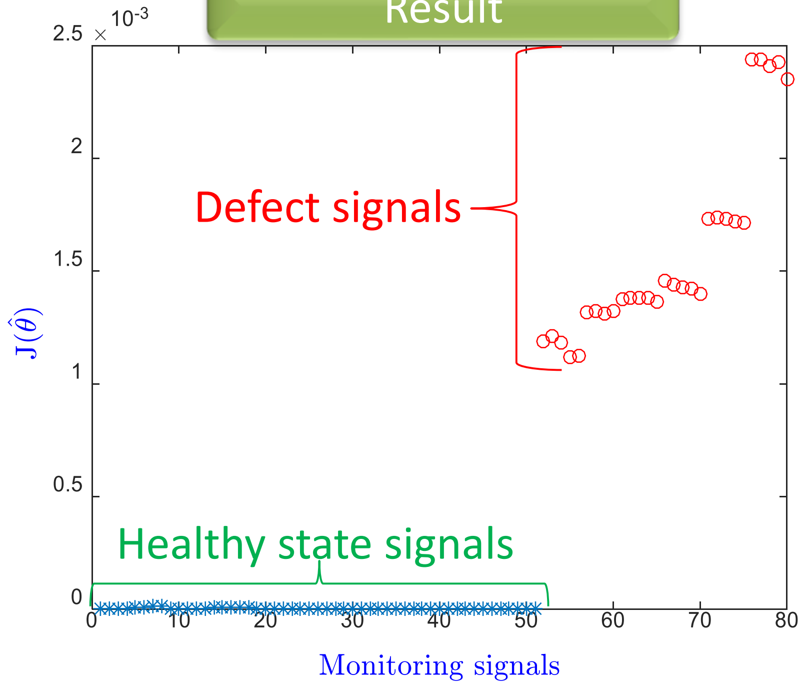
5.4 Method 3 : Sparse representation (damage detection)

Principle



Result

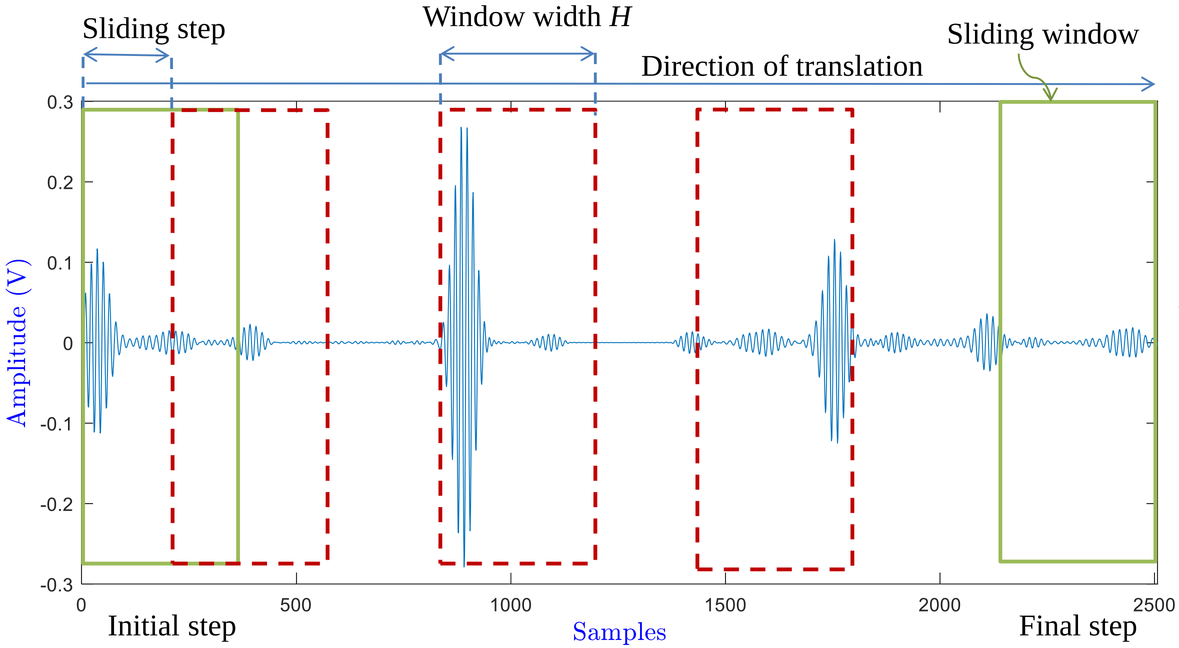


El Mountassir, M., Yaacoubi, S., Mourot, G., & Maquin, D. (2018). Sparse estimation based monitoring method for damage detection and localization: A case of study. Mechanical Systems and Signal Processing, 112, 61–76.

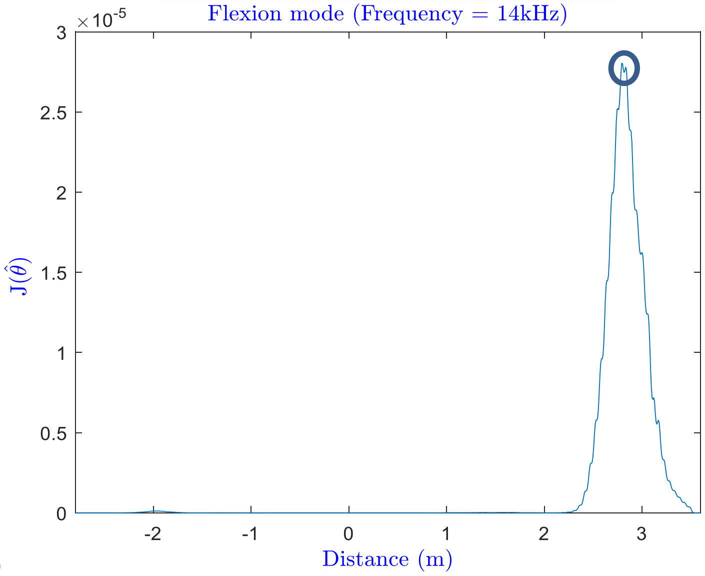
5 SHM in non-stationary environment

5.4 Method 3 : Sparse representation (damage localization)

Sliding window



Results



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6 Conclusions and perspective

❑ Conclusions

- Variation in EOCs represent a real challenge when implementing an SHM strategy
- Sparse representation of signal can deal with the variation of EOCs with a good damage sensitivity.
- Damage can be detected using the error of estimation of the current signal
- Damage can be localized by calculating the error of estimation on a sliding window over the damaged signal.

❑ Perspective

- Test of the proposed method on a real piping system

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THANK YOU
FOR
YOUR ATTENTION!