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MDPI

DAMAGE DETECTION AND LOCALISATION IN BURIED PIPELINES USING ENTROPY IN INFORMATION THEORY

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INTRODUCTION

- **Entropy measures**, and more specifically, spectral entropy have emerged as an **efficient method for the damage assessment** of both mechanical systems and civil structures.

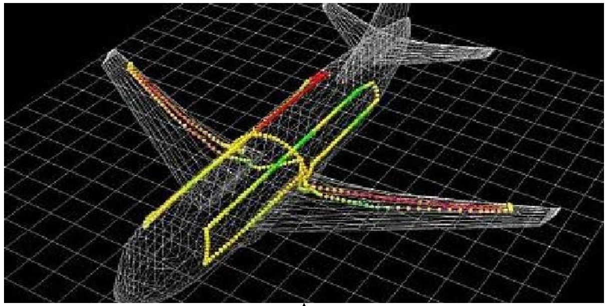
Entropy is a measure of Gaussianity, i.e. naturally works with noise

Very noisy environment

Buried pipelines
+
Fiber Optic system

Entropy can be estimated from each output channel, i.e. provides localisation capabilities

distributed system



BURRIED PIPELINS

- Steel Pipes (SP) → "flexible". The soil-pipe integrated system supports the mechanical loads.

Best choice:

Wiener Spectral Entropy

due to the low uncertainty in the material properties

$$H_w = Q \frac{\sqrt[Q]{\prod_q S(q)}}{\sum_q S(q)}$$

- Pre-stressed Concrete Cylinder Pipes (PCCP) → "rigid". The loads are mostly carried by the structure of the pipeline itself, with minimal contribution from the surrounding soil.

Best choice:

Shannon Spectral Entropy

due to its higher sensitivity to smaller cracks

$$H_s = -\sum_q P(q) log_2[P(q)]$$

$$P(q) = \frac{S(q)}{\sum_q S(q)}$$

$S(q)$: Discrete power spectrum of the signal

DAMAGE DETECTION METHOD

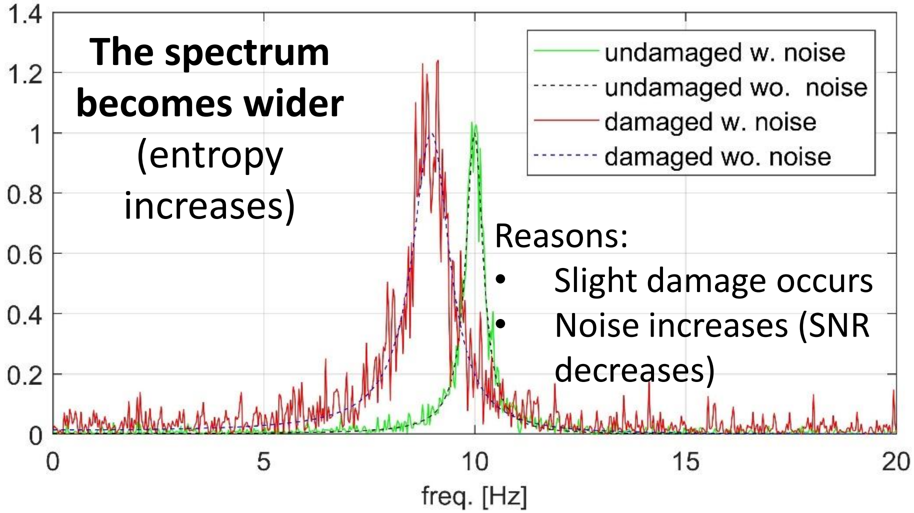
- It is the ratio between the geometric mean and the arithmetic mean of the power spectrum. ← **Wiener Spectral Entropy** preferred due to the low uncertainty in the material properties

↓

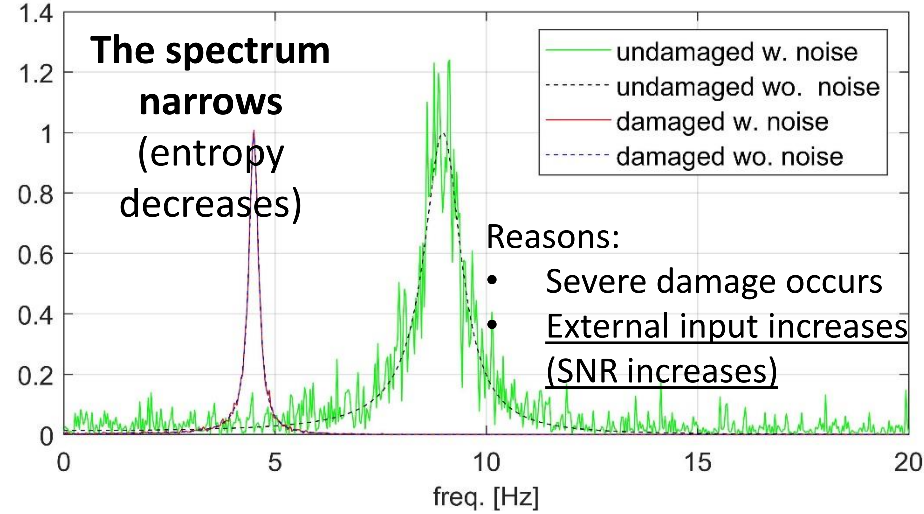
Define the "**flatness**" of the spectrum

$$H_w = Q\,\frac{\sqrt[Q]{\prod_q S(q)}}{\sum_q S(q)}$$

Slight damage
(lose of correlation)



Severe damage
(drastic change in the system properties)



DAMAGE DETECTION METHOD

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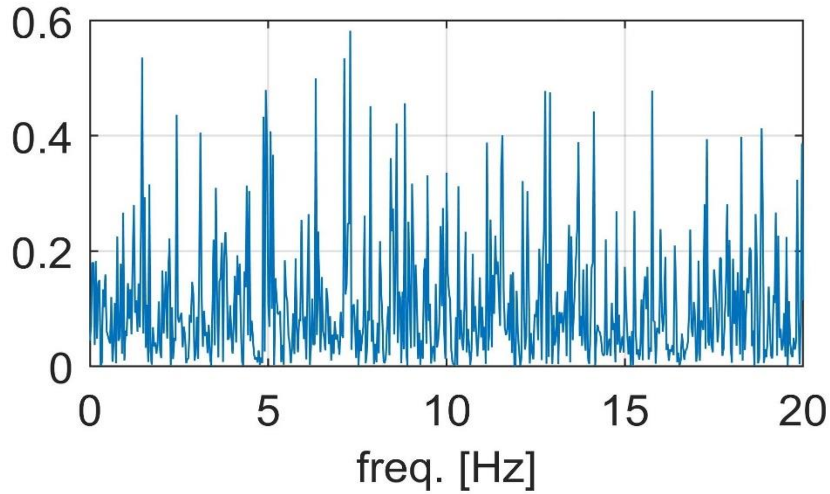
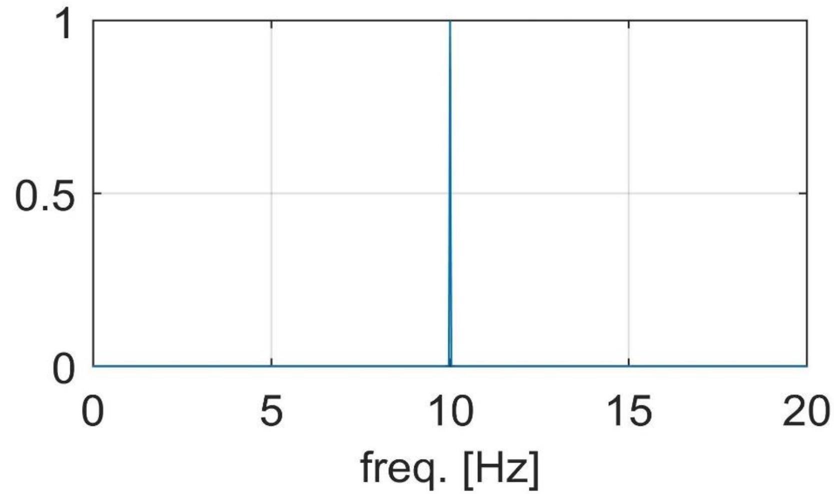
Maximum entropy for Gaussian noise



Minimum entropy for perfectly concentrated spectrum



DAMAGE DETECTION METHOD

- **Monitoring Wiener Entropy over time and space** to detect, quantify and locate damage by entropy variations.

Variation in entropy due to variation of **noise does not** sensibly **affect** entropy estimates

No actions are needed

- Robust to noise and less affected by false alarms.

Variation in entropy due to variation of **input sources may** sensibly **affect** entropy estimates

Actions are needed

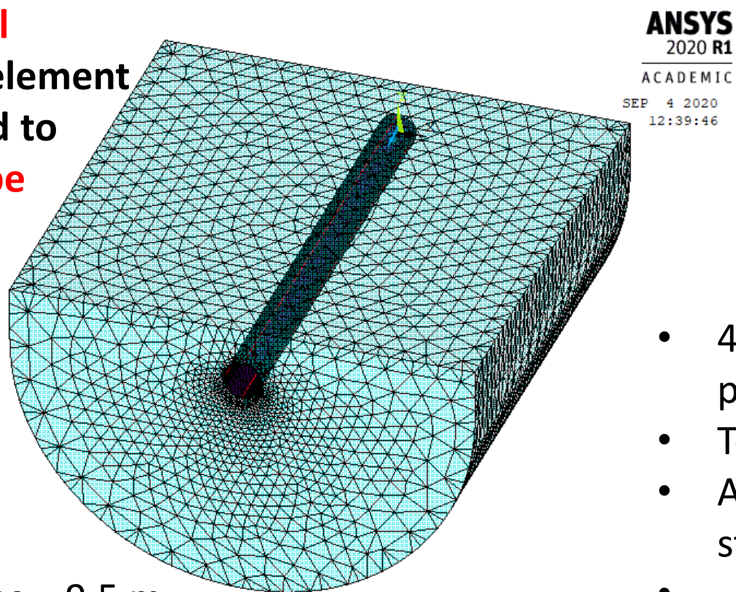
- Statistical estimates;
- Accounting the variation of input sources;
- Both … exc.

Assuming no sensible variation of external factors in operational conditions

NUMERICAL CASE STUDY

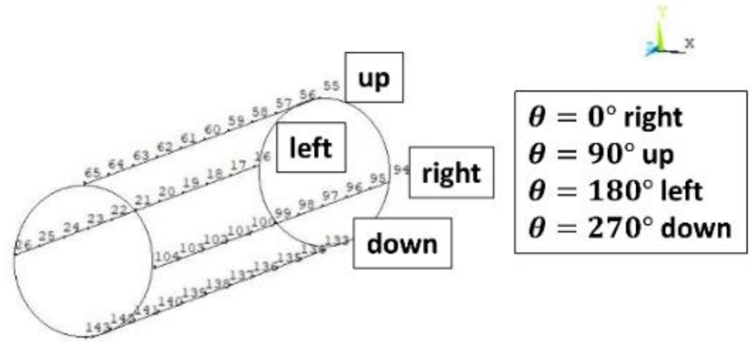
Buried Steel Pipes (SP)

- **4-node brick element has been used to model the soil**
- **4-node shell element has been used to model the pipe**



- Length of pipes = 9.5 m.
- Thickness = 0.04 m.
- Internal diameter = 1.48 m.
- Pipes buried at 2.25 m under the free surface.
- Radius of the soil = 9.5 m (**defined after sensitivity analysis**).

Virtual Fiber Optic System



- 4 optic fibres (surrounding the pipeline in position θ = 0°,90°,180°,270°).
- Total monitored length = 9.5 m.
- Acquisition of axial strains was discretised at steps of 0.50 m, …
- … Resulting in **44 measurement points**.

Table 1. Mechanical properties of the FE models.

Soil			Steel		
Density	1850	kg/m^3	Density	7850	kg/m^3
Young's Modulus	24	MPa	Young's Modulus	$210.7 \cdot 10^3$	MPa
Poisson's Ratio	0.20	–	Poisson's Ratio	0.30	–

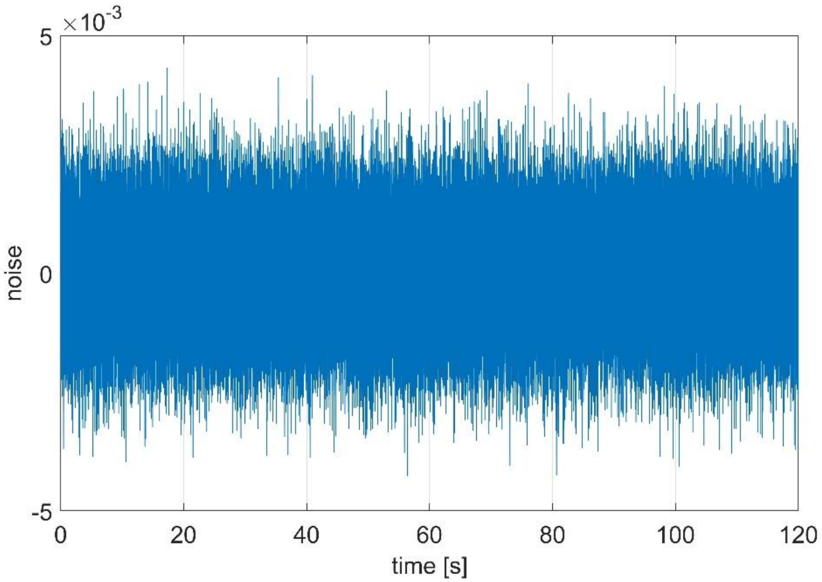
NUMERICAL CASE STUDY

The damage was modelled as a 50% reduction of the pipe cross-section **between *x* = 2.5 and 3.0 m, and *ϑ* between 0° and 90°.**

↓

Assumption: modelling sudden damage caused by persistent corrosion (e.g. **flaking**)

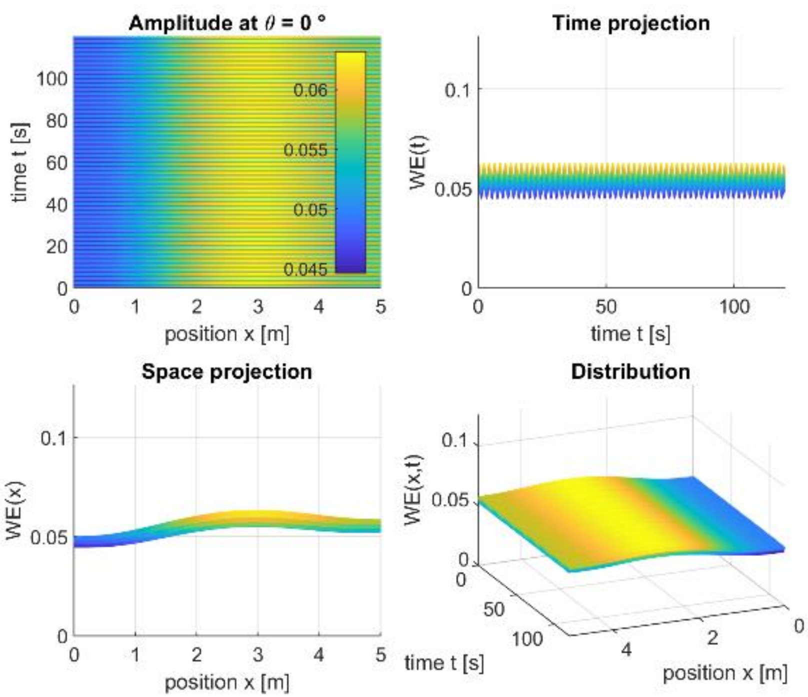
- Gaussian noise was applied to simulate input ambient vibrations.
- **Axial strain** signals sampled at 1000 Hz.
- **Damage supposed to occurs at 60 s** over a monitoring time of 120 s.
- Output signals were **corrupted** with 5% of uncorrelated Gaussian noise after the analysis.



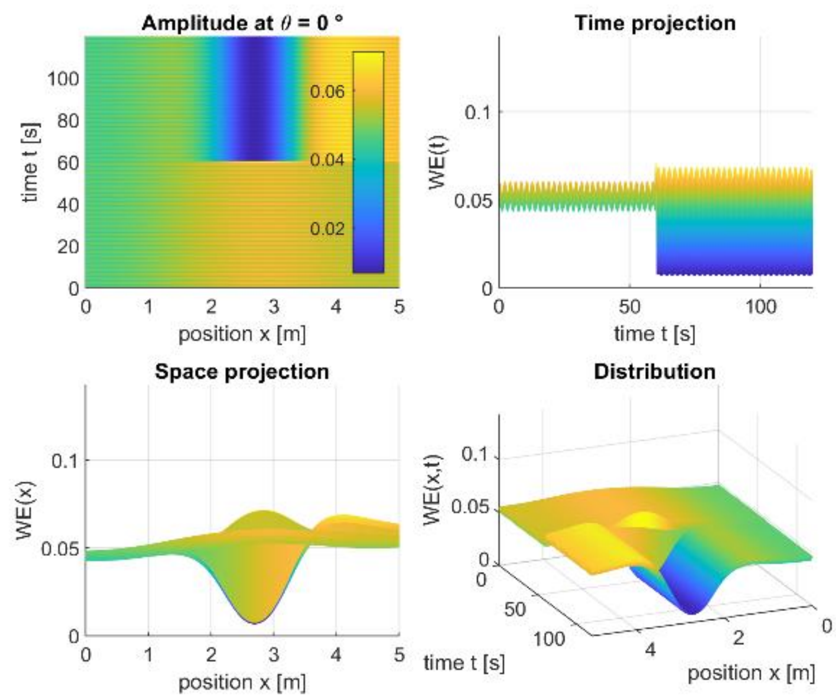
RESULTS

Uncorrupted (noise-free) output signals: comparison of the undamaged and damaged cases at ϑ=0° in ideal conditions.

Undamaged pipeline



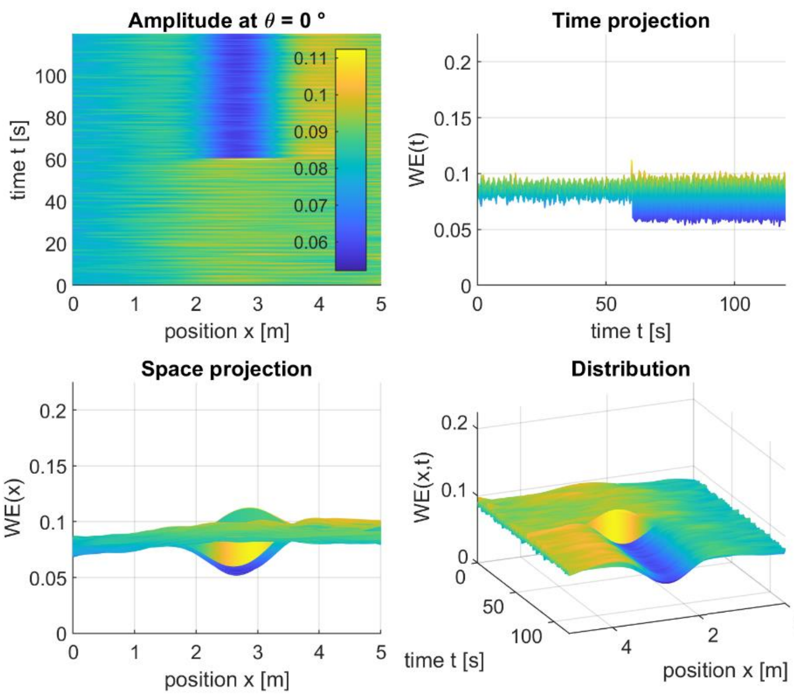
Damaged pipeline



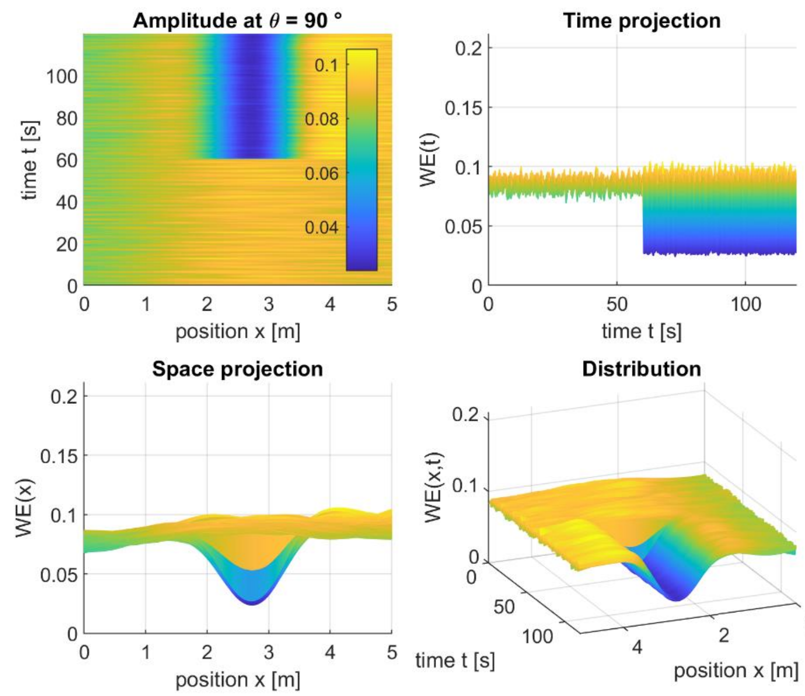
RESULTS

Corrupted output signals: damage analysis (with artificially added 5% of noise) **at *ϑ*=0° and *ϑ*=90°.**

Damaged pipeline *ϑ*=0°



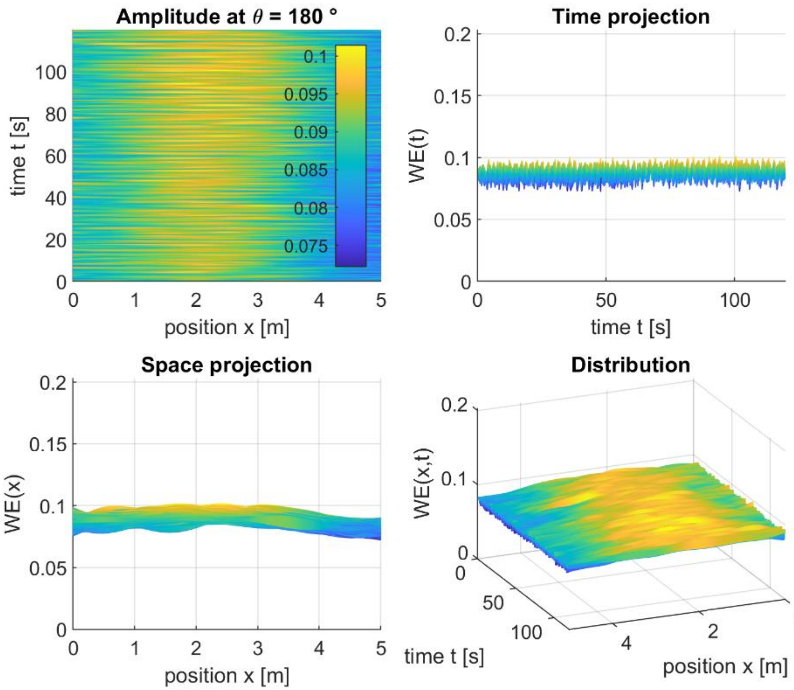
Damaged pipeline *ϑ*=90°



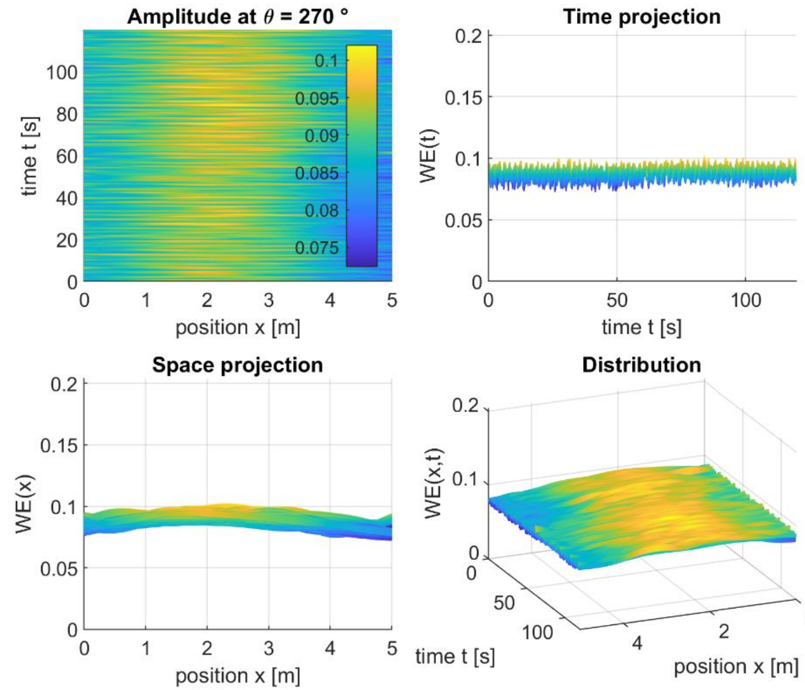
RESULTS

Corrupted output signals: damage analysis (5% of noise) **at ϑ=180° and ϑ=270°.**

Damaged pipeline ϑ=180°



Damaged pipeline ϑ=270°



CONCLUSIONS

- The damage detection method based on the WE variation proved to be a **valid and promising approach** for real-time monitoring of steel pipelines.

- **Future works**:

1. this method is in its first stage application and could be implemented in future research taking in consideration the variation of entropy associated to the **severity of the damage** (level 3 according to the Rytter's Hierarchy).

2. by combining the method with **considerations on external input sources** (e.g. air/ground temperature) a more robust estimate of the damage may be reached by estimating the entropy of frequency response functions of the system instead of that one of the output channels spectrum.

THANK YOU!

Questions?