Machine Learning for damage sensing in composite structures

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Why we need it ?

Composite materials enhance important mass reduction.

Mass reduction is a hot topic in transportation sector.

The spread of composite materials is limited by:

- Reliability: failure and damaging models are not enough accurate
- Post impact resistance; low-energy impact speed up the damaging

To overcome this problem a Structural Health Monitoring (SHM) system can be adopted to assess damages int the structures.

SHM can forecast catastrophic and unexpected failures caused by accidental impact or material degradation

This would overcome the issues curbing the spread of composite materials and pave the way to reliable and lightweight design.

Objectives

Define a monitoring system able to detect local stiffness decrease in composite structures, that can be addressed to the presence of damages.

Most of Structural Health System present in literature are limited to well defined load conditions, our goal is to:

- Monitor structures undergoing variable loads, in both amplitude, frequencies and direction
- Achieve a good accuracy in damage sensing by minimizing the number of features, corresponding to the amount of sensors to be mounted on the structure

To achieve this objective a statistical pattern recognition approach has been pursued. First, strain data are reduced and de-correlated by a Principal Component Analysis. Second, reduced data are used to train a with One Class Support Vector Machine Classifier. System performance has been tested on a shell plate with damages variable in entity and position.

Last, a case study of a composite material suspension of a car is investigated to assess the capability of the method to assess damage in complex structures.

AKNOWLEDGMENTS

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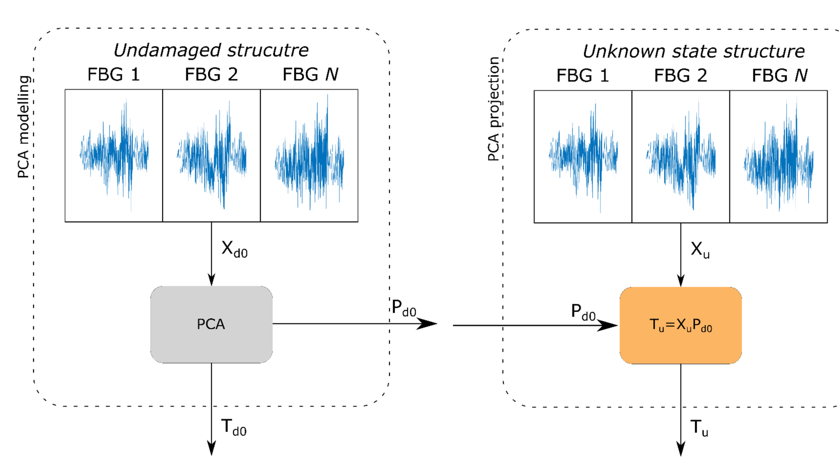
- CARS – Centre for Automotive Research and Sustainable Mobility
- Smart Data
- AddFor

Combining a **P**rincipal **C**omponent **Analysis** with a **O**ne **C**lass **SVM** classifier we can assess the presence of a **damage** in a **composite structure**, by processing distributed strain measures collected during pseudo-random excitations.

METHOD

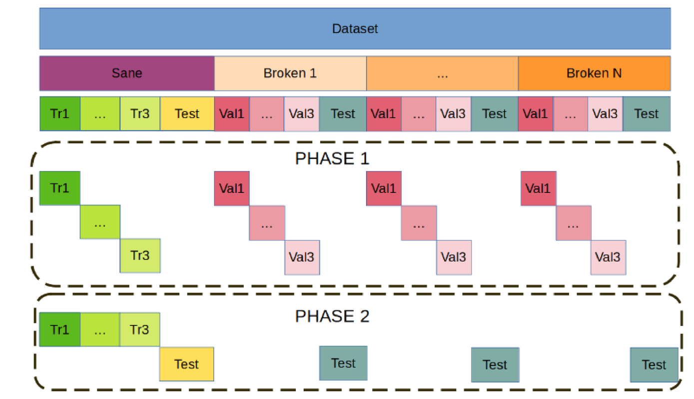
1 PCA Modelling and projection



PCA Modelling:
Data from pristine structure are processed to determine the principal system

PCA projection
Data from monitored structure are projected on the principal axes

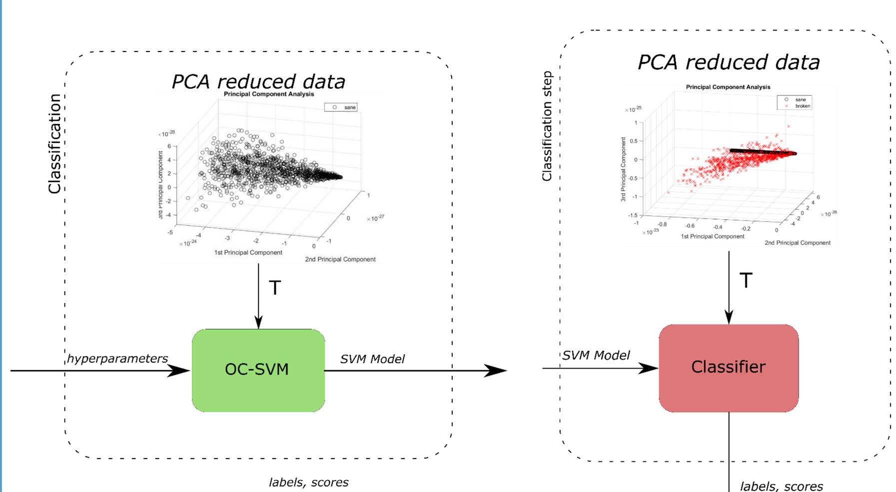
3 Cross validation for parameters optimization



Parameters:

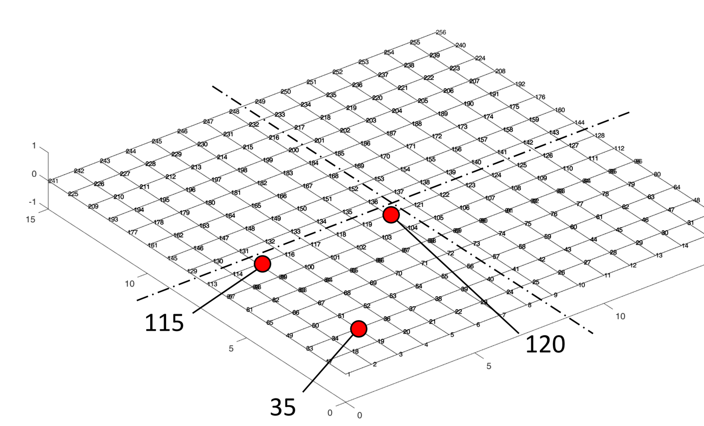
- Kernel shape parameters
- N° of principal components
- N° of dropped principal components

2 OC-SVM training and classification



OC SVM:
A single class classifier with a radial basis kernel function is trained with reduced data

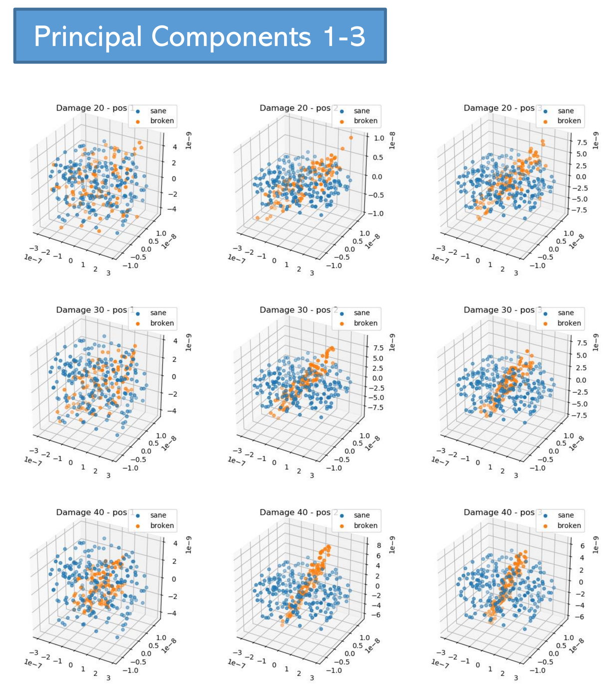
4 Test case



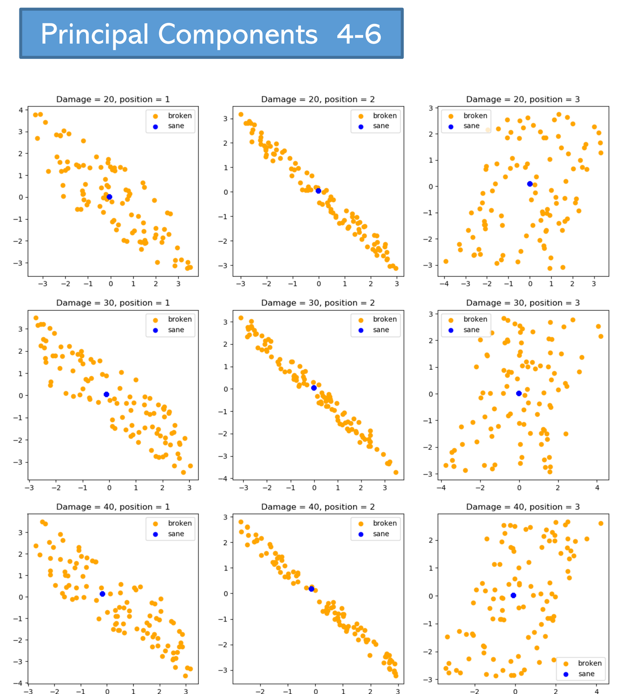
Laminated plate:
The system performance have been assessed on a squared cantilever plate loaded with random tip force. The structure is monitored under nine damage configurations, differing for entity and position of the damage.

4 Results – Test case

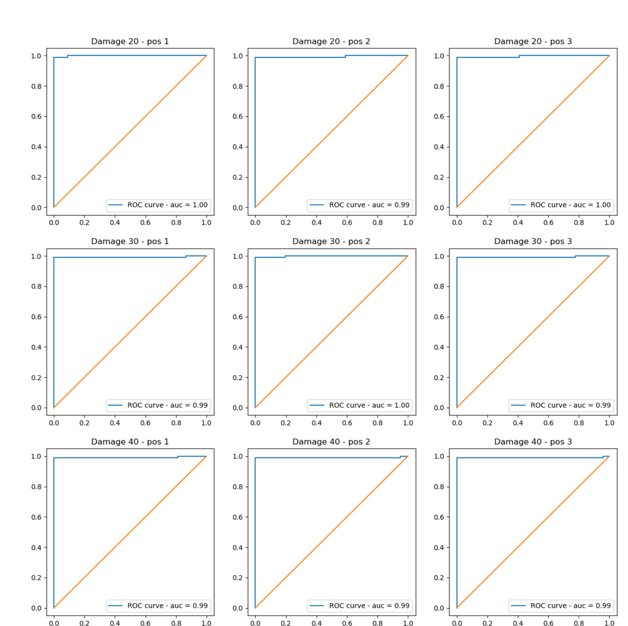
Principal Components 1-3



Principal Components 4-6



ROC Curves



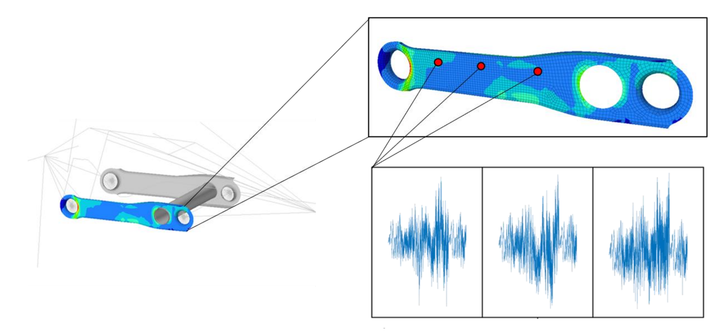
Observation
Data pattern described by the first three principal components is not easily classifiable, especially for the first damage position where points cloud is scattered. On the contrary, principal components following the 3rd are quasi null for undamaged component and non-null in presence of damage, leading to a AUC of the monitoring system of 0.99 in every configurations.

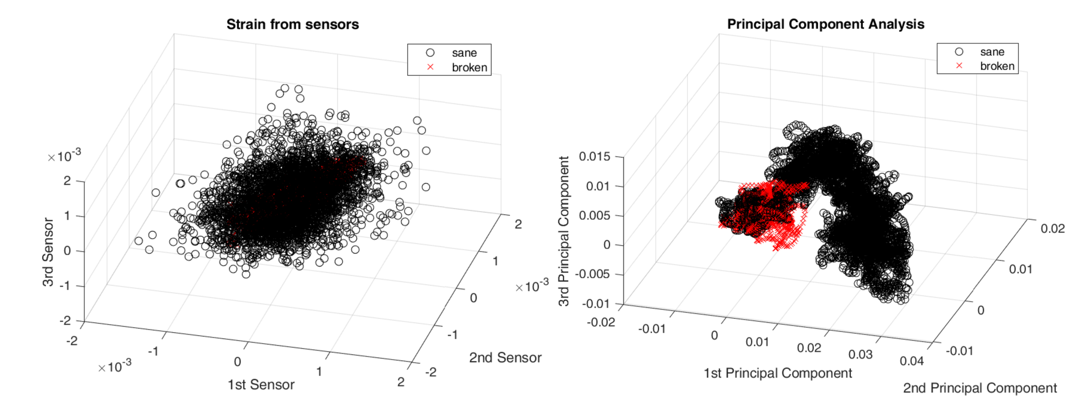
CASE STUDY

MONITORING OF A COMPOSITE AUTOMOTIVE SUSPENSION

Finite Element Model
Simulated strain data are extracted from a FEM representing the full rear suspension system

PCA
The Principal components evidently de-correlates the strain data, giving a clearer picture of the phenomena.

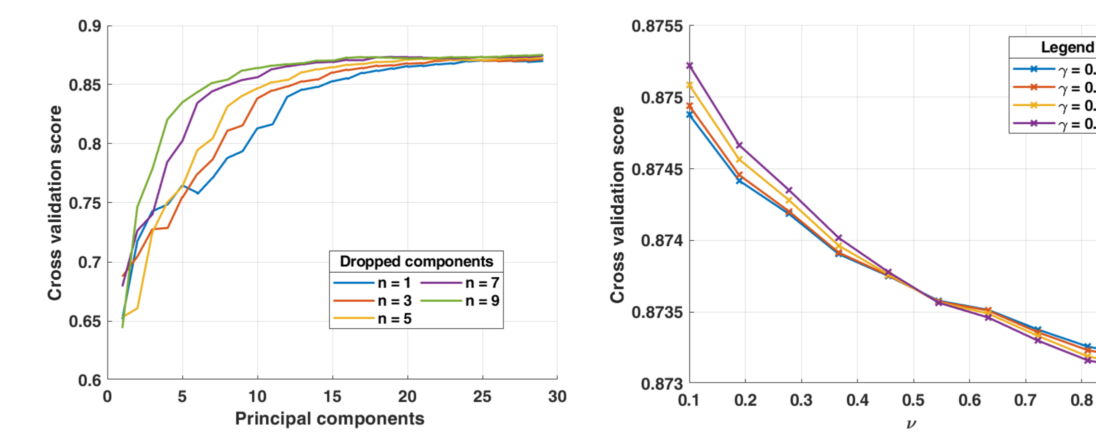




Cross validation

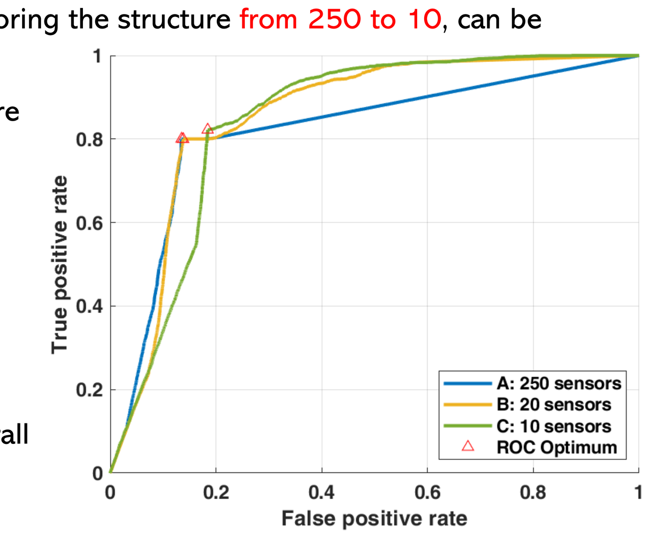
The observation made for the test case are confirmed by the cross-validation performed on the case study.

First principal components are less effective for the anomaly detection in the strain data pattern:



Sensors density sensitivity

Varying the number of sensors monitoring the structure from 250 to 10, can be observed that the AUC of the entire pipeline is not affected. This results are obtained by reducing the number of sensors keeping then equally spaced along the structure. A further optimizations will aim at defining the correlation between the strain signals and cluster them to preserve the overall system information.



Results