# SHM of composite aeronautic structures: exploiting printed piezoelectric transducers

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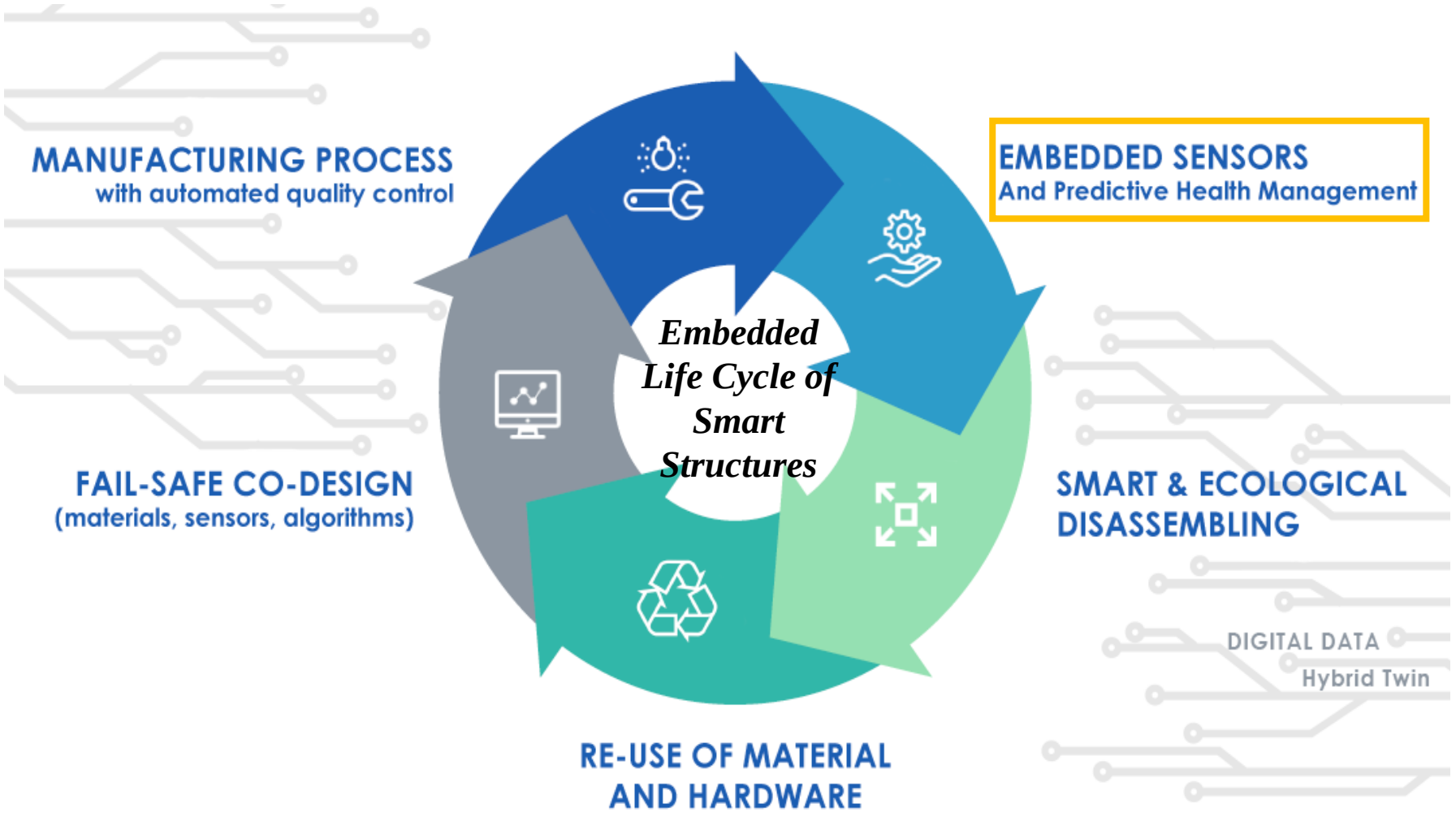
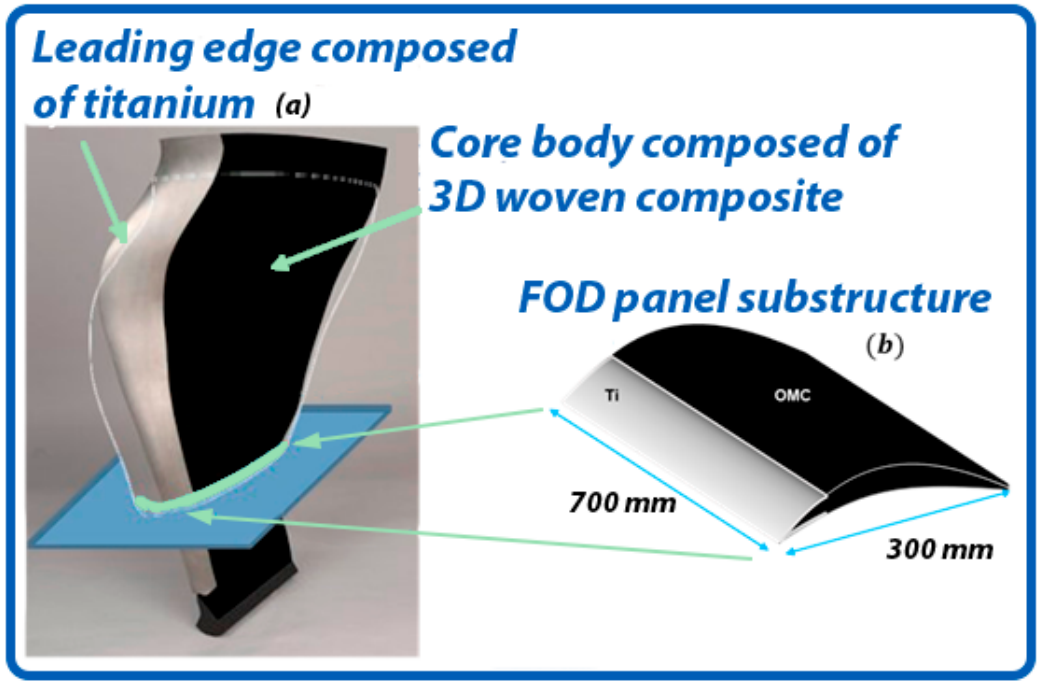
# MORPHO (*Manufacturing, Overhaul, Repair for Prognosis Health Overreach*)

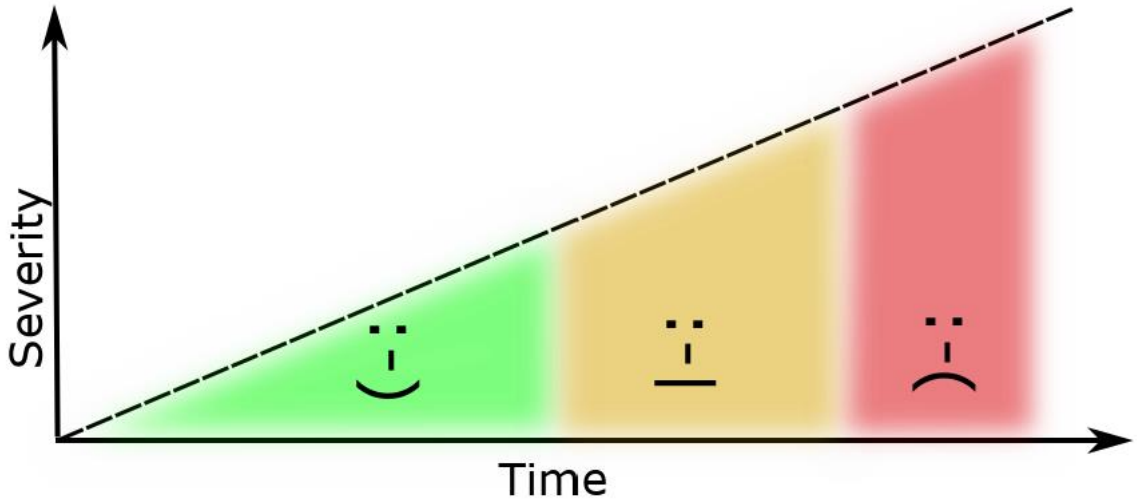


# From rotor fan blades to FOD panels

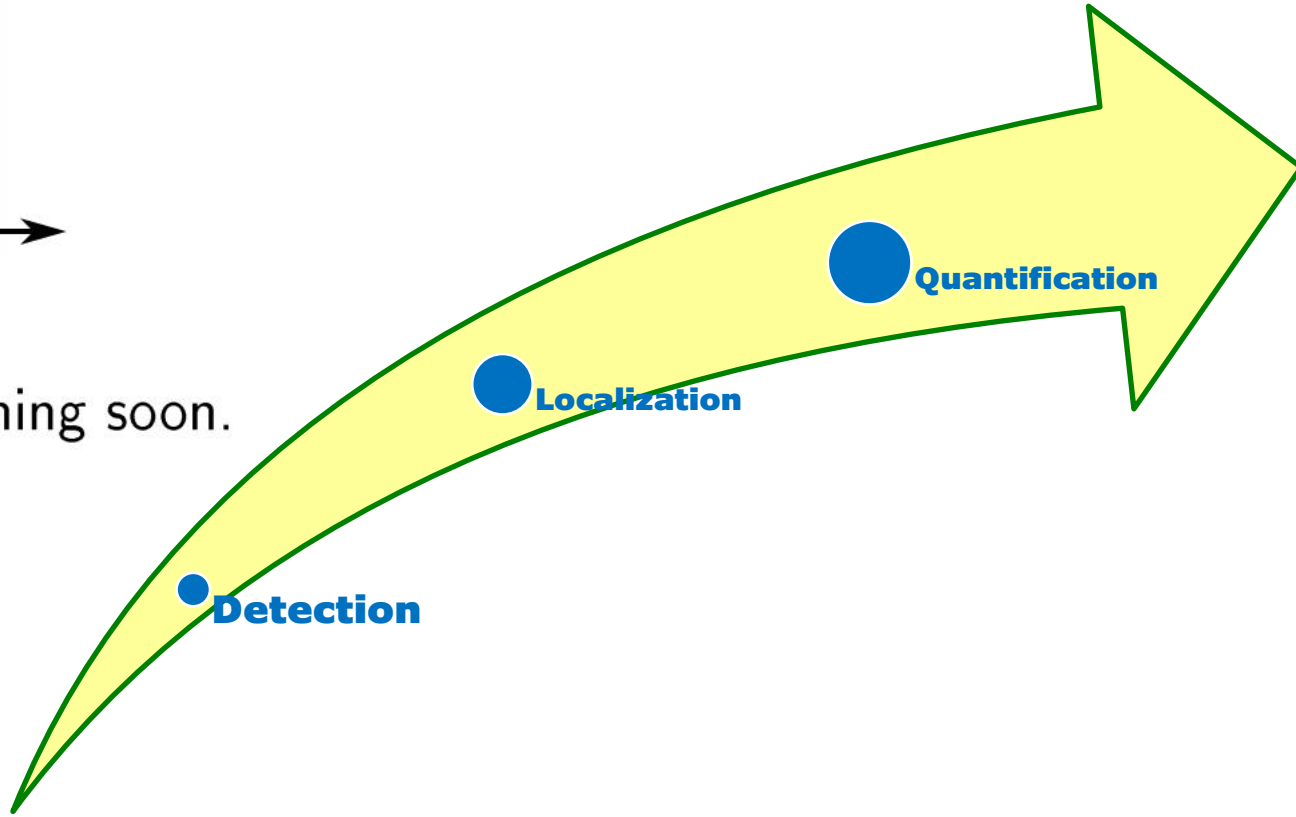
Courtesy: Paris Air Show, June 2023



# Predictive health management & Structural Health Monitoring

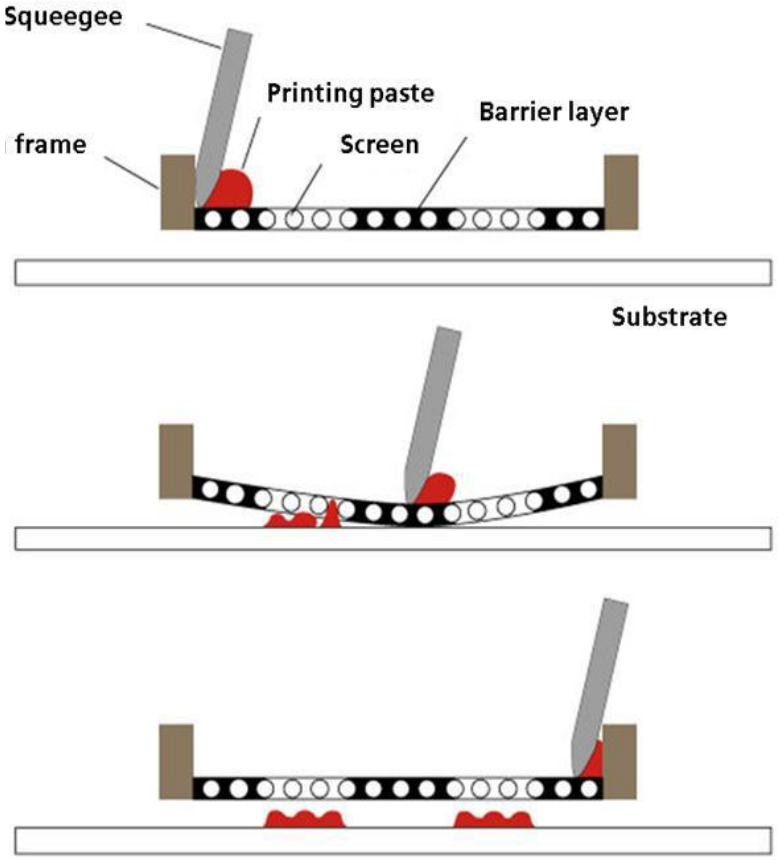


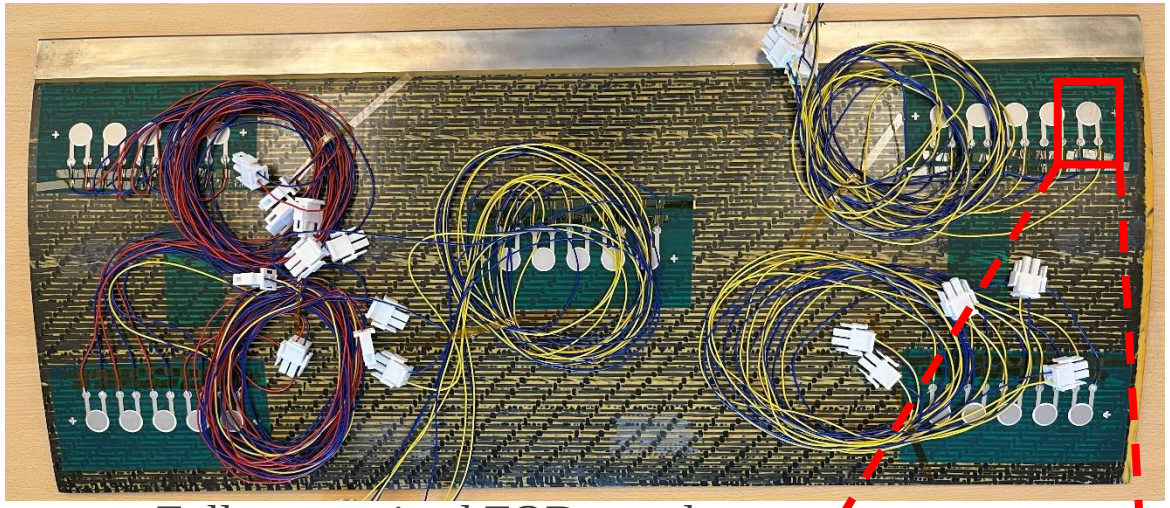

- :-) **Too early** → Wasted time and money.
- :-| **Best moment** → No real damage, but coming soon.
- :-( **Too late** → Failure already happened...



# Printed piezoelectric transducers

- ***Screen printing*** at Fraunhofer IFAM, Germany
- Electrodes - Silver conductive paste
- Active layer – Piezoelectric paste



Fully sensorized FOD panel

***Advantages over ceramic piezoelectric transducers***

- ***Low weight***
- ***Less fragile***
- ***Arbitrary shape***
- ***Can Handle curved surface***
- ***Wires can also be printed***

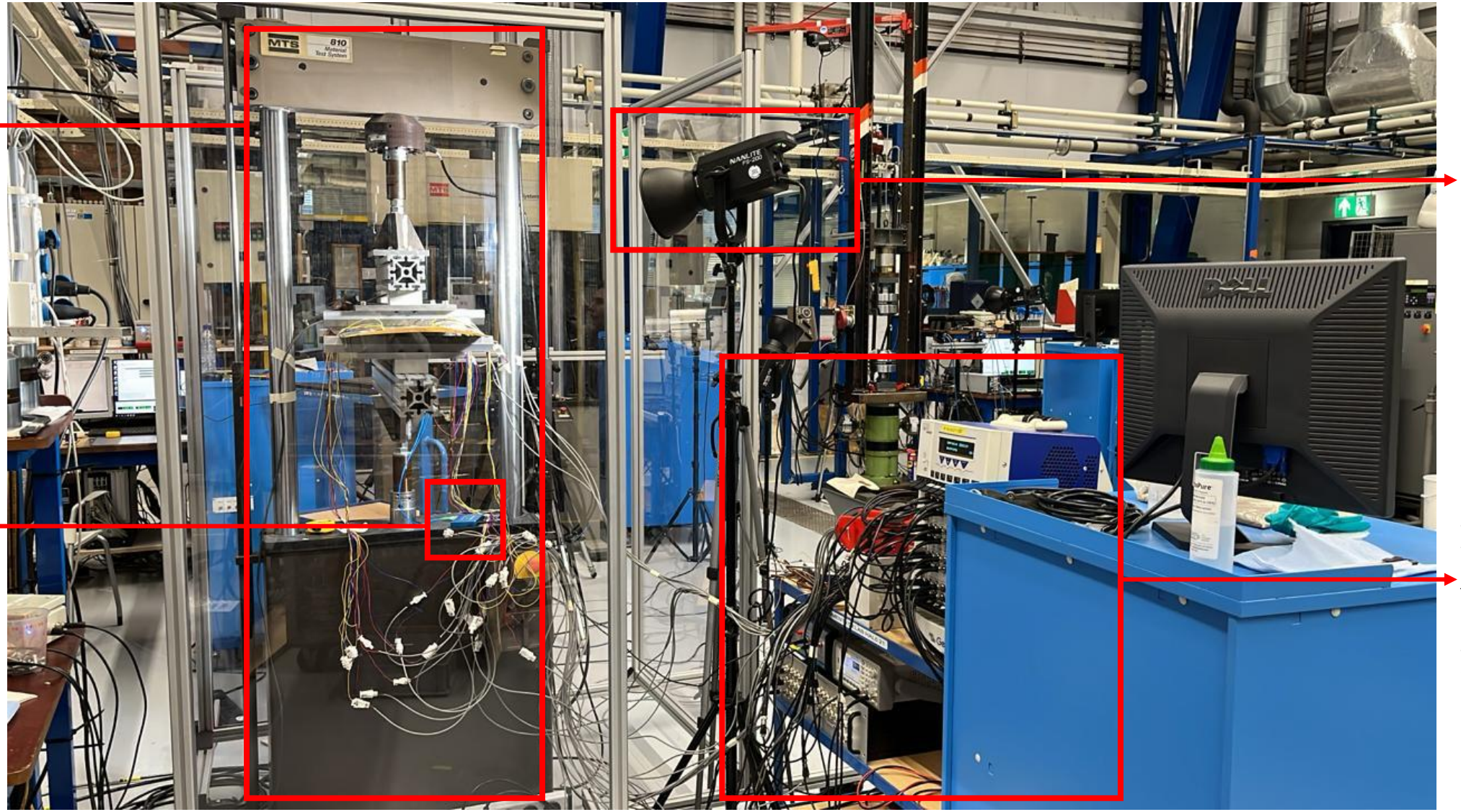
A printed PZT

# What can be expected from printed piezoelectric transducer?

- **Electromechanical Impedance**
  - Transducer health monitoring
  - Local damage monitoring
- **Impact measurements**
  - Detection & localisation of impact events
  - Estimation of impacts energy
- **Acoustic Emission**
  - Passive monitoring of damage during the damaging process
  - Allows to follow online and in-situ damage from its premisces
- **Lamb waves interrogation**
  - Active monitoring of damages
  - Allows to follow online and in-situ damage evolution

***One single sensor technology can handle several complementary functionalities***

# Experimental testing of fully sensorized FOD panels



# Experimental Schema

**4 - point Bending Tests** (400 cycles x 11 blocks)

**FBG Measurements**

**Camera**

**Passive SHM** *After 20/10/5 cycles in every block*

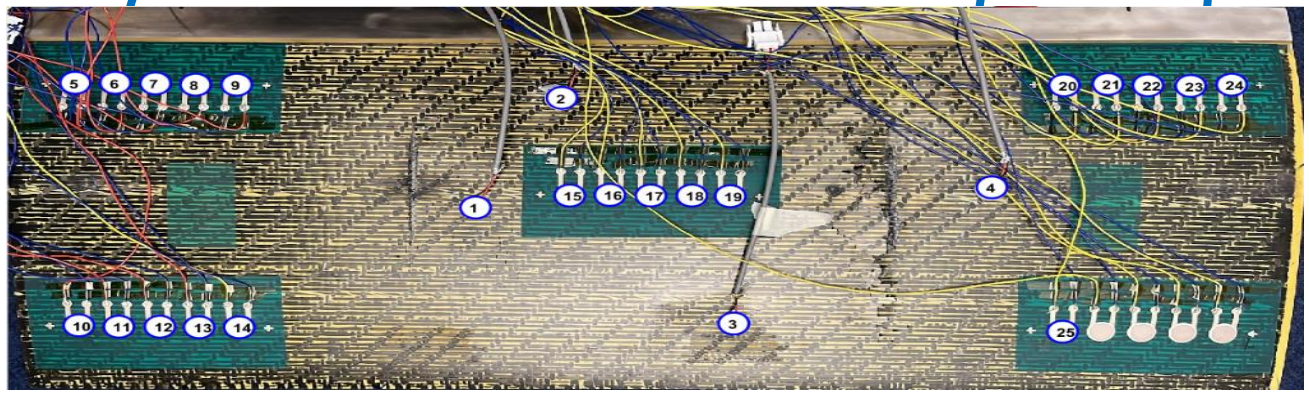
*Every 200/ 100/ 50 cycles*

**Guided Waves SHM** (standard ceramic PZTs as actuators)

- Baseline measurements for guided waves based SHM in healthy state
- Impact using a drop tower apparatus

***Measurements at various degradation states of FOD***

## FOD Panel




| Load | FBG | Camera | Passive | Active |
|---|---|---|---|---|
| 4 kN | const. | 20 cycles | 20 cycles | 200 cycles |
| 8 kN | const. | 20 | 20 | 200 |
| 12 kN | const. | 20 | 20 | 200 |
| 14 kN | const. | 20 | 20 | 200 |
| 16 kN | const. | 10 | 10 | 100 |
| 18 kN | const. | 10 | 10 | 100 |
| 20 kN | const. | 10 | 10 | 100 |
| 22 kN | const. | 10 | 10 | 100 |
| 24 kN | const. | 10 | 10 | 100 |
| 26 kN | const. | 5 | 5 | 50 |

# Electromechanical Impedance principle

- **Piezoelectric transducer health monitoring**

$\varepsilon_0$: *Air dielectric permittivity*

$S$ : *surface*

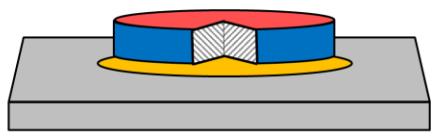
$x$: *bonding quality*
(1 : *perfect bonding* − 0 : *debonded*)

$C$ : *capacity*

$$C = \frac{\varepsilon_0 \times S \times (1 - x)}{e}$$

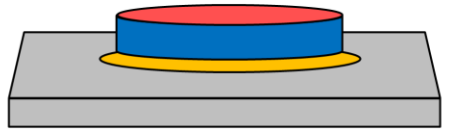
$e$: *thickness*

**Damaged** piezo

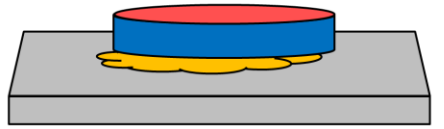


$S \searrow \Rightarrow C \searrow$

**Perfect** bonding



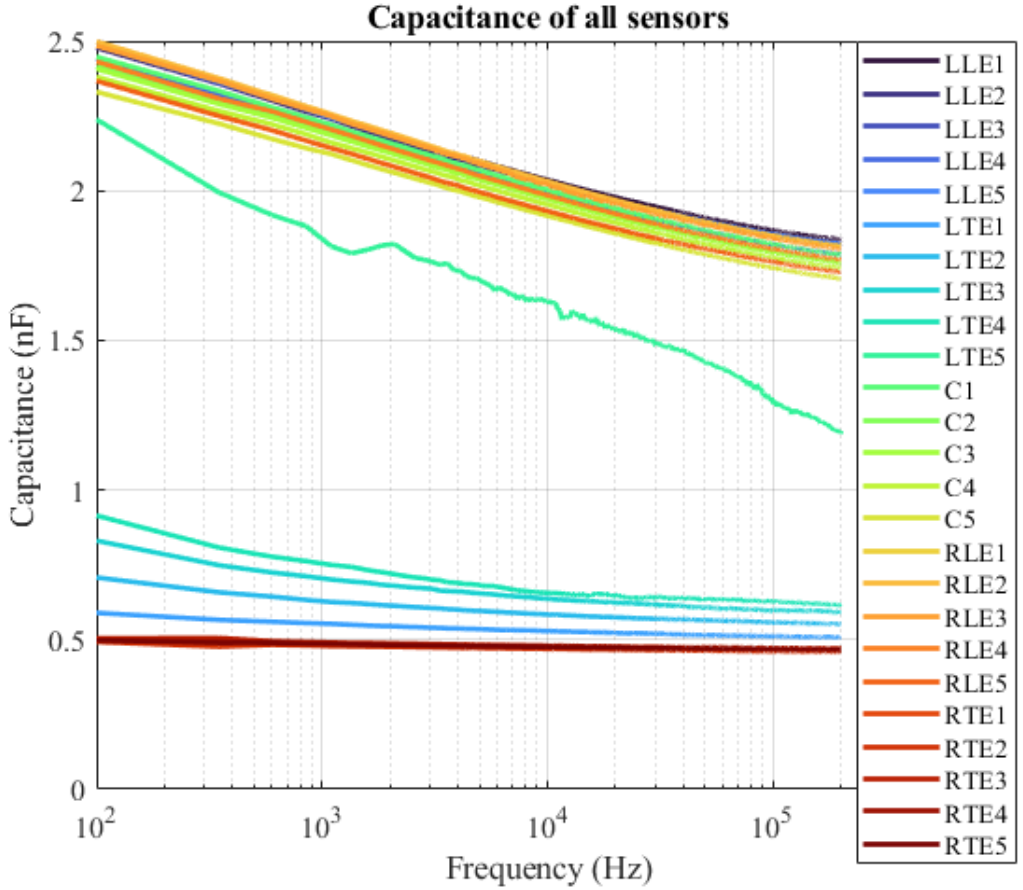
**Bad** bonding

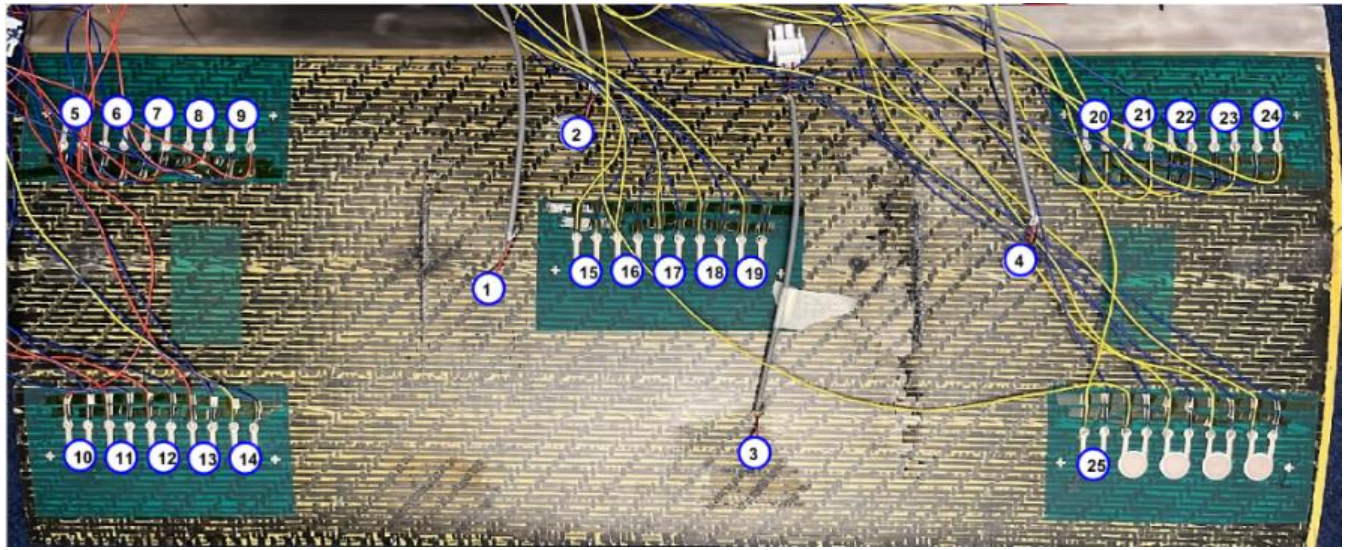


$x \searrow \Rightarrow C \nearrow$

- **Local damage monitoring:** The real part of the electromechanical impedance will be influenced by damages in the vicinity of the piezoelectric transducers.

# Electromechanical behavior of Printed PZTs

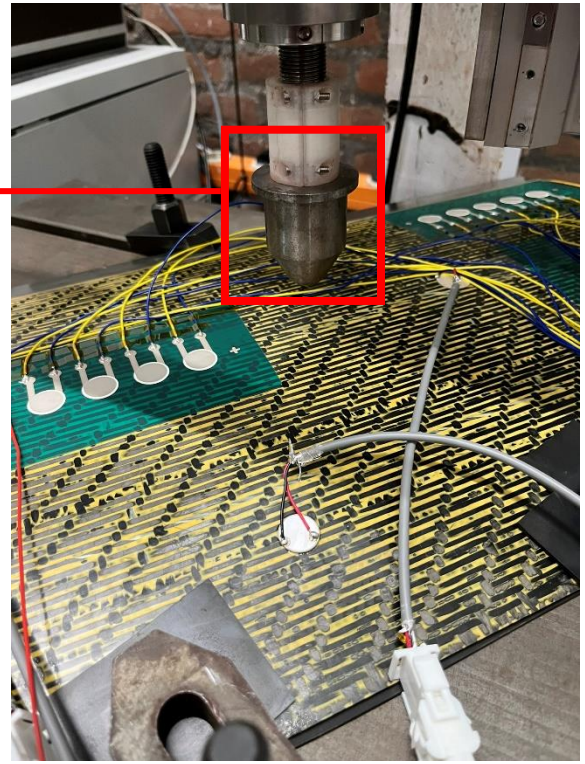


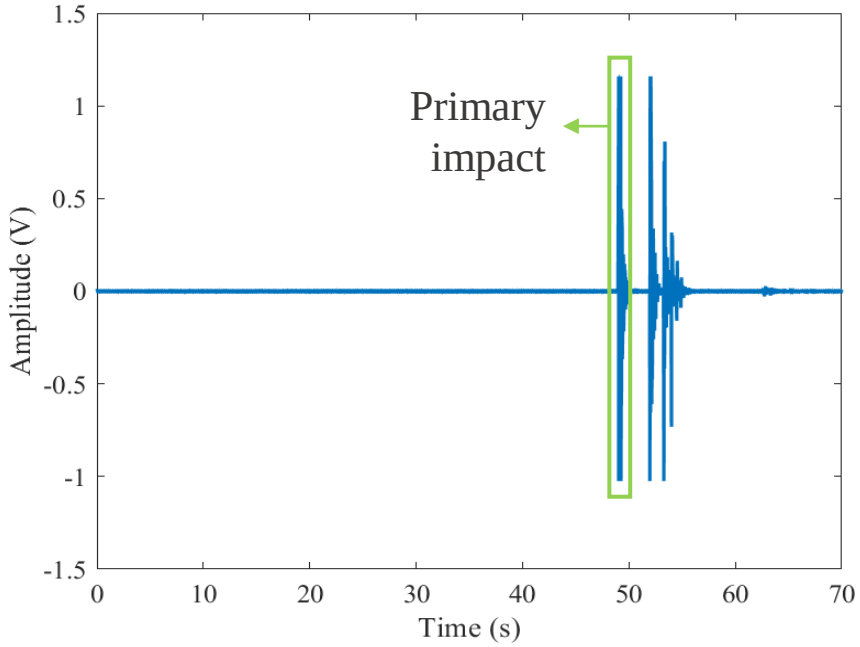



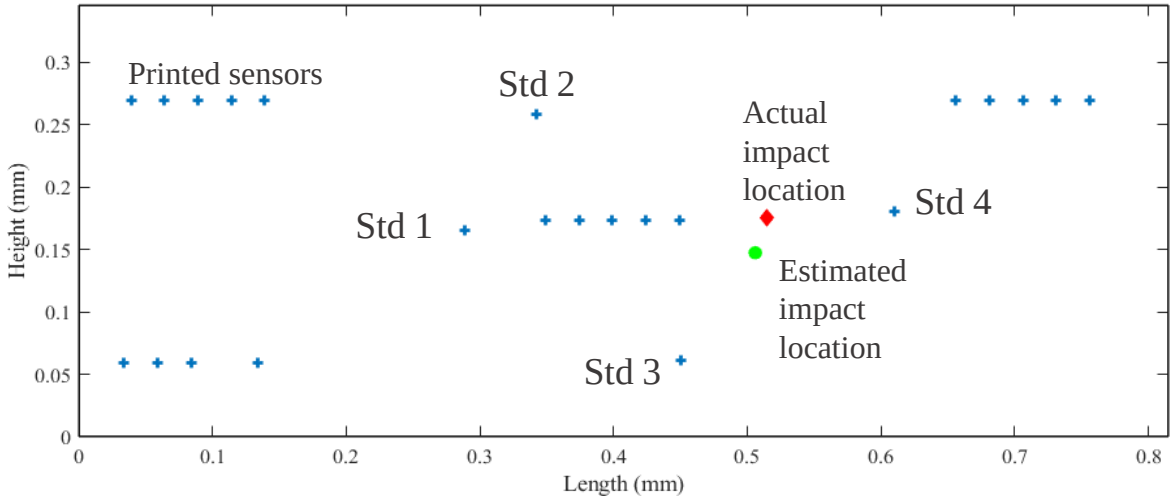

- Most of the sensors are well connected
- Highly repeatable process
- Observed deviations due to µ-size variations of surface

***Screen printing technology has the potential for large scale deployment during manufacturing***

# Impact Measurement by Printed PZTs

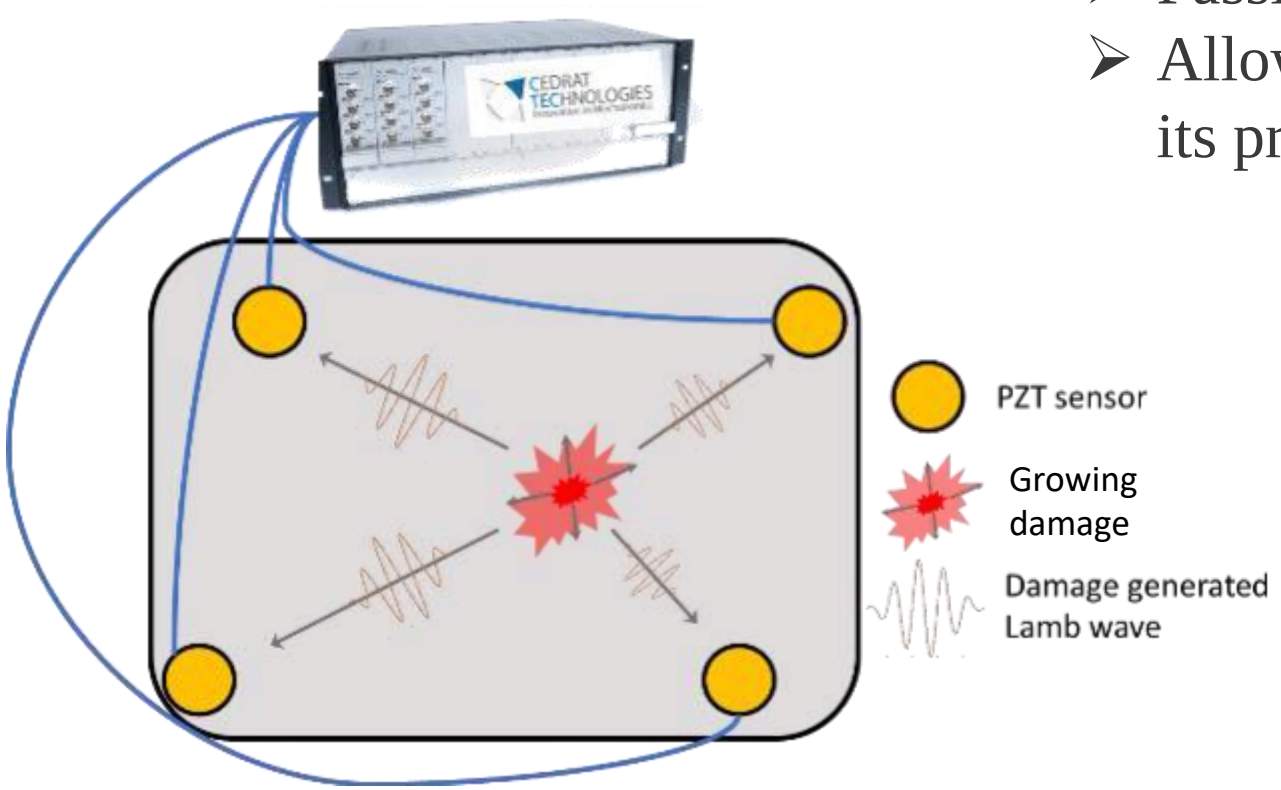


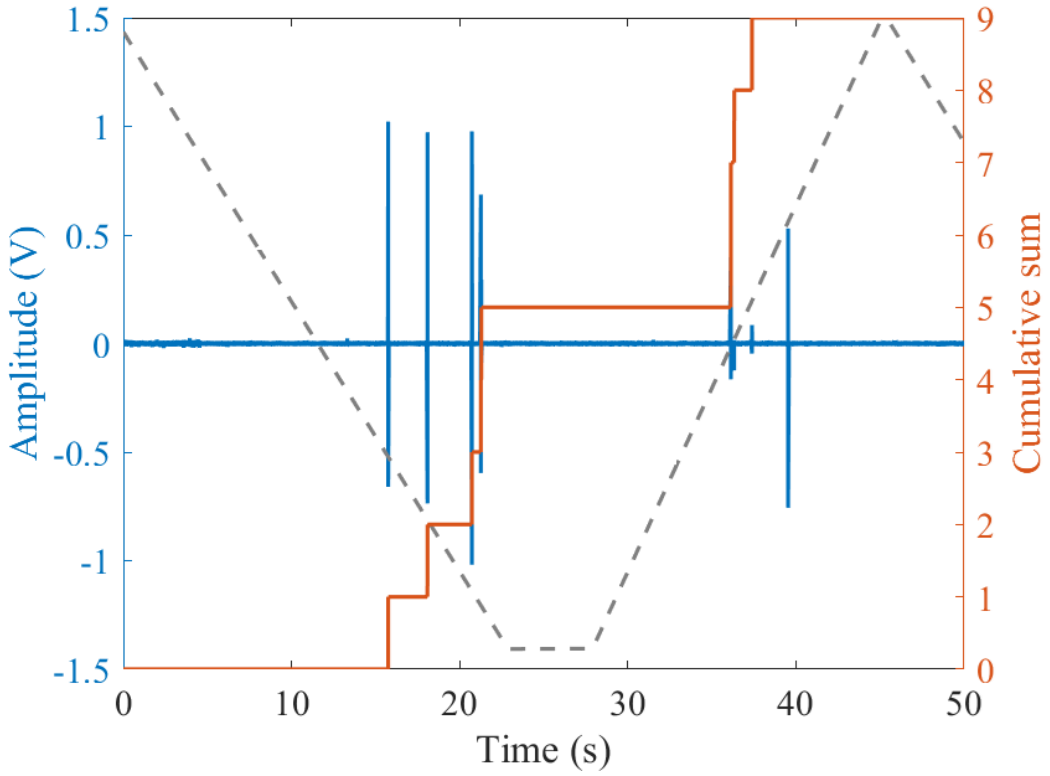




***Printed PZTs can detect and locate impacts successfully***

# Acoustic Emission Principle

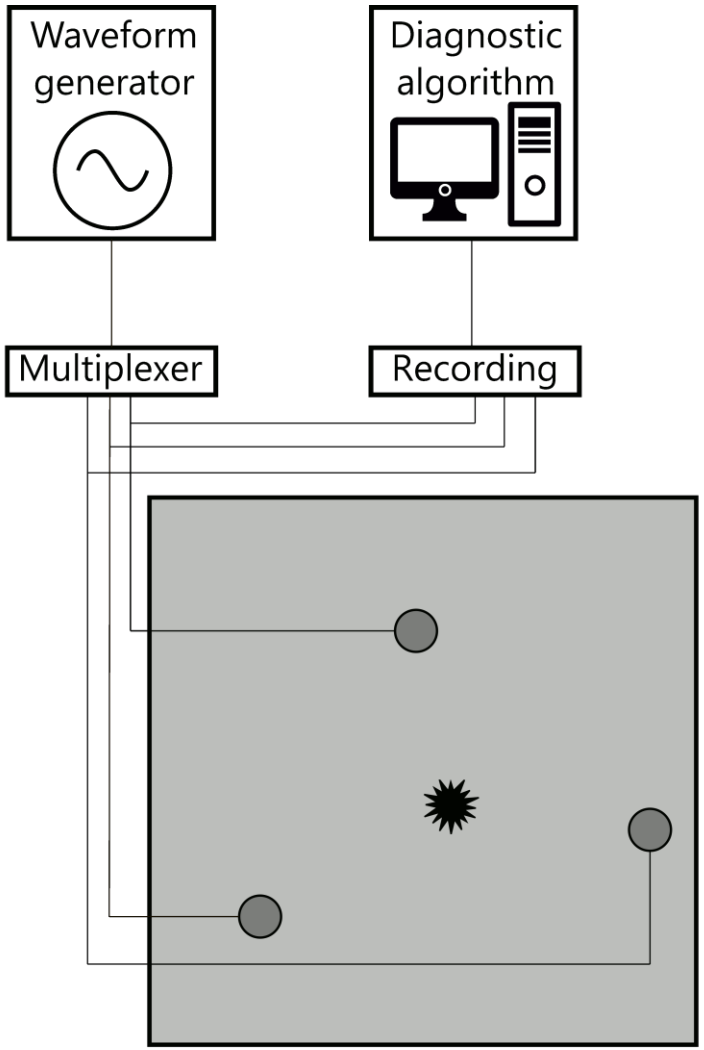



- Passive monitoring of damage during its growth
- Allows to follow online and in-situ damage from its premisces

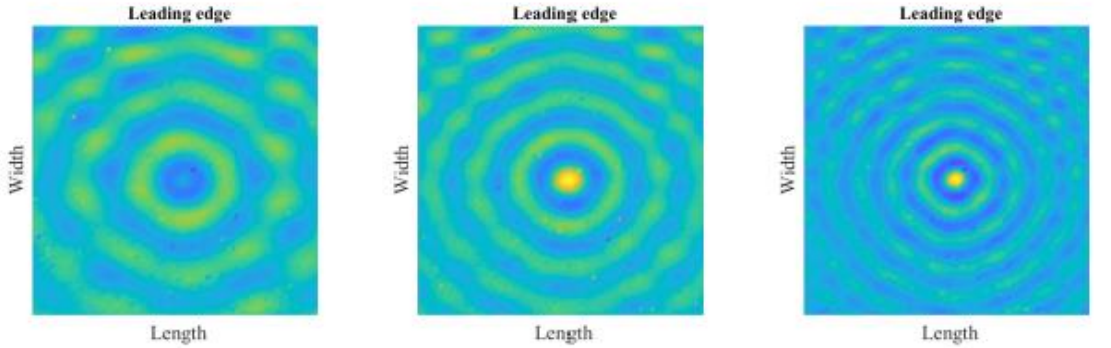



***Printed PZTs are suitable for acoustic emission***

# Guided Waves Measurement principle



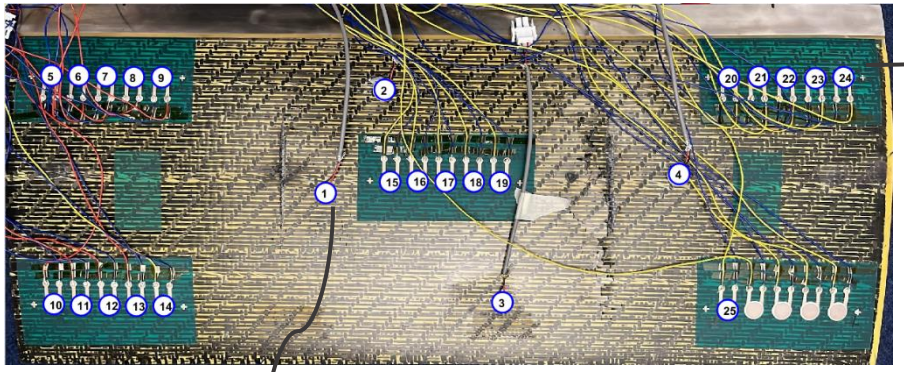

- Active monitoring of damages
- Allows to follow online and in-situ damage evolution

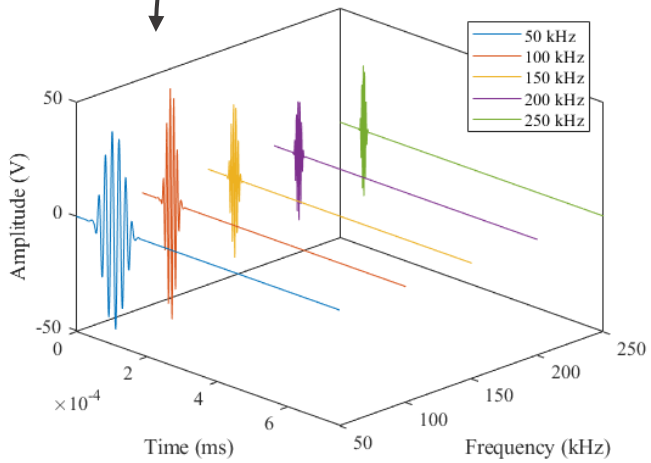



(a) 34.5 kHz (b) 49.5 kHz (c) 74.5 kHz

***Printed PZTs can emit guided waves***

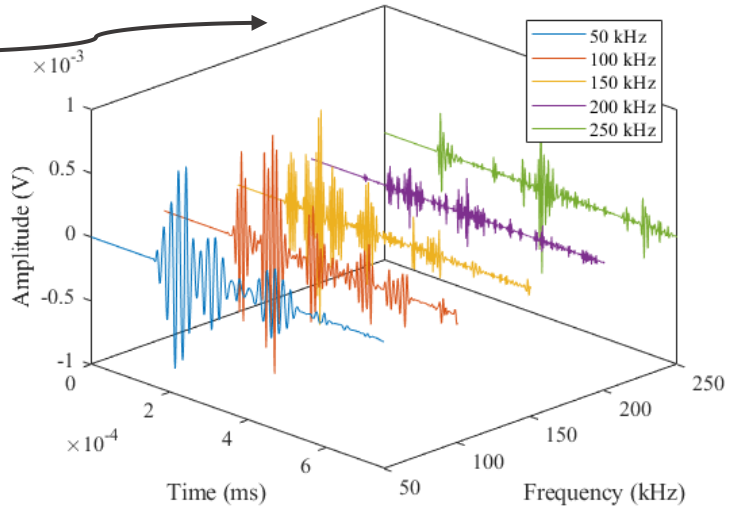
# Guided Waves Measurement by Printed PZTs



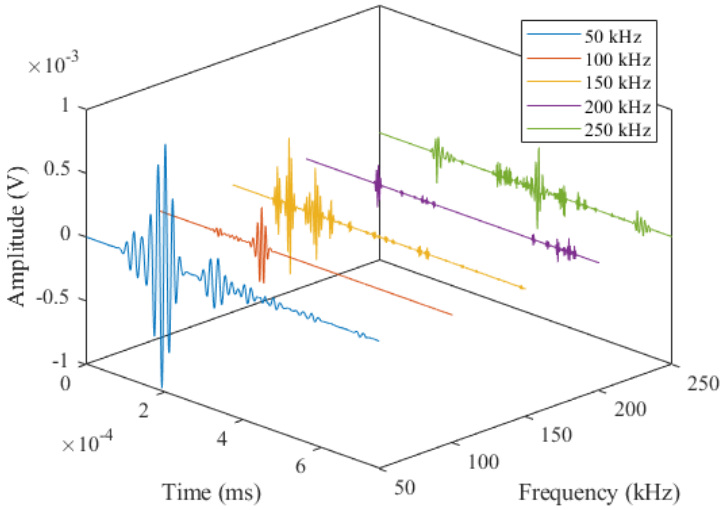



5-cycled toneburst excitation:
50, 100, 150, 200, 250 kHz

Sensor 9




Sensor 18




***Printed PZTs emit and measure guided waves successfully***

# Conclusions

- **Electromechanical Impedance:**
  - Transducer health monitoring
  - Local damage monitoring
- **Impact measurements:**
  - Detection & localisation of impact events
  - Estimation of impacts energy
- **Acoustic Emission:**
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***One single transducer technology can handle several complementary functionalities.***

# Perspectives

- Define a common HDF5 format for data storage and to feed IA algorithms
- Organize experimental and simulation campaign to comply with this format
- Provide tools for real-time and offline data visualization


*Data will be published in open access along with a data description paper to feed IA algorithms for PHM*

# Thank you!