INSTITUTE OF THERMOMECHANICS
CZECH ACADEMY OF SCIENCES
Dolejškova 5, 182 00 Praha 8

The 13th International Conference SPMS 2022
Stochastic and Physical Monitoring Systems
23.6. - 27.6.2022

Application of Neural Networks for Acoustic Emission Method

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AI for AE

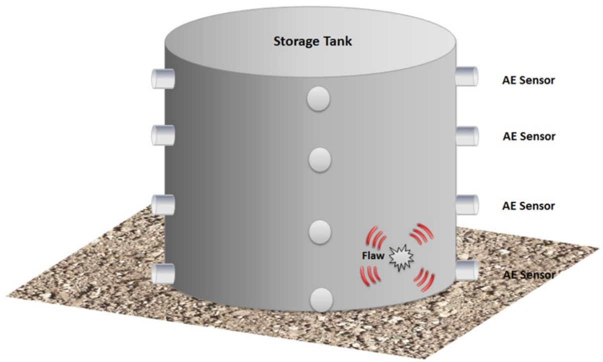
- Acoustic emission (AE)
- BP (feed-forward) networks for location of AE sources
- Identification of helicopter gear box modes
- Detection of plastic deformation in materials
- Detection of AE bursts (material cracking) in noisy continuous signals
- Challenges for the future

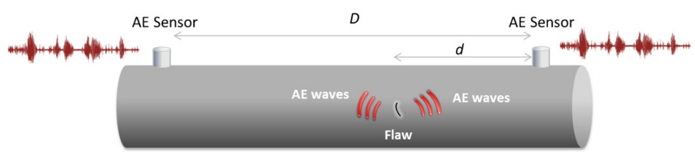
ACOUSTIC EMISSION (AE) METHOD

Passive monitoring of ultrasonic elastic waves initiated by various processes in materials.

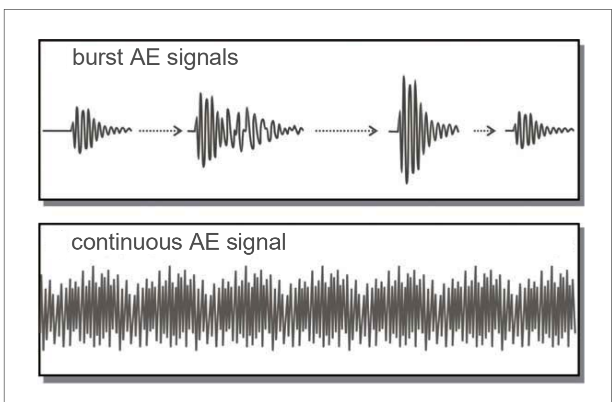
Burst AE: *plastic deformation of metals, crack growth, friction, material failure...*

Continuous AE: *leakage of liquids under pressure, machining, welding, monitoring of technological processes and devices...*





MACHINE LEARNING APPLICATIONS



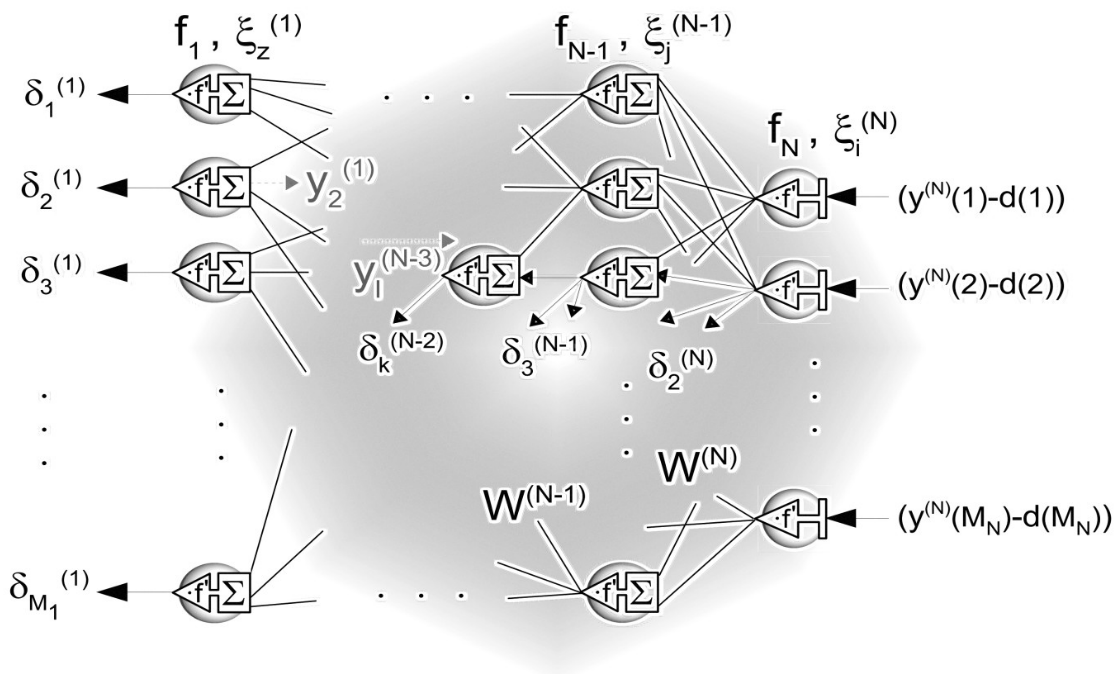
Multilayer Back-propagation networks

Localization of material defects
(especially for cases of complex structures)

Convolutional neural networks (CNN)

Condition monitoring of rotating mechanisms
(bearings, gearboxes, etc.)

Backpropagation (feed-forward) networks



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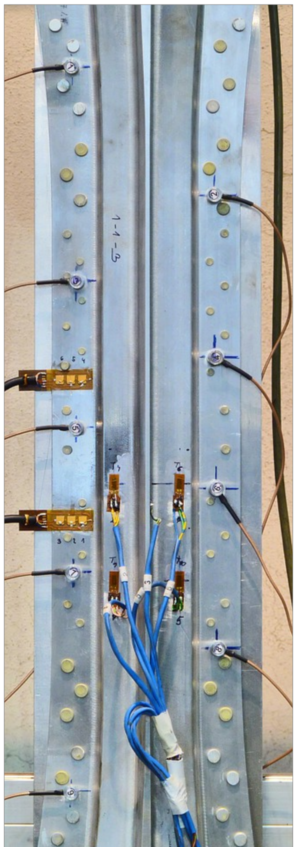
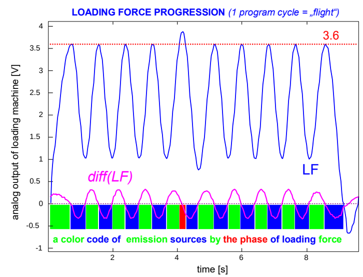
Long-term fatigue tests of riveted aircraft wing flange

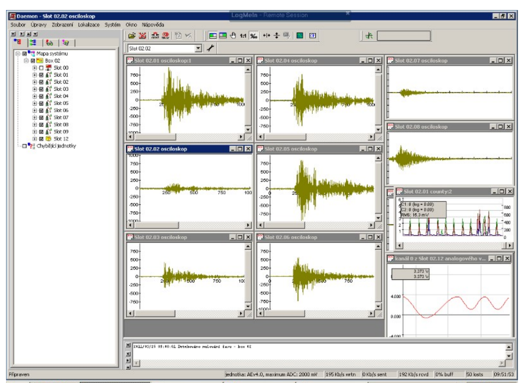
SPECIMEN
(WING FLANGE)



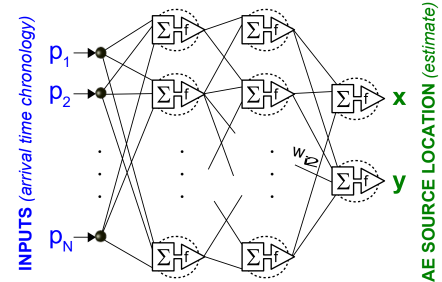
FATIGUE LOADING

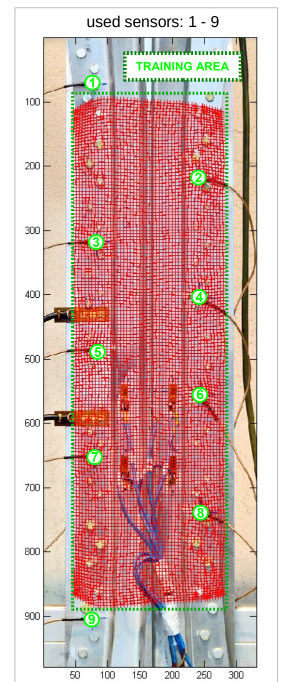


REMOTE AE MONITORING

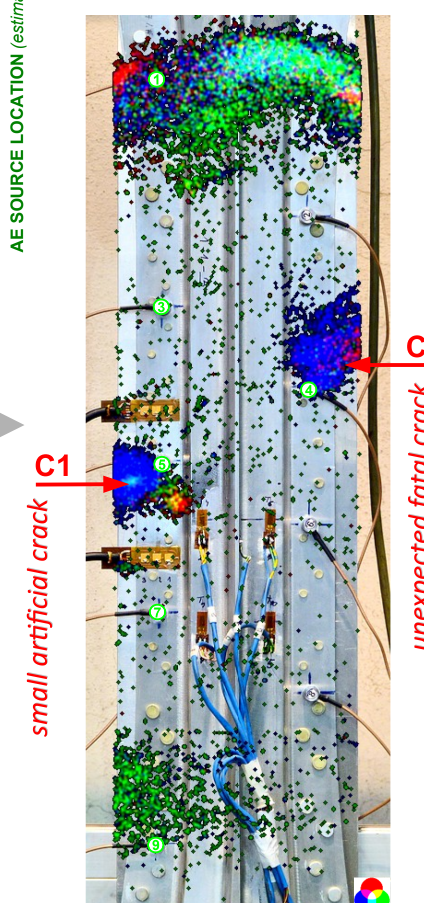


TWO-HIDDEN-LAYER BP NETWORK



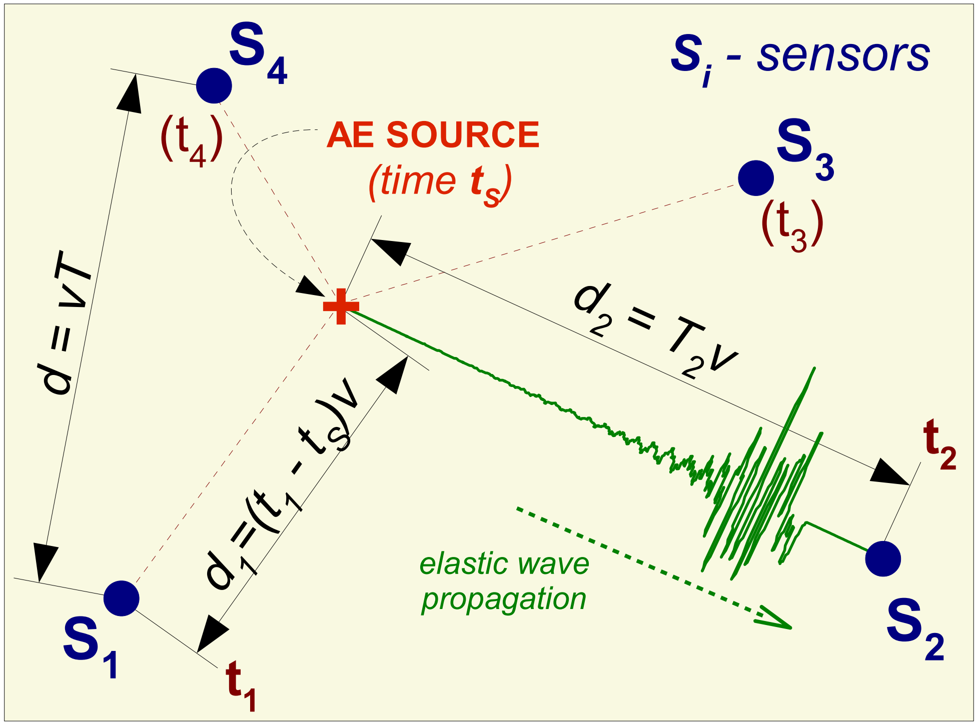


LOCATION OF AE SOURCES



Demonstration scheme of AE signal measurement (2D model)

- configuration of AE sensors S_1-S_4 placed on planar body



tested area

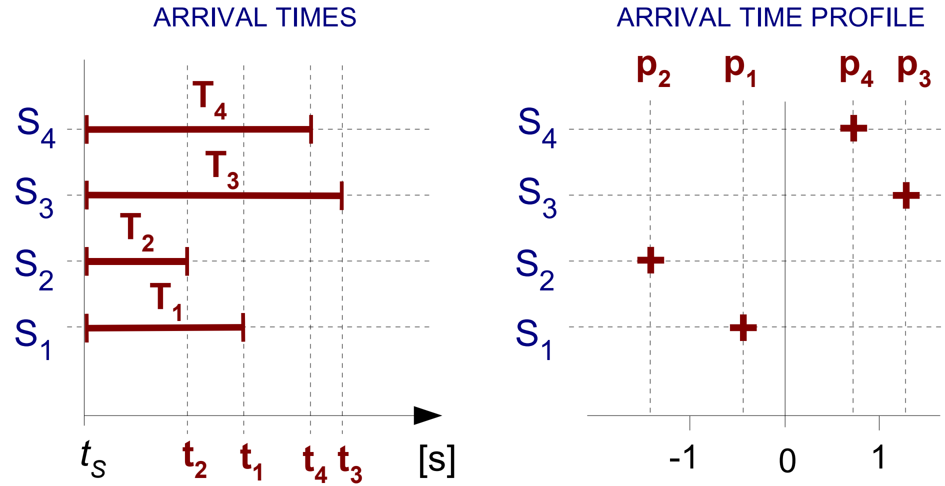
notation:

- t_s - time of AE source inception
- t_i - signal arrival time
- T_i - signal propagation time from source to sensor Si
- T - normalization period
- d_i - the distance between AE source and sensor
- d - the distance between two appropriately selected points
- v - elastic wave velocity

- **Definition of arrival time profile (ATP)**

- signal arrival time treatment is inspired by the analysis of signal detection chronology

$$p_i = \frac{N\,T_i - \sum_{j=1}^{N} T_j}{\sum_{k=1}^{N} \left| T_k - \frac{1}{N}\sum_{j=1}^{N} T_j \right|}$$

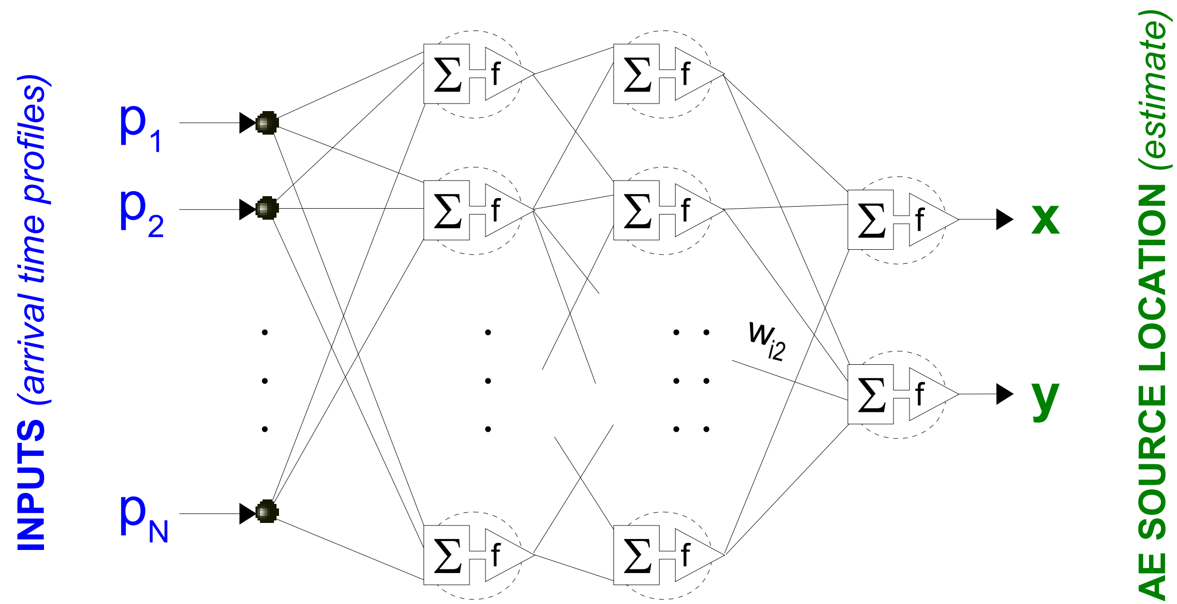


- **Independence of ATP on wave velocity and scale changes**

Only the AE signal arrival times t_i are available. Assuming t_s as the time of AE source initiation, it is easy to revise the original formula, while $T_i = t_i - t_s$

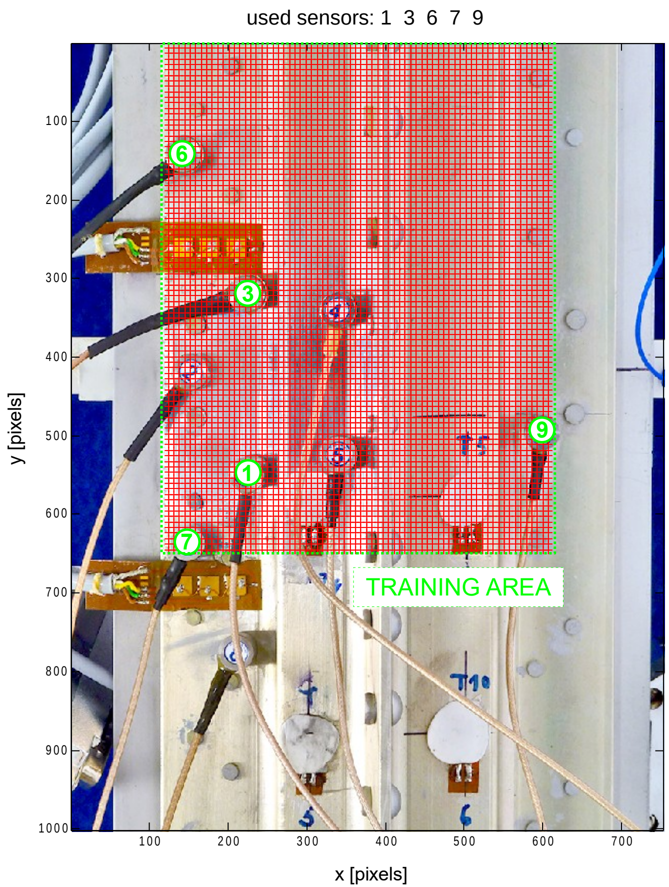
Training of neural network

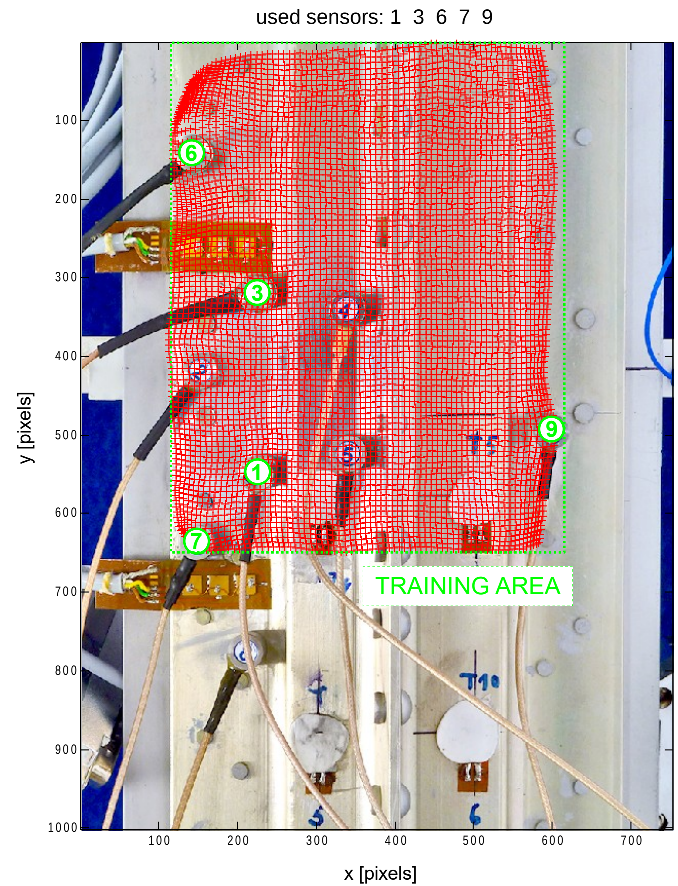
- network *architecture (approximate numbers of neurons in each layer)*: ***N-35-25-2***
- initial weights were adjusted by *statistical optimization* of starting neuron potentials
- weights and biases were adjusted by fast *resilient back-propagation* algorithm with *momentum* and *regularization (training data - set of virtual AE sources)*



APPROXIMATION FEATURES OF ANN

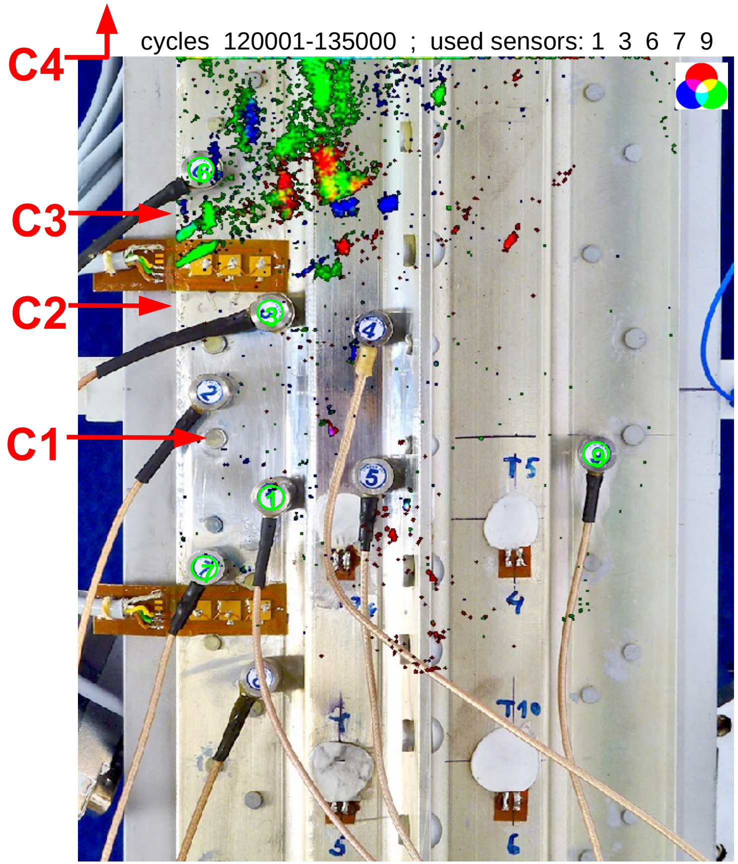
- Spreading of virtual training sources and their projection by learned neural network

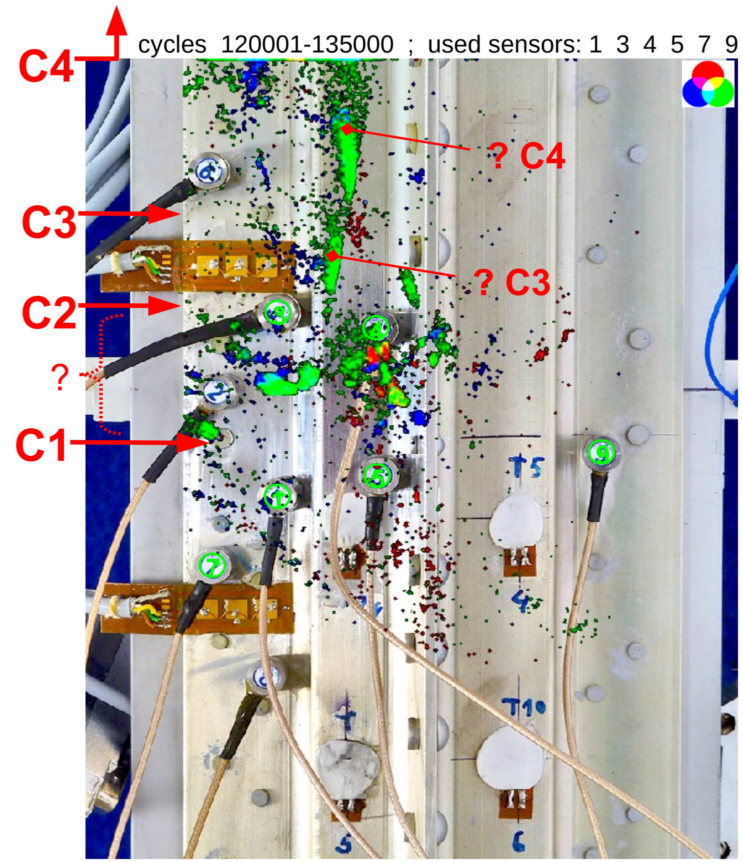


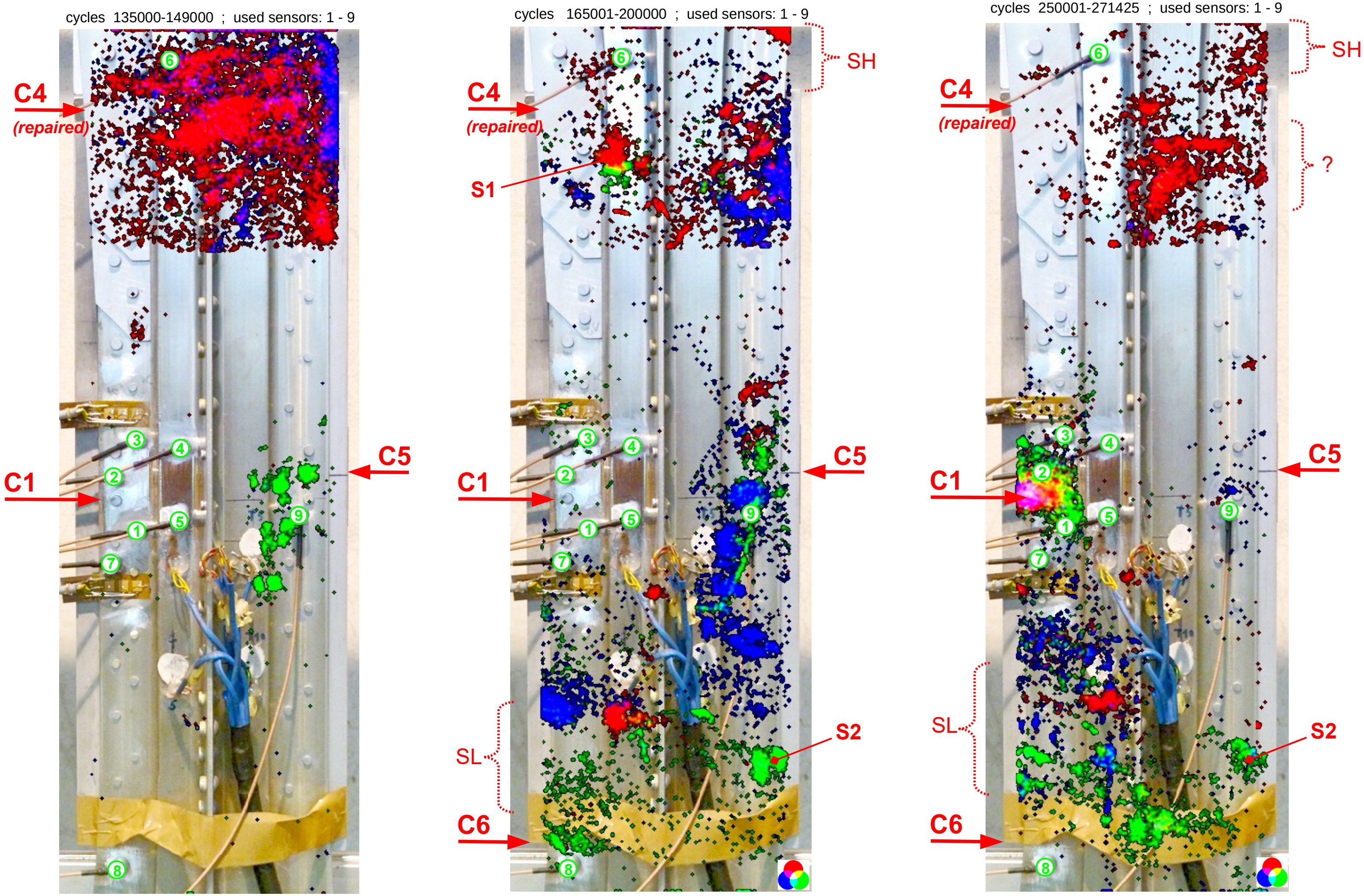


LOCATION OF REAL AE SOURCES

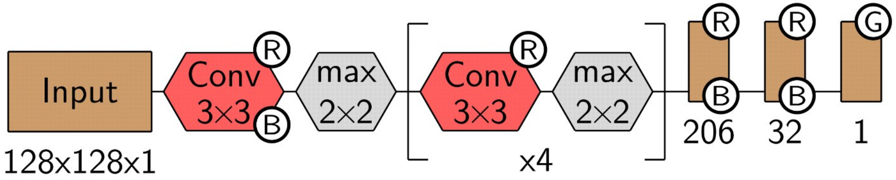
- Results for two different configuration of sensors



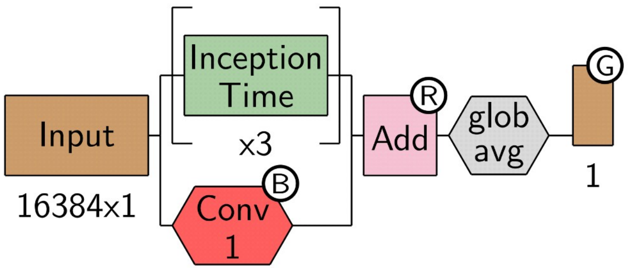



cycles 135000-149000 ; used sensors: 1 - 9
C4
(repaired)
C1
C5
cycles 165001-200000 ; used sensors: 1 - 9
SH
C4
(repaired)
S1
C1
C5
SL
C6
S2
cycles 250001-271425 ; used sensors: 1 - 9
SH
C4
(repaired)
?
C1
C5
SL
C6
S2

Convolutional networks

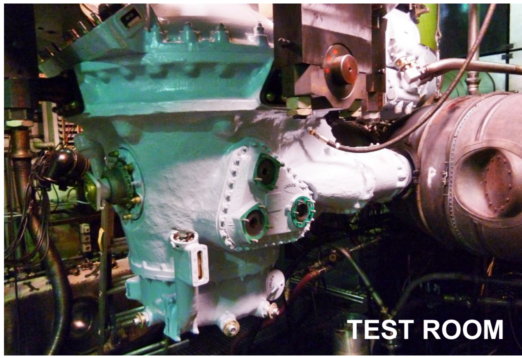


Simple ConvNet architecture.

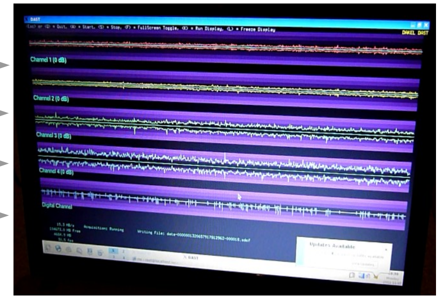


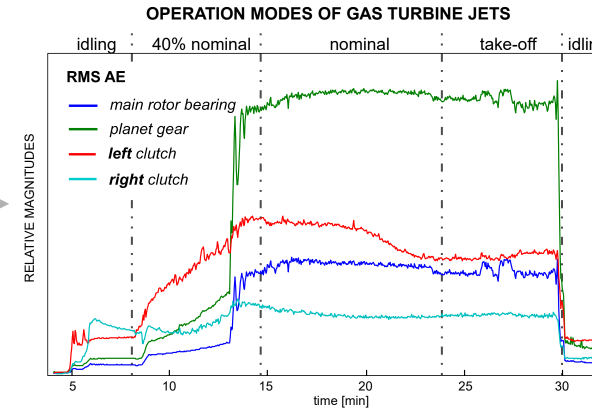
InceptionTime architecture.

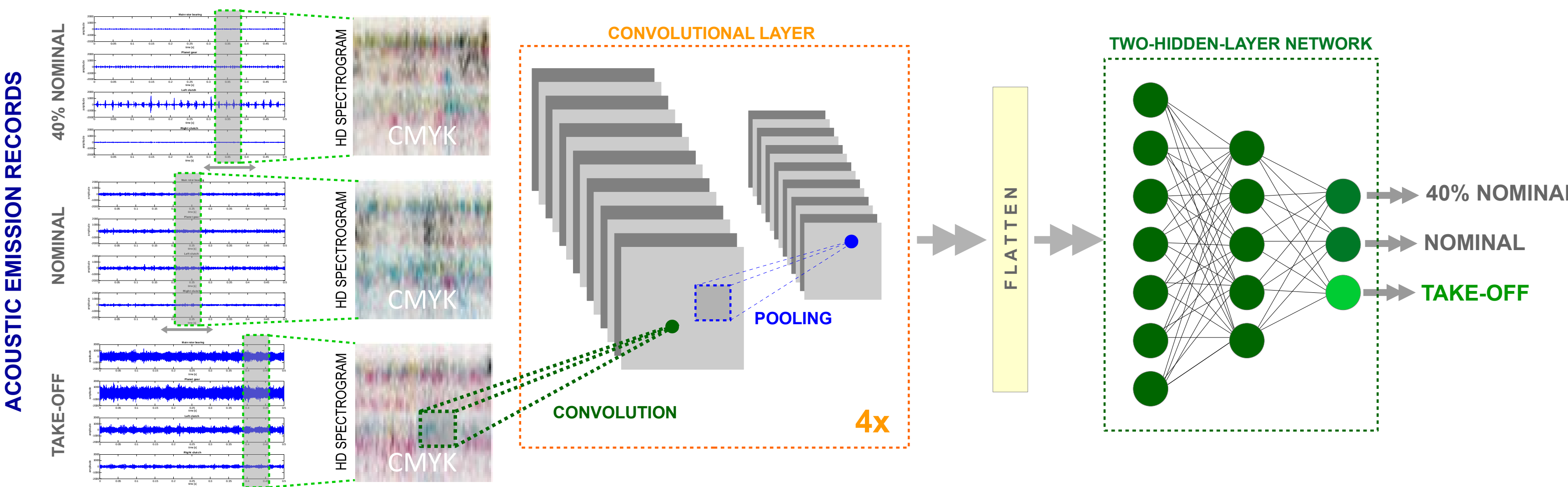
Renewed helicopter gear box running-up



4-channel AE momitoring

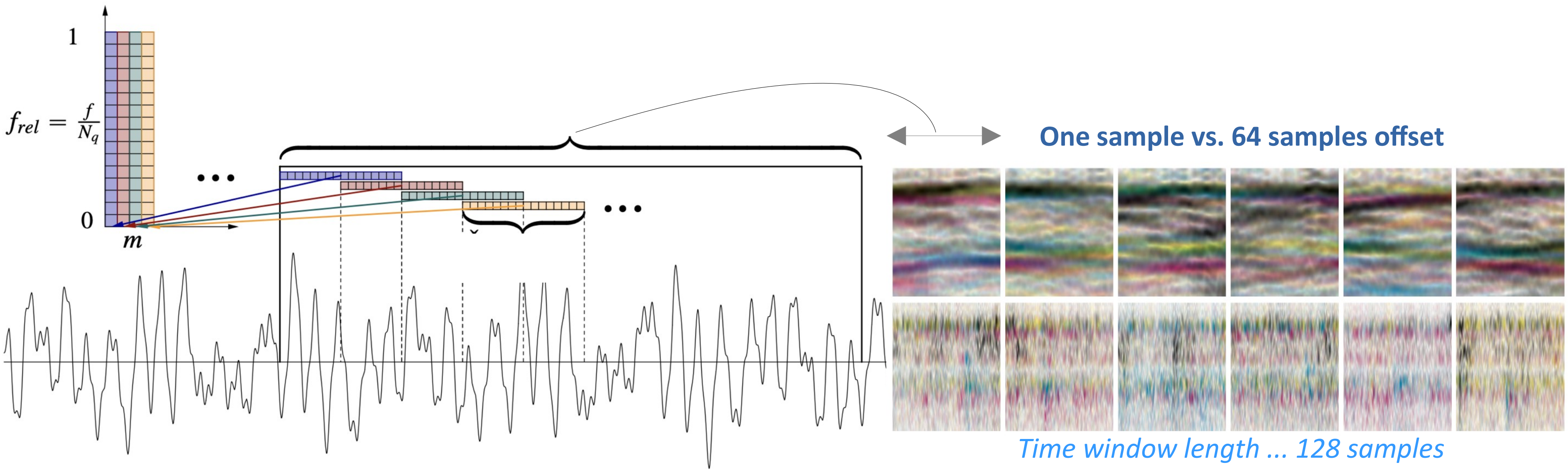




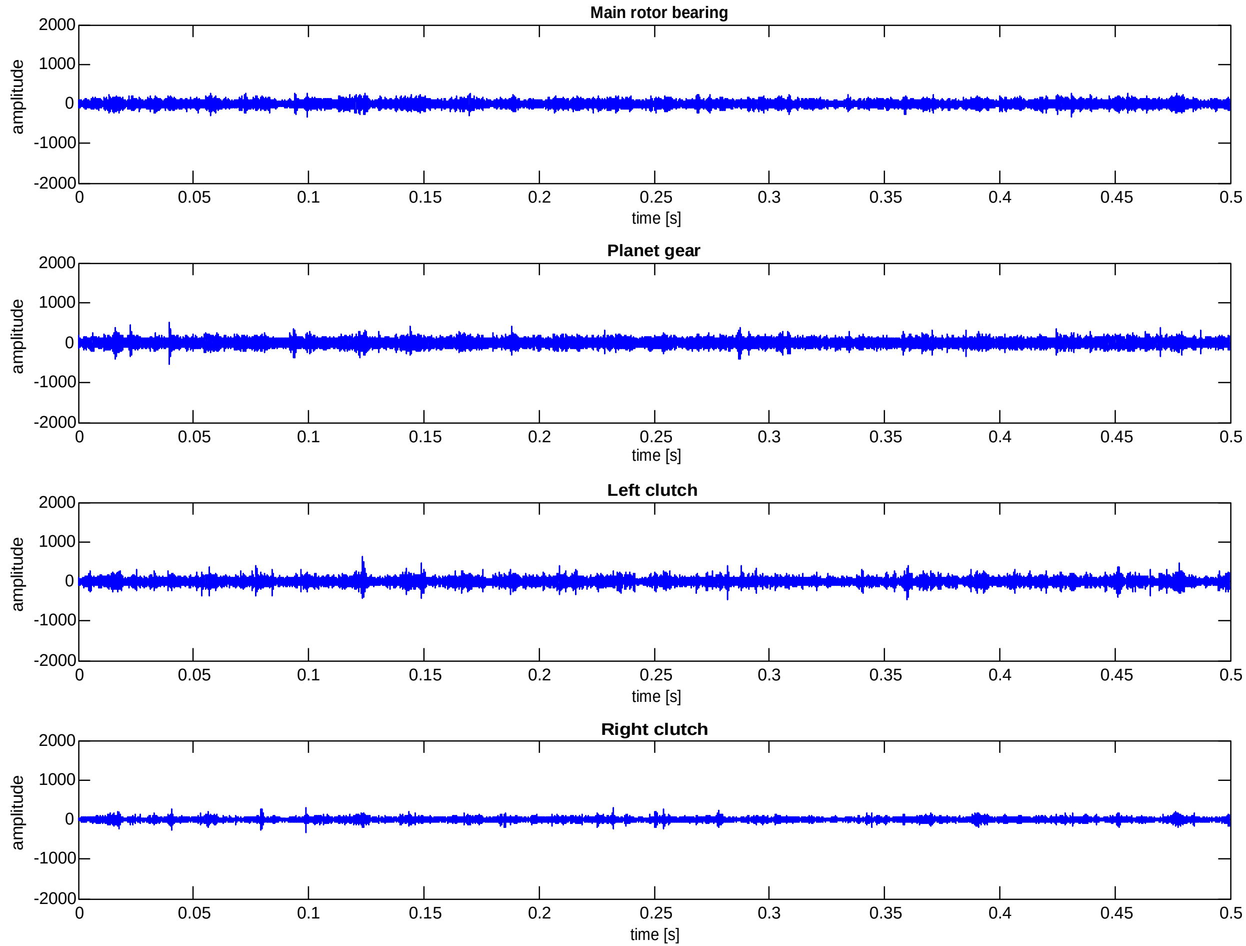


High-frequency-density spectrogram

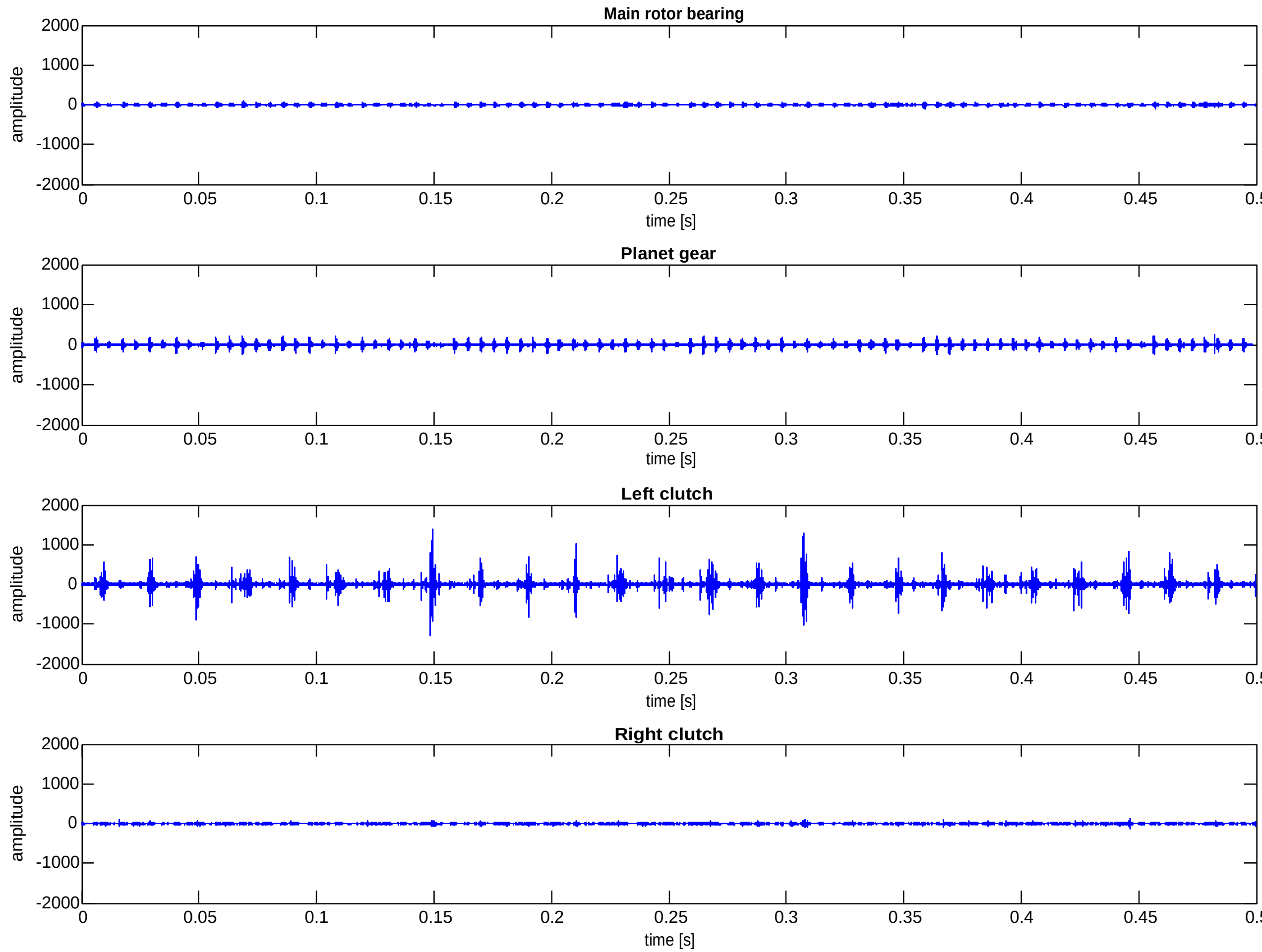
$$P(m, f_{rel} \cdot N_q) = \left| \sum_{n=0}^{N-1} x(n\Delta_s) \mathrm{e}^{-\pi i n f_{rel}} \omega(n - k \cdot m) \right|^2$$



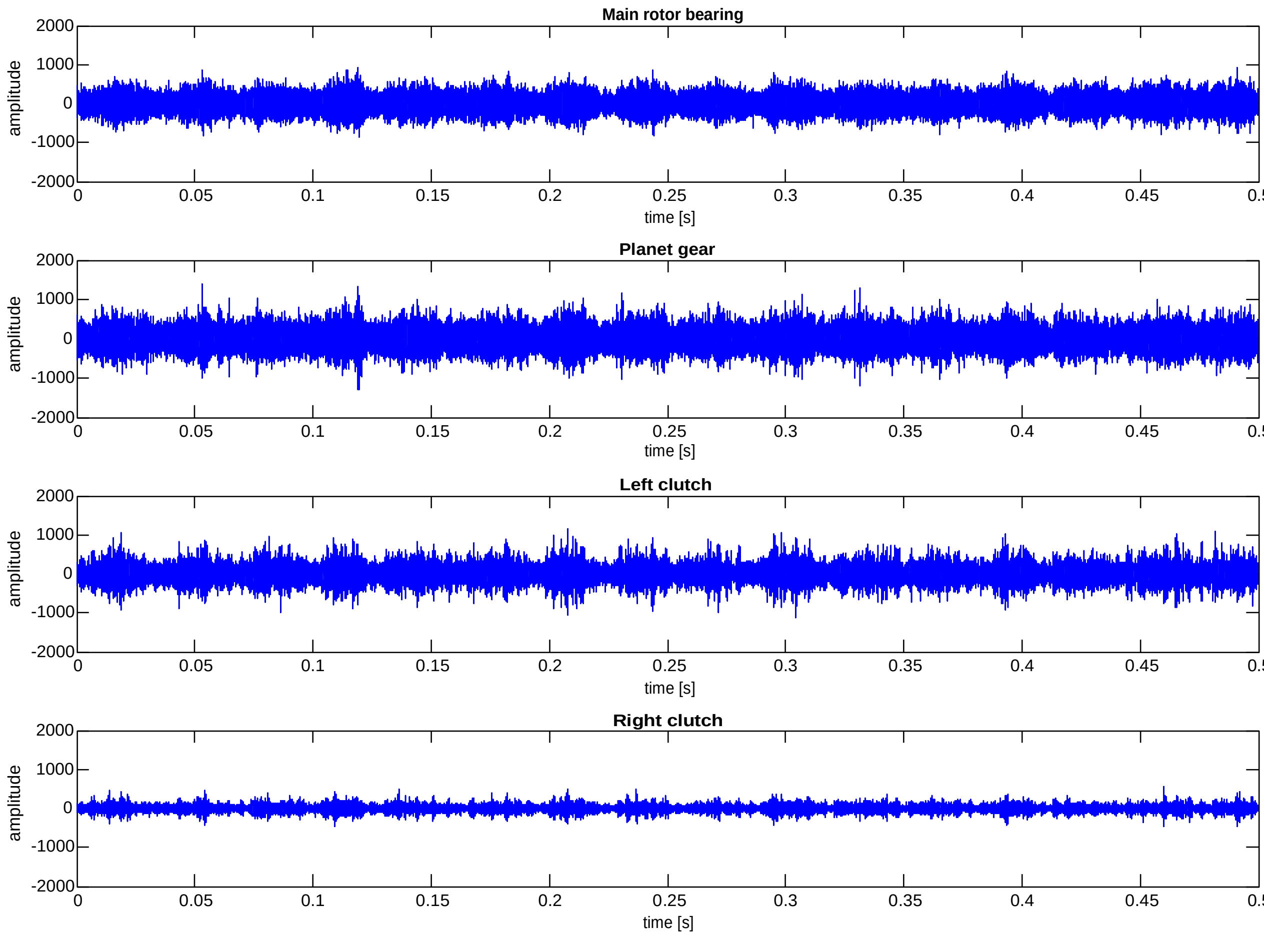
Signals from emission channels - „idling“ mode



Signals from emission channels - „engine starting“ mode



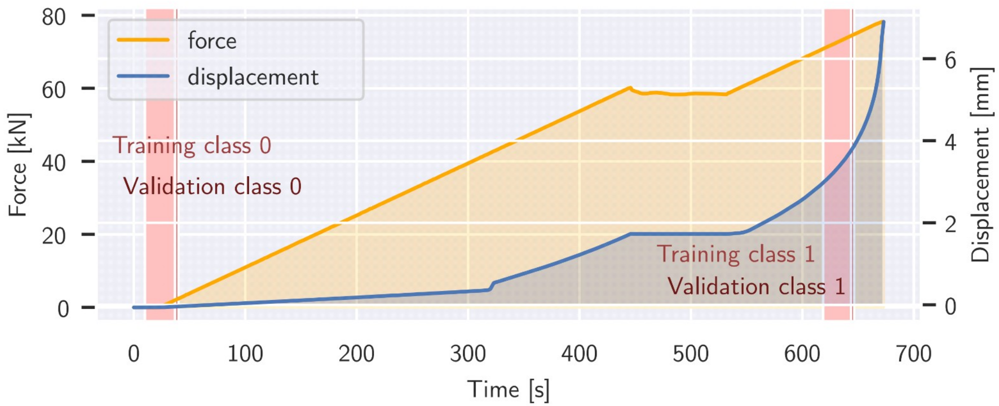
Signals from emission channels - “L nominal, R 80%“ mode

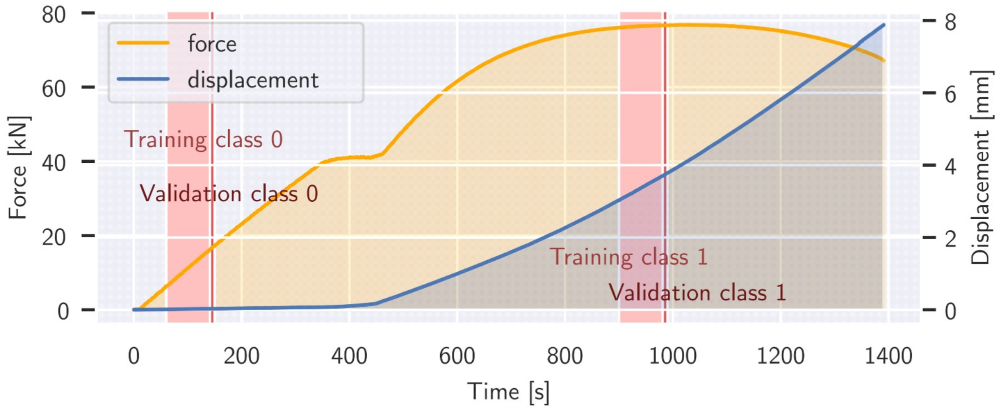


Tensile tests

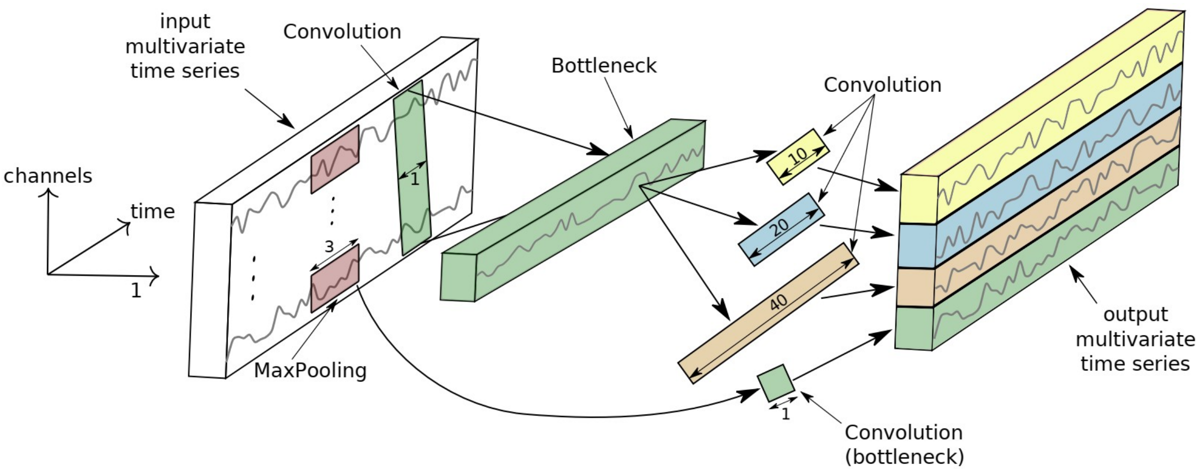
Experimental setup

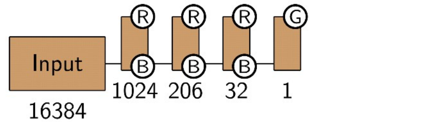
Training and validation data selection for Exp. A and B



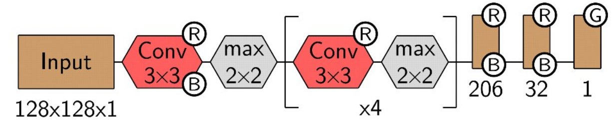


Application of *Inception Time* architecture

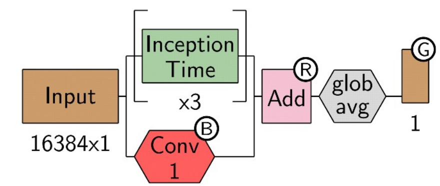




Perceptron architecture.

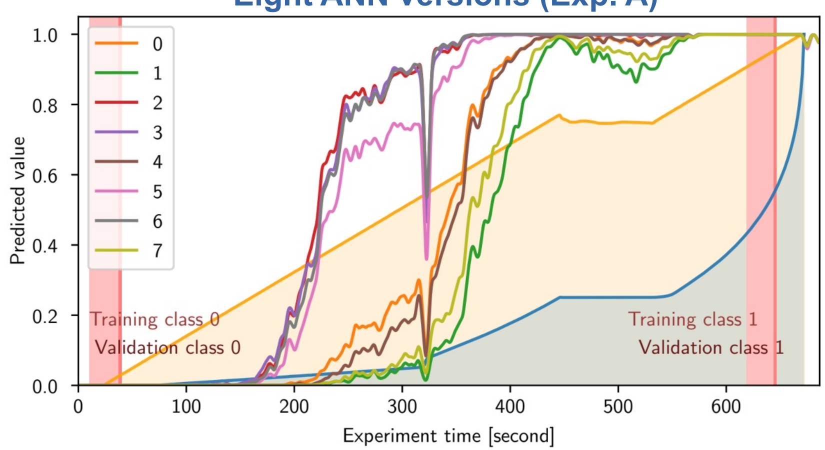


Simple ConvNet architecture.

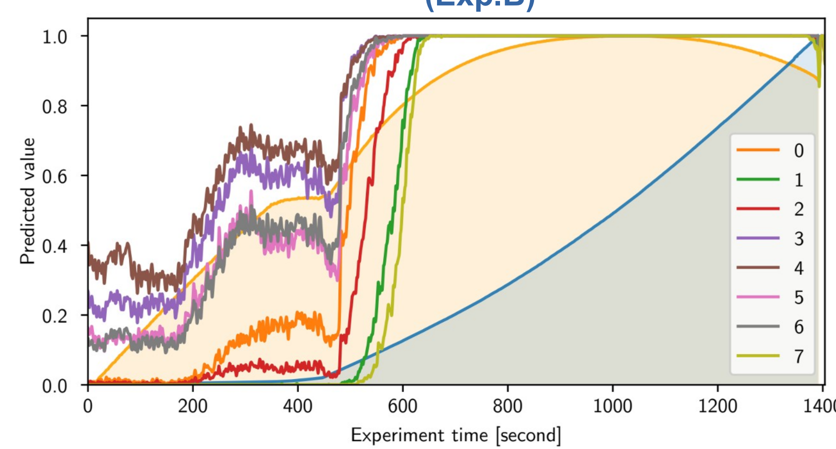


InceptionTime architecture.

Eight ANN versions (Exp. A)

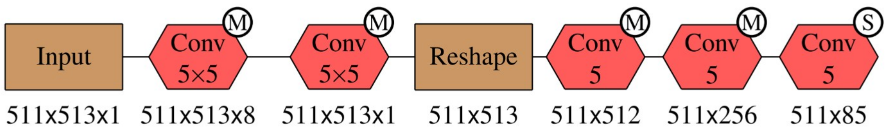


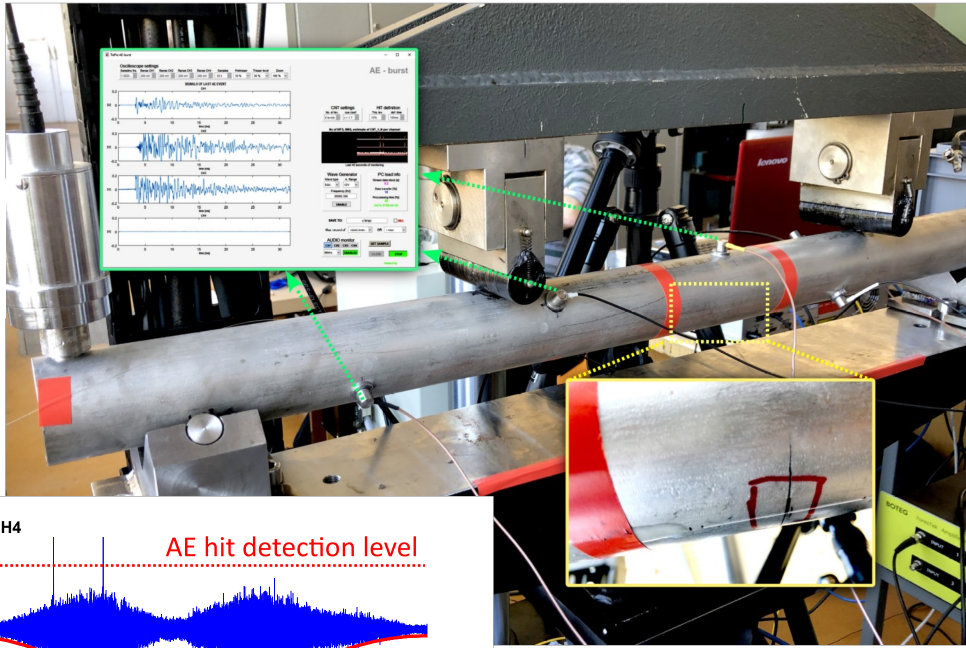
(Exp.B)

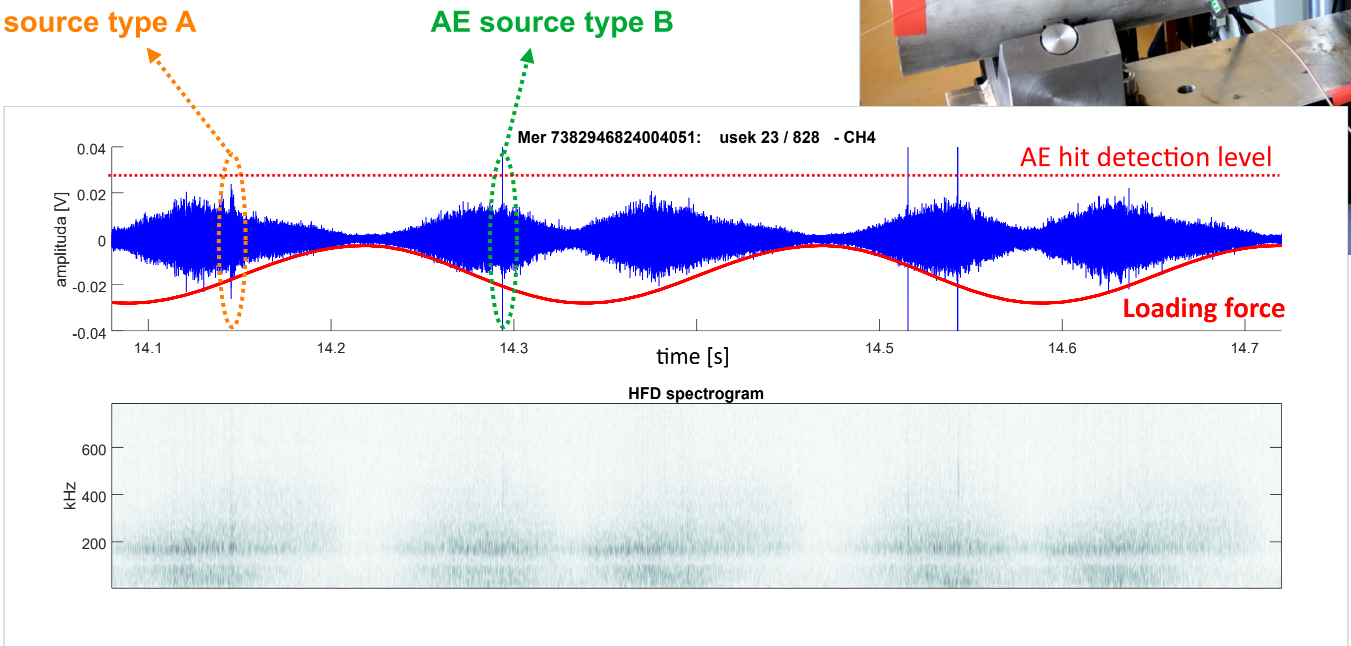


Identification of AE sources during fatigue tests

ANN-based detection of AE sources

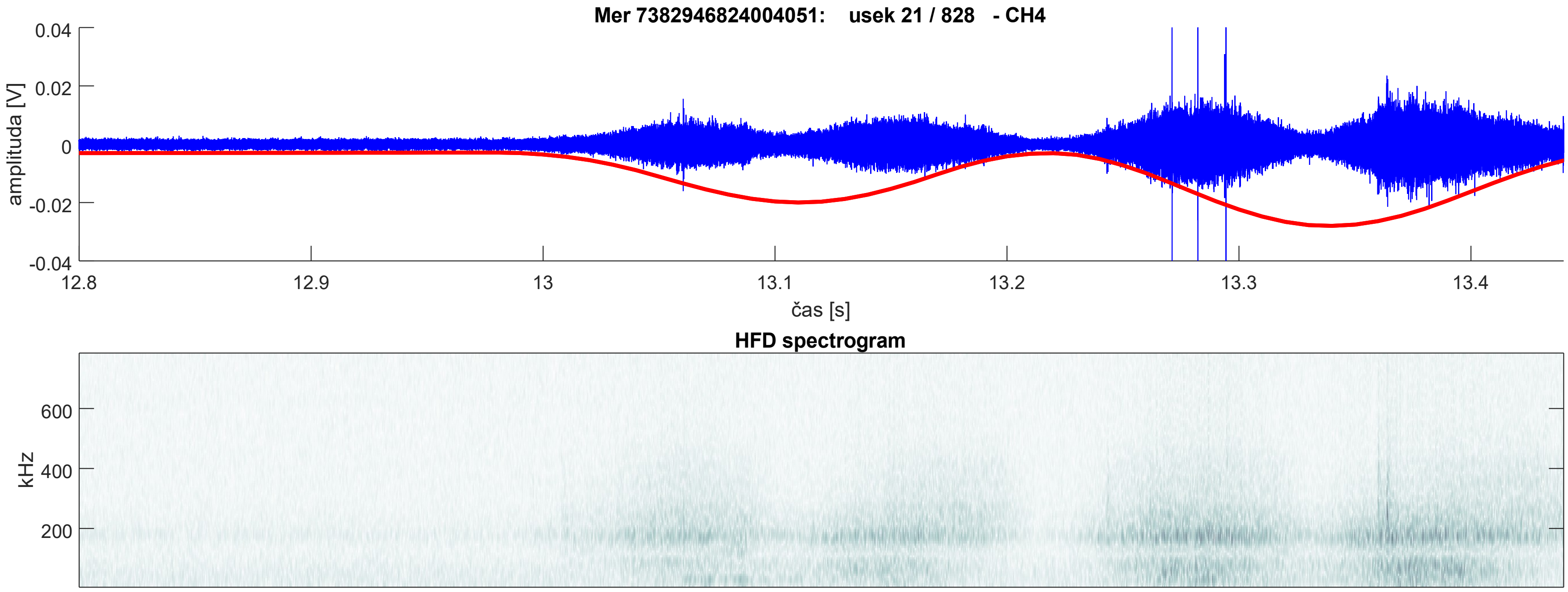




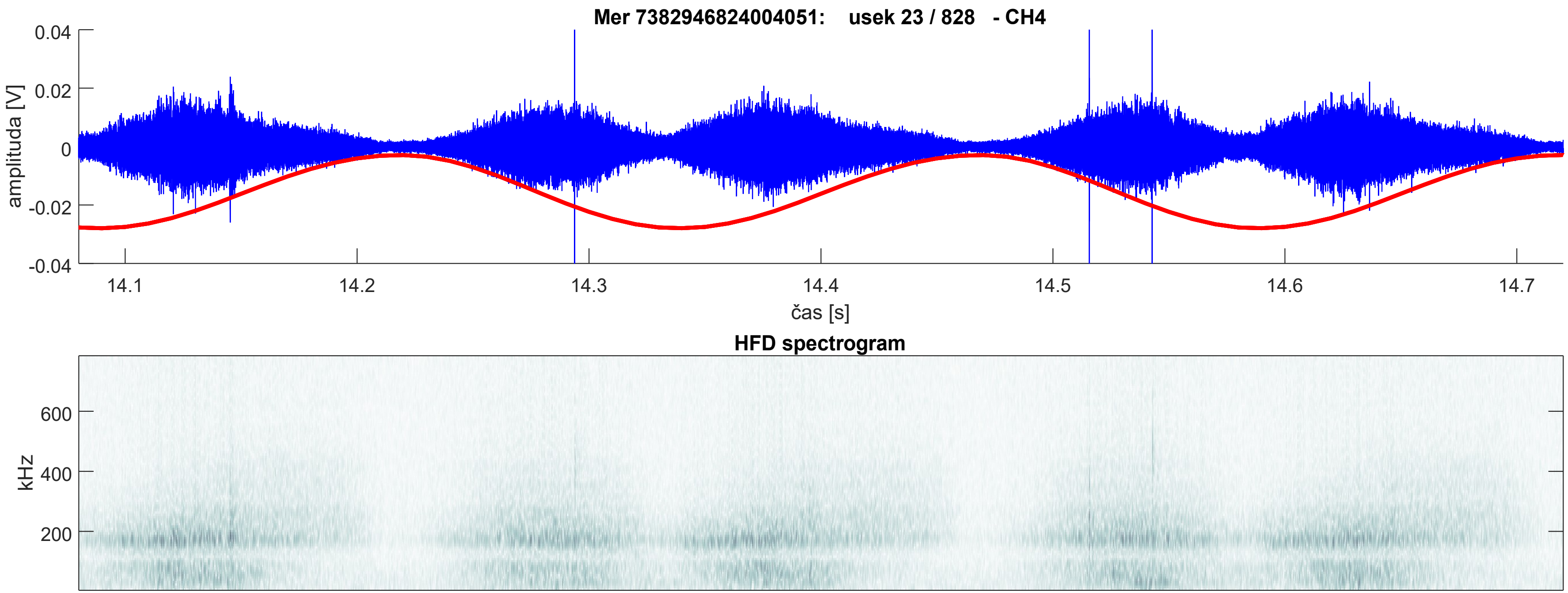


?!
DATA
ANNOTATION

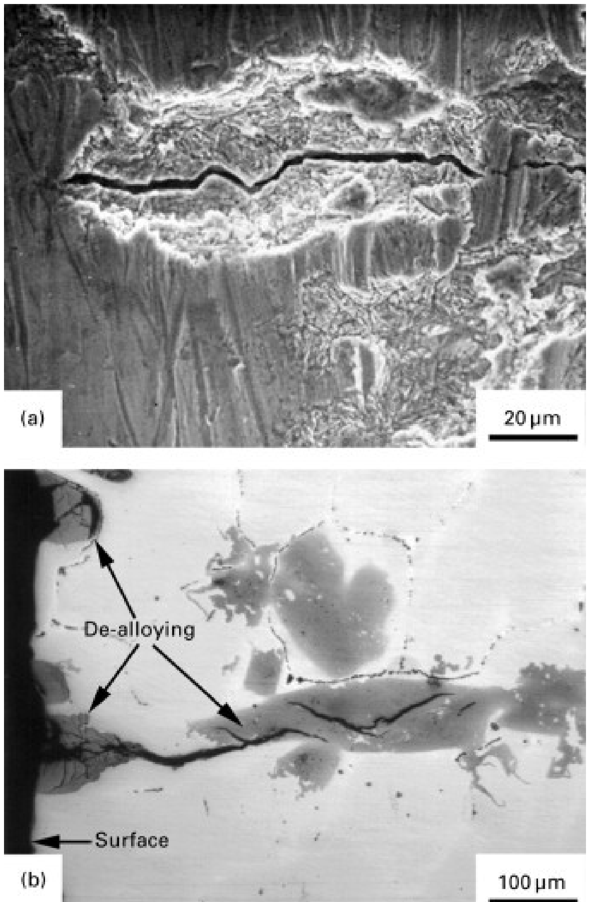
AUDIO demo of AE signal

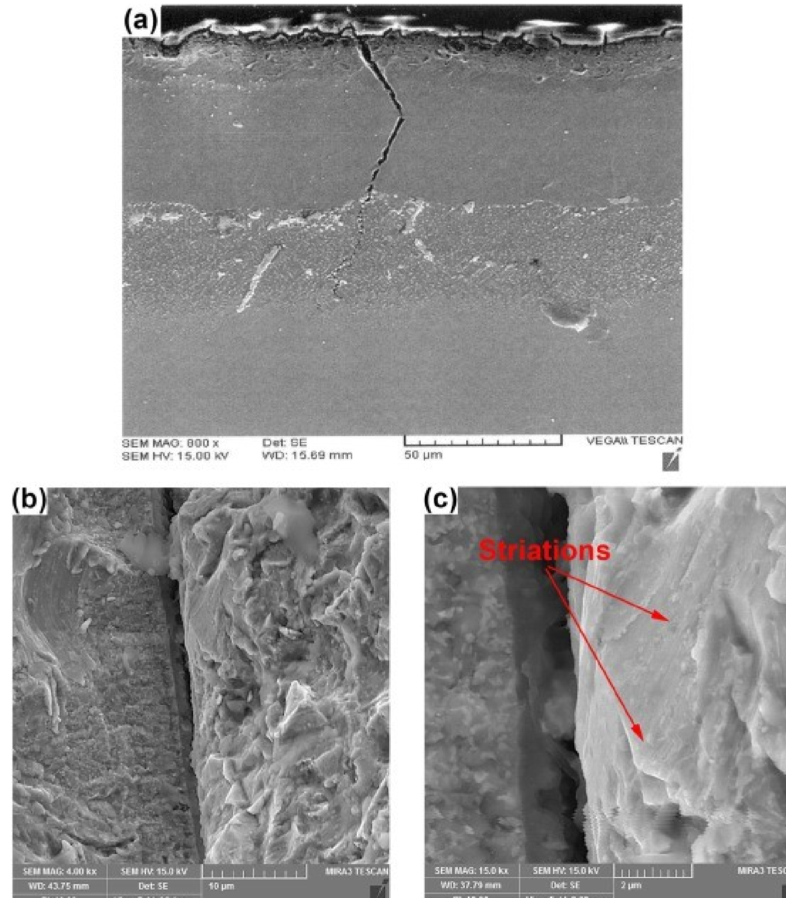


AUDIO demo of AE signal

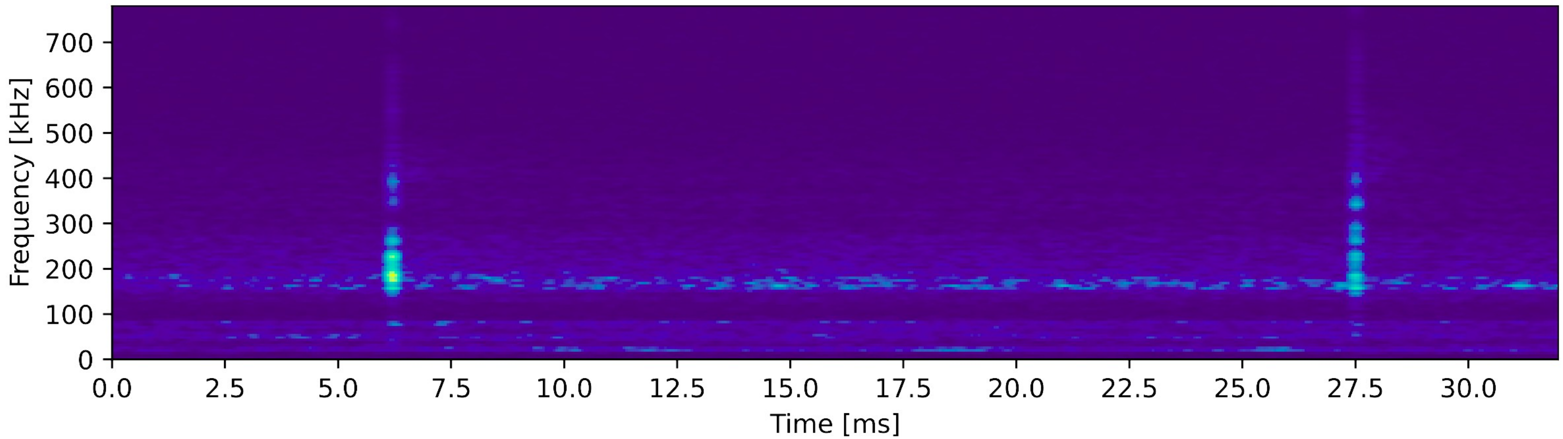


Initiation of Crack - an overview *(source: ScienceDirect)*

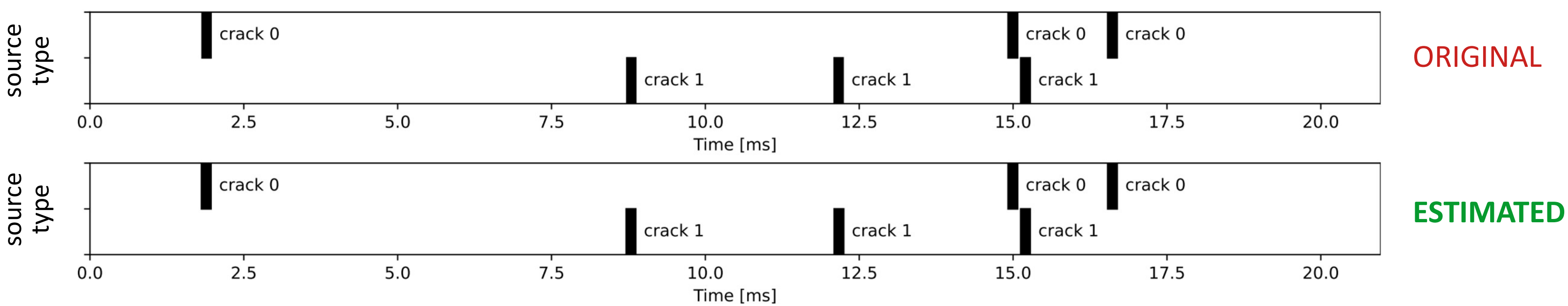




AE SIGNAL DEMO BLOCK

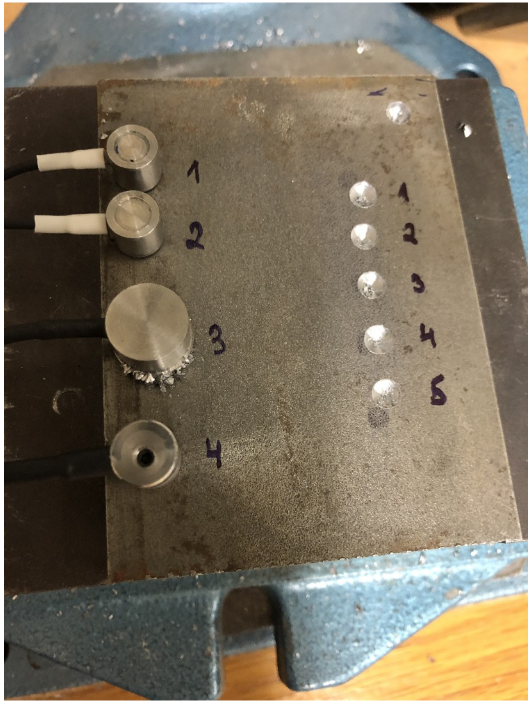


DEMONSTRATION OF TYPICAL AE EVENT LIST ESTIMATION **BY ANN**



Estimation of **drill bit sharpness**

Experimental setup

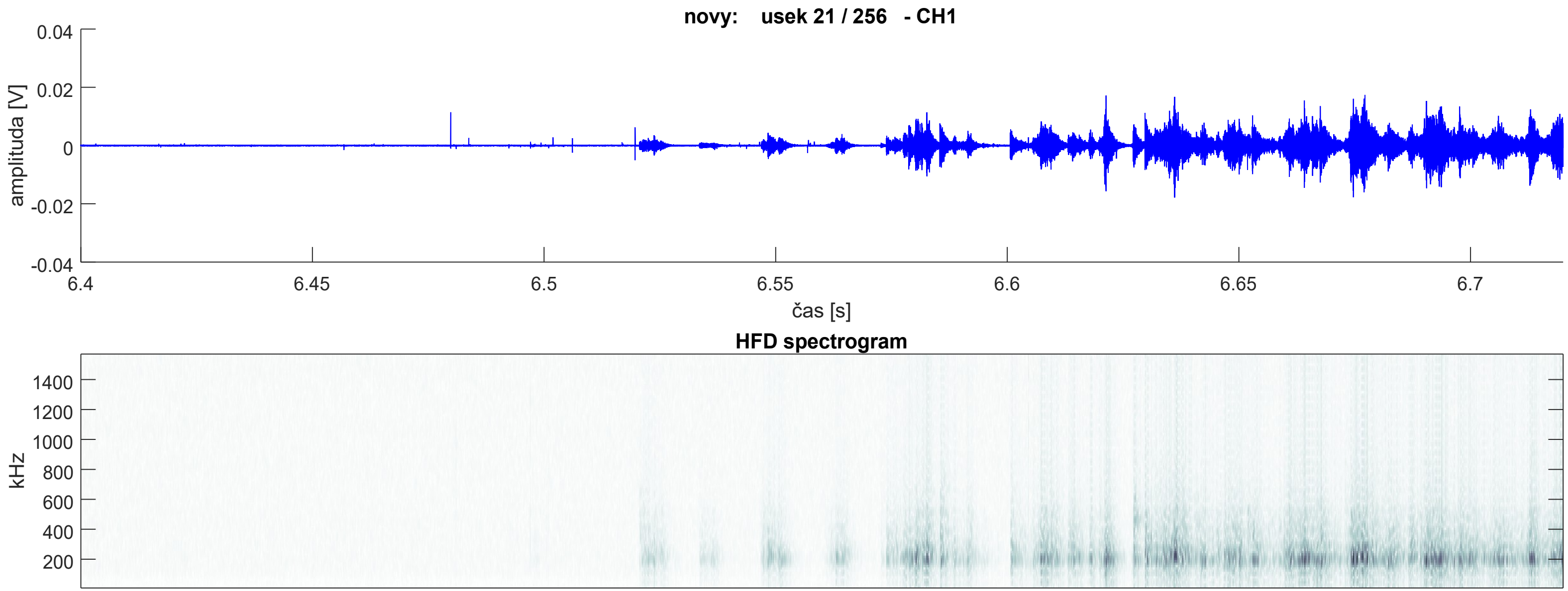


Specimen and AE sensors

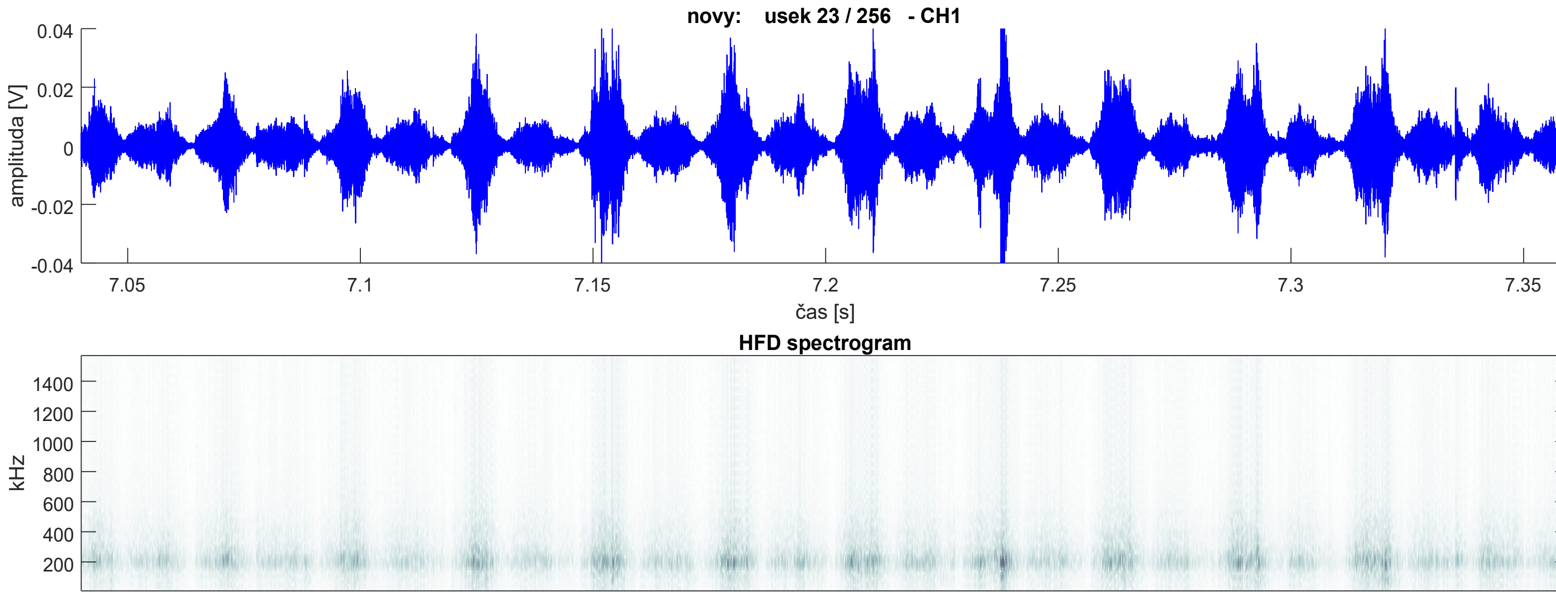
Drill bit dulling

(audio demos...)

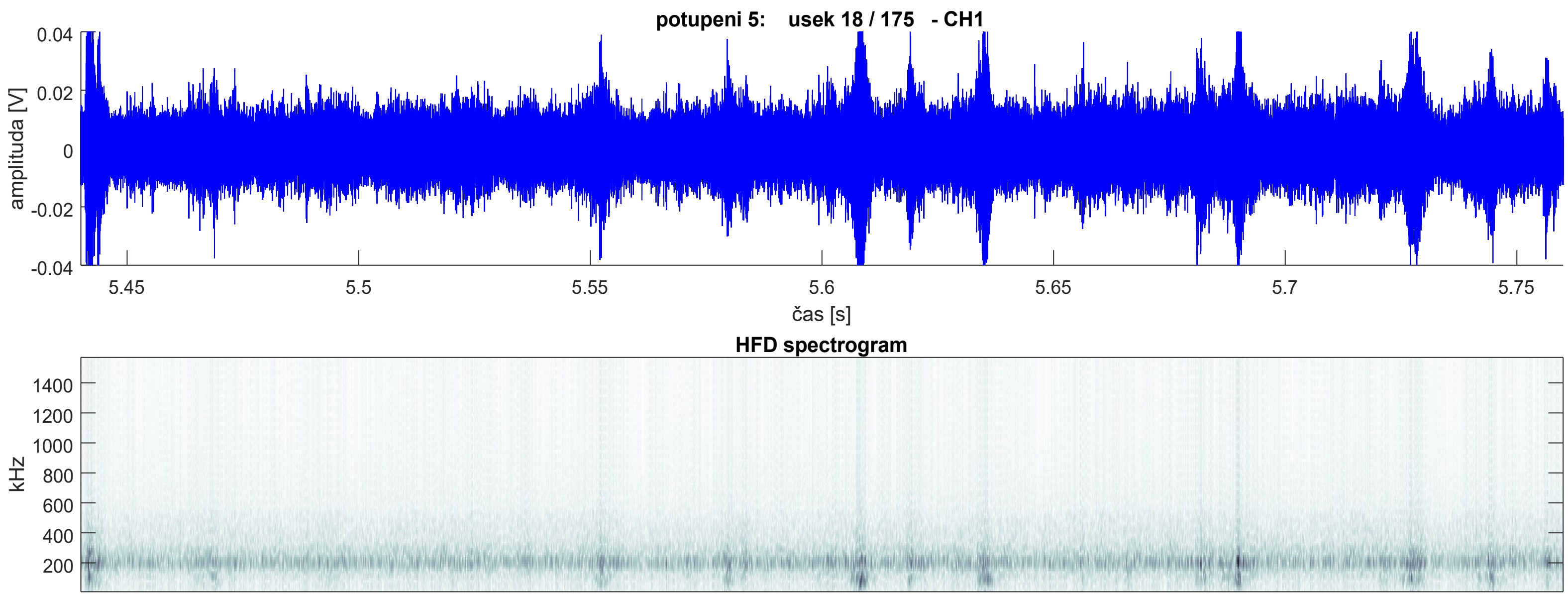
NEW drill bit “sound”



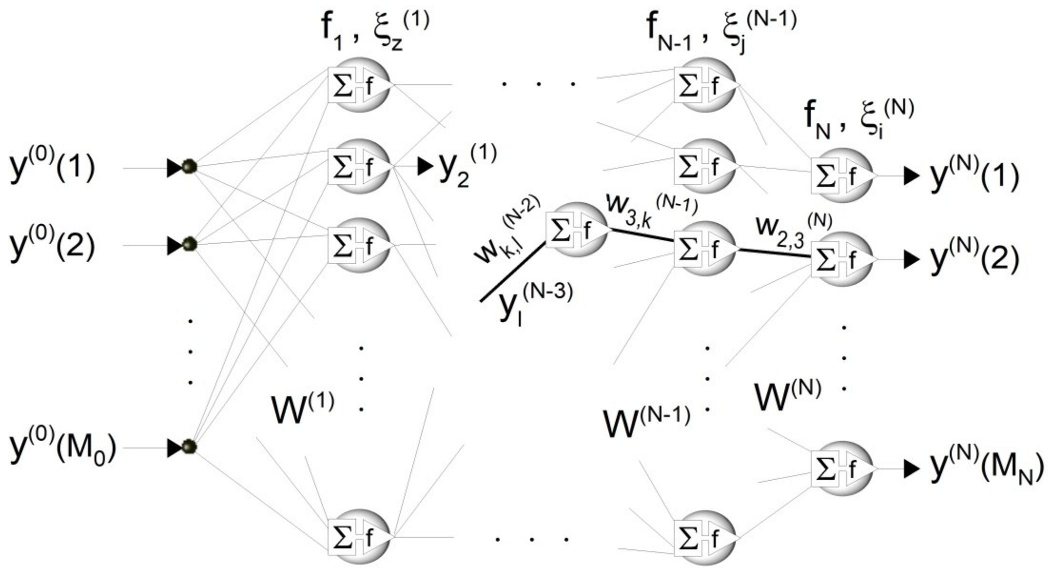
NEW drill bit “sound”



Drill bit "sound" after 5th dulling



AI model?



Thank you for your attention...