Gefördert durch:
Bundesministerium für Wirtschaft und Energie
aufgrund eines Beschlusses des Deutschen Bundestages

Universität Bremen

Elektronische Fahrzeug- und Mobilitätssysteme

Automatic detection of fractures during tensile testing using vibroacoustic sensors

J.V. Pimentel[1*], R. Klemm[1], M. Dalgic[2], A. Irretier[2], K.-L. Krieger[1]

Abstract

The detection of structure-borne sound can be used to monitor the structural health of solid structures and machine parts. One way to achieve such an implementation is to place vibroacoustic sensors in contact with the structure. The sensors will typically generate an electric signal in response to vibrations on the contact surface – in particular, to the acoustic emissions caused by specific events, such as fractures in the structure.

In this work, vibroacoustic sensors were used to detect structure-borne sound during static tensile testing of metallic samples until complete fracture. Simultaneously, force and deformation were measured by different systems.

An algorithm was written to process the data acquired from the piezo elements and automatically detect relevant events via a simple comparison with a pre-defined voltage threshol, detecting signals above the background noise level. A comparison of the vibroacoustic signal with the strain gauge measurements from the tensile test showed a very strong correlation between actual fractures (both the failure as the material breaks off and its posterior propagation of small or micro fractures) and the automatically detected events.

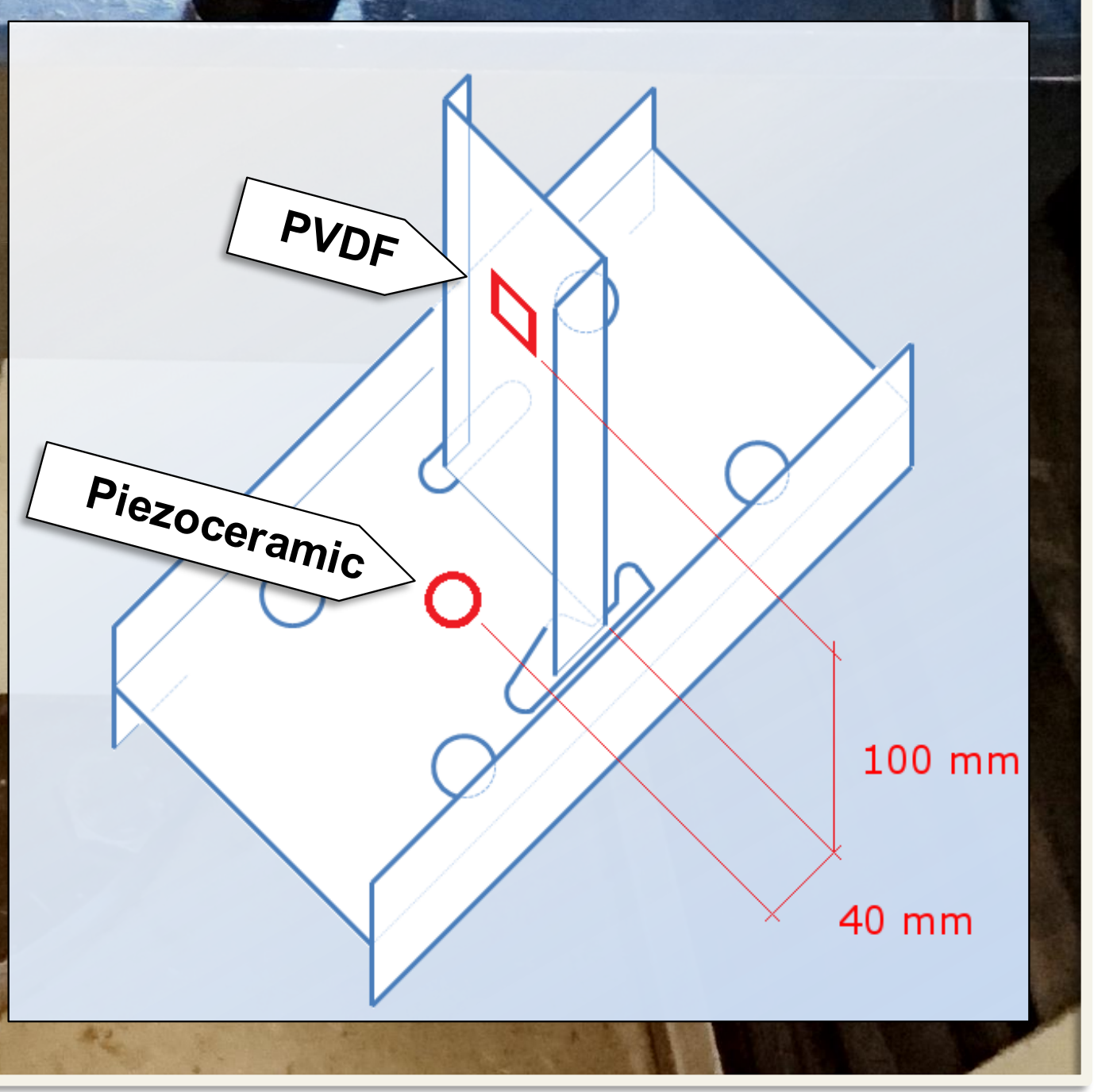
Motivation

- Vibroacoustic signals can be used to monitor the structural health of a structure
- Events such as fractures generate acoustic emissions that can be identified by their spectra
- The detection of VA signals can be carried out with passive sensors
- Unlike strain, structure-borne sound can be detected at distant points in the structure

⟶ **Structural Health Monitoring**

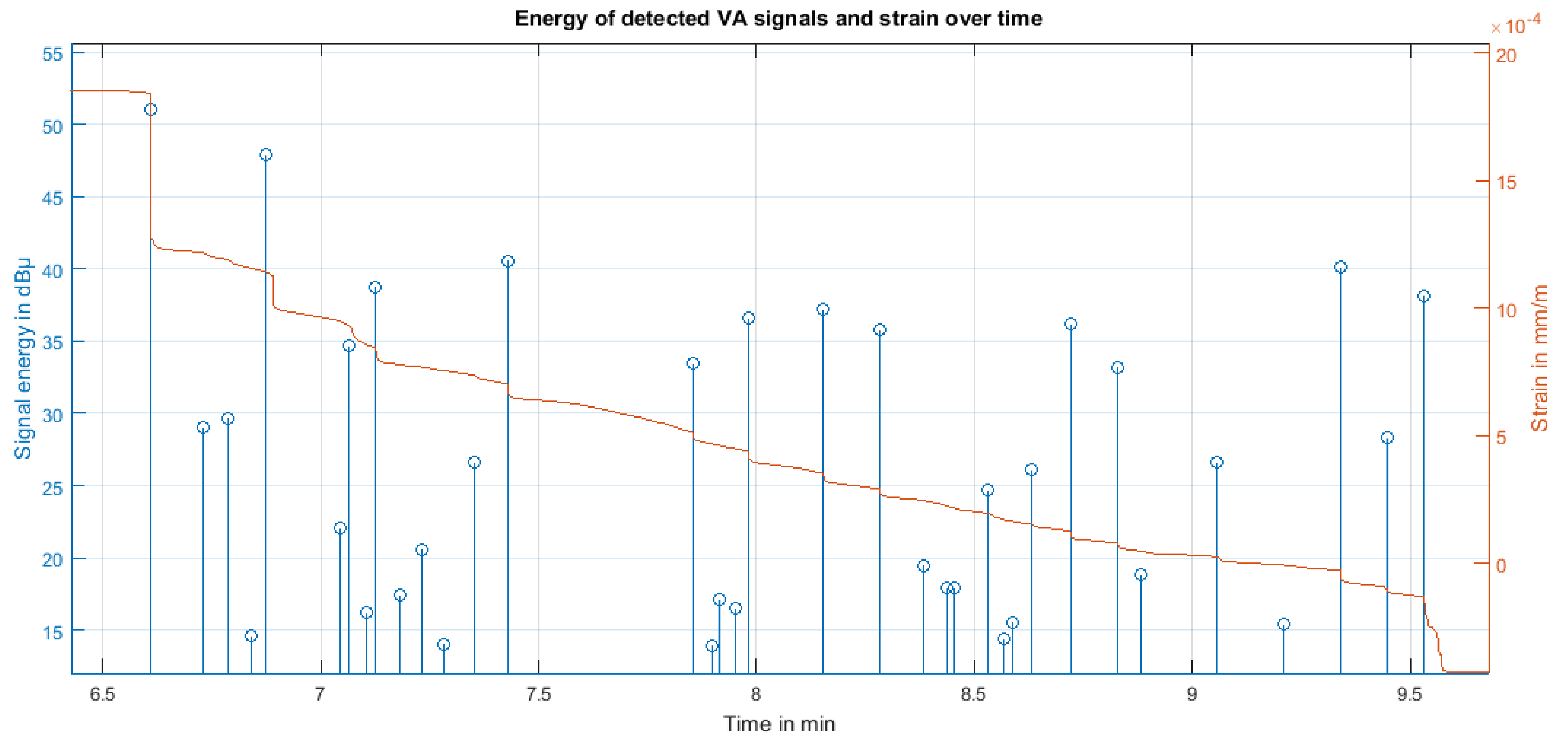
Experimental details

- Two types of piezoelectric sensors were used: PVDF film sensors glued to the sample; and ceramic sensors attached to the sample with a magnet adapter.
- The sensors were placed 100 mm and 40 mm away from the welded joint (see figure) where the fracture was expected.
- The samples used were sections of longitudinal beams made out S700 MC steel, 4 mm thick.
- Vibroacoustic signals were expected in a bandwidth of up to 2 MHz, measured with a samplig rate of 5 MHz.
- Strain gauges were used to measure strain on the test structures at a rate of 25 Hz.
- Fractures in the material lead to drops in the force and strain values measured.
- Sudden drops in strain values were used as a primary indication of micro- and macrofractures. We used the value of its time derivative for a quantitative comparison with the intensity of the detected vibroacoustic signals.



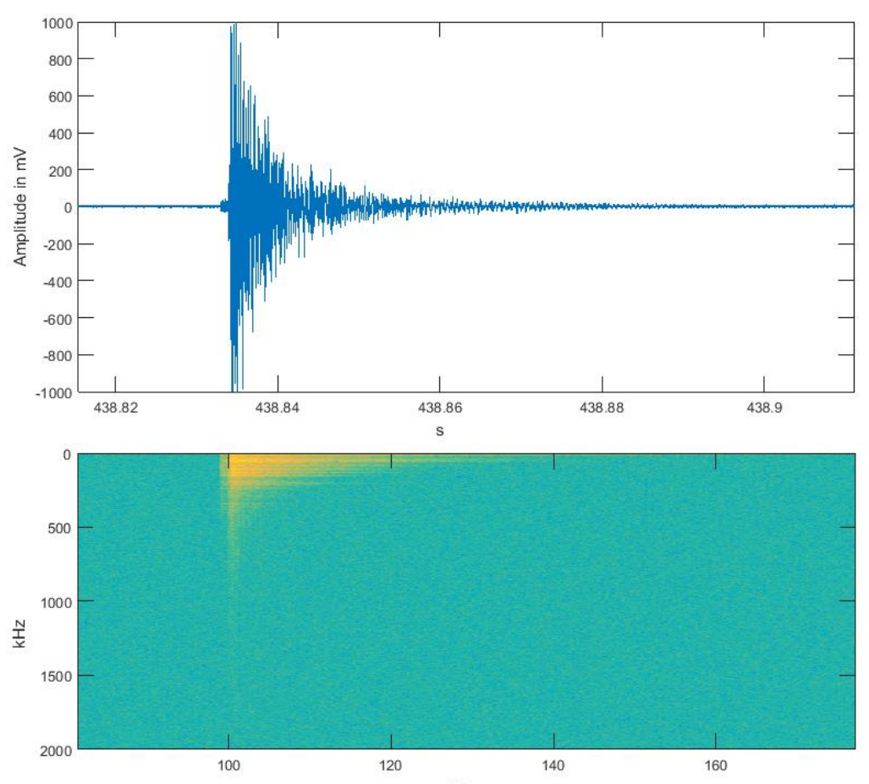
Measurement results (example)

- A linearly increasing force was applied to the sample, starting at 55 kN.
- At approximately 100 kN the sample fractured.
- Time until fracture: 6.6 min
- Strain at fracture: 1.85 µm/m



Automatic detection of vibroacoustic events

- A voltage threshold is defined above background noise
- To allow for the decay of the acoustic signal, a time window is set before which another threshold-crossing is not counted.
- A typical time window of $v_t = 1$ s is enough for most events, but may count several events as one.
- The value of the energy v_e in each detection was used for comparison in discrete instants.

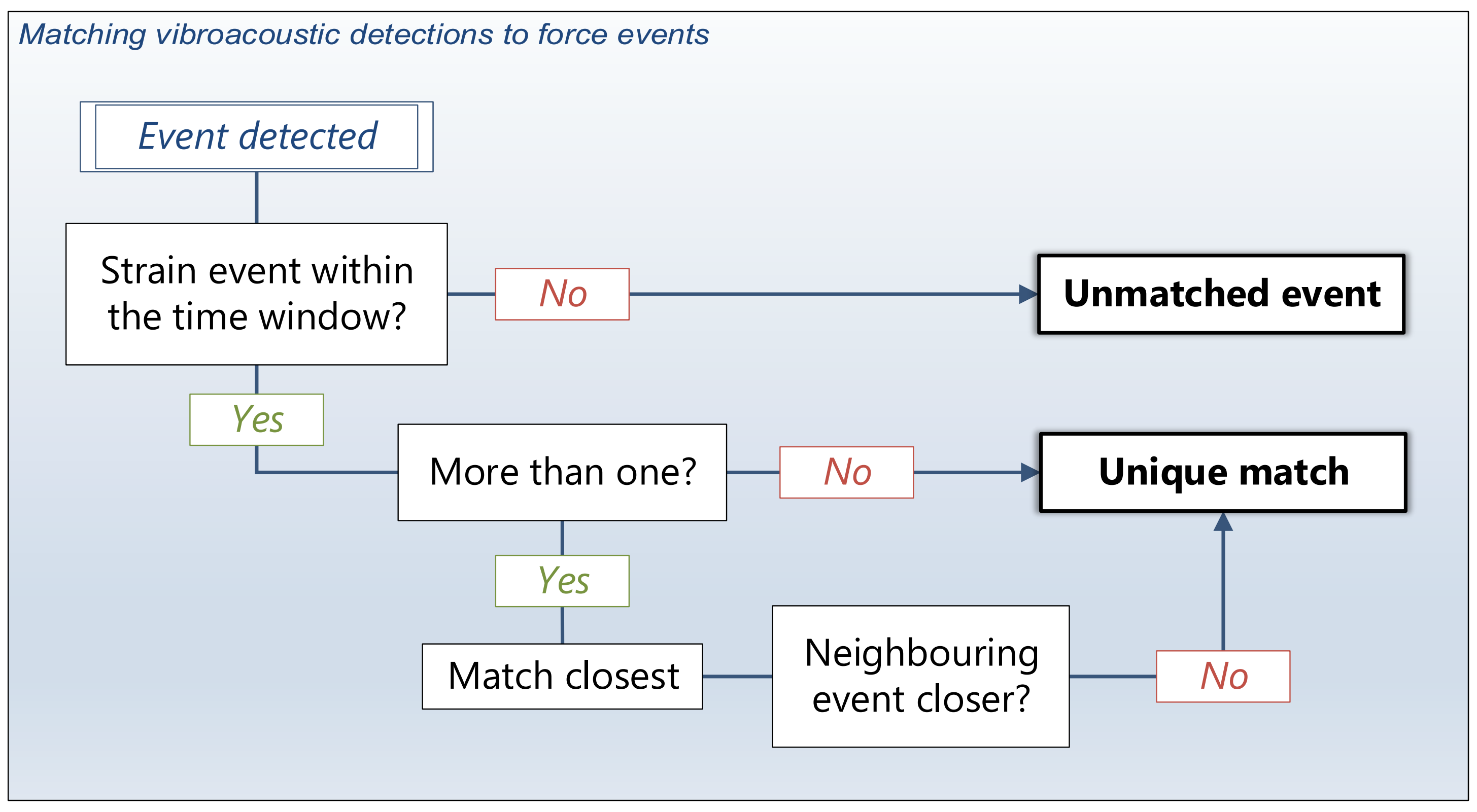


Comparison between strain values and detected vibroacoustic signals

- The two sets of data were synchronized using the failure event – Usually corresponding to the strongest signal under both methods.
- To determine discrete times from the strain measurement, a drop threshold s_d was defined. If the threshold was crossed, the signal was integrated for $s_t = 0.1$ s and the maximum within this window was set as the instant of the event.
- Each VA detection was matched to drops in strain within its time window. In case more than one was found, the closest was considered as a *unique match*, and the remaining as *redundant* matches.

It can be clearly seen that the larger VA signals correlated very strongly with drops in the strain. For weaker signals, it was not always the case. A 100% match was not expected, since not every source of acoustic signal will correspond to a relaxation of the structure. Nevertheless, stronger emissions were always aligned with a sudden decrease in strain.

We therefore considered only acoustic signals above a certain energy level for comparison.


Matching vibroacoustic detections to force events

Event detected

Strain event within the time window?

No

Unmatched event

Yes

More than one?

No

Unique match

Yes

Match closest

Neighbouring event closer?

No

Quantitative limits

- VA events with energy > 20 dBµ
- Strain events with drop > 2.5 mm/m·s
- Time window of 1 second

Results

- 20 unique matches
- All but one VA event could not be matched to drops in strain
- Maximum time difference between corresponding events: 0.14 s

The process described was repeated with other identical longitudinal beams tested under similar conditions.
Automatic detection and comparison were performed.
The results were coherent, as shown.

Sample	A	B	C
Energy threshold dBµ	20	0	0
Strain/force threshold (%)	0.87	0.26	6
Unique matches	20	11	9
Unmatched VA events	1	0	1
Unmatched force events	3	6	3
Maximum delay (s)	0.14	0.22	0.43

Conclusions

- Vibroacoustic signals can clearly be correlated to sudden large drops in strain or force
- For weaker signals, the correlation is not as strong
- Structure-borne sound can be used to detect fractures and failures in metallic structures with a reasonable reliability

*Contact:
Dr. João Pimentel
University of Bremen, ITEM
Otto-Hahn-Allee, NW 1
Raum W3050
Tel.: +49 (421) 218 62567
Email: jpimentel@uni-bremen.de

[1] University of Bremen
ITEM, Automotive Electronic Systems
Prof. Dr.-Ing. Karl-Ludwig Krieger

[2] Bremen Institute for Materials Testing (MPA)
Metallic Materials and Structures
Dr.-Ing. Andree Irretier

Universität Bremen

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