Feature Extraction and Sensor Fusion for change/damage detection in concrete using embedded ultrasonic sensor

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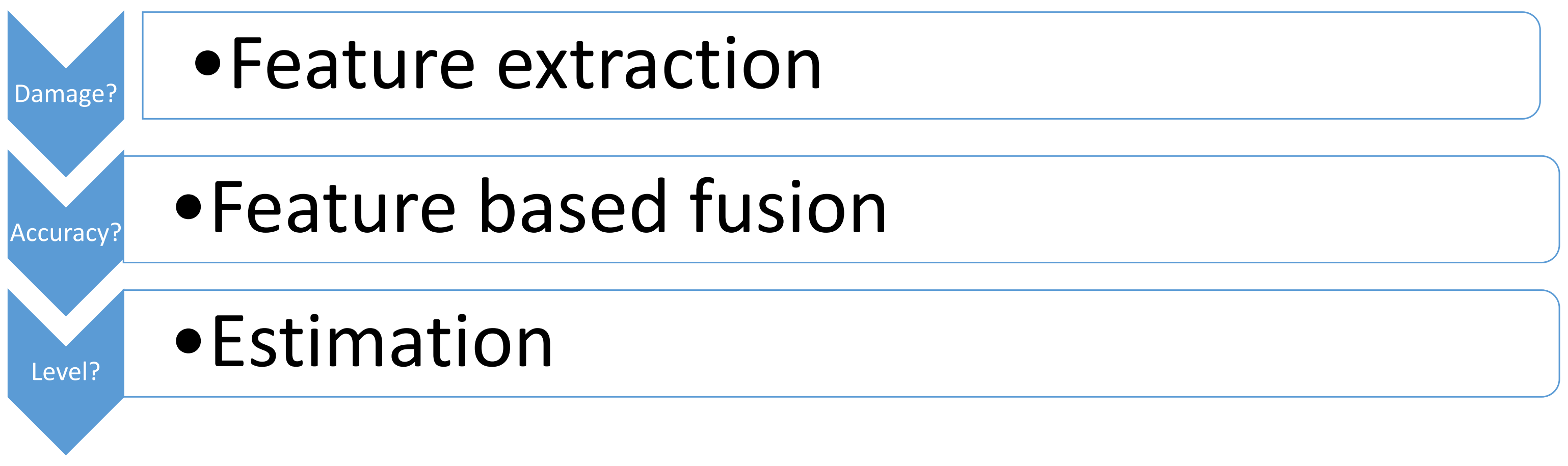
Problematic

There are a lot of Structural health monitoring systems in concrete structure, but not always give good results.

- Modal-based damage/change detection methods usually require large amount of high-quality data.
- Large number of sensors strategically located.
- Inspection of the presence of damages in the structure.

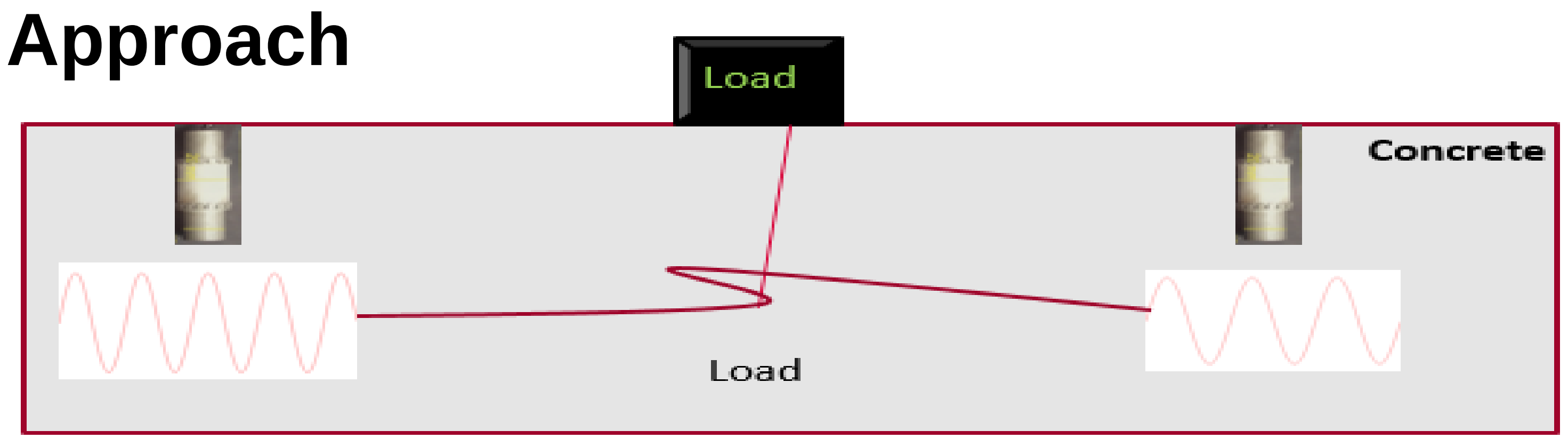
Objective

The idea behind data fusion is to combine information from multiple sensors to improve overall performance of damage detection and quantification. Techniques to integrate the information coming from multiple sensors located in the same area of the structure and synchronized in time, that do not show the same accuracy (different uncertainties), have received relatively little consideration in structural health monitoring (SHM). Multi-Sensor fusion techniques seek to address these challenges:



- Feature extraction
- Feature based fusion
- Estimation

Approach



- ✓ Ultrasonic system is based on sending and receiving ultrasound waves inside a structure.
- ✓ The main benefits of is its sensitivity.
- ✓ Normally above 20 kHz frequency introduced into the material.
- ✓ Need at least two sensor to do the Ultrasonic test.

Data acquisition system

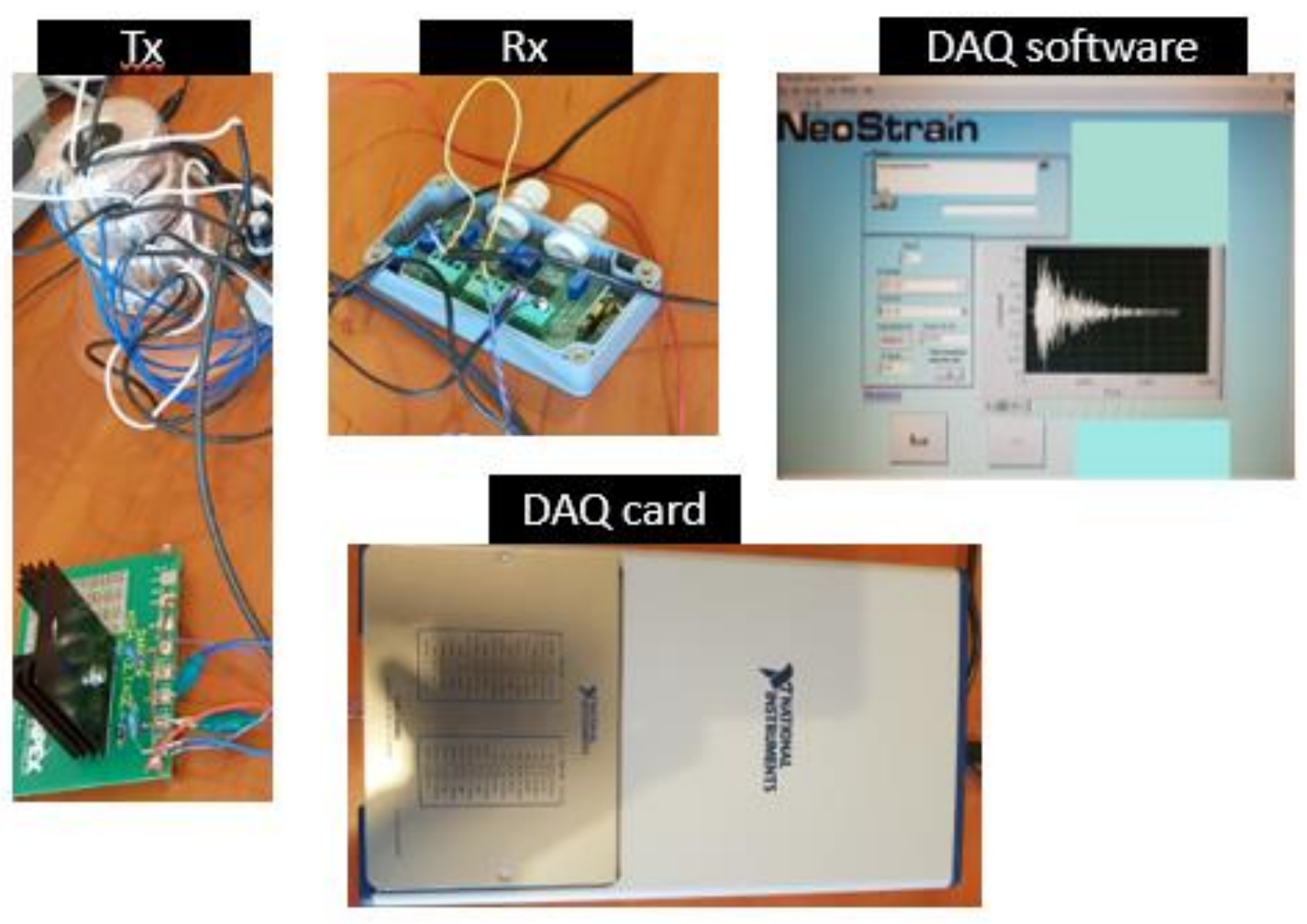
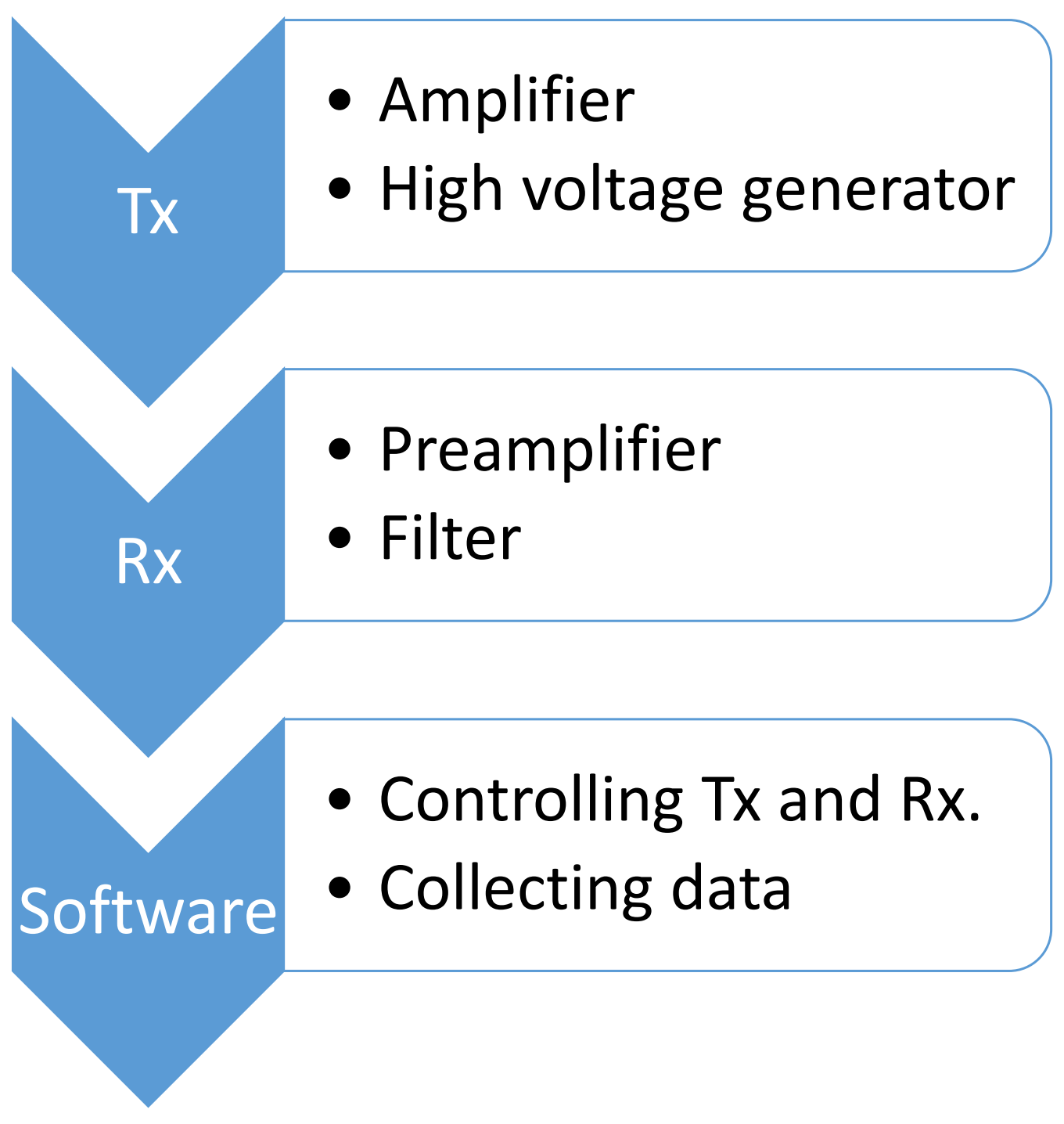


Figure 1: Measurement System



- Tx
  - Amplifier
  - High voltage generator
- Rx
  - Preamplifier
  - Filter
- Software
  - Controlling Tx and Rx.
  - Collecting data

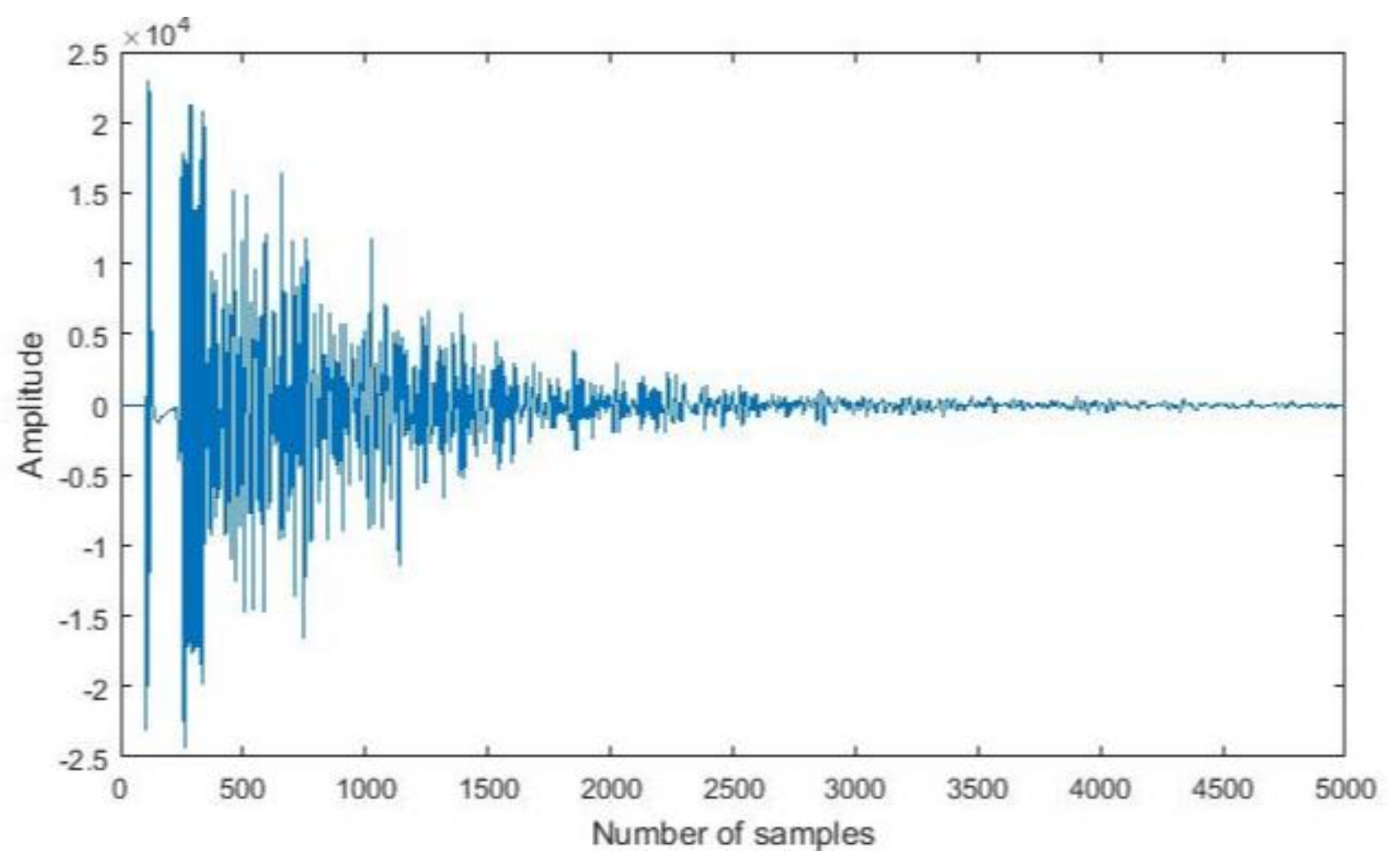


Figure 2: shows the ultrasonic reference signal

Figure 3: BLEIB Structure at Horstwalde, Berlin.

Methodology

Figure 4 illustrates the general frame of data fusion, where $X_{1,1} \ldots . X_{1,n}$ is the vector of data from one transducer pair T_{11}, $F_{1,1}$ is a feature value from one transducer pair, and D_1 is the decision from the m features extracted from $X_{1,1} \ldots . X_{1,n}$. In step 1, "Feature level fusion" boxes represent the step of computing the features from all transducer pairs and the use of a threshold (for receiver operating characteristic (ROC) analysis to each feature of each of the transducer pairs. In Step 2, the decisions taken from each sensor pair, are fused thanks to a binary declaration in terms of operational changes (like, "presence/absence of load", "presence/absence of crack" etc.).

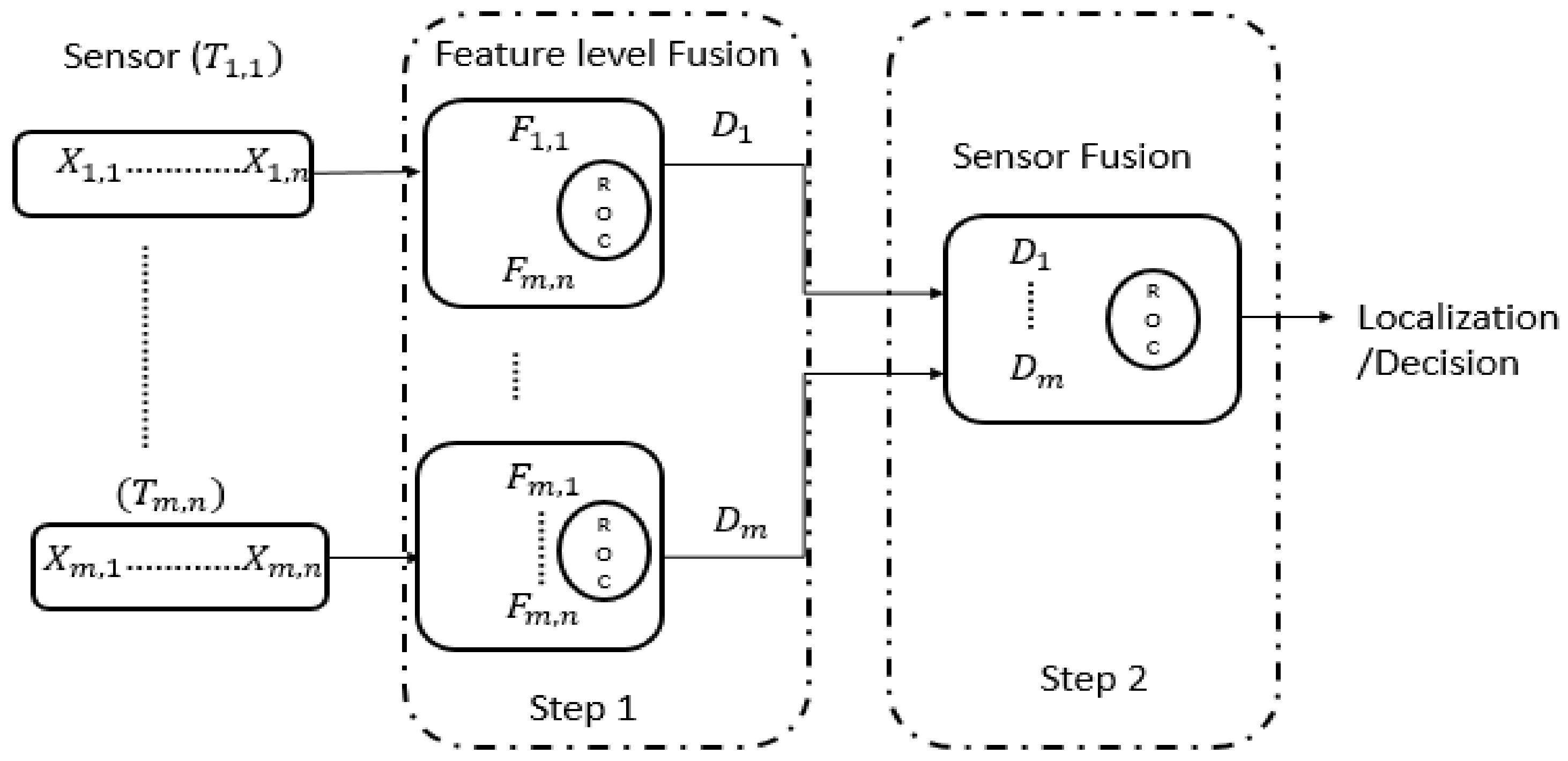


Figure 4: shows the two-step feature based sensor fusion model

Features extraction

Features extracted from one sensor pair	Equation
Drop in Correlation Coefficient (decorrelation) [Hay et al., 2006]	$\rho_{xy} = \frac{\int [u_i(t) - \mu_{u_i}][u_p - \mu_{u_p}]dt}{\sigma_{u_i}\sigma_{u_p}}$ $D_{cc} = 1 - \rho_{xy}$ (Eq. 4) Where, $u_i(t)$ is a reference ultrasonic signal and $u_p(t)$ is the monitored signal. μ_{u_i} and μ_{u_p} are the mean values of the two signals.
Autoregressive model [Clark et al., 2008]	$\varepsilon(t) = u_i(t) - \sum_{i=1}^{n} \alpha_i \overline{u}_i(t-i) + e_m$ (Eq. 5) Where, $u_i(t)$ is a reference ultrasonic signal and $\overline{u}_i$ is a predicted signal. e_m is a Noise. And α_i is a coefficients of the AR model

- Two features are computed from the time-domain signals collected on the BLEIB structure by one pair of ultrasonic sensors (S13E14).
- The features are obtained from the decorrelation coefficient D_{cc}, and the coefficients Ui(t) of an autoregressive model (Table).
- For each of the two features a predetermined threshold is swept over the range of the feature values (ROC).
- A perfect detector, that calculates the features accuracy, measures the value area under the curve (AUC).

Results

- ❖ It can be observed that both features perform fairly well in their ability to separate the quasi-static and dynamic loads states in the presence of noises. .
- ❖ High decorrelation coefficients may be an indicator of the opening of cracks. The drop in correlation coefficient is larger (AUC = 0.69) than the one of the feature extracted from the autoregressive model (AUC = 0.62).

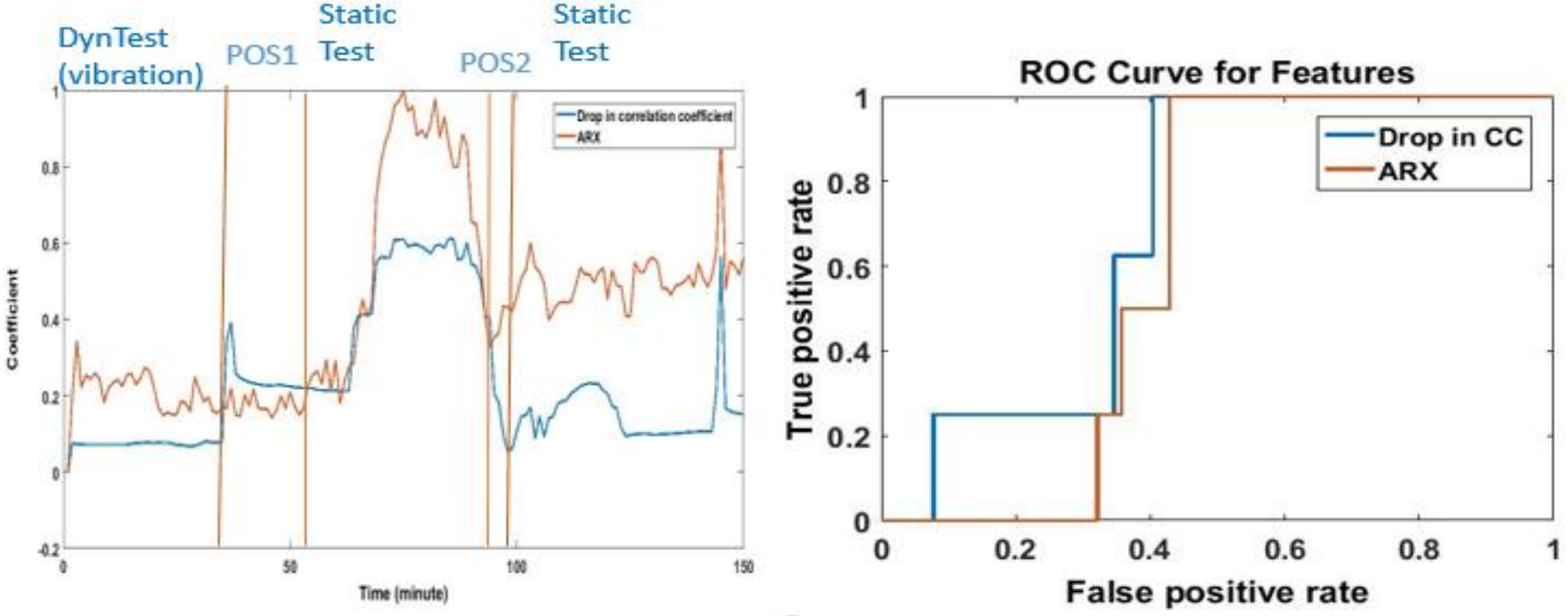
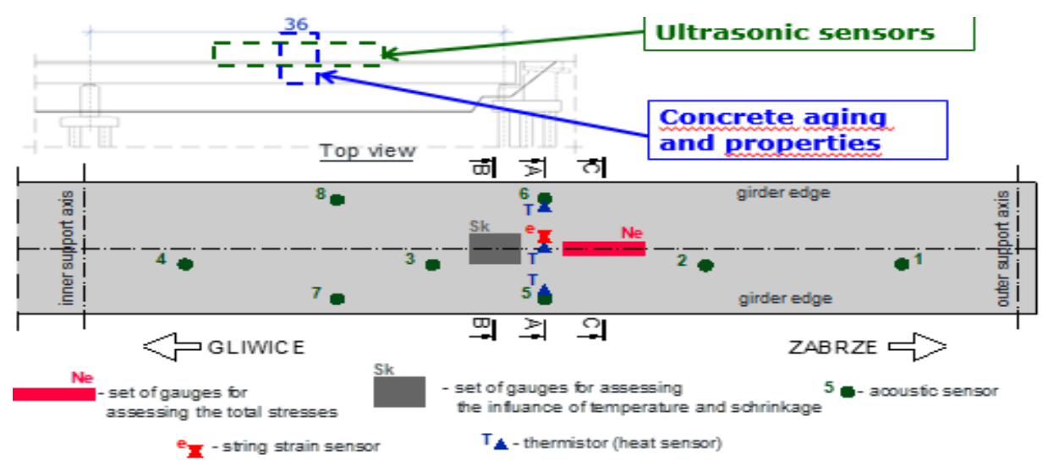


Figure 5: results obtained from the ultrasonic one transducer pair as a function of time during the loading experiment features and ROC

Conclusion and Future work

- ❖ Hence, even though a best feature may exist for a particular transducer pair and a specific threshold, it may be suitable to use the information from all features of all transducer pairs to detection of operation changes (such as crack opening or concrete damaging).
- ❖ We will use fusion technique for our next test

at our lab and sensor in Gliwice Bridge.



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