On Board Monitoring for Railway Infrastructure Condition Assessment

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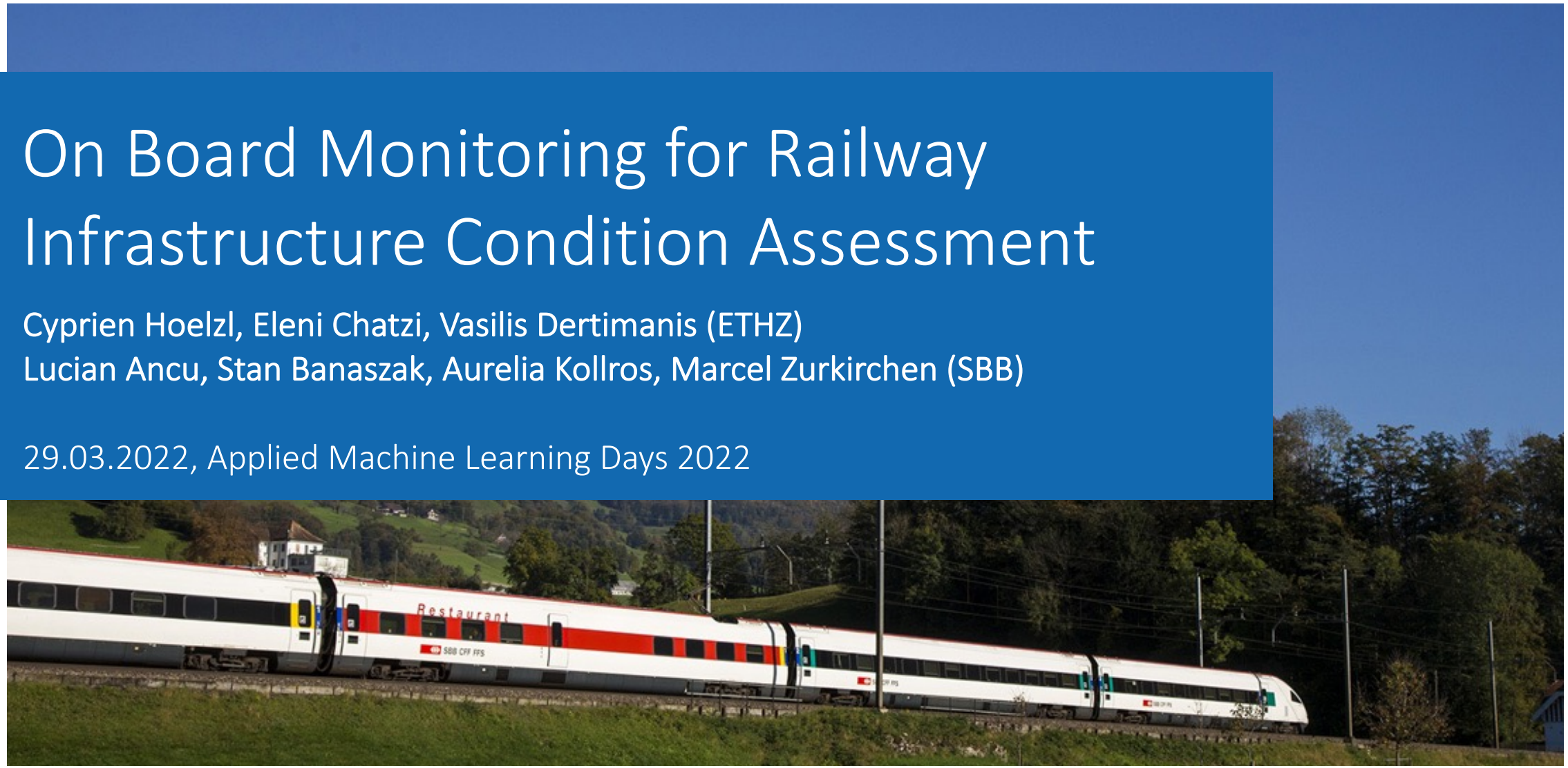
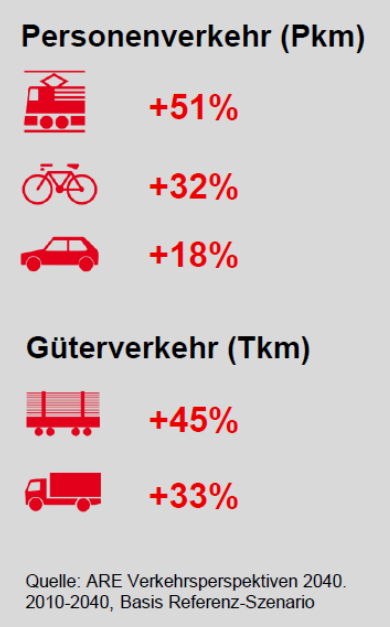
Lucian Ancu, Stan Banaszak, Aurelia Kollros, Marcel Zurkirchen (SBB)

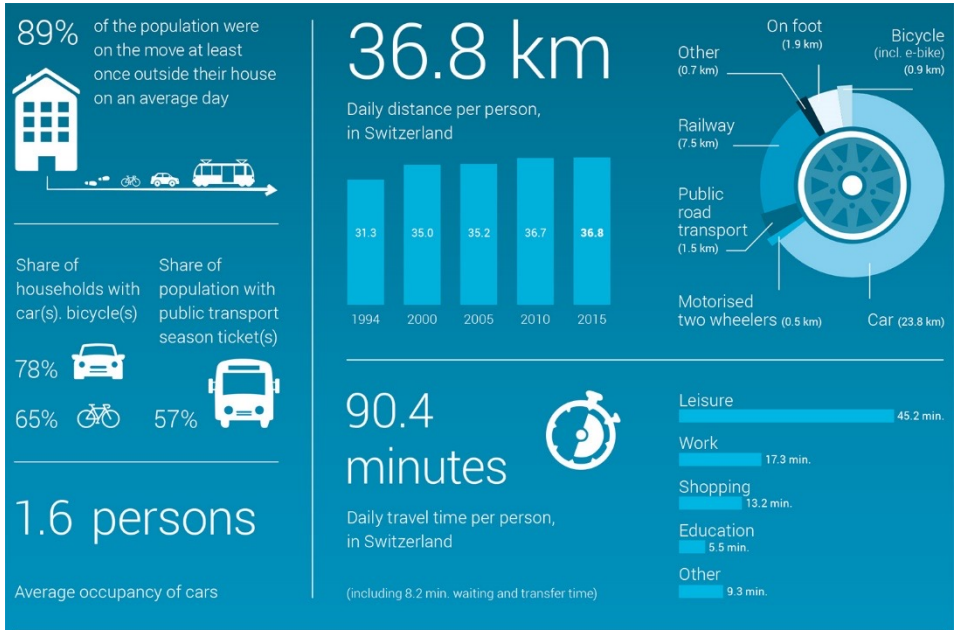
29.03.2022, Applied Machine Learning Days 2022



Background & motivation



Vison und Strategie der SBB (2017).



MMTC (2015).

Company.sbb.ch

The increasing demand in mobility is one of the biggest challenges Switzerland will have to face in the near future.

(Vision Mobilität Schweiz 2050).

Industrialization and digitalization of railway monitoring

Traditional

Industrial

On Board Monitoring (OBM)

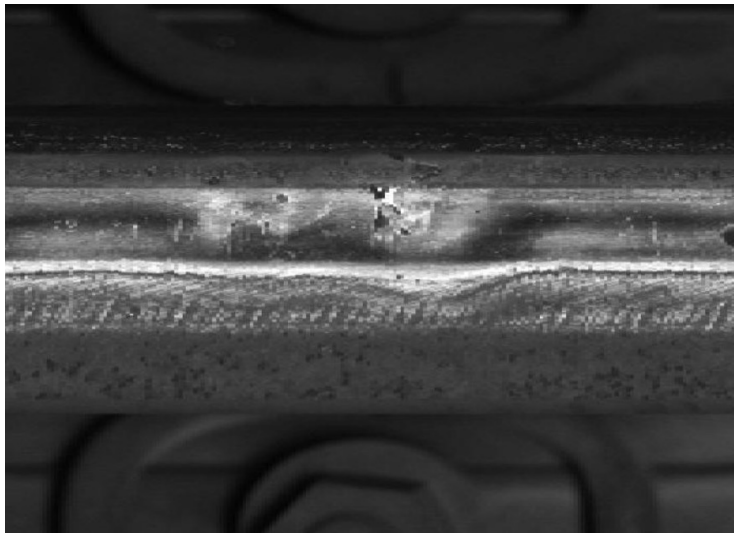
Continuous measurements to increase safety and reliability and reduce life cycle costs

Machine vision rail condition monitoring: AISI SBB*

Insulated joints

Welds

Surface defects & squats

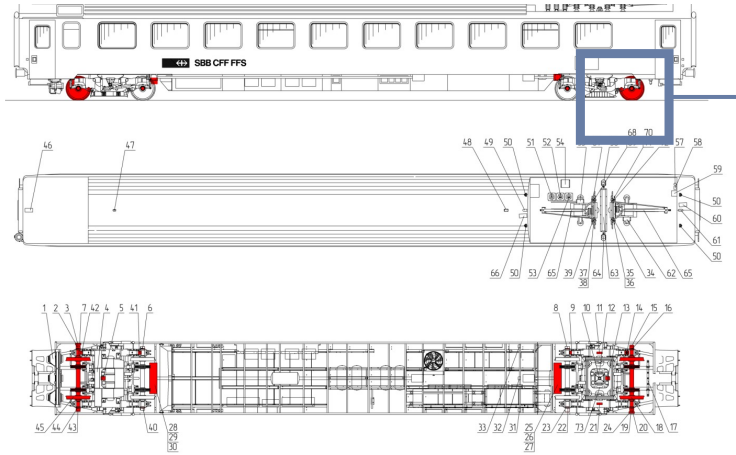


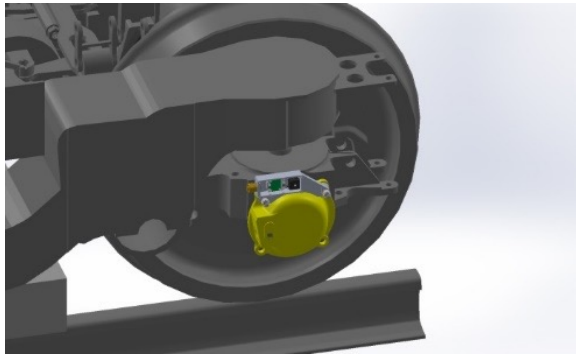
There are >80’000 welds and >3’800 insulated joints detected using machine vision on the tracks crossed regularly by the diagnostic vehicle.

*Fetai Ilir, ***AI in Railways inspection: theory VS reality**, AI & Industry, AMLD 2022

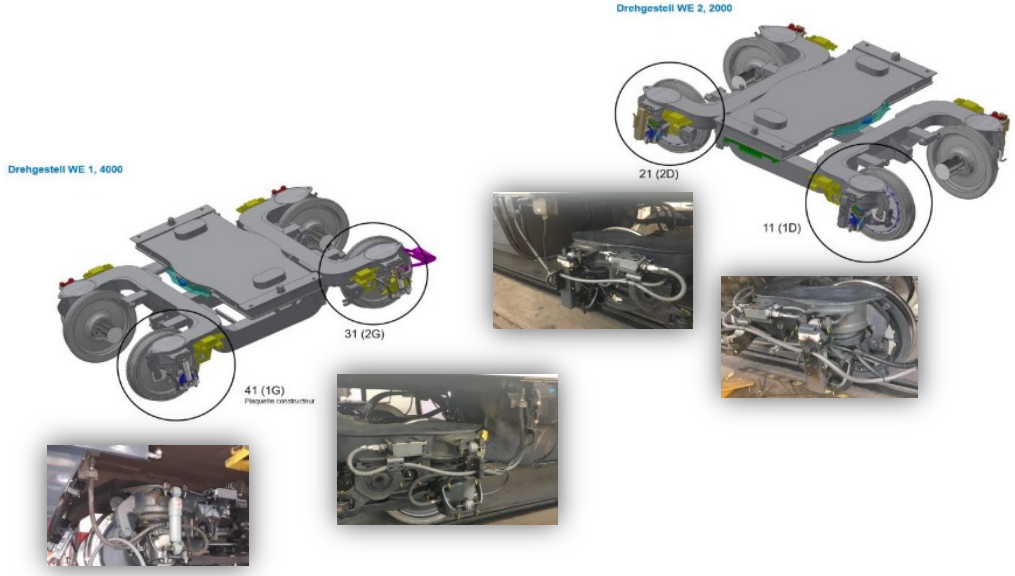
Monitor railway track condition with accelerations

- gDFZ



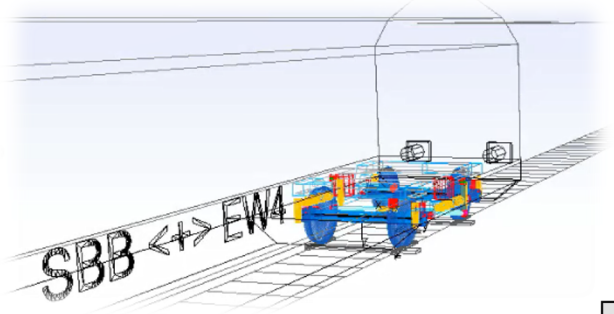


- OBM-ICN

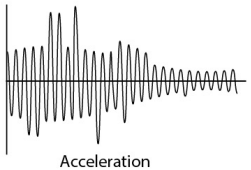


Estimation of wheel contact force/roughness

Data from GPS

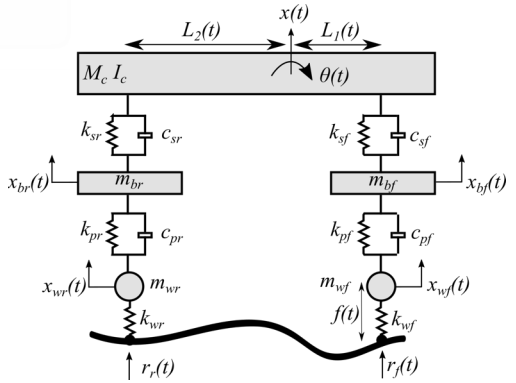


Full Order Model

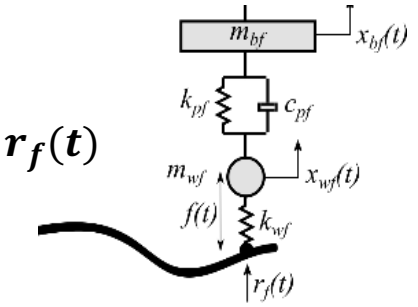


Acceleration

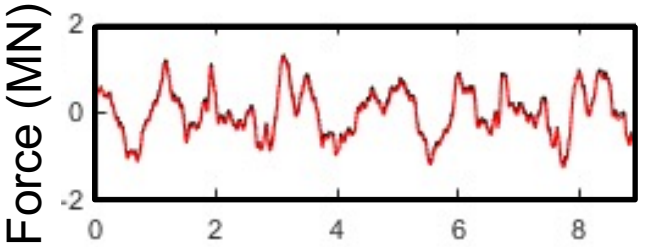
Simplified Model



$$F = k_{wf} \cdot r_f(t)$$



Forced displacement $r_f(t)$



Time (s)

State input estimation problem

Measured axle box vibration → **Simplified vehicle mode** → **Kalman filter** → **Contact force**

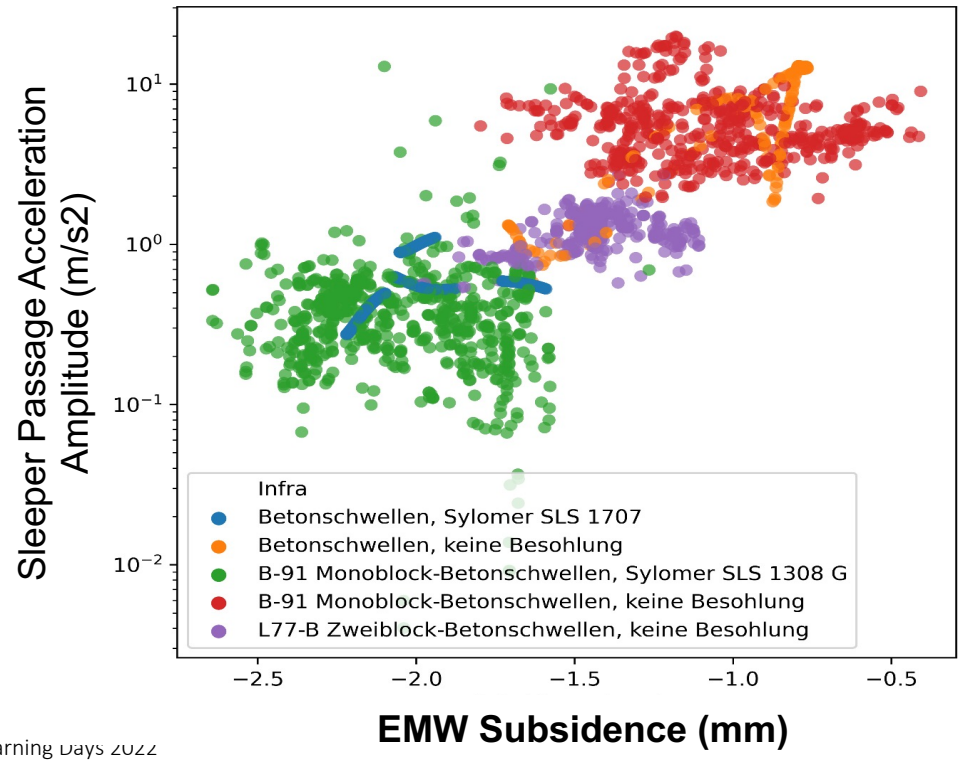
Track stiffness estimation from axle box accelerations via Vold-Kalman Filters

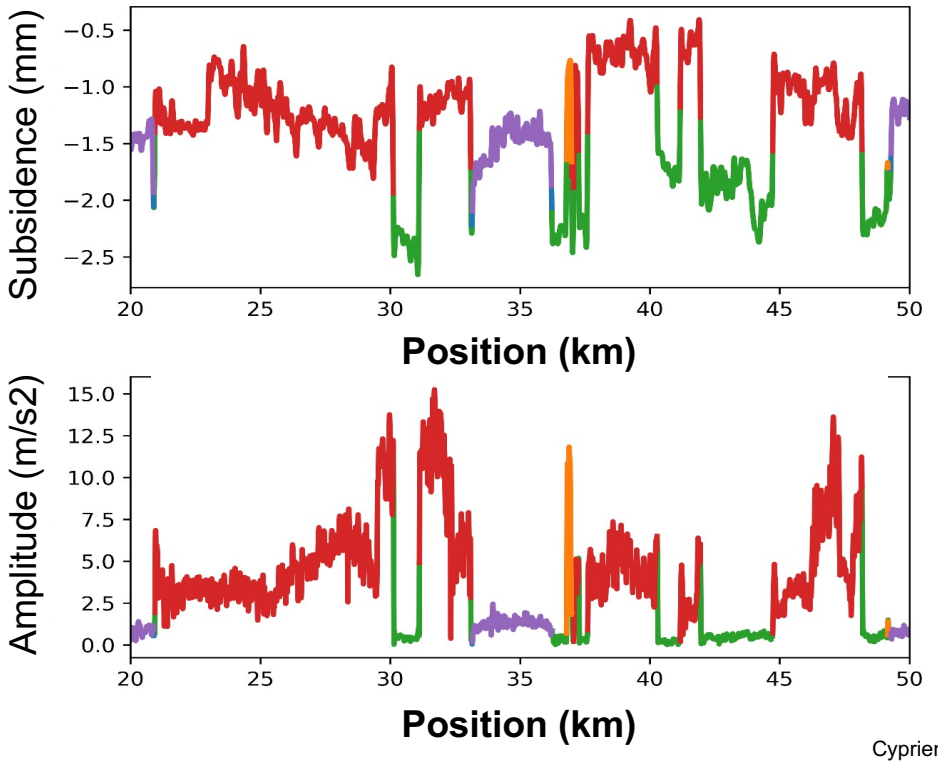
- $y(t) = x(t) + \nu(t)$

Where y(t) is measured, x(t) is deterministic harmonic signals ∝ v(t) and ν(t) is random noise and untracked components.

- $x(t) = \sum_{k=1}^{n} A_k(t)\rho_k(t)$ and $\rho_k(t) = e^{2\pi i k \int_0^t \omega(u)du}$

Where $A_k(t)$ is a complex envelope and $\rho_k(t)$ a phasor and $\omega(t)$ is the instanteneous shaft speed.

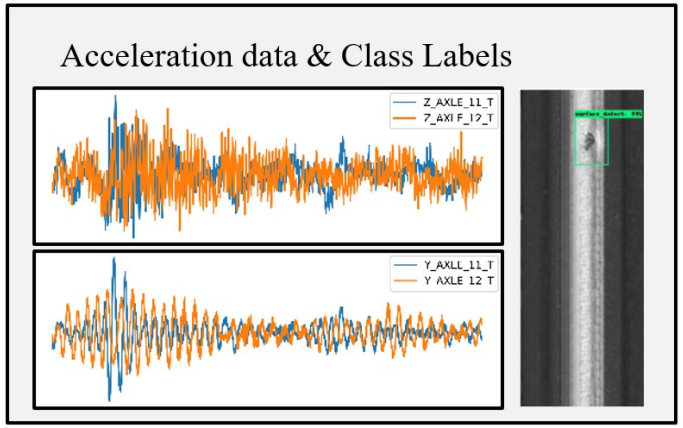




Acceleration based event classification using machine learning

Proc. IMAC2022-XL

- Surface Defect
- Weld
- Insulated Joint

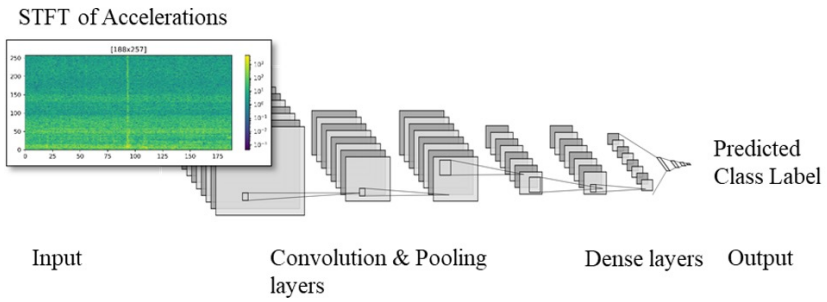


Extraction of Indicators
- Longitudinal Level D0, D1, D2
- DWT Coefficients

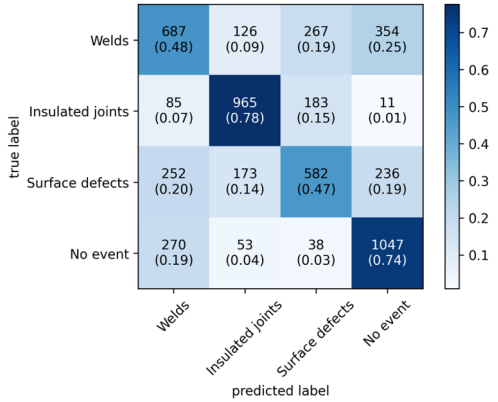
Computation of Basic Features
- Statistical Parameters
- Energy & Entropy

Features Selection
- All Features or Empirical selection
- PCA,…

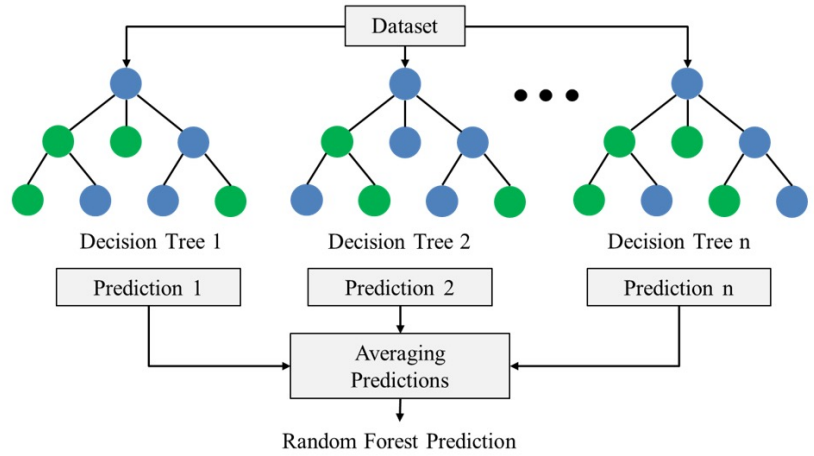
Convolutional Neural Network for CWT, STFT, DWT of ABA



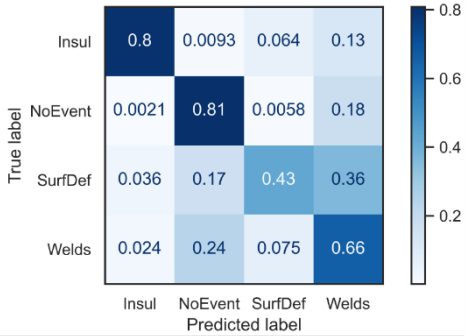
CNN-model on speed normalized STFT



Random Forest Model Classification for different features sets



Random Forest Classifier

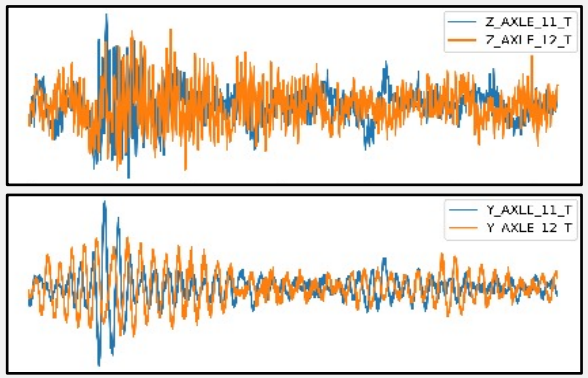


(b) Normalized

Normalized confusion matrix
Train score: 0.94
Test score: 0.71

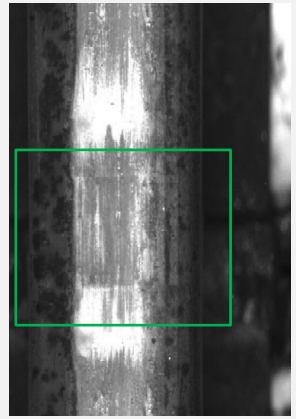
Data-driven assessment

Acceleration data on weld from OBM or DFZ



Database of welds
- UUID
- Track position
- Side (left /right)

Observation DB of welds
- UUID
- Campaign
- Image

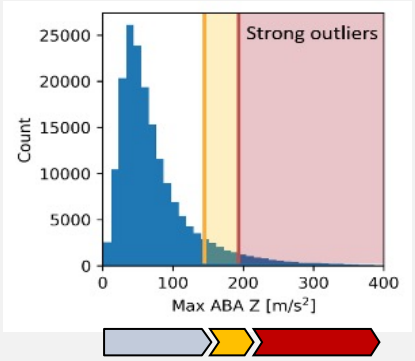


Extraction of indicators
- Longitudinal level D0...
- DWT coefficients

Feature computation
- Statistical parameters
- Energy & entropy

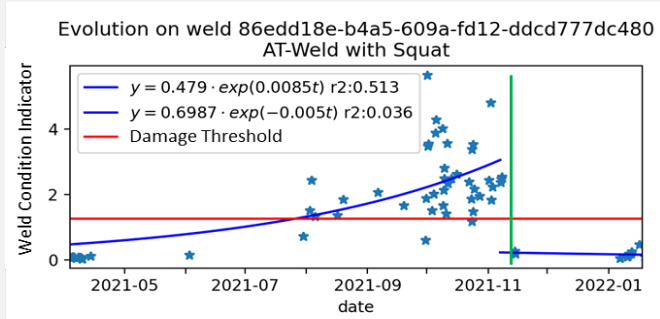
Features selection
- All features or empirical selection
- PCA,…

Extreme Value Analysis & Outlier Identification



Expert Evaluation
- Damage type, urgency,…

Regression & Prediction



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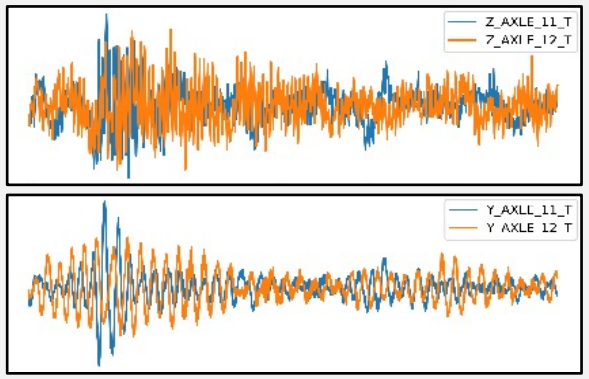

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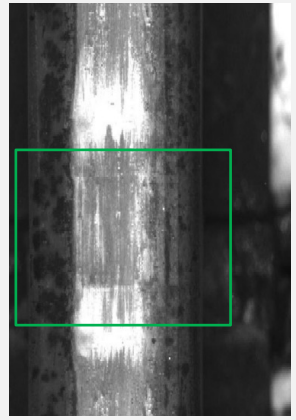

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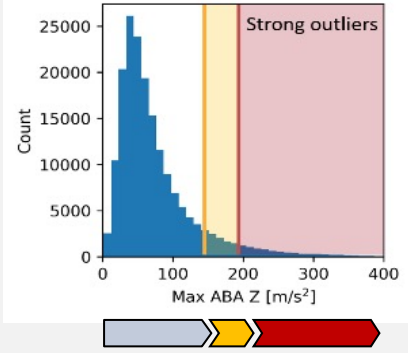

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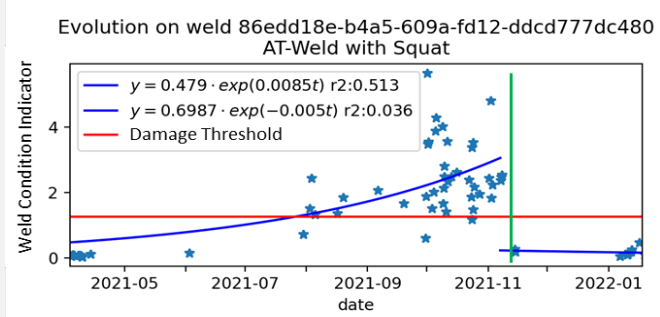
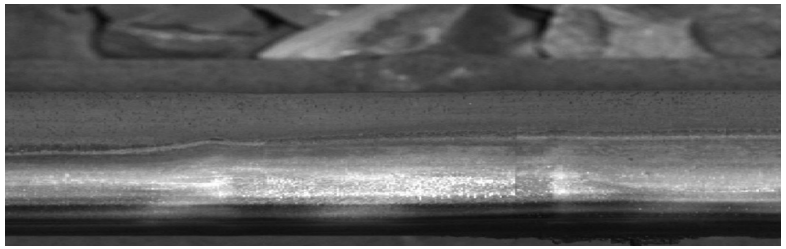
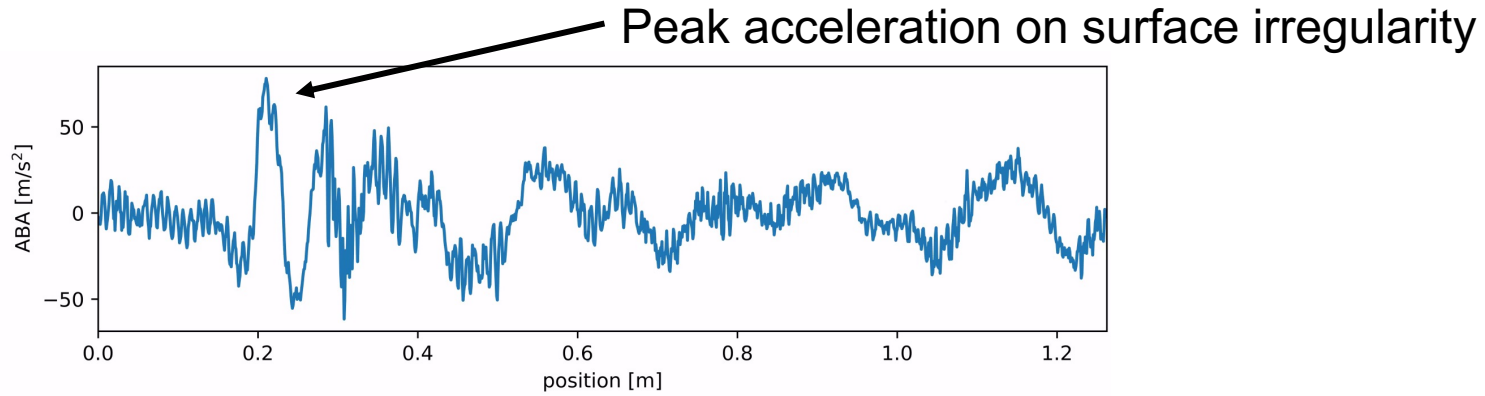


Extraction of acceleration based condition indicators

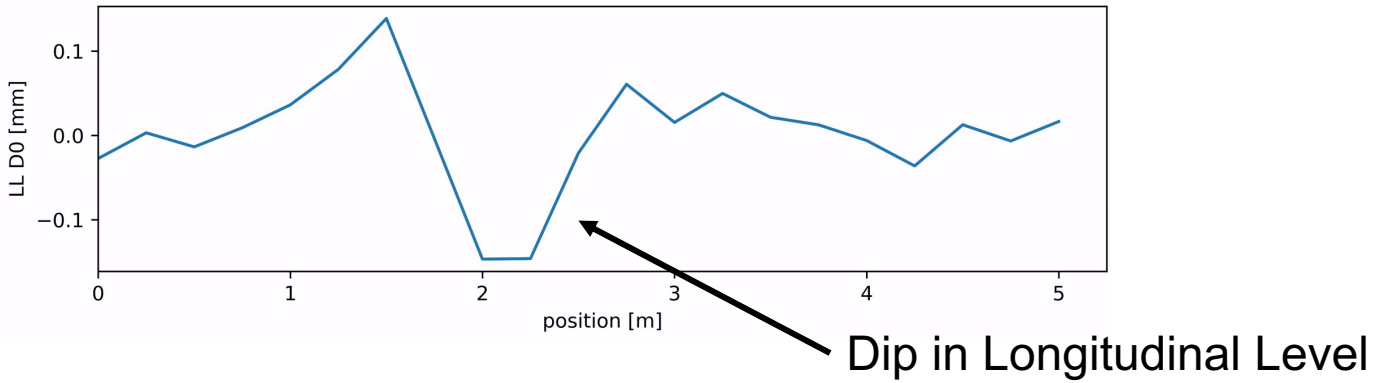
Image of event



Time series Accelerations:

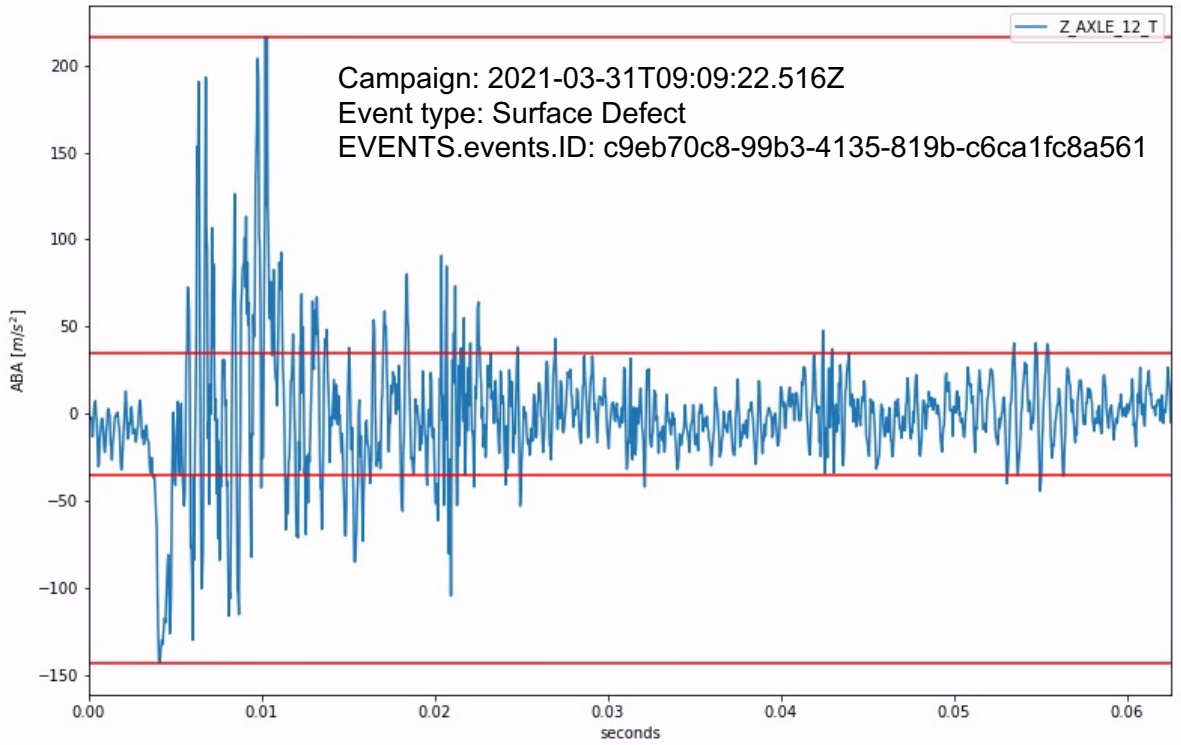


Longitudinal Level D0:



Statistics on Signals (time series, D0, Wavelets,…)

- Maximum, Minimum, Quantiles (1,5,25,75,95,99)



Max

Std

Min

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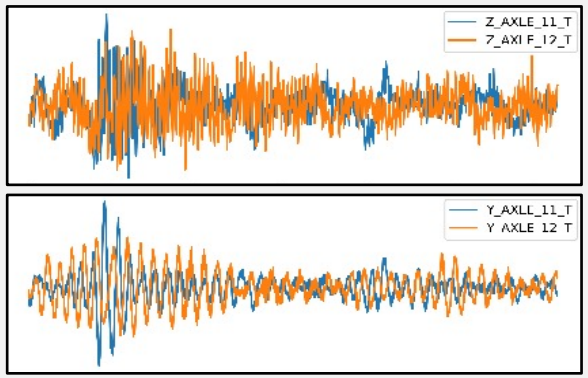

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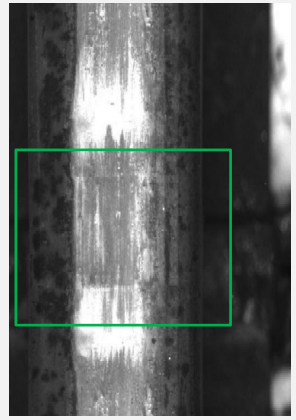

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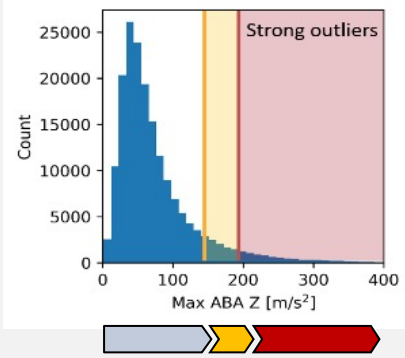

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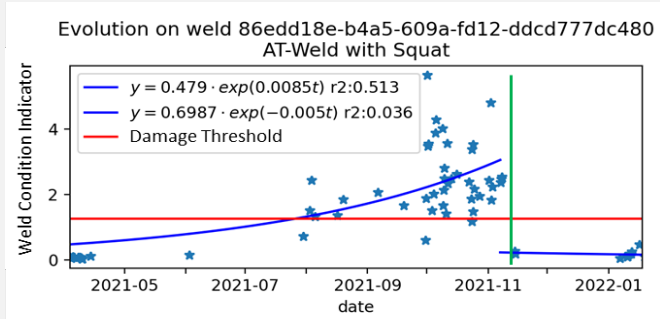
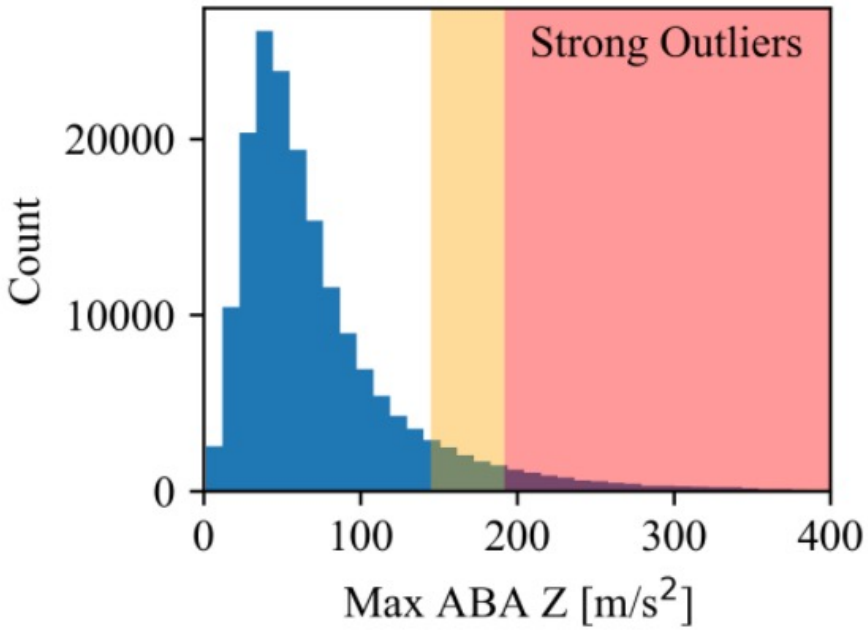
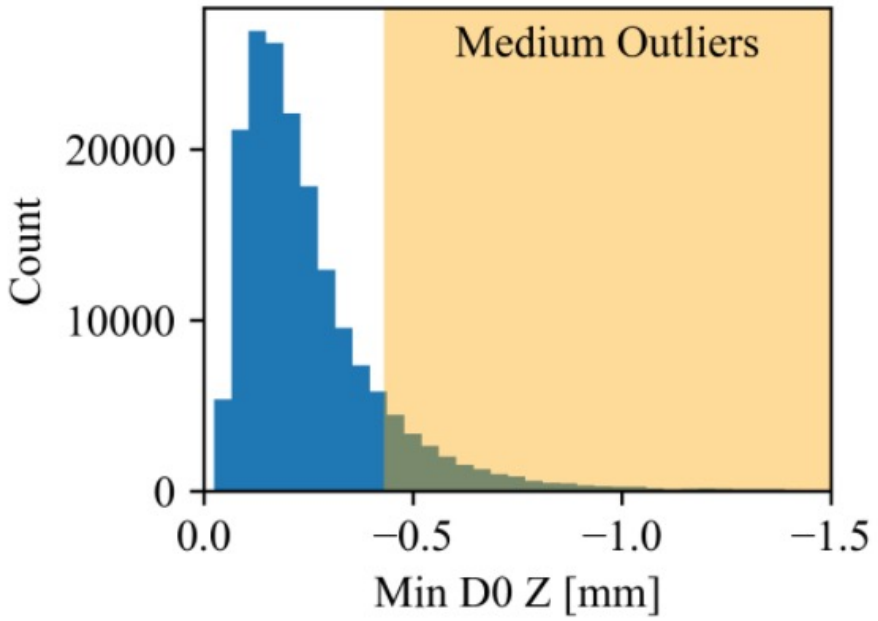


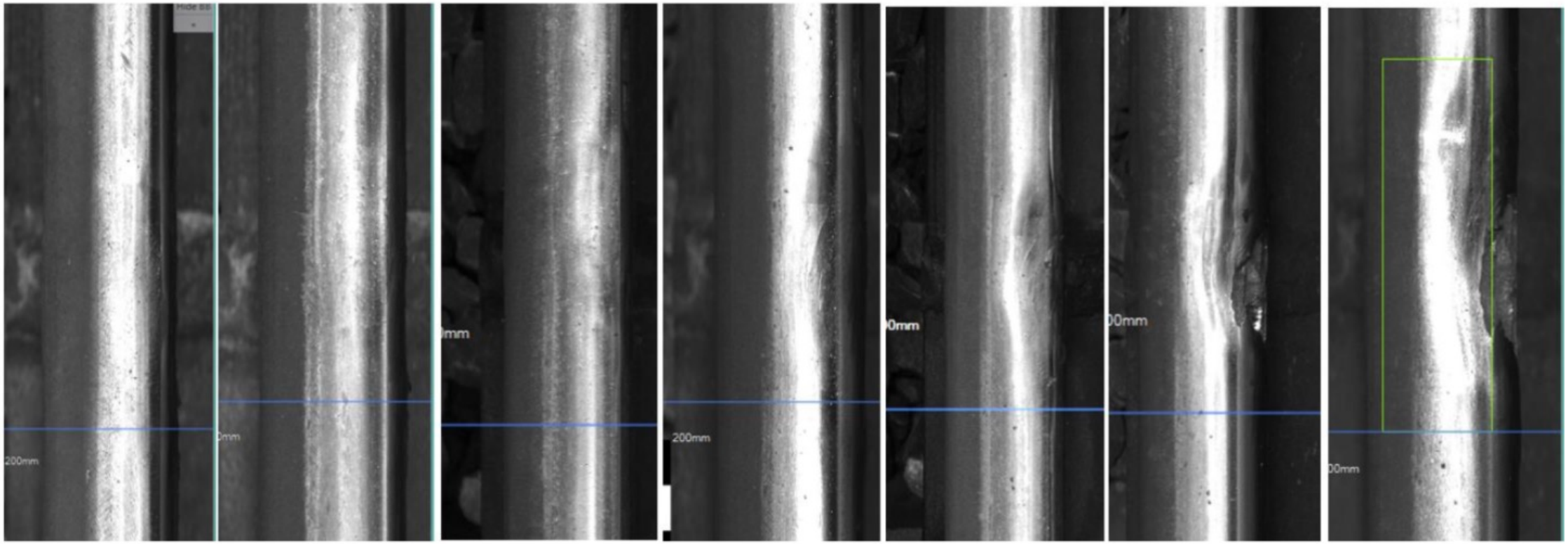
Distribution of acceleration parameters on welds





What is the threshold at which a weld is defect? What are the significant parameters defining a defect weld?

Case study: evolution of a weld until breakout

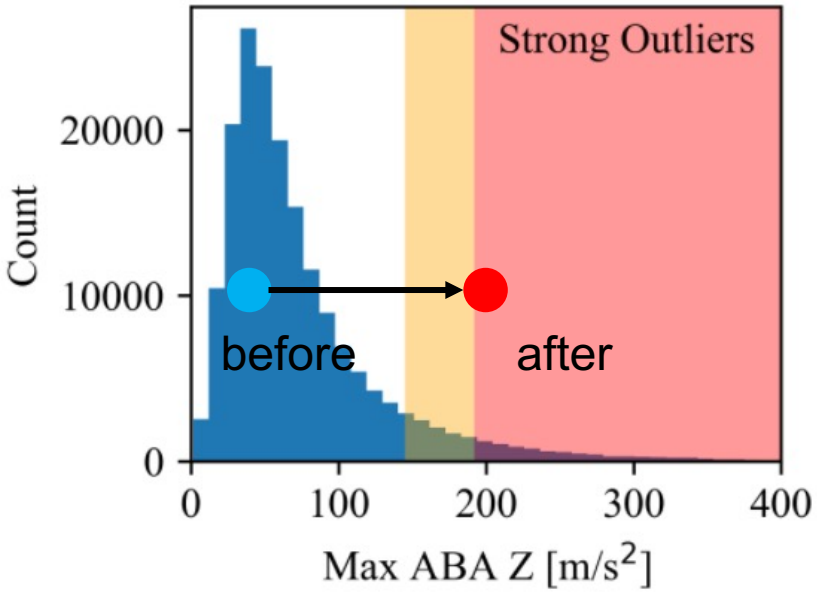


12.10.2020	10.11.2020	10.12.2020	04.01.2021	01.02.2021	01.03.2021	29.03.2021
16:50:17.311	10:05:47.158	12:08:45.769	16:05:22.604	16:33:47.382	16:31:04.293	16:31:39.522
gDFZ	gDFZ	DFZ	gDFZ	DFZ	DFZ	gDFZ
Keine Erkennung	**Schweissung**	Keine Erkennung	Keine Erkennung	Keine Erkennung	keine Erkennung	**Schweissung**

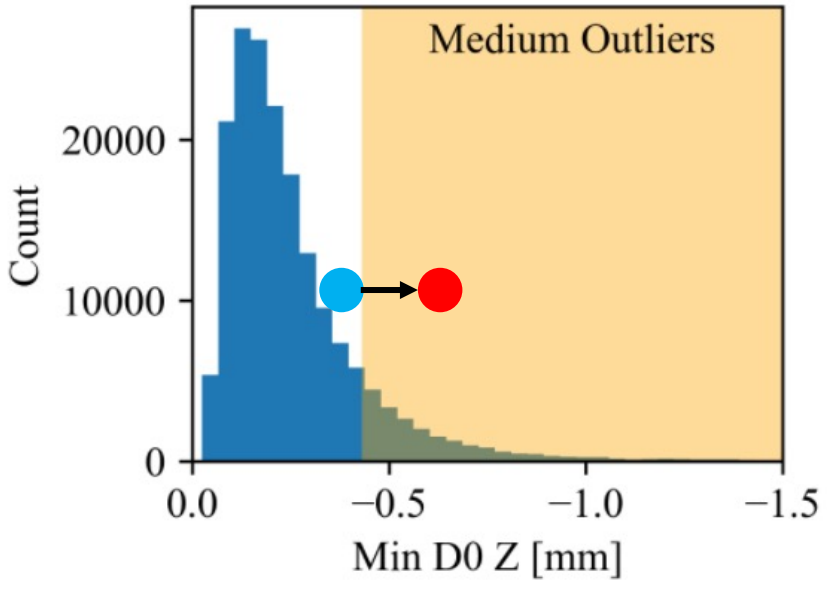
10

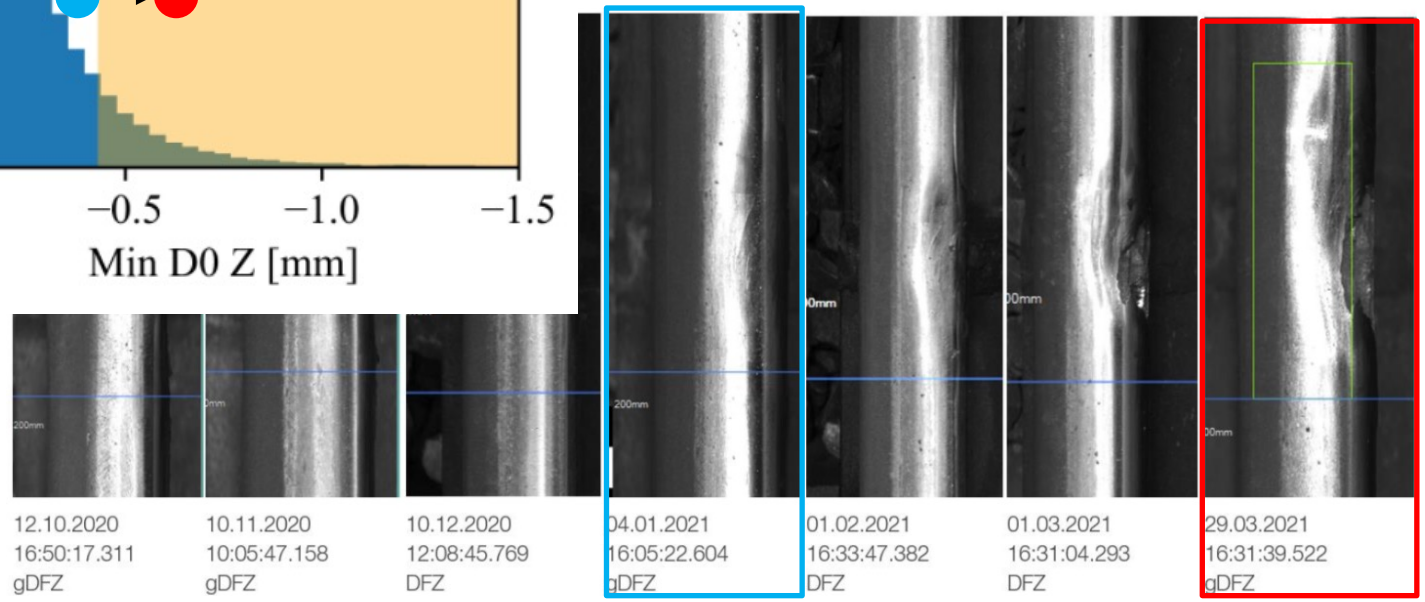
Case study: evolution of a weld until breakout

Distribution of maximum acceleration

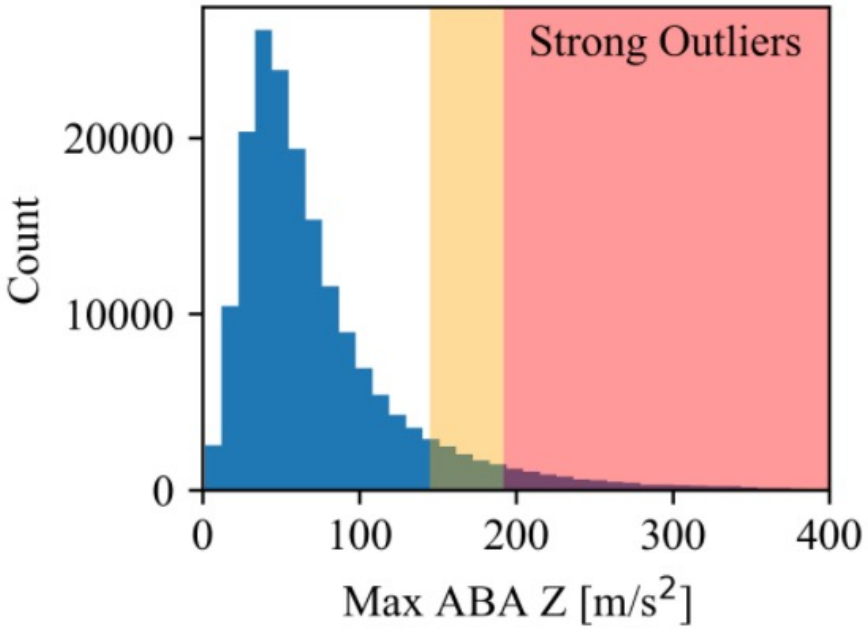


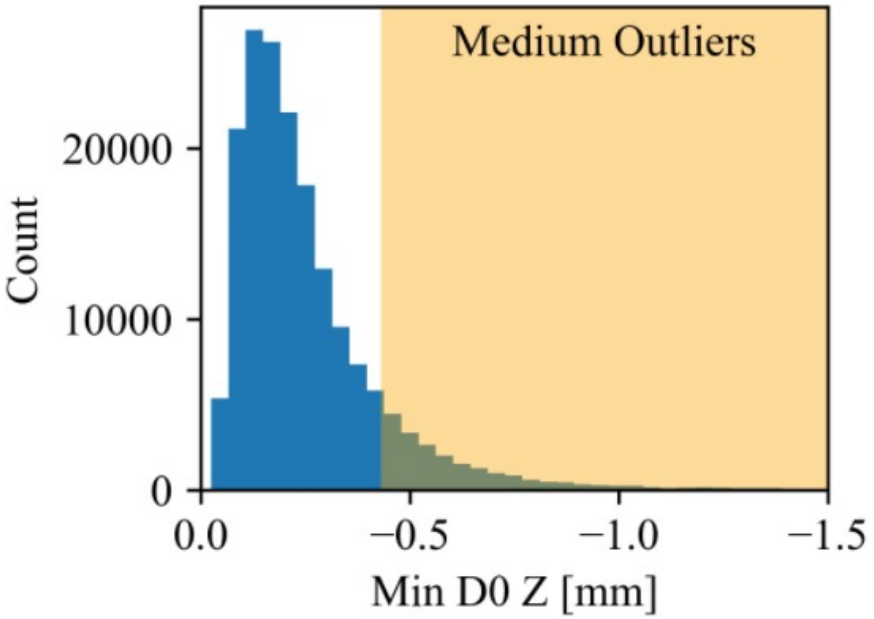
Distribution of longitudinal level D0





Outlier scores





$$O_{score,strong} = \frac{(ABA_{Z,max})}{(ABA_{Z,max}^{q98\%})} > 1$$

$$O_{score,medium} = \left(\left(\frac{(ABA_{Z,max})}{(ABA_{Z,max}^{q95\%})} \right)^2 + \left(\frac{(D0)_{Z,min}}{(D0)_{Z,min}^{q95\%}} \right)^2 \right)^{0.5} > 1$$

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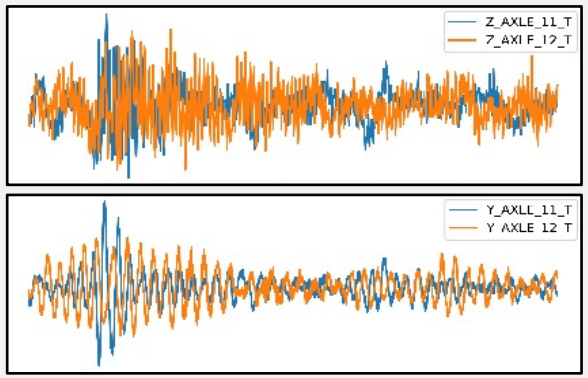

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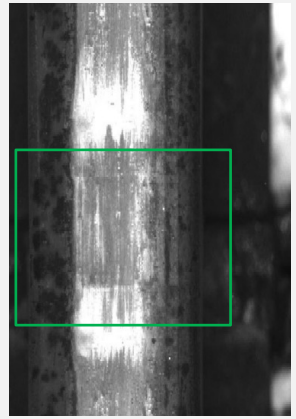

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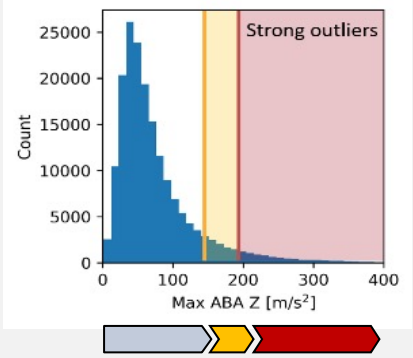

Expert Evaluation
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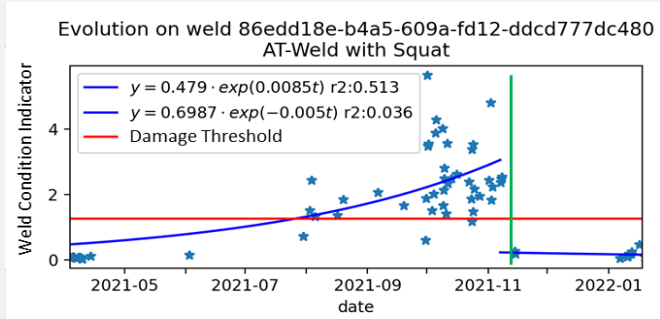
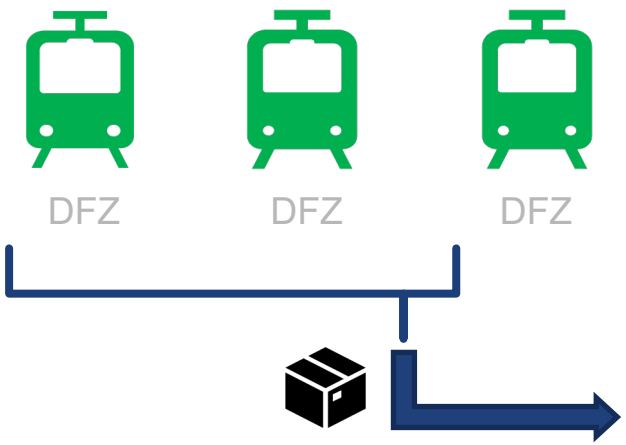
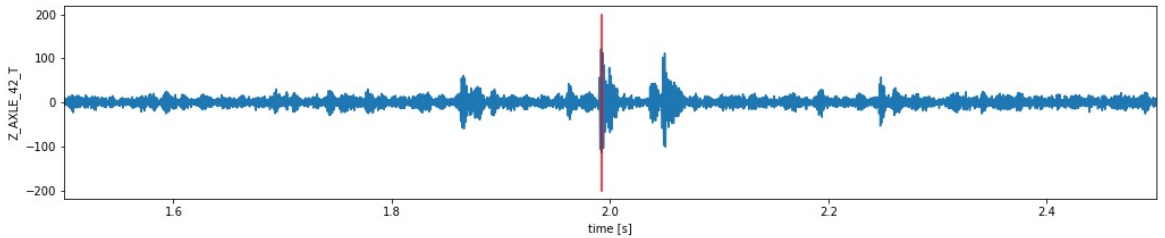
Regression & Prediction



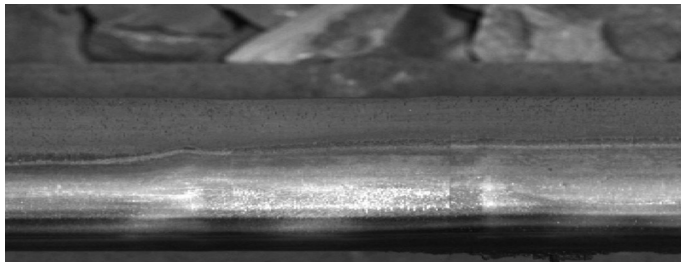
Obtaining expert feedback on weld condition



1. Data processing: researchers ETH/SBB



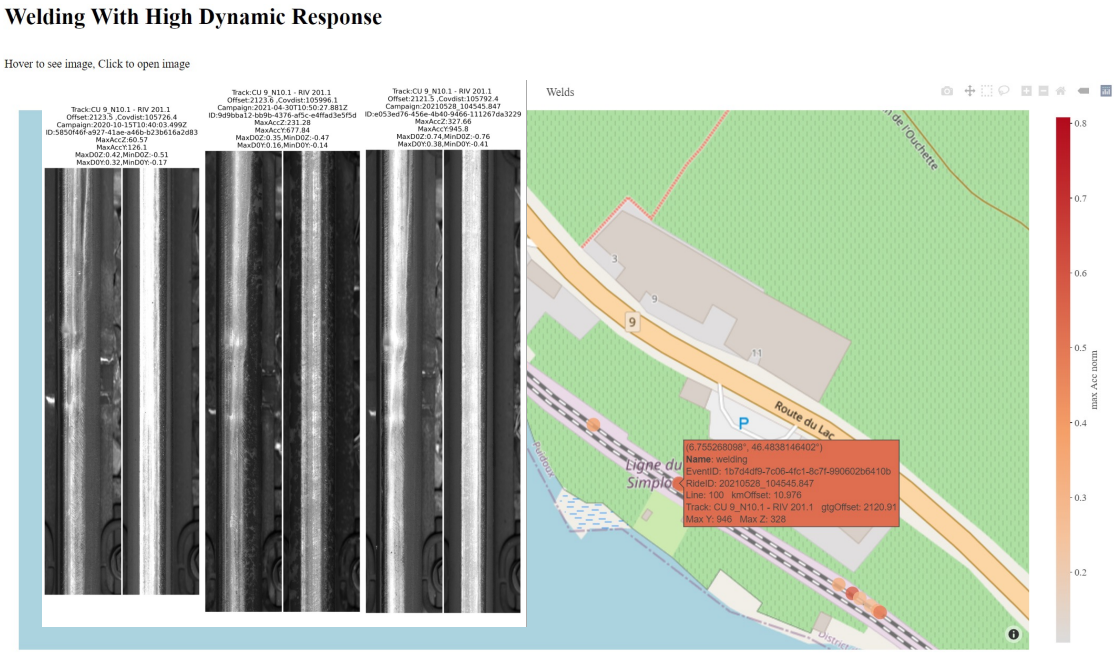
2. InOffice validation: experts from automated track inspection

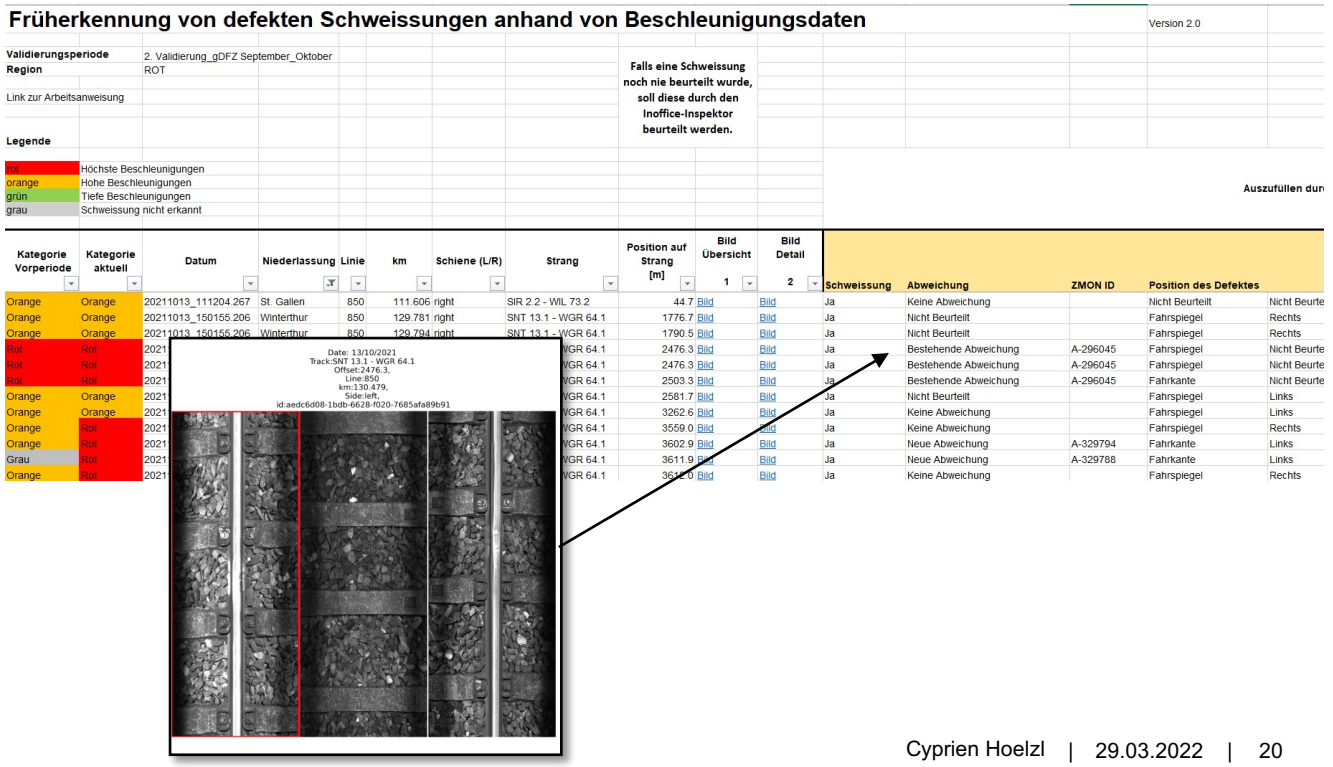


3. Manual validation: track inspectors

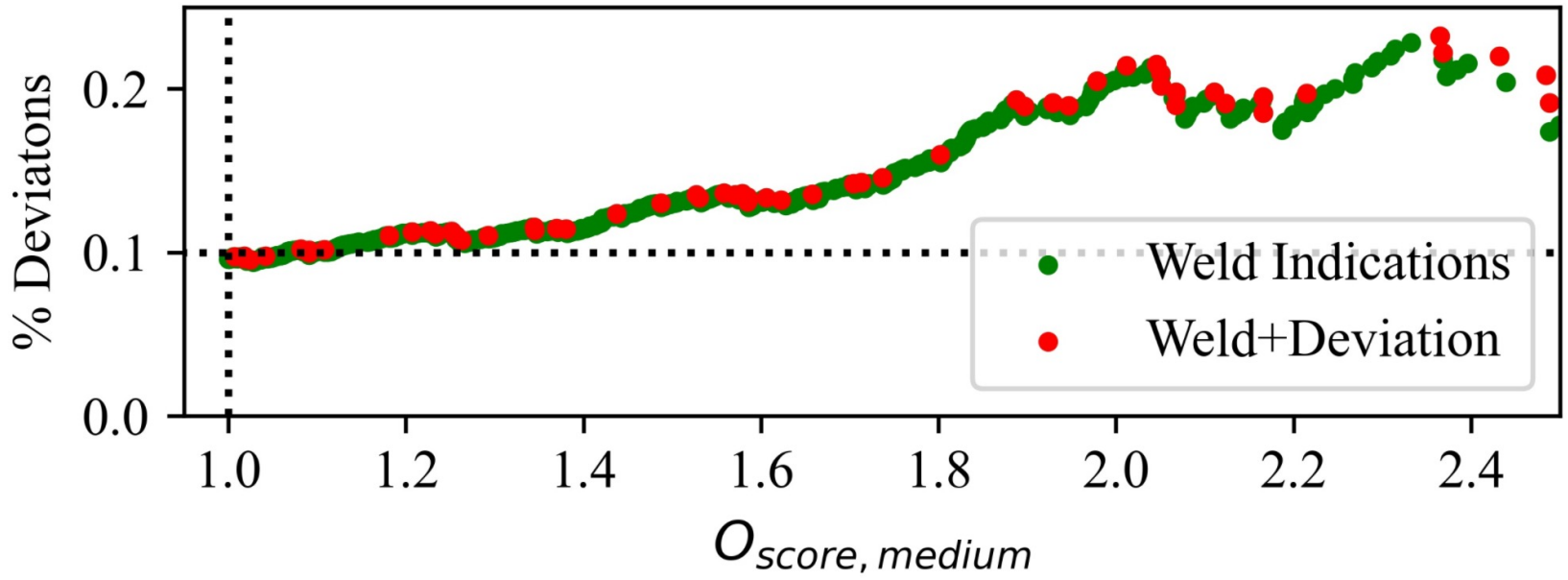
Delivery of outlier welds:

- Detected **outliers** are delivered to asset managers via:
  - Excel + Images
  - HTML pages/applets with Events
  - Density Maps / Heat maps



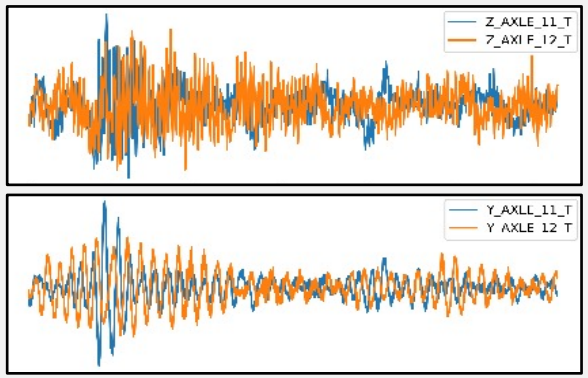


Defect welds distribution in the validated welds



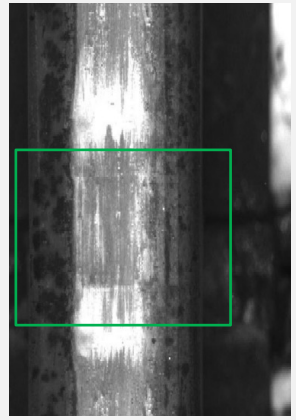
Data-driven assessment

Acceleration data on weld from OBM or DFZ



Database of welds
- UUID
- Track position
- Side (left /right)

Observation DB of welds
- UUID
- Campaign
- Image

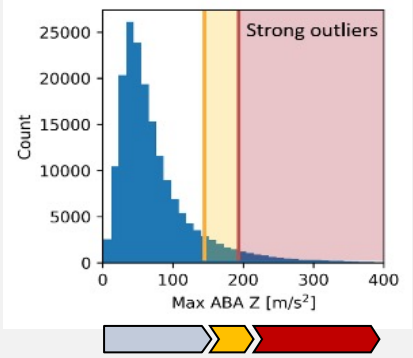


Extraction of indicators
- Longitudinal level D0...
- DWT coefficients

Feature computation
- Statistical parameters
- Energy & entropy

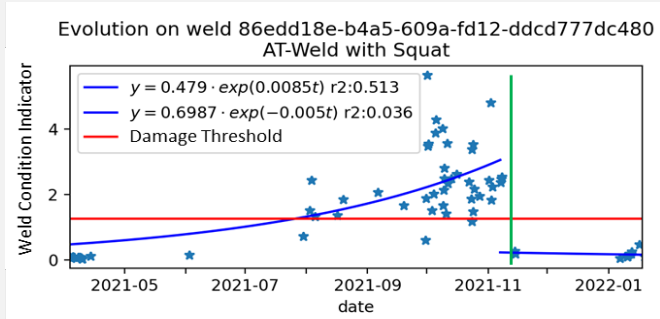
Features selection
- All features or empirical selection
- PCA,…

Extreme Value Analysis & Outlier identification



Expert Evaluation
- Damage type, urgency,…

Regression & Prediction



Evolution in time using OBM data

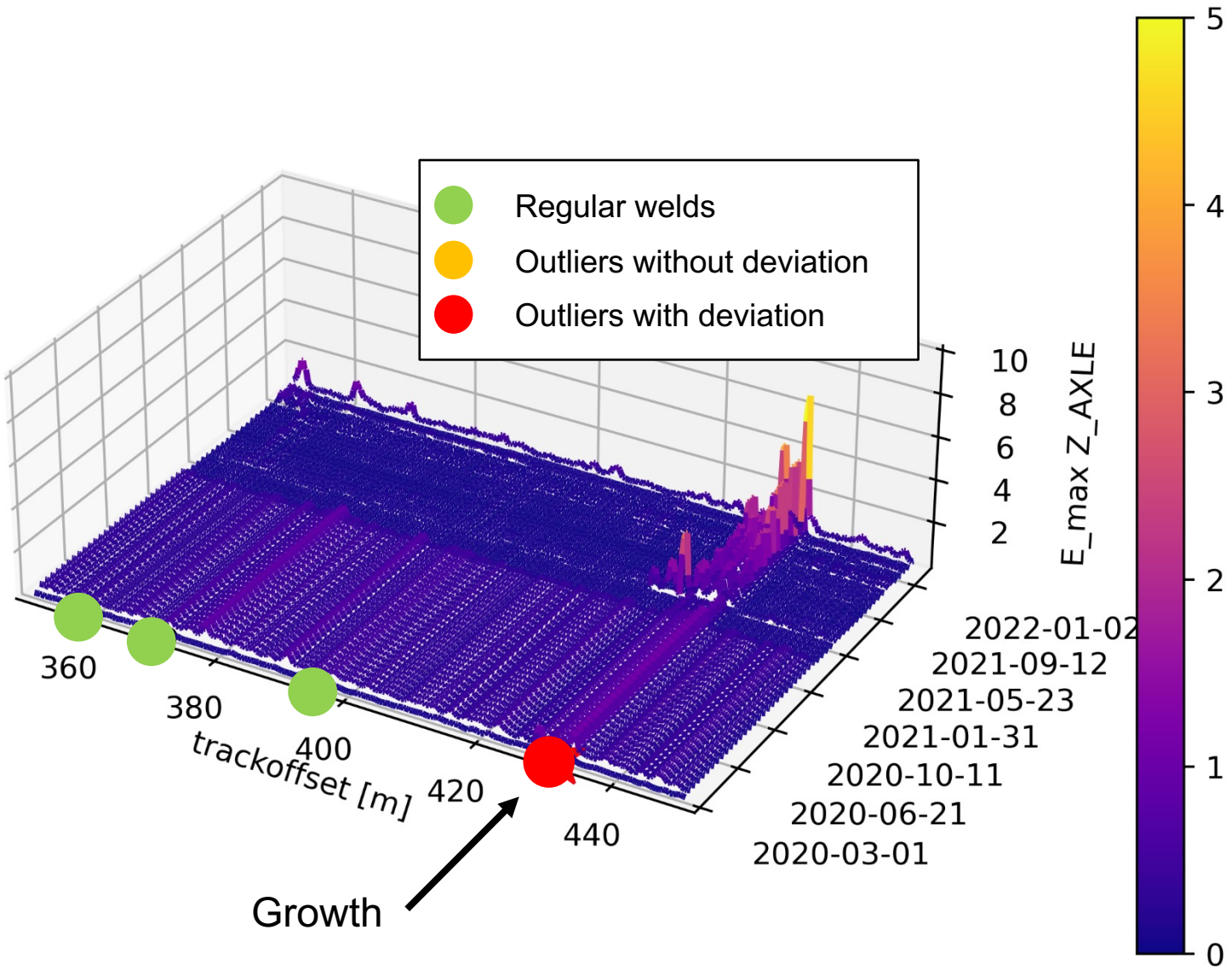
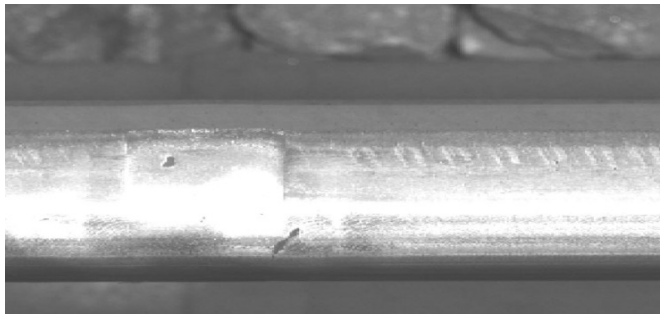


Illustration of the corresponding weld

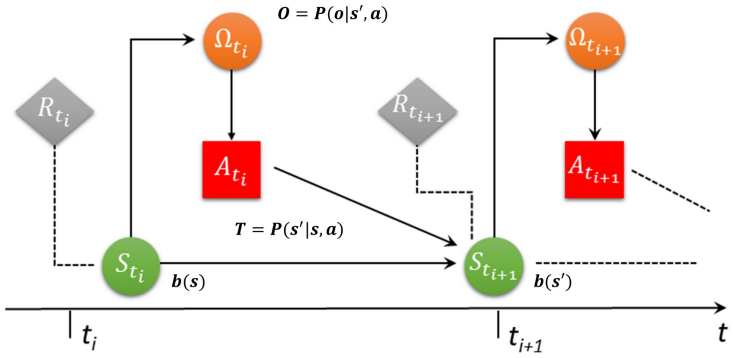


In Summary

- Vehicle Track interaction at the origin and driver of fault appearance and growth
- End-to-end validation chain to obtain information about the asset condition
- Good potential for early detection of weld deviations

Outlook:

- Improvement in detection via an expert in the loop approach:
  - Ground truth from validations
  - Bayesian Networks will be used to incorporate the uncertainty due to variability in accelerations and variability in expert judgement.



- Sensor fusion between AISI & ABA.

We welcome questions/comments/collaboration:

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