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Deriving Meaning from Acceleration Measurements on Train Wheelsets

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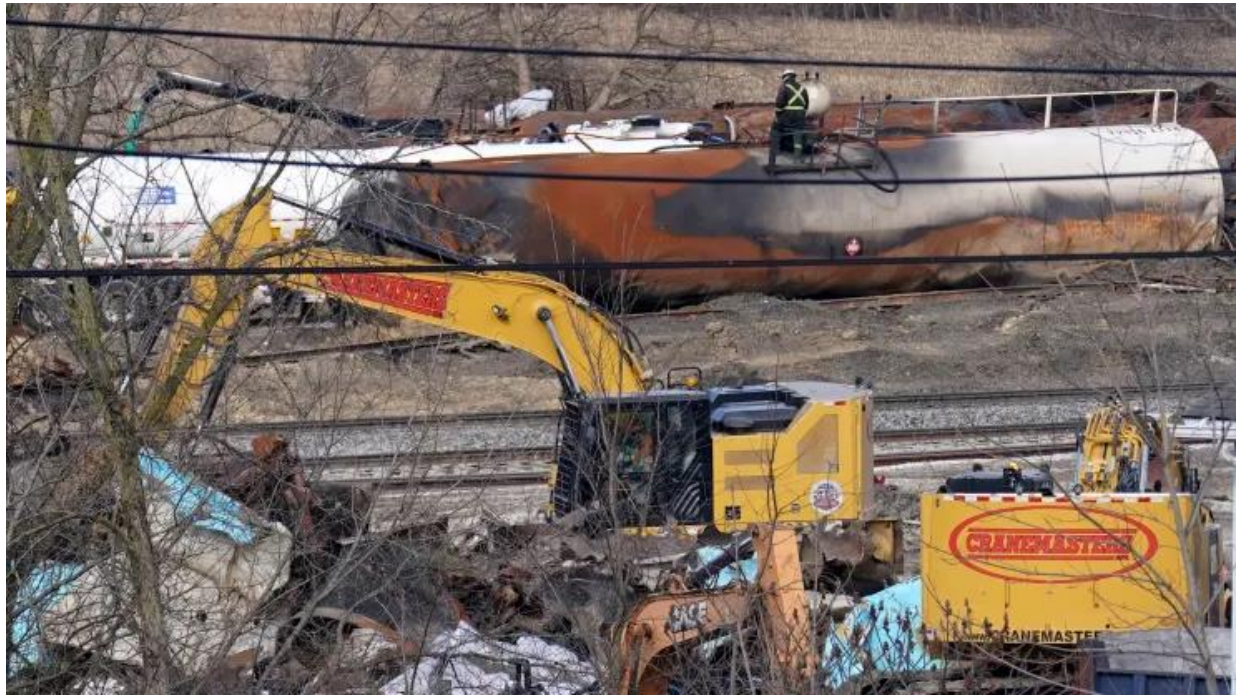
Contents

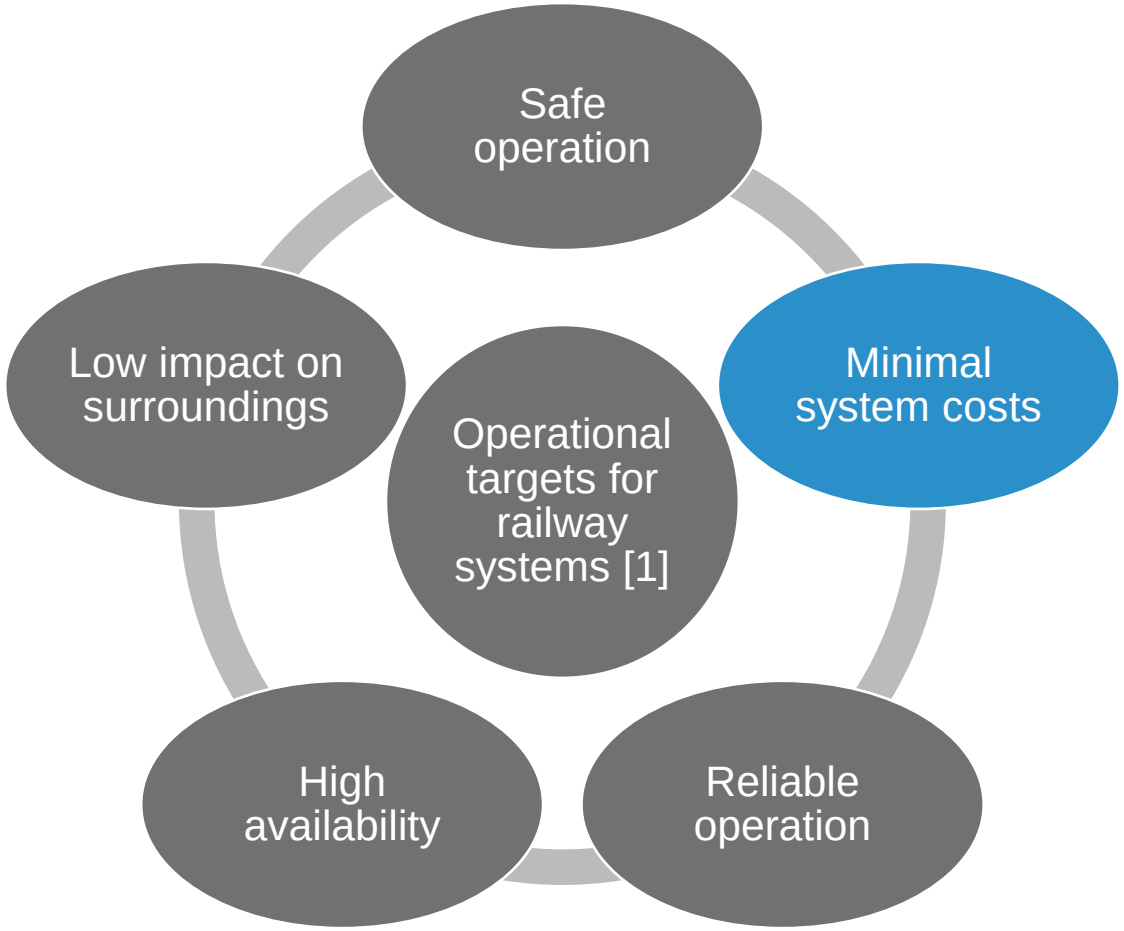
Motivation: The Rail System's Operational Goals



Derailed tank cars in East Palestine, Ohio on Feb. 21, 2023 [2]

[1] Rösch, W. (2019). *Kompendium Schienenfahrzeuginstandhaltung*. PMC Media House GmbH
[2] Sheidlower, N. (2023, February 23). *Feds point to overheated wheel bearing in report on Ohio train derailment*. CNBC. https://www.cnbc.com/2023/02/23/ntsb-norfolk-southern-train-derailment-preliminary-report.html

Maintenance Costs



Direct maintenance costs

- Maintenance operations efforts
- Maintenance operations materials

Indirect maintenance costs

- Unplanned failures
- Sub-optimal efficiencies
- Effects on the surroundings and the environment

- Maintenance can comprise up to 20% of the Life Cycle Costs (LCC) of rolling stock assets [1]

Maintenance Costs

Current efforts to mitigate the workloads and expenses

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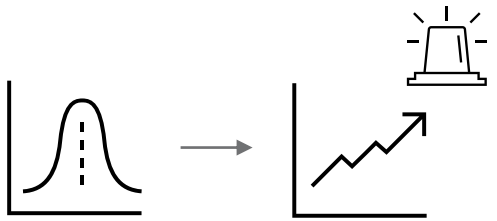
Direct maintenance costs

- Longer use of assets lifetime
- Precise identification of needed spare parts

Potential of the «age of information»

Transition from preventive to Condition-Based Maintenance (CBM)



Indirect maintenance costs

- Early fault detection
- Faster error source identification
- Improving plannability of maintenance

- But don’t forget(!): CBM has a cost too!
- The benefits in each case must be (reliably) quantified and compared to the initial and running costs of the CBM system

Measurands Encoding Information About Moving Machinery

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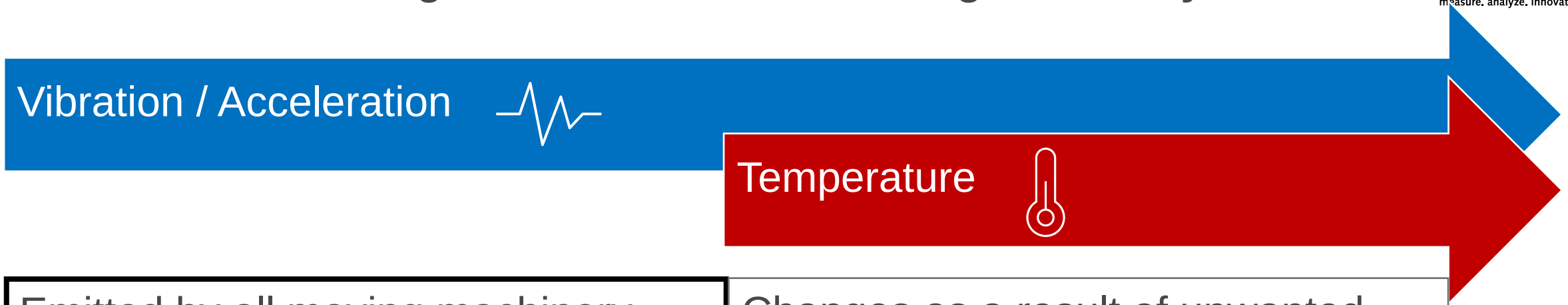

Emitted by all moving machinery Transmission in solids at speed of sound Immediate response to changes Encodes a high amount of information (for instance on the origin of a parasitic vibration based on characteristic spectrum)	Changes as a result of unwanted vibrations and friction Transmission in solids via thermal conductivity Slow response to changes Can encode less information (heat is caused by any part of the machine)

Information Encoded In Vibrations Detectable on the Bogie

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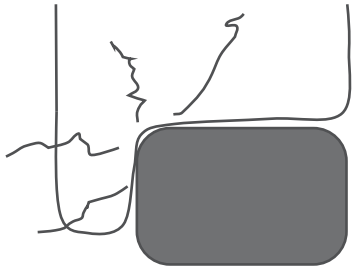
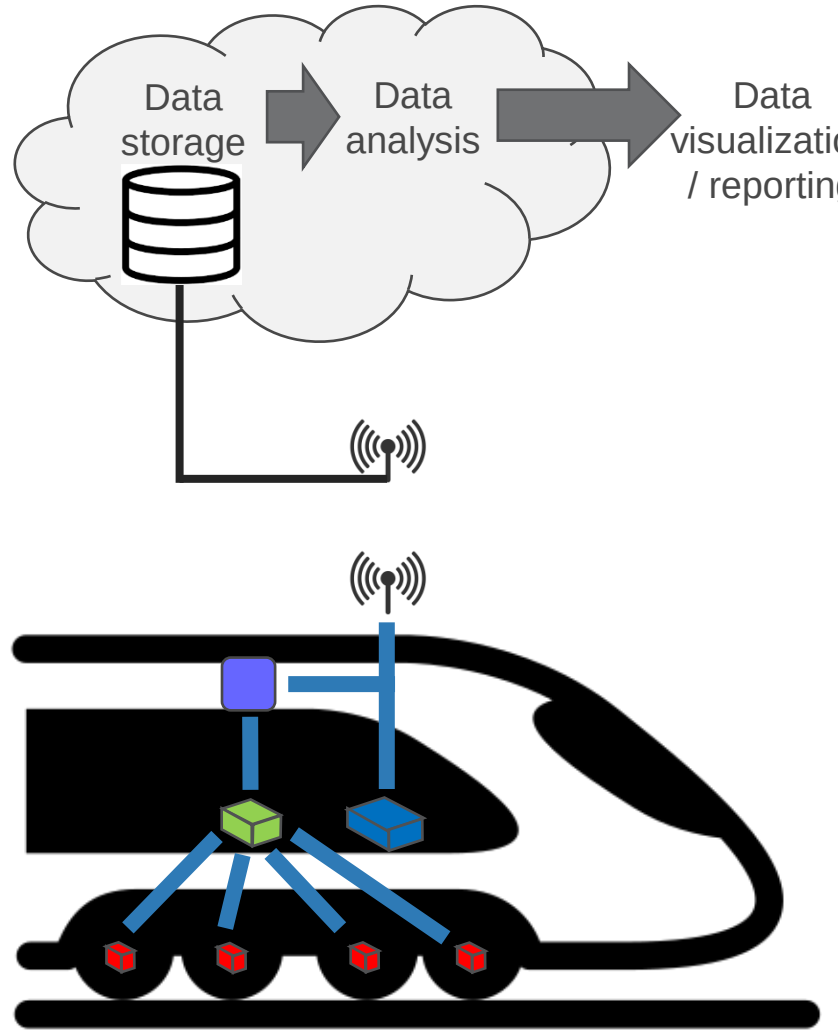
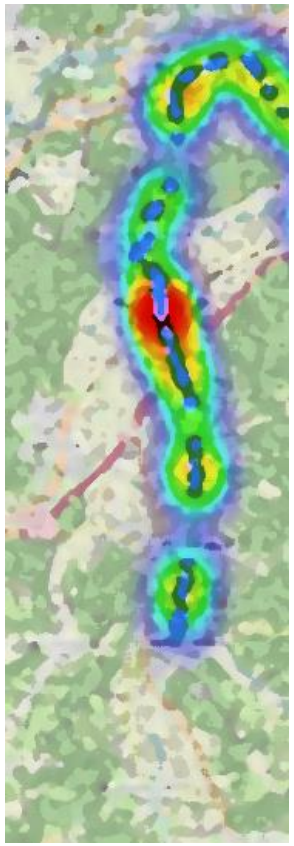
Rolling stock health ⟷ Track-wheel interactions ⟷ Infrastructure health



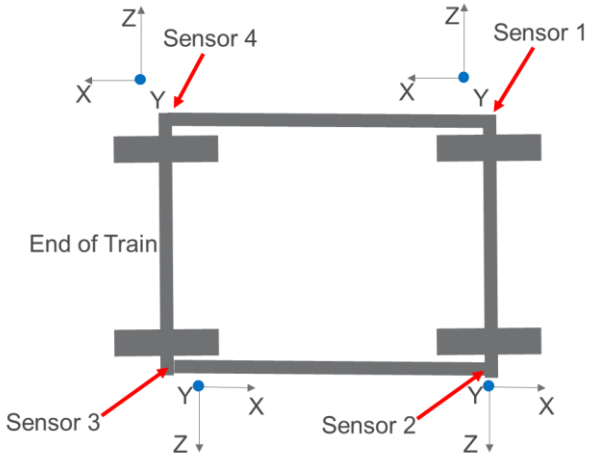
Onboard Rail Monitoring System

Setup and features

Components	Architecture	Project Scope
Cloud solution Edge computer DAQ/GPS Accelerometers		Collaboration between Aargau Verkehr AG (AVA) and Kistler Idea (AVA): use system for online monitoring of noise for rail-head conditioning control **Track-wheel interactions** -Squeal events -Flange friction events -High energy events (Optimal velocity profiles) **Rolling stock condition** -Wheel health (Gearbox health) (Bearing health)

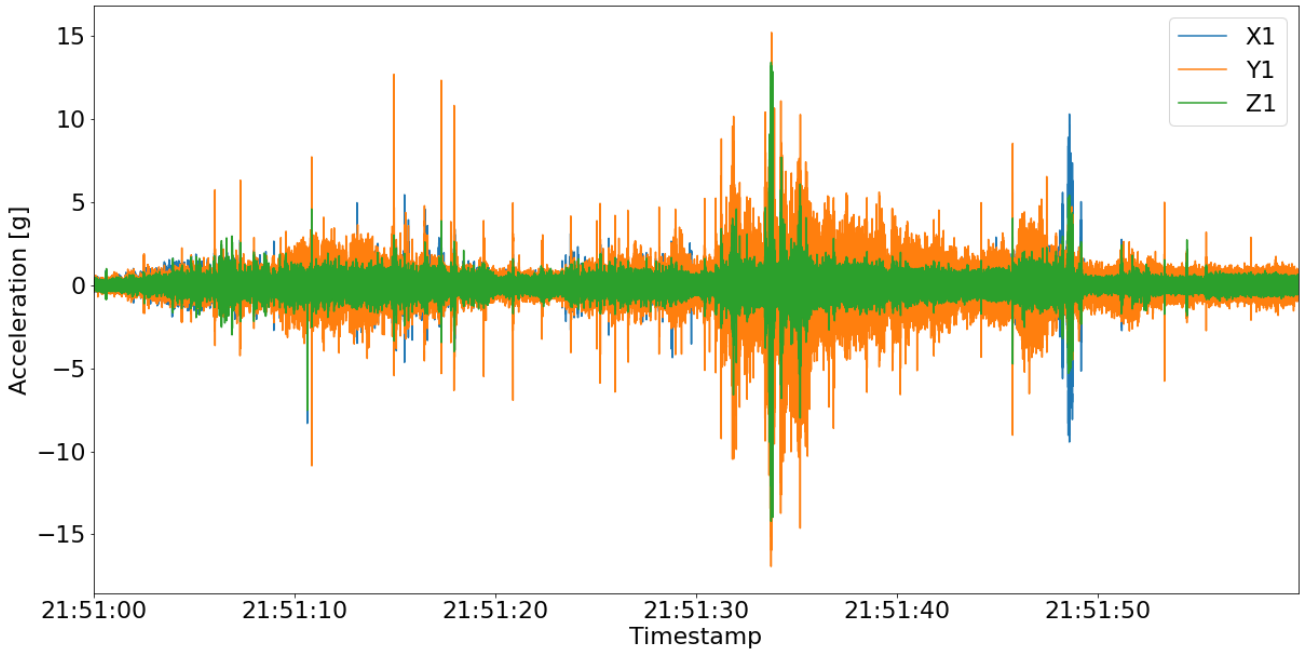


Sensors and Raw Signals



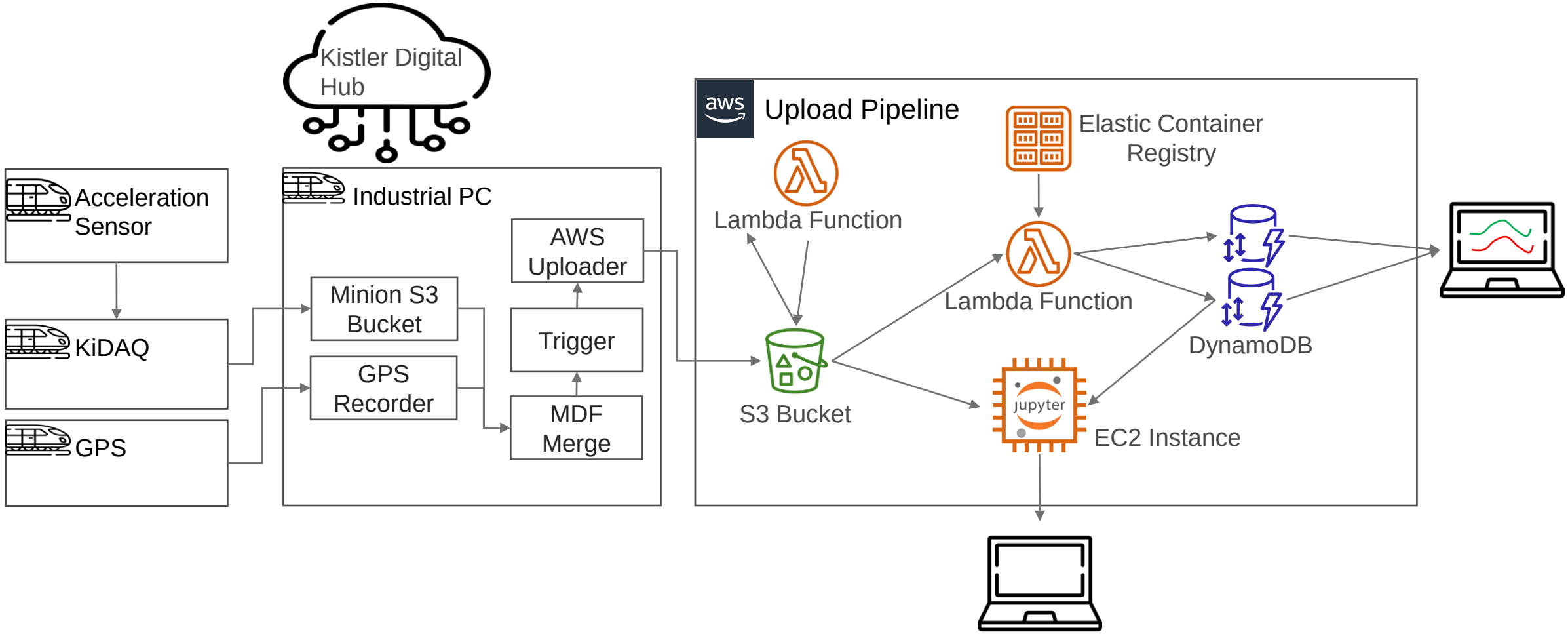
Acceleration Sensor
Sampling Rate: 50 kHz

GPS Module
Sampling Rate: 10 Hz



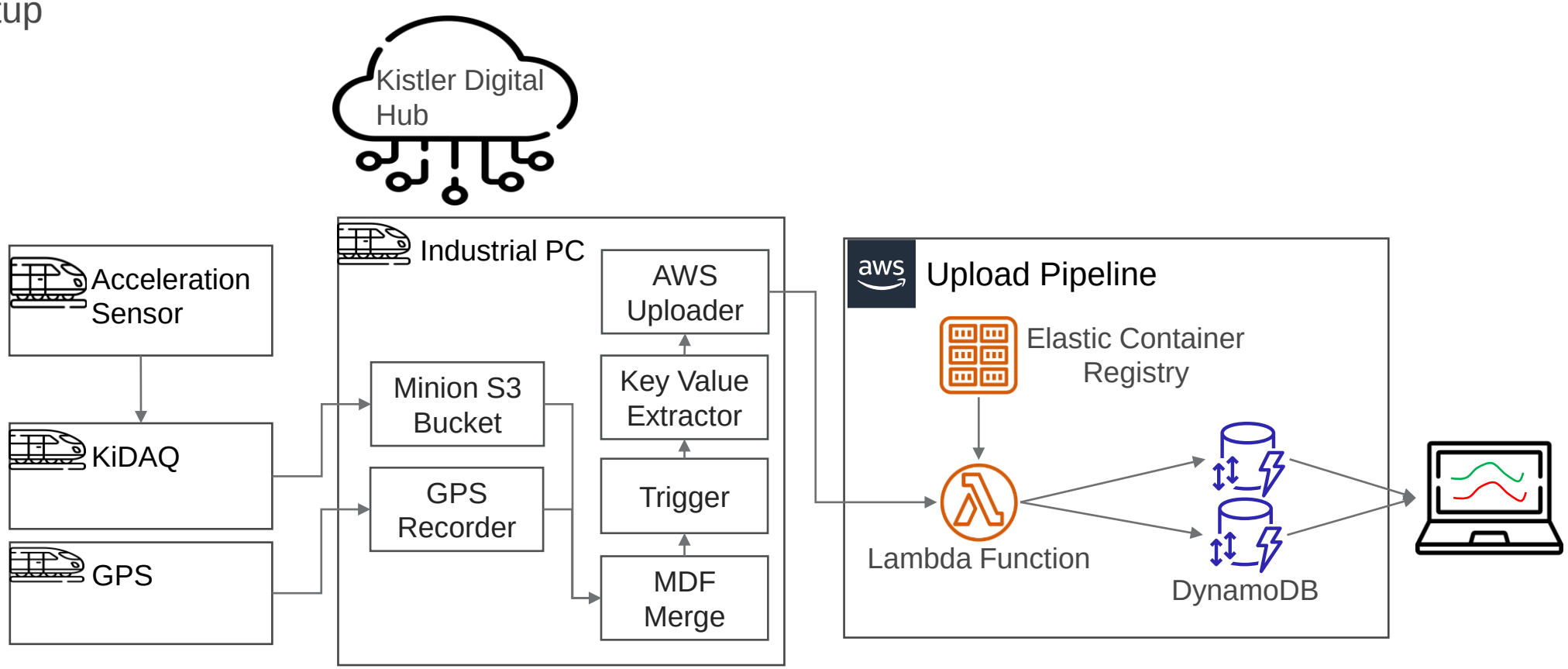
System Architecture / Cloud

Development Setup



System Architecture / Cloud

MVP Setup

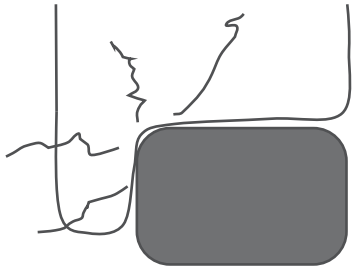


Example: Track-Wheel Interactions

Intro

Rolling stock health

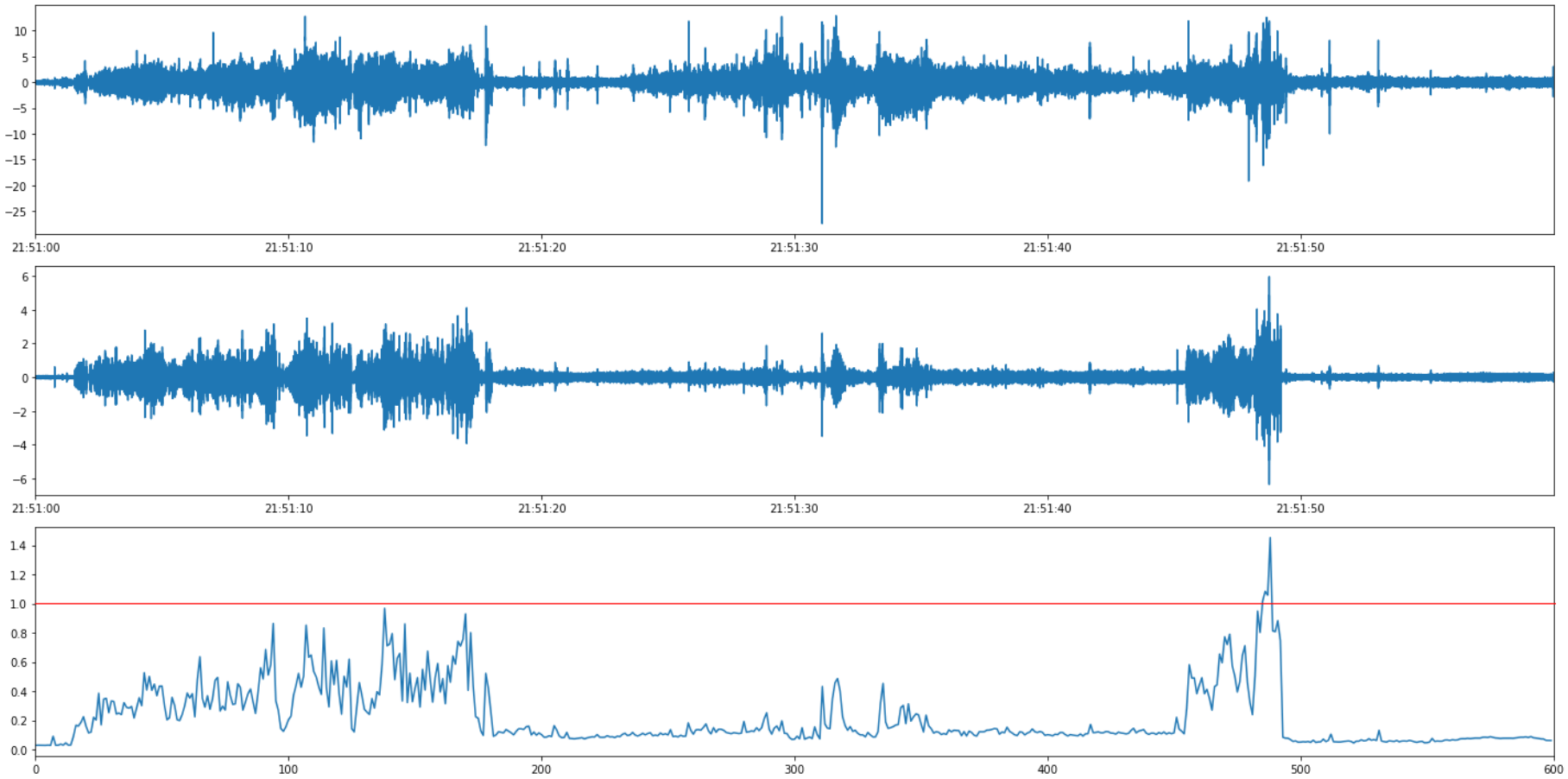
Track-wheel interactions



Infrastructure health

Example: Track-Wheel Interactions

Algorithm



Input Signal
f(t)

Filter Signal with Band Pass Filter (1500 Hz, 5000 Hz)

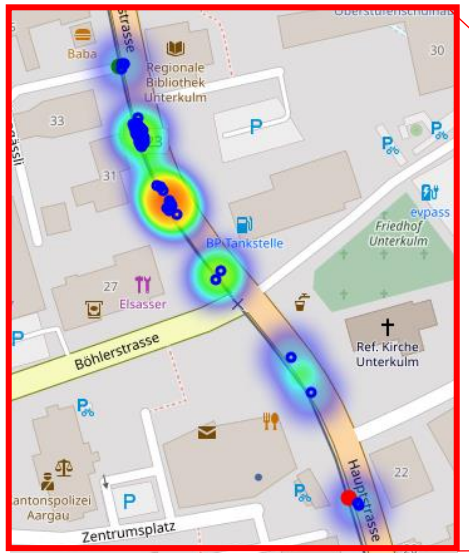
Split Signal into 4096 long windows with an overlap of 2048 samples

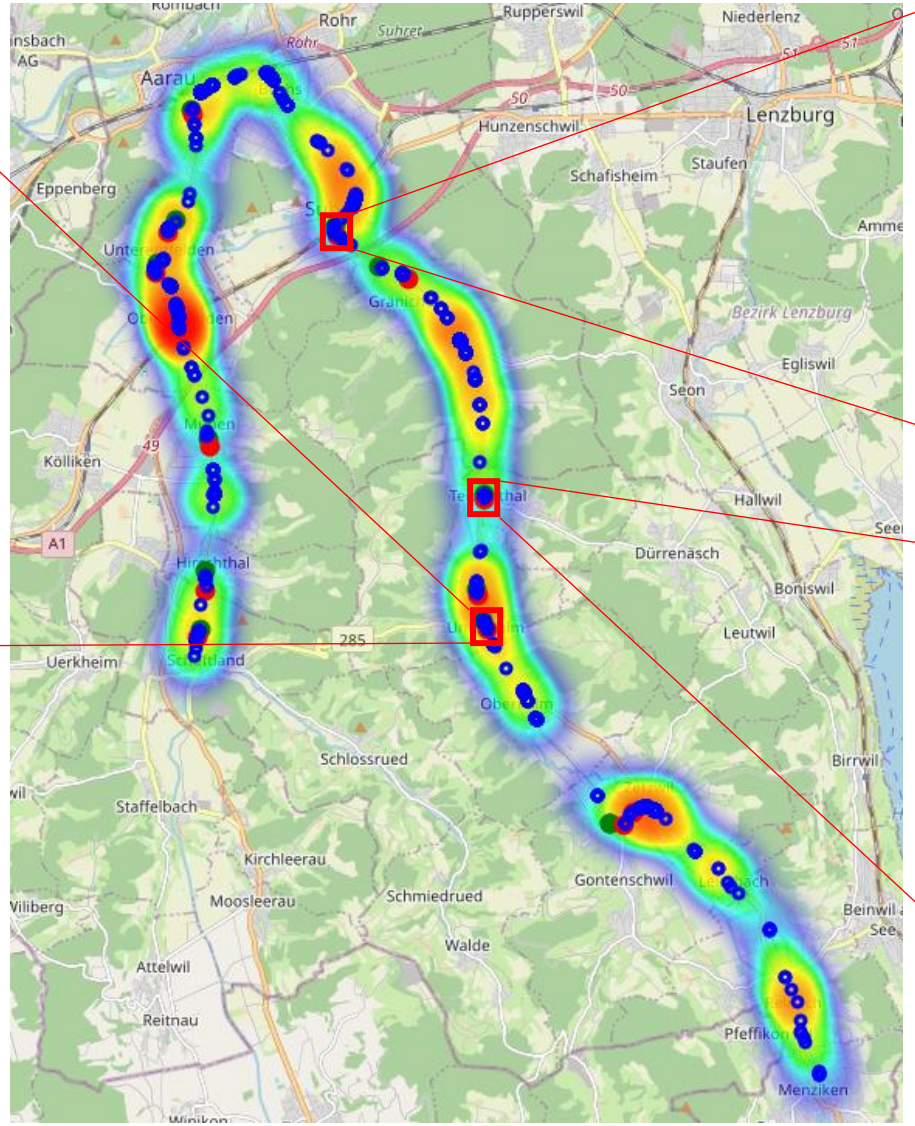
Compute the RMS of all windows

Set as Squeal when values is higher than threshold

Example: Track-Wheel Interactions

Results



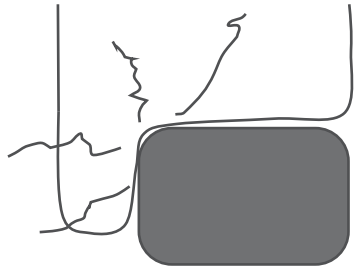


Example: Rolling Stock Health

Intro

Rolling stock health

Track-wheel interactions



Infrastructure health

Example: Rolling Stock Health

Theory / algorithms

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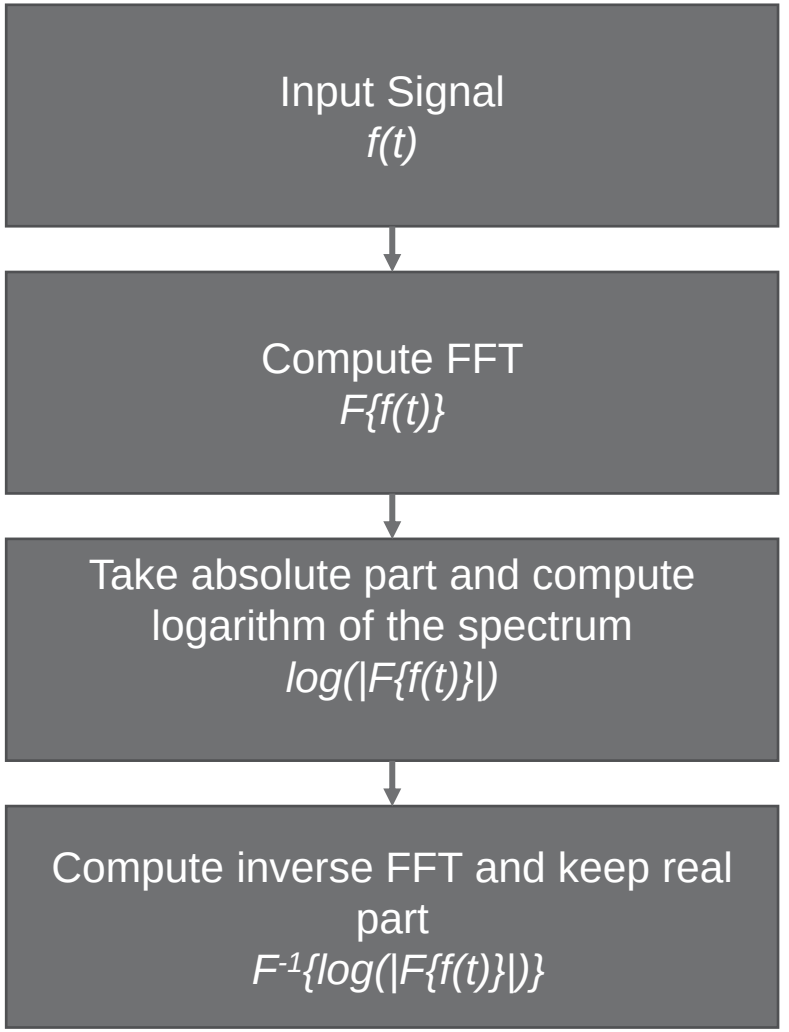
Definition of the real Cepstrum:

$$C_r = \mathcal{F}^{-1}\left\{\log(|\mathcal{F}\{f(t)\}|)\right\}$$

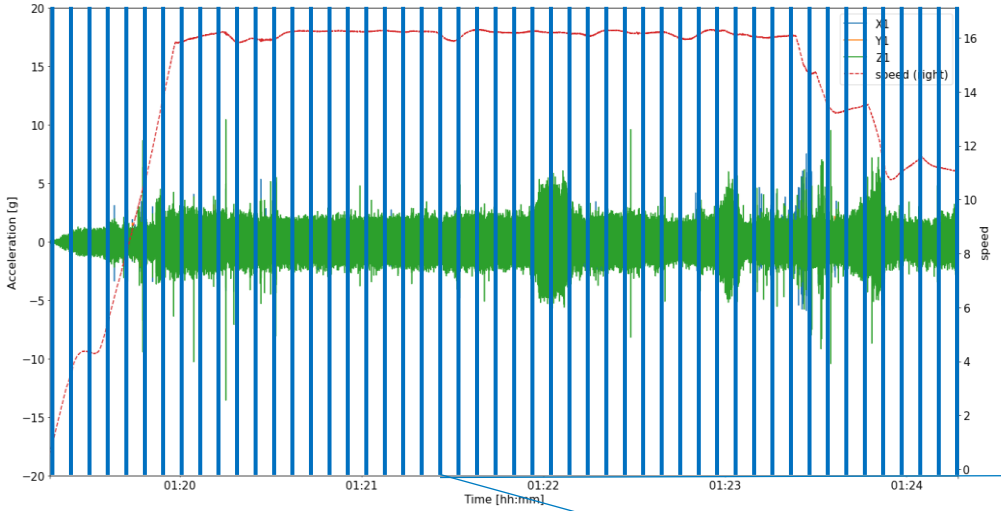
The real Cepstrum shows **repeating** sequences which are ”hidden” in signals.



[3] Baasch, B.; Heusel, J.; Roth, M.; Neumann, T. Train Wheel Condition Monitoring via Cepstral Analysis of Axle Box Accelerations. Appl. Sci. 2021, 11, 1432. https://doi.org/10.3390/app11041432

Example: Rolling Stock Health

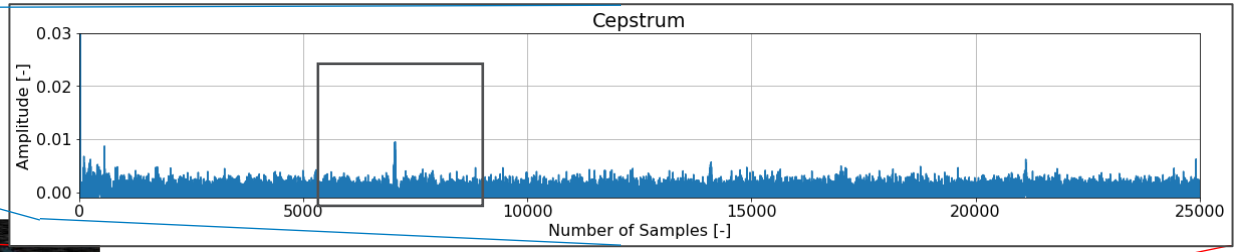
Cepstrogram

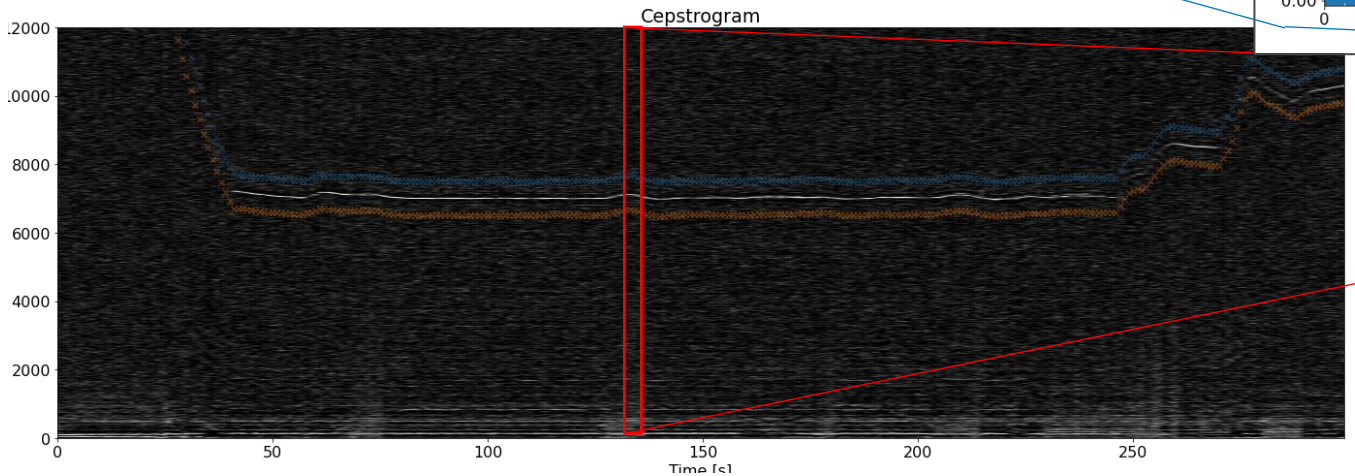


Divide input Signal into 1 second windows

Compute cepstrum for current window

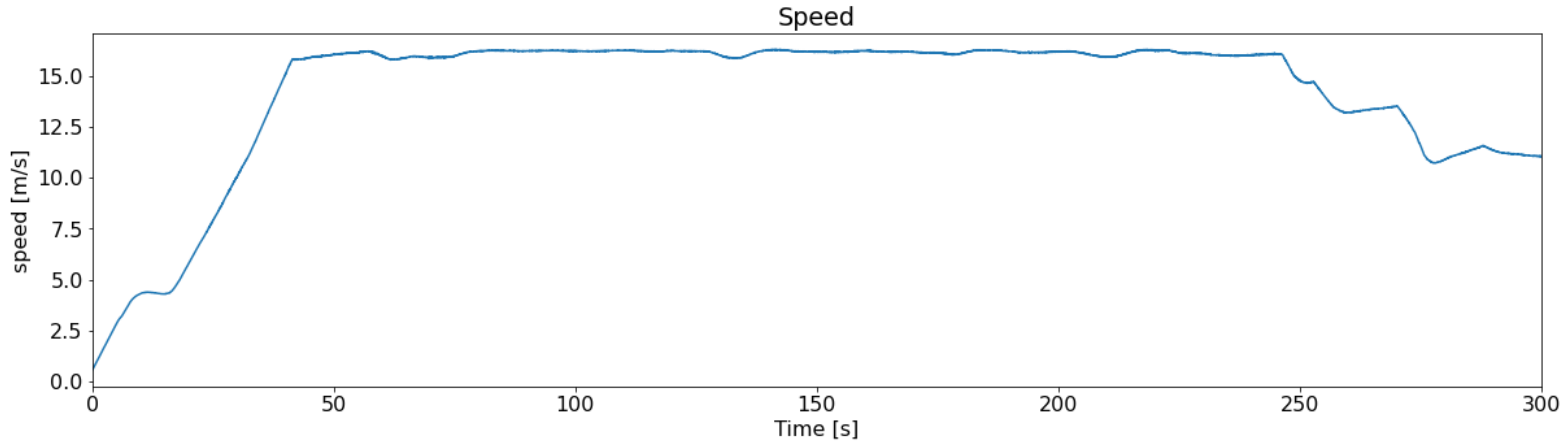
Plot cepstrum vertically in Cepstrogram





Example: Rolling Stock Health

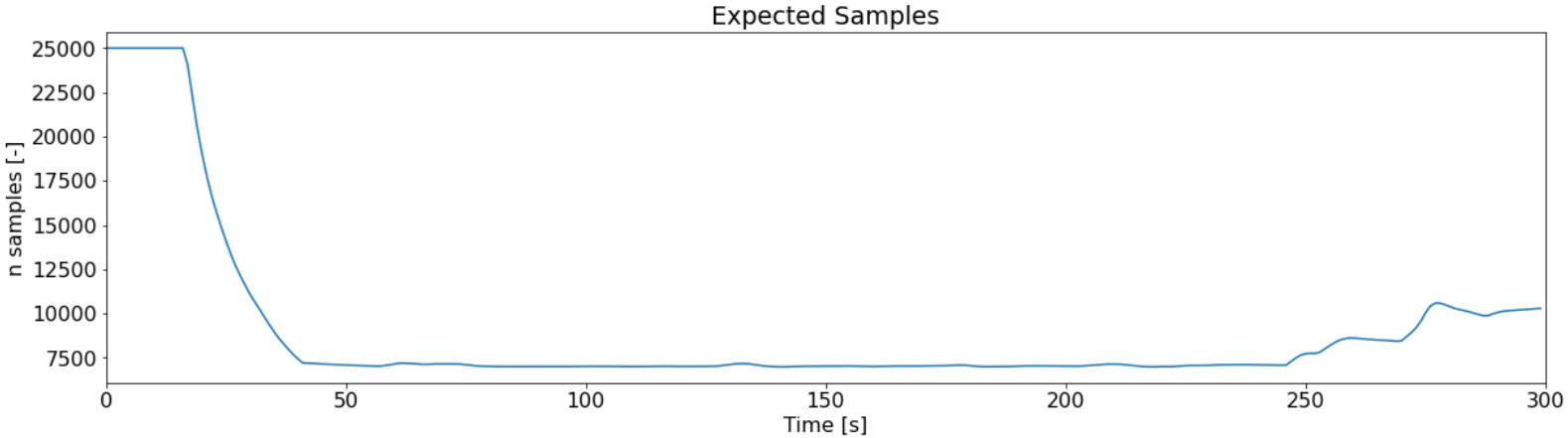
Selection of search range



$$n_{samples} = \frac{fs \cdot \pi \cdot d}{fe \cdot v}$$

$fs = Sample\ Rate$
$d = Wheel\ Diameter$
$v = Speed$

$fe = Expected\ Frequency\ per\ Revoltuion$



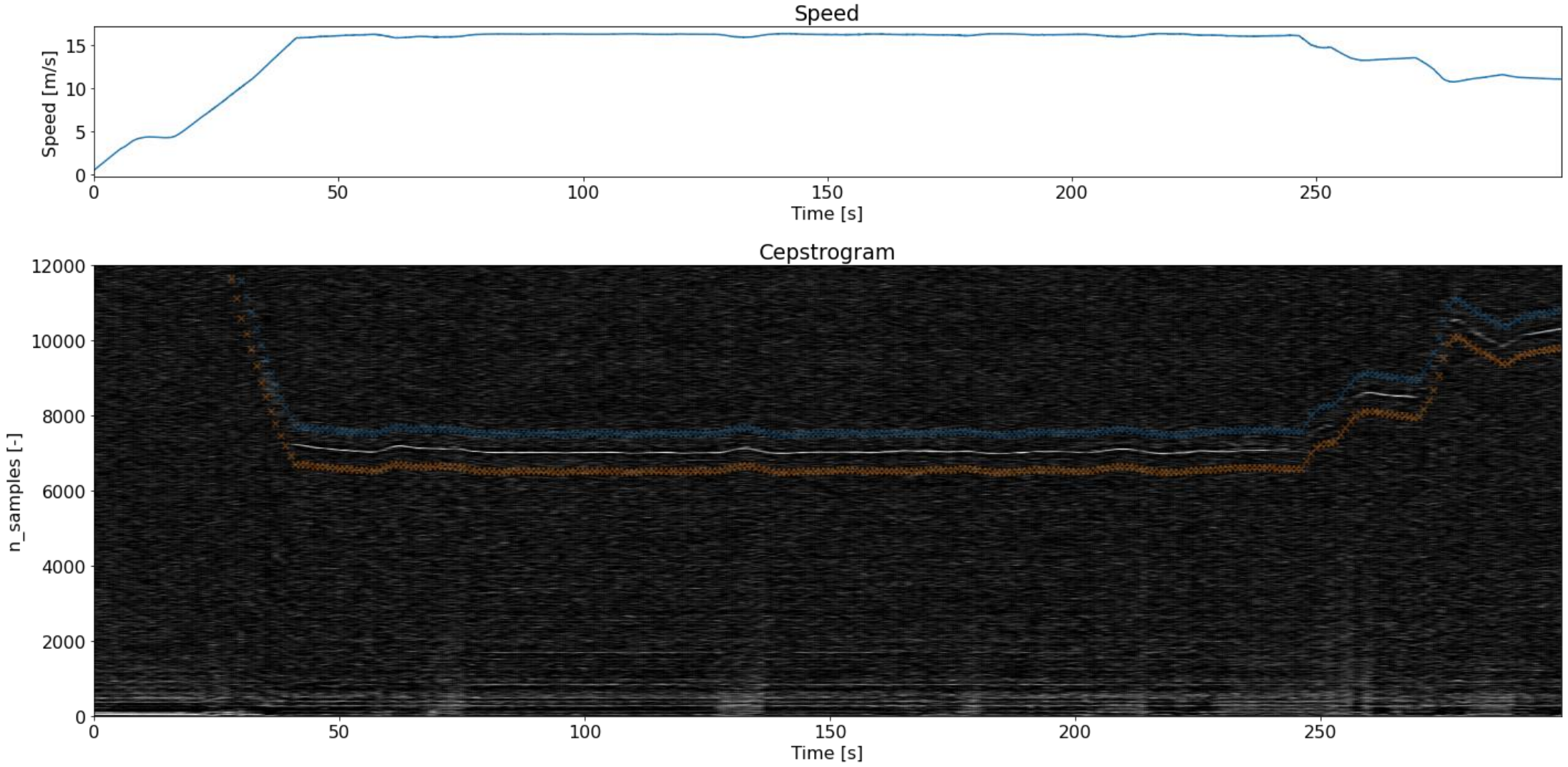
Estimate the expected frequency of events for the monitored component

↓

Derive expected samples out of speed information

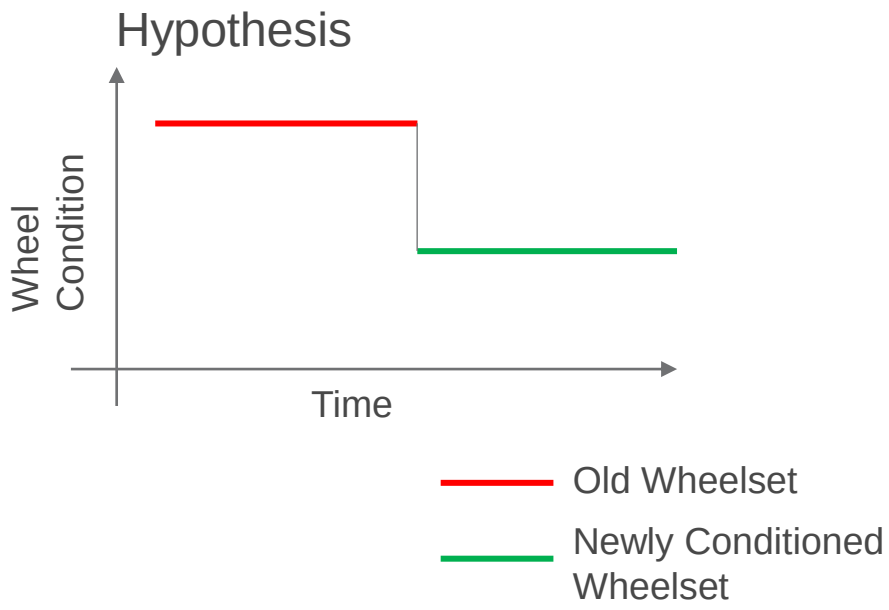
Example: Rolling Stock Health

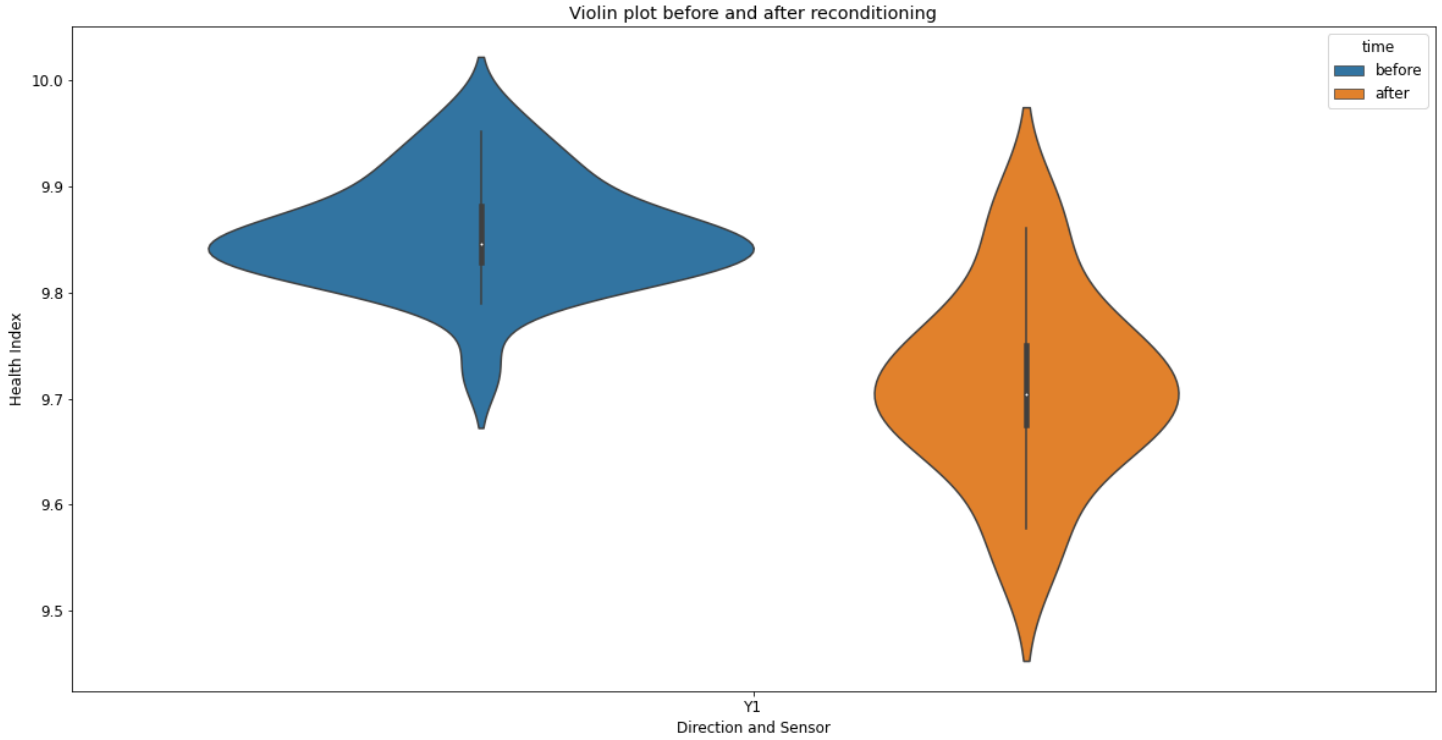
Cepstrogram – a closer look



Example: Rolling Stock Health

Wheel Health Index (WHI) – before and after maintenance





Summary and Outlook

Motivation	• Safety, reliability, ecological compatibility and availability to be fulfilled with lower costs
The role of CBM	• CBM is a chance to realize this and always requires measuring systems
The challenges	• Getting the entire system of systems to work (sensors, mounting, data acquisition, edge and cloud computing, proper visualization)
Turning data into value	• Kistler developed a POC ORMS with inputs from AVA, capable of showing **wheel health** and **track-wheel interactions** with accelerometer data
The special role of visualization	• Converting a meaningless acceleration signal into interpretable information about the assets being monitored
Outlook	• New use-cases, data pipeline and GUI for live visualization