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Human senses mimicking:

Self-evaluating vehicles with focus on vibro-acoustics

Amir Hosseini
Industrial PhD Student

SEEIT
Sensor informatics and Decision-making for the Digital Transformation

LINKÖPING UNIVERSITY

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Project Participants

Academic Partner: Linköping University

Academic Supervision team:

Daniel Jung, PhD.
Linköping University

Erik Frisk, PhD.
Linköping University

Industrial Partner: Volvo Cars Corporation

Industrial Supervisor:

David Lennström, PhD.
Volvo Cars Corporation

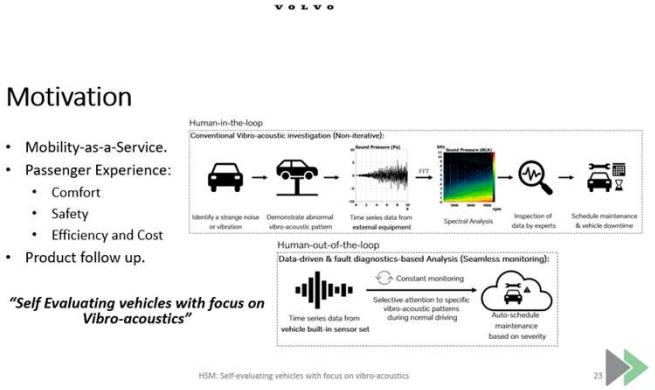
Project is funded by Volvo cars and Vinnova/FFI.

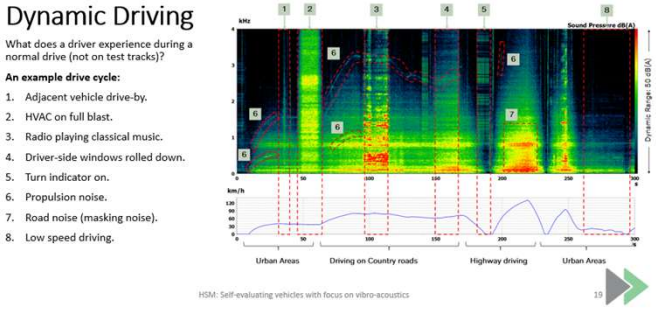
Brief Recap

Objectives/Motivation:

- Human-out-of-the-loop detection.
- Using Microphone as non-intrusive diagnostic tool
- NVH anomalies are context-dependent and depend on masking condition
- Known Anomalies -> use vehicle Insight.
- The case of ***propulsion noise: Tonal footprint***
- Vibroacoustic response of propulsion (aka Order)

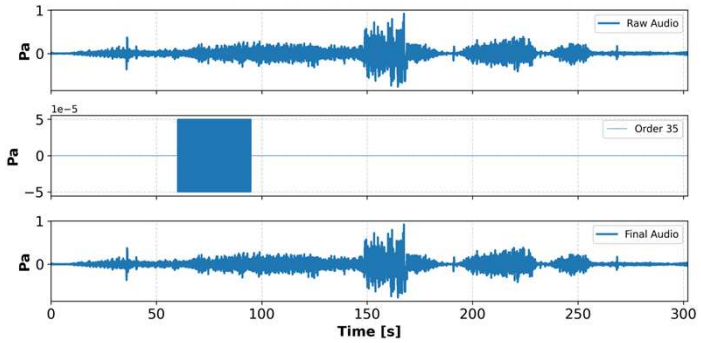
$$Frequency = \frac{Order \times RPM}{60}$$

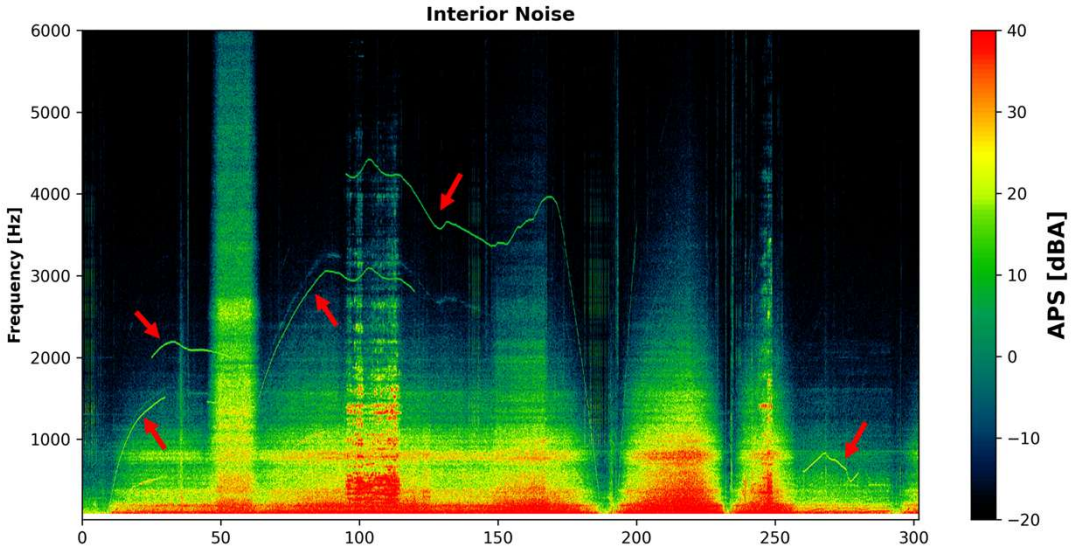




The special case of ghost orders

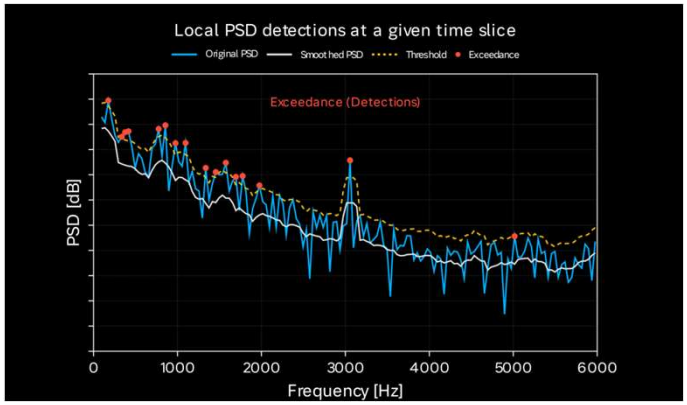
- Manufacturing imperfections: e.g., gear surface waviness, bearing imperfections.
- Intermittent as they are torque sensitive

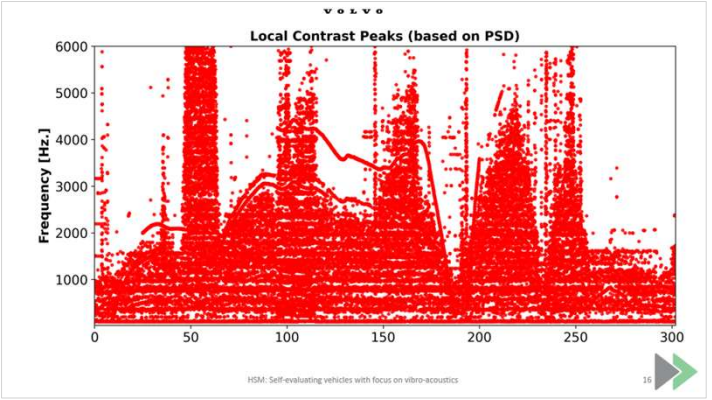




Spectral Detections

- Signal to Noise Ratio (SNR) based.
- NVH Thresholds implicitly applies psycho-acoustics aspect.
- Noisy detection as it only depends on the local energy.





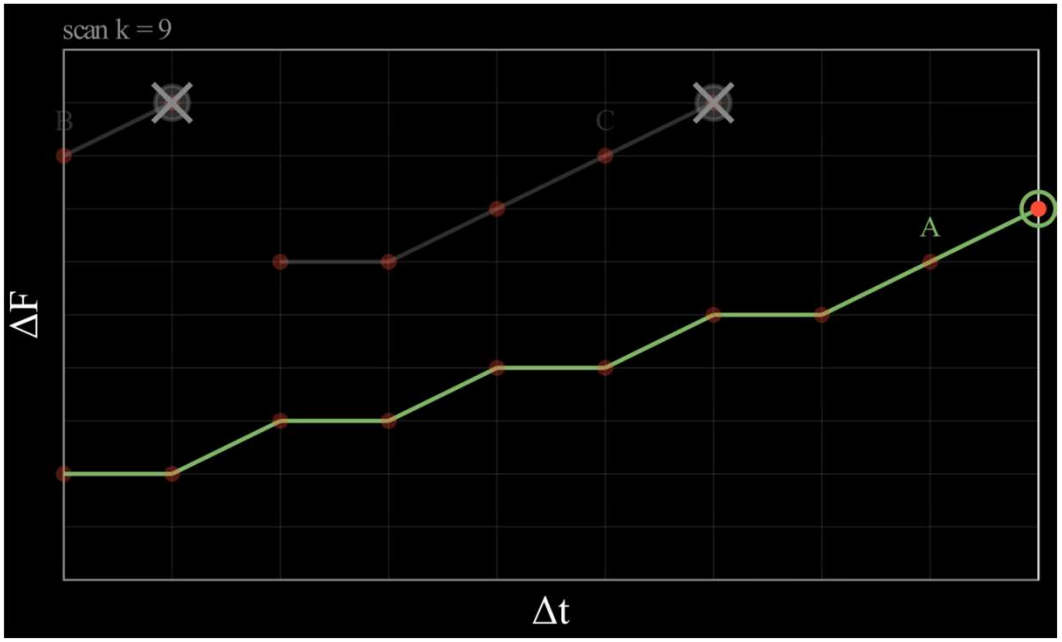
How do we find the evolution of tonality among these many detections?

How do we automate this process?
- Perhaps in real-time -

Automatic Tonal component Tracking

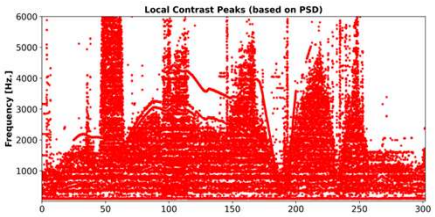
- Inspired by the concept of target tracking.
- A simple M/N logic applied (observed peaks over successive records).
- Incorporate vehicle insight:
  - Freq=(Order × RPM)/60
- The model doesn't expect any specific 'order' number and tracks 'blindly'
- Some relevant work:

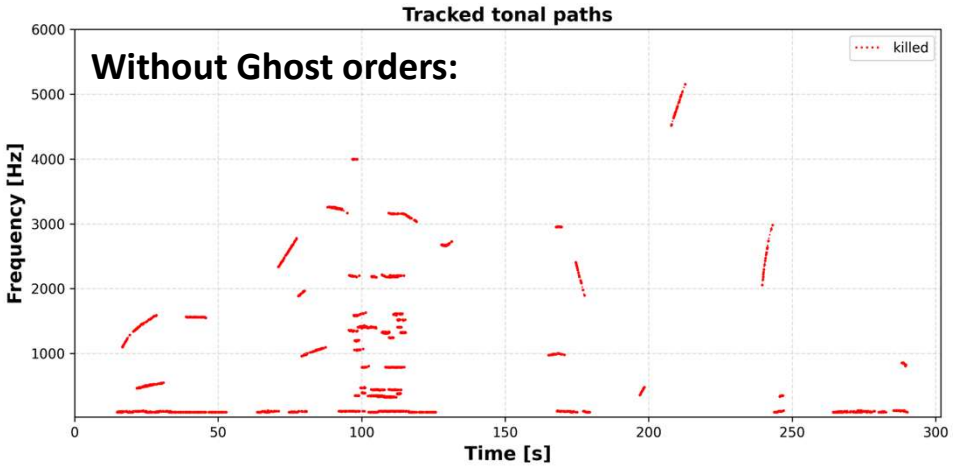
  Seto, M. L. "Application of tonal tracking to ship acoustic signature feature identification." (2011): 064501.

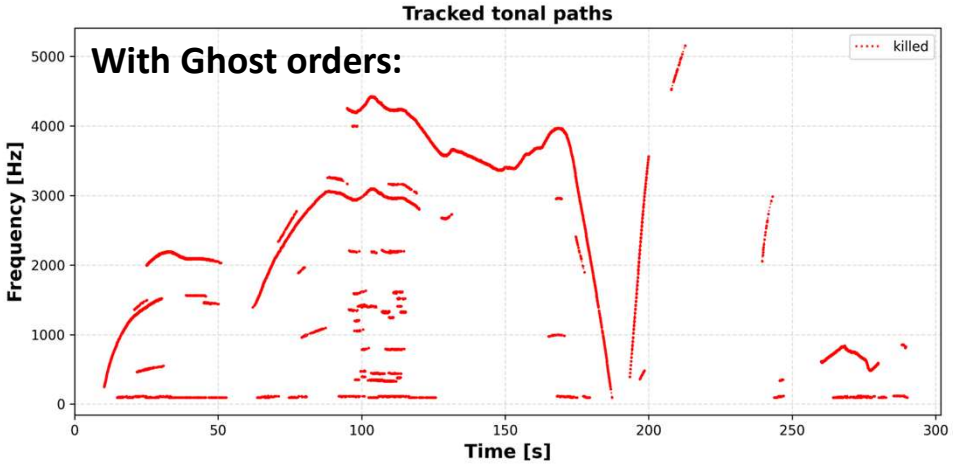


Results:

- The model can trace and detect tonal components at different frequencies.
- Ongoing activities:
  - Robustness test
  - Performance metrics
  - Miss-detection root cause analysis
  - Investigate isolability and detectability of these ghost orders







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Med finansiering från:

VINNOVA

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Research status

Completed

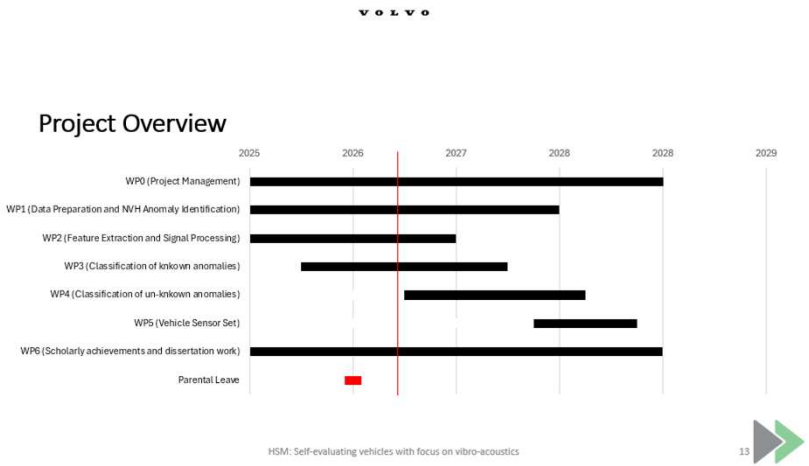
- Initial case studies concluded
- Python Pipeline is operational

Ongoing

- Literature survey
- 13th SAFEPROCESS 2027 - IFAC Conferences

Next Steps

- Other NVH anomalies
- Data-driven benchmark studies



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Appendices

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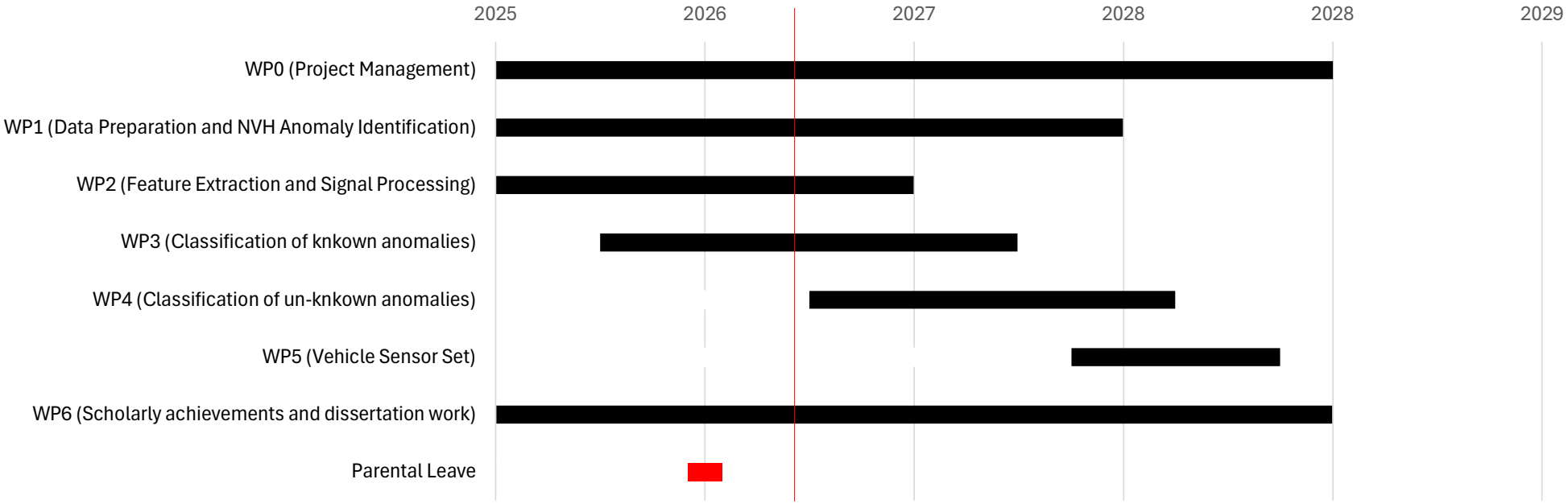
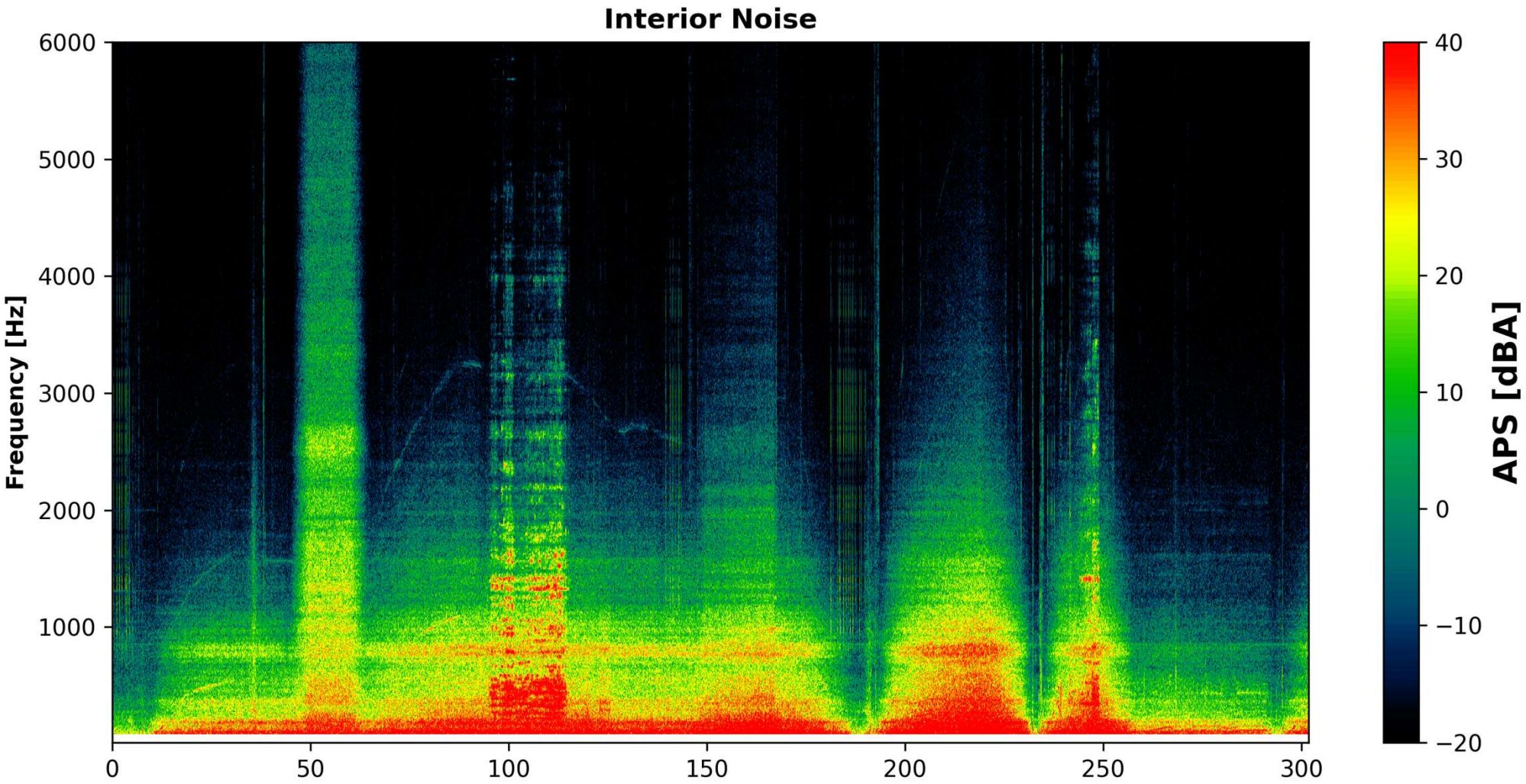
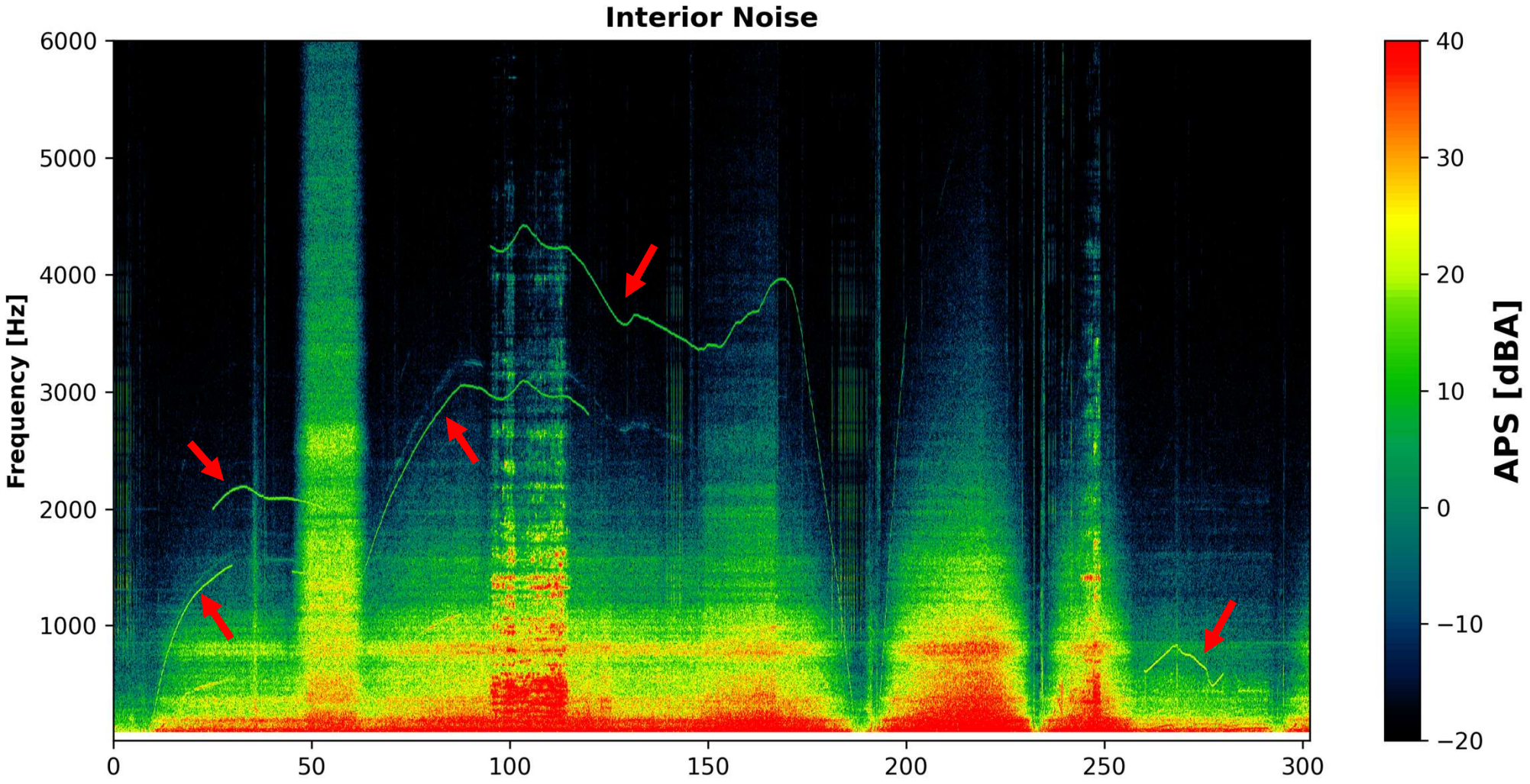
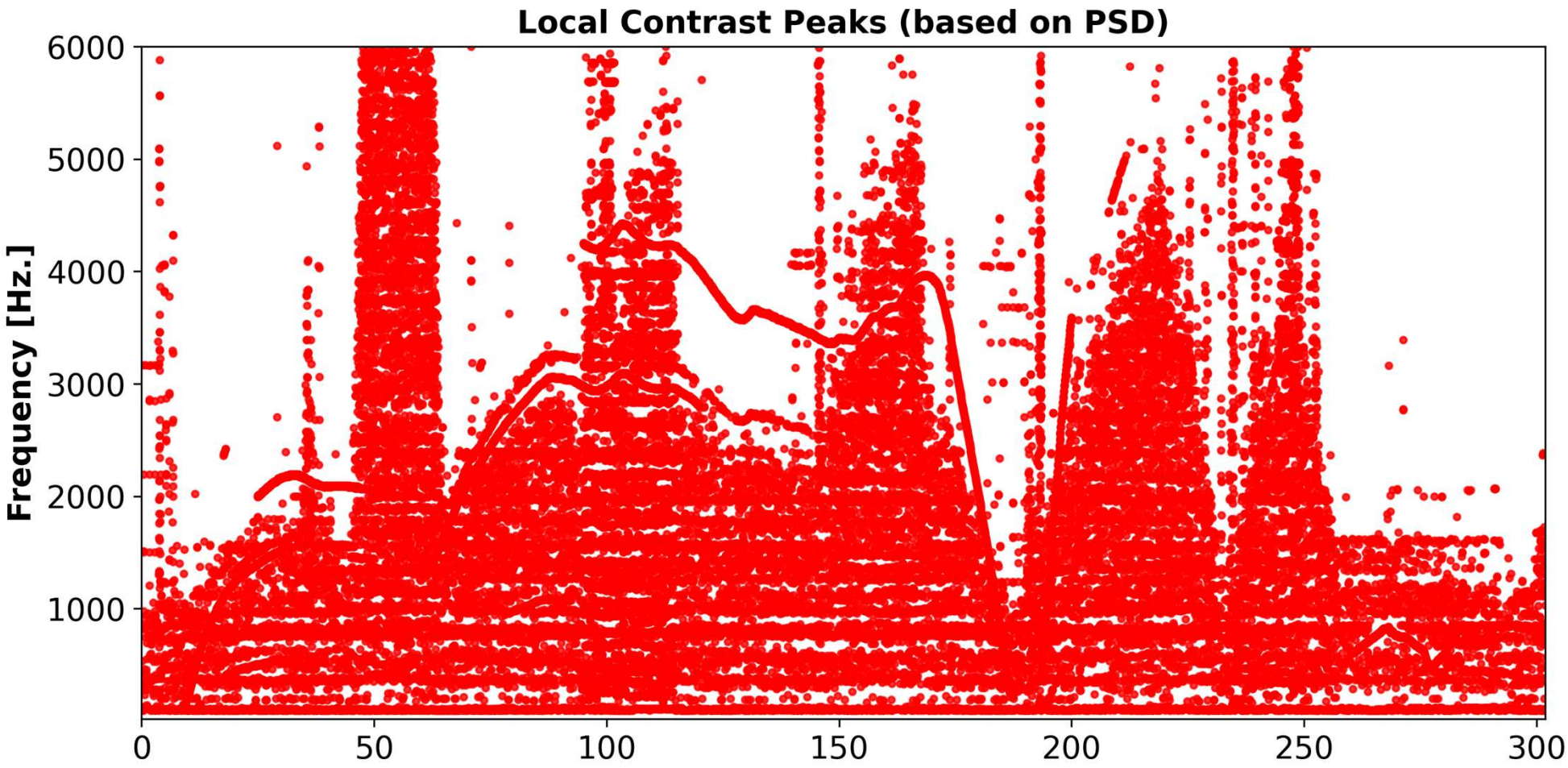
Project Overview





NVH anomalies are inherently **context-dependent**, as their detectability depends on the surrounding soundscape and **masking conditions**.


Interior Noise
Frequency [Hz]
6000
5000
4000
3000
2000
1000
0
50
100
150
200
250
300
APS [dBA]
40
30
20
10
0
−10
−20


Local Contrast Peaks (based on PSD)
Frequency [Hz.]
6000
5000
4000
3000
2000
1000
0
50
100
150
200
250
300

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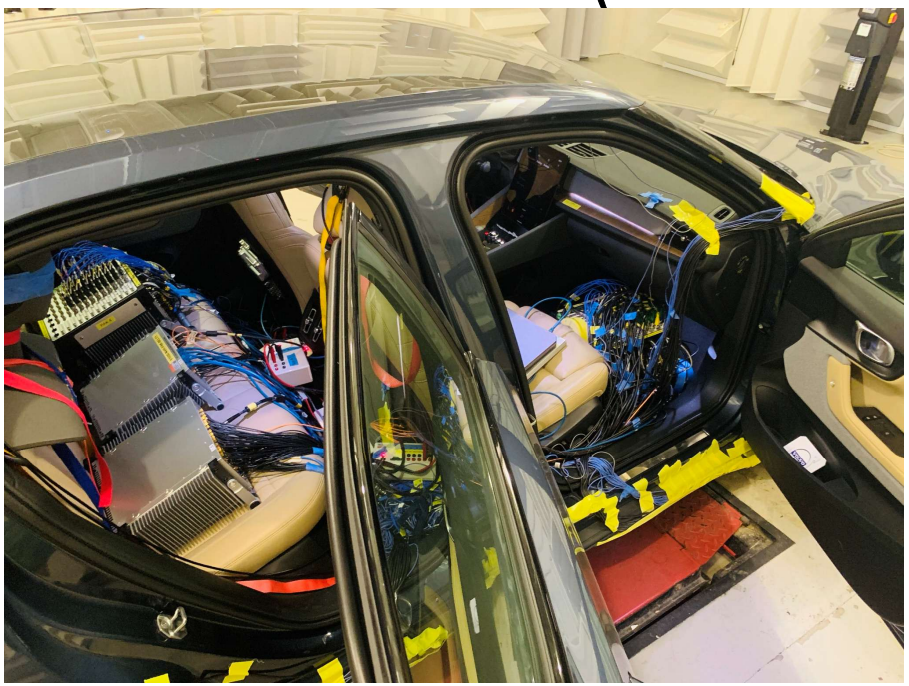
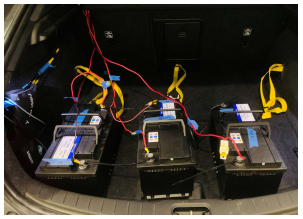
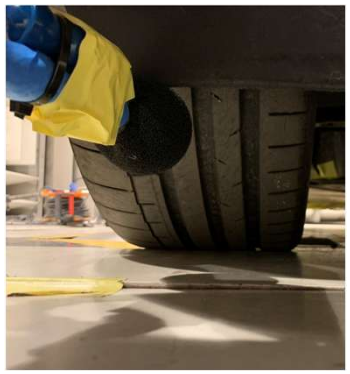
NVH Simulator (Instrumentation)







Indicator	Channel
EFAD	**94**
Airborne	15
Reference Accs	1
Structure-Borne	78 (26 tri-axial Accs)
ERAD	**70**
Airborne	15
Reference Accs	1
Structure-Borne	54 (18 tri-axial Accs)
Interior	**11**
Response	4
Tactile	7
Resolver	**6**
Suspension	**20**
Front Airborne	4
Front Structure-Borne	6
Rear Airborne	4
Rear Structure-Borne	6
Total	**201**

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How does it all work

Equalization

*.wav

Measurements

Vehicle Sensitivity (ATF)

Vehicle Instrumentation

Constant Torque Sweeps

Constant Speed

Coast Downs/ Constant Pedal

Vehicle Sensitivity (VTF)

Source Path Contribution

Source Strength (AB - Volume Velocity) $(Pa.s)/m^3$

Source Strength (SB - Forces) Pa/N

Data Preparation Tool

Extract Propulsion Ord

Order Files

Order Files

Remove Propulsion Ord

Constant Speed

Multiple

Road Noise SB

Road Noise AB

Wind Noise

Performance Data Preparation

Performance Model

NVH Simulator

Blending of Order Sound Object

+

Blending of Array Sound Objects

+

Performance Model

+

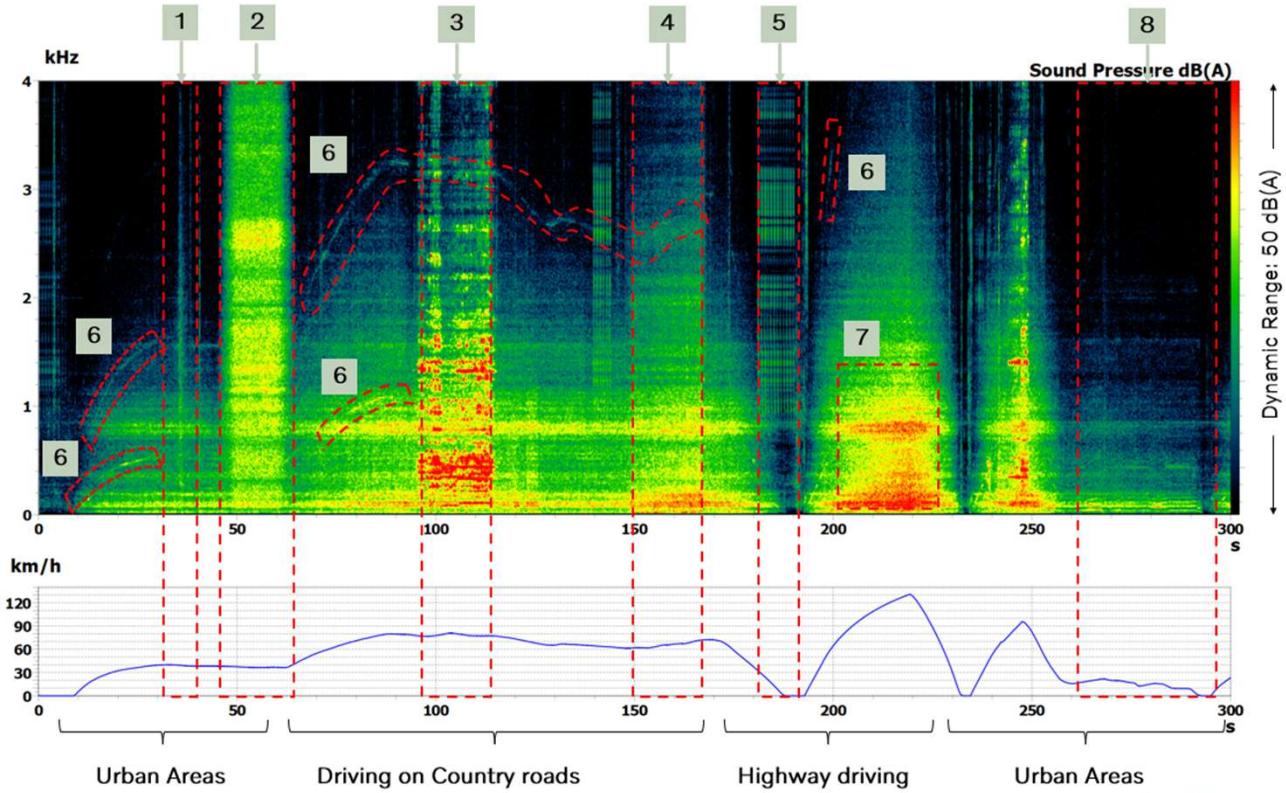
Real-time

Dynamic Driving

What does a driver experience during a normal drive (not on test tracks)?

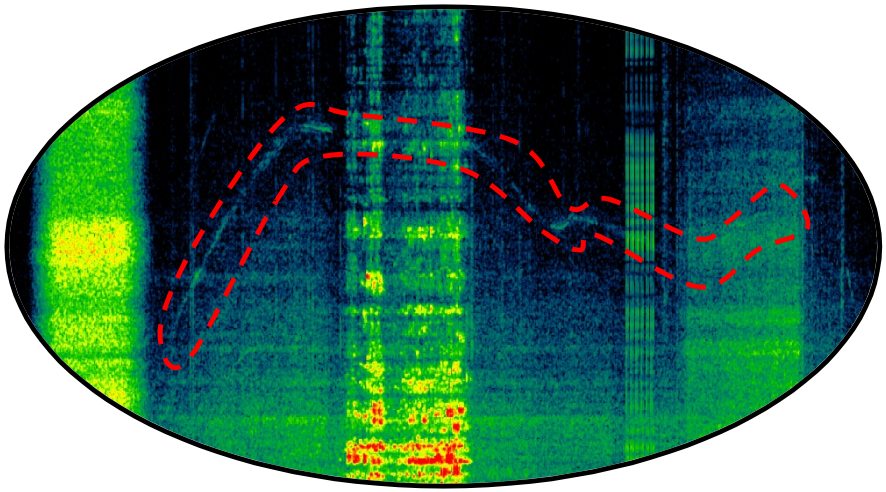
An example drive cycle:

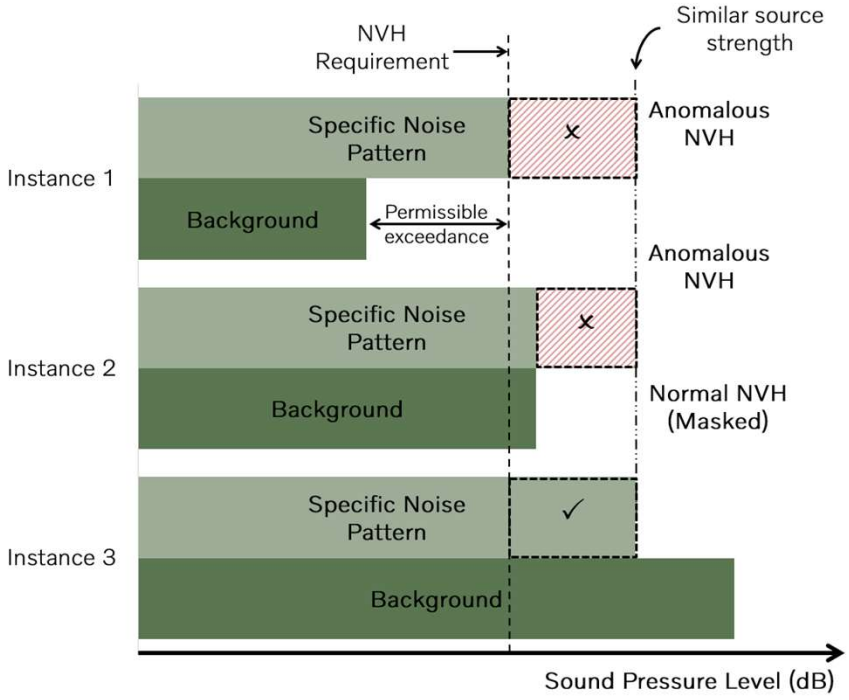
1. Adjacent vehicle drive-by.
2. HVAC on full blast.
3. Radio playing classical music.
4. Driver-side windows rolled down.
5. Turn indicator on.
6. Propulsion noise.
7. Road noise (masking noise).
8. Low speed driving.



NVH Anomaly

- Noise, Vibration and Harshness
- An NVH anomaly affects the average customer however, an expert (system) is required to isolate the noise and





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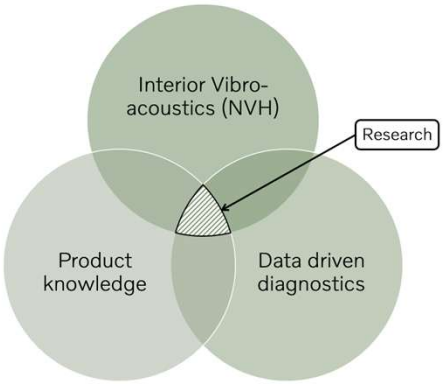
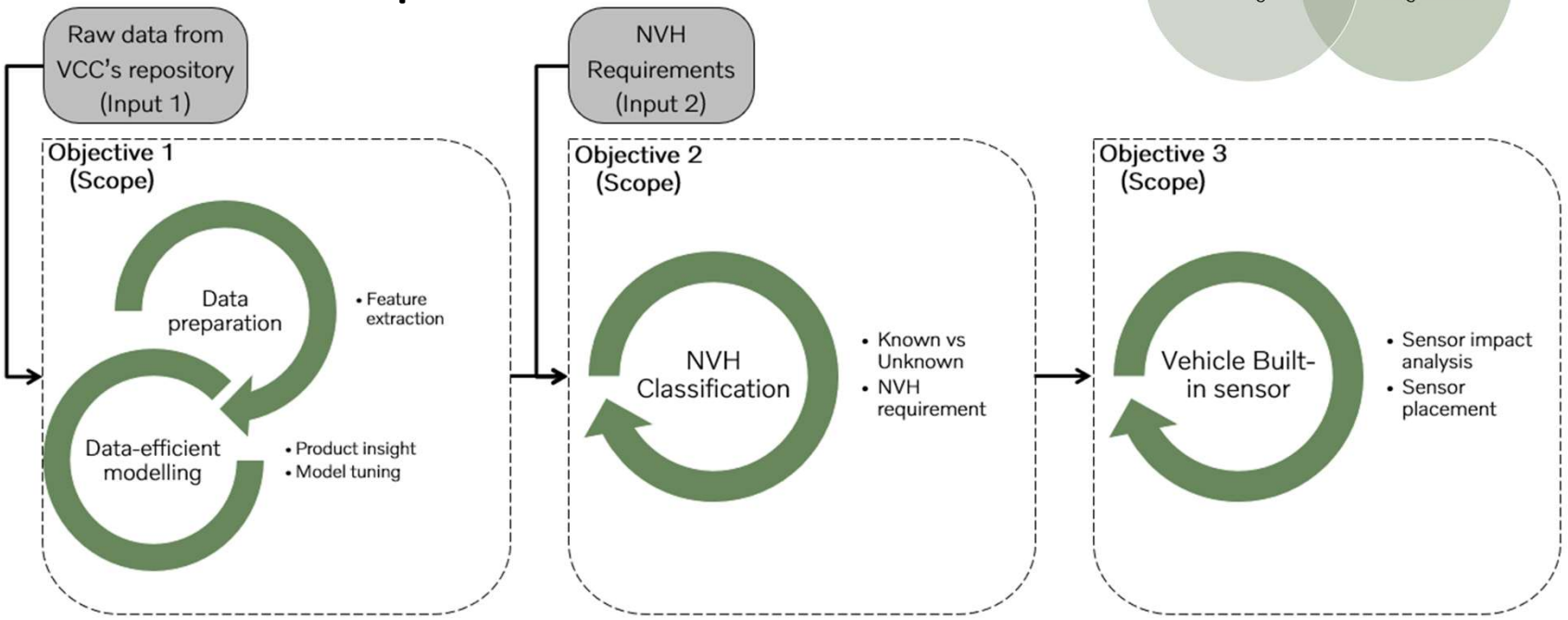
Research Scope





Develop a methodology to model vibro-acoustic signature data.

Establish a method to classify vibro-acoustic anomalies.

Formulate a framework for conducting impact analysis of in-vehicle sensor data

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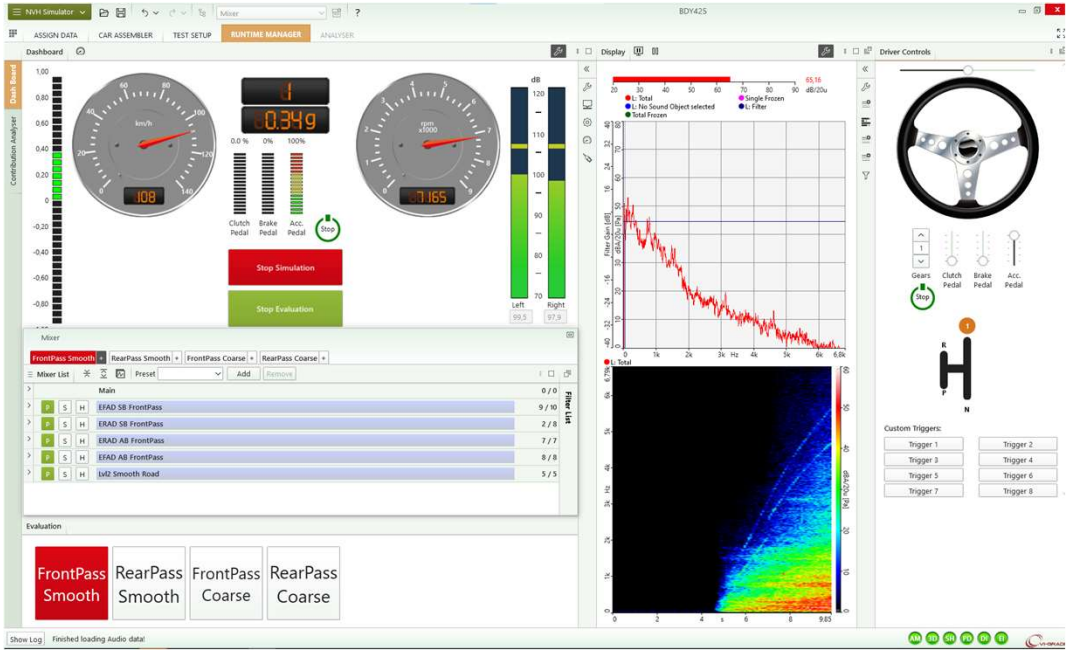
NVH Simulator



- Drive a virtual vehicle in a virtual environment.
- Real-time auralization of NVH data.
- Experience the sound for any driving condition.
- HB&K (VI-GRADE)

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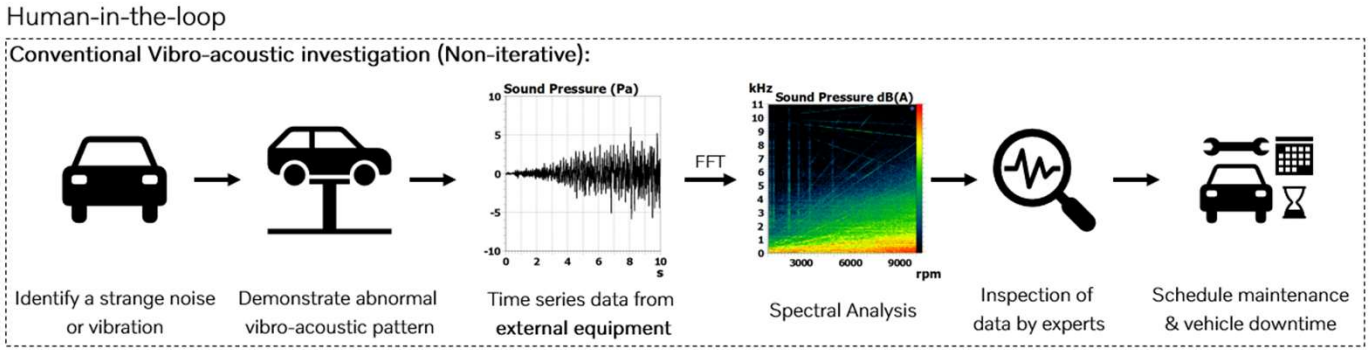
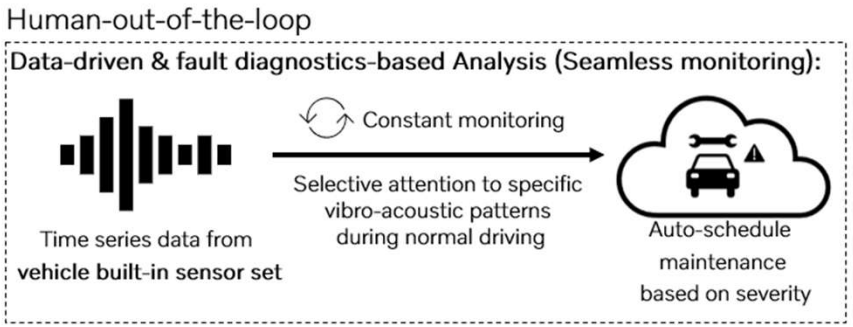
Motivation

- Mobility-as-a-Service.
- Passenger Experience:
  - Comfort
  - Safety
  - Efficiency and Cost
- Product follow up.

"Self Evaluating vehicles with focus on Vibro-acoustics"





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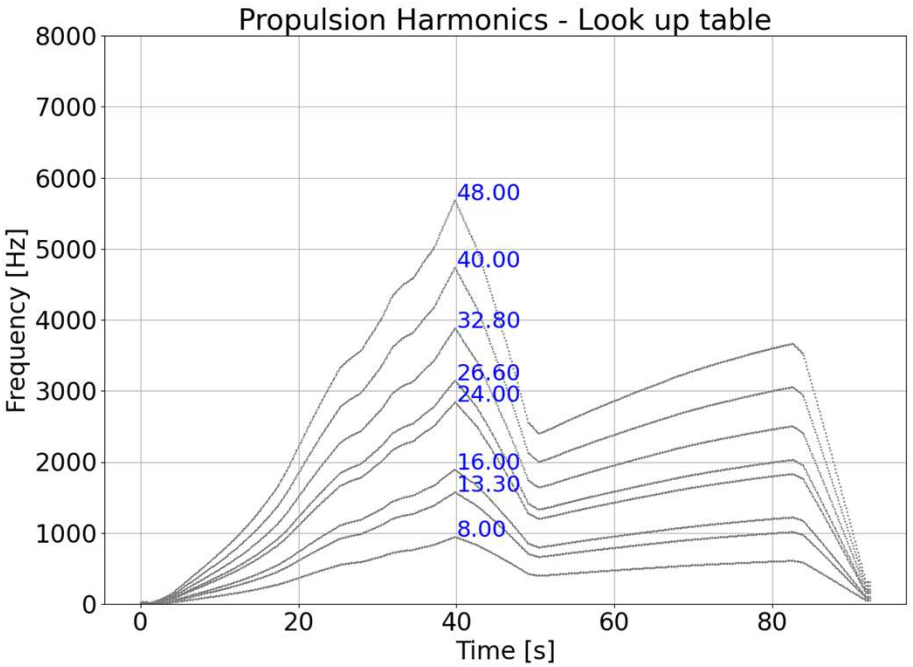
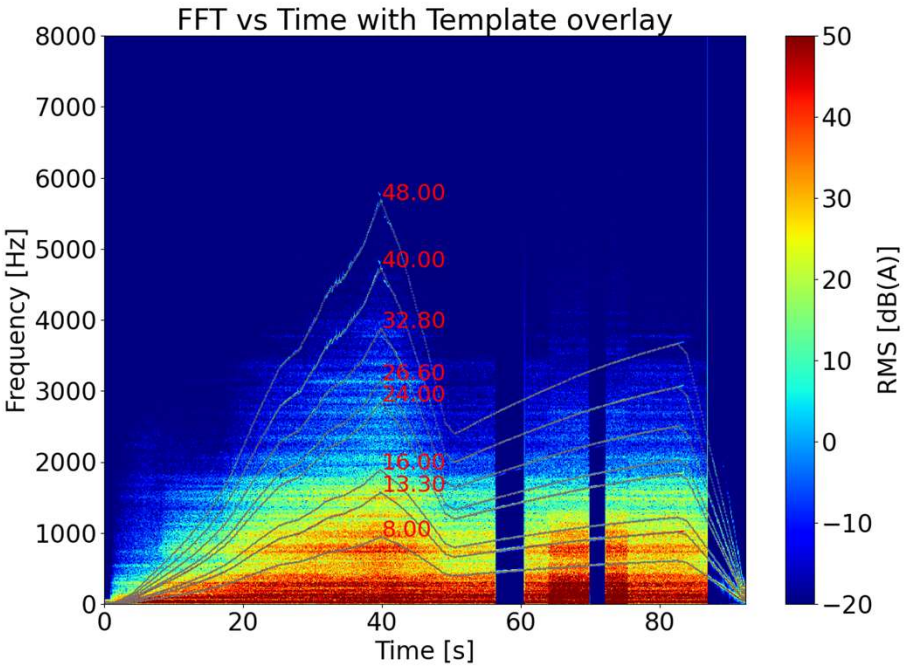
Template matching



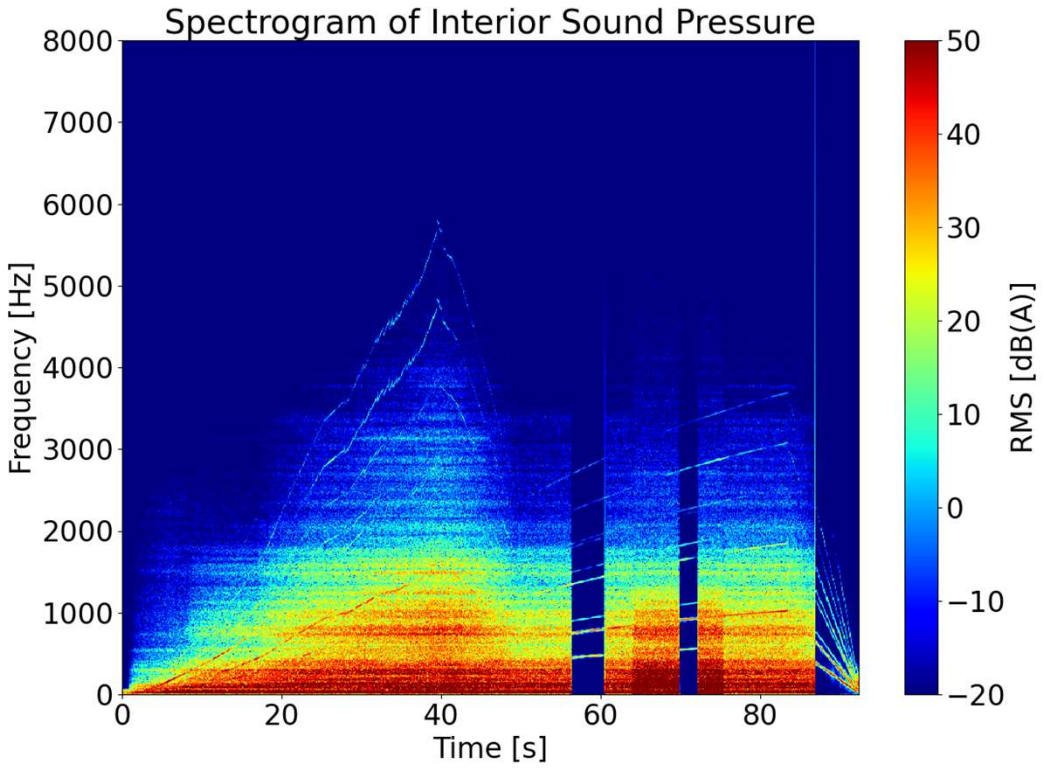


Case Study: Propulsion noise

Interior Noise

- Vibroacoustic response of propulsion: aka Order.
- Linear relationship:

$$Frequency(Hz) = \frac{Order\ \#\ \times RPM}{60}$$



Project Progress

- Focus on WP6 with coursework.
- Partial focus on WP1 and WP2.
- Milestone 1: Identification of relevant scenarios and NVH content for initial investigations.

Next steps

Implementation of relevant psychoacoustics analysis in Python, namely:

- Tonality
- Tone to Noise Ratio
- Prominence Ratio
- Fluctuation strength
- …