



Universität St.Gallen

Hearing Problems: Exploring Acoustic-sensing for Predictive Maintenance

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From insight to impact



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Agenda

1. Modern Manufacturing and Machine Maintenance
2. Acoustic Sensing
3. Pumped Storage Hydropower Acoustic-sensing
4. Summary and Takeaways

1. Introduction

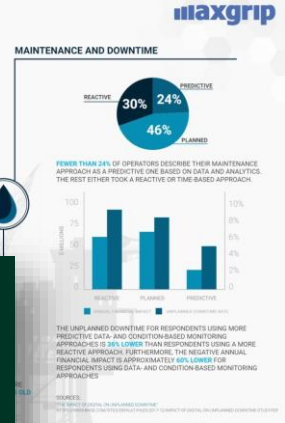
Modern Manufacturing and Machine
Maintenance

Machines can fail for multiple reasons

- Downtimes are **costly**, but **very costly** when unplanned

- How, in our current “Industry 4.0” era, we can **improve** existing predictive maintenance processes?

THE UNPLANNED
COST OF DOWNTIME



annual cost to a typical large plant through unplanned downtime (up 65% in two years)

\$1.5 trillion

annual downtime losses for Fortune Global 500 firms

70% rise

in losses for Fortune Global 500 firms compared to two years ago

11% of annual revenues

amount lost to unplanned downtime over the Fortune Global 500 companies

Scheduled vs Predictive Maintenance

Scheduled maintenance

- Regardless whether it is the manufacturing or automotive industry, railway companies, or power plants, **manual inspection is a burden**

Condition-based Monitoring (CbM)

- Monitoring machines or assets using sensors to measure current state of health

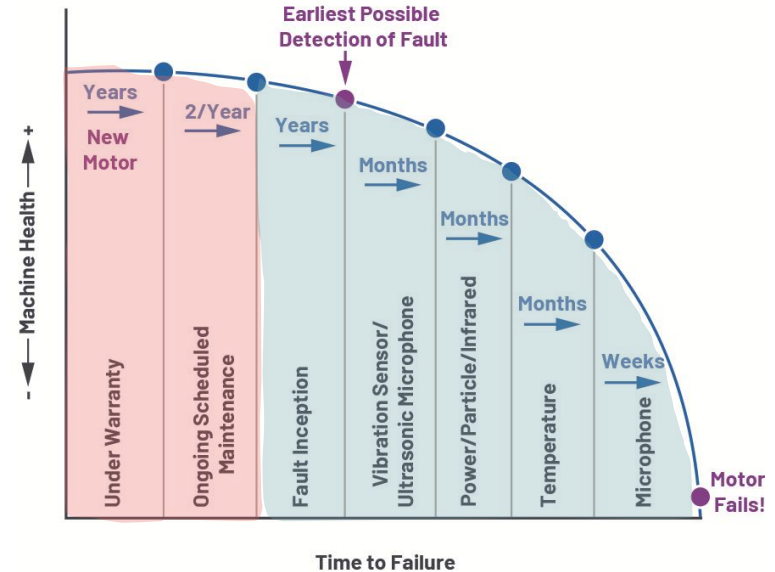
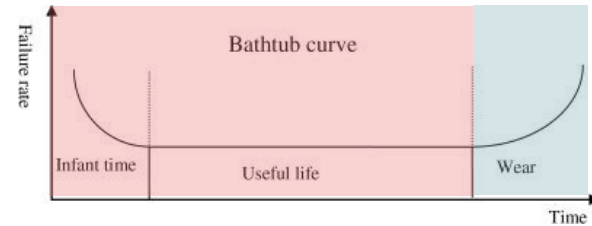
Predictive maintenance (PdM)

- Combination of techniques, including CbM, and ML and Data Analytics to detect patterns and predict anomalies (e.g., MTTD, MTTR, MTBF)

At its core, predictive maintenance is an “Industry 4.0” activity by leveraging sensor data and analytics to optimize costs and maximize machine uptime

A Critical Look at the Bathtub Curve

Georgia-Ann Klutke, Peter C. Kiessler, and M. A. Wortman



Predictive Maintenance Classifications

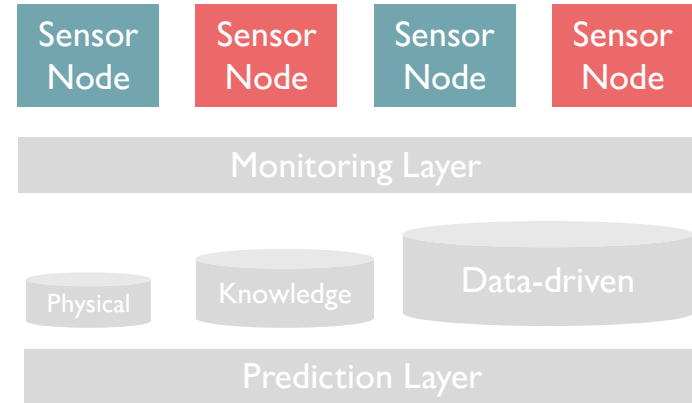
Approaches

Another essential content related PdM regards the three classifications of the approach used for prediction(Deutsch and He, 2018, Wang et al., 2018, Wu et al., 2017c):

- **Physical model-based:** has as its main feature mathematical modeling with reflexes in the condition of a component, needing the precision of the condition and measurement of failure, and statistical methods to limit these indices(Wu et al., 2017c);
- **Knowledge-based:** approaches that reduce the complexity of a physical model, for this reason, is often used as a hybrid strategy, for example, expert systems or fuzzy logic(Ayad et al., 2018, Wu et al., 2016);
- **Data-driven:** models most found in the current evolution of PdM solutions are statistics-based, pattern recognition, or artificial intelligence (AI) and models based on machine learning algorithms.

Zonta, Tiago, Cristiano André Da Costa, Rodrigo da Rosa Righi, Miromar Jose de Lima, Eduardo Silveira da Trindade, and Guann Pyng Li. "Predictive Maintenance in the Industry 4.0: A Systematic Literature Review." *Computers & Industrial Engineering* 150 (2020): 106889.

*PdM may not always rely **learning-based** approaches, it can also involve **physical** models (e.g., stress, wear) or **knowledge** (e.g., threshold rules or statistical analysis).*



Sensors

VIBRATION: Rotating machines (motors, pumps, bearings)

TEMPERATURE: Heating-generating equipment (typically also rotating)

PRESSURE: Hydraulic systems and pneumatic equipment

ACOUSTIC: Can detect subtle changes in machine sounds (often not human-perceived).

Among these sensors, *acoustic sensing is crucial for identifying anomalies early and accurately.*

2. Hearing Anomalies

Acoustic Sensing

Acoustic Sensing Principles

Definition

A method of capturing and analyzing sound waves (vibrations in air or other mediums) emitted by machinery or processes.

Principles

- **Frequency analysis:** different types of failures, different/unique sound patterns that can be verified using a **Fourier Transform**
- **Sound emission and wave propagation:** understand sound signatures during normal (and/or faulty operations)

Modeling considerations

Environment plays a significant role

- Multipath fading
- Signal reflections, collisions
- **Positioning of microphones is key**

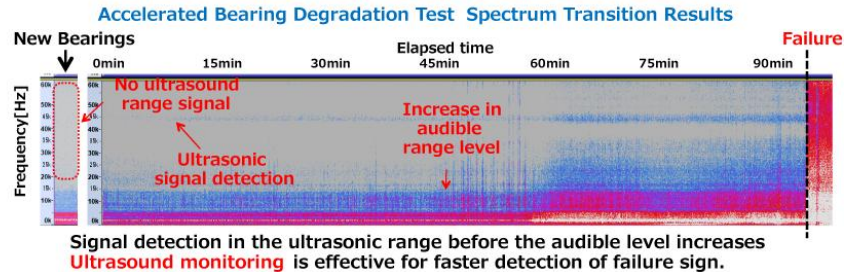
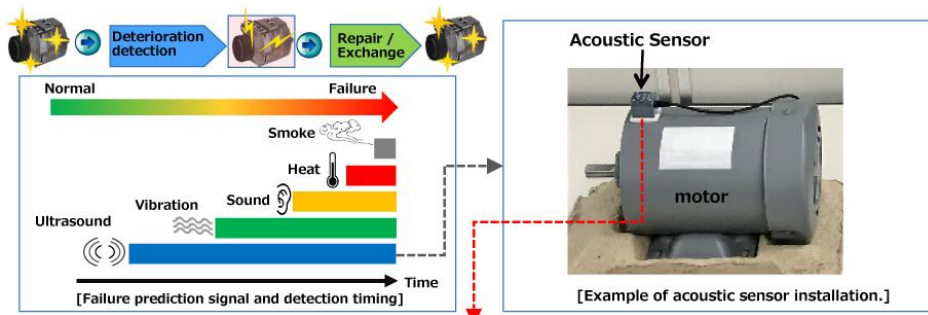
Sound events have diverse acoustic characteristics

- Short, transient-like sounds, longer duration and harmonic
- **Filter unwanted noises**

Difficult to profile noise characteristics in a specific model

- Requires lots of data and good analysis: relatively high-cost benefit in contrast to other approaches (e.g., vibration sensors)

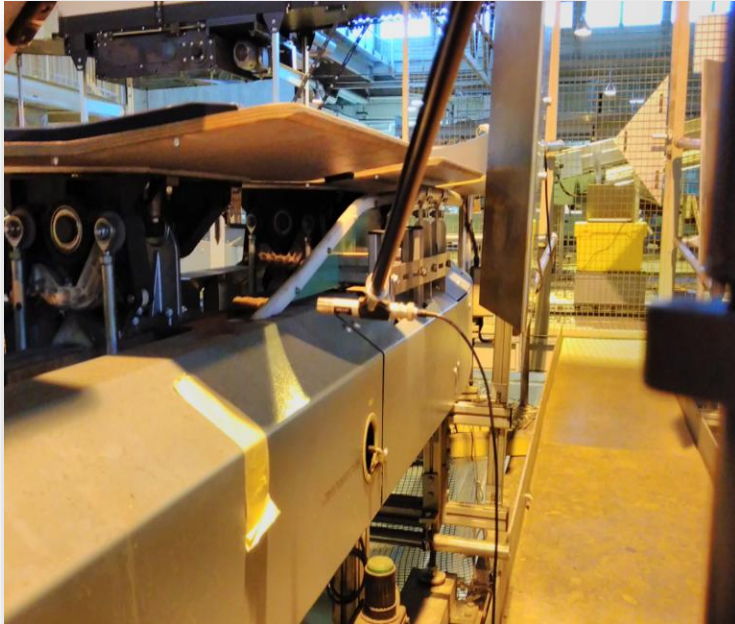
Example – Rotating Equipment



Rotating equipment used in factory production equipment has the risk of sudden production line stoppage due to **failure caused by bearing wear or damage**, so it is managed by regular maintenance and parts replacement depending on the usage time in general. In preventive maintenance, **even usable parts are maintained and replaced**, which results in wasted worker resources and parts replacement costs.

<https://www.nisshinbo-microdevices.co.jp/>

Example - Logistics



“...In a pilot project at the Swiss Post, we were able to successfully demonstrate the benefits of an acoustic solution for monitoring tilt tray sorting systems. Thanks to a single mounted sensor and our Deep Learning-based AI solution, we managed to assign **a unique acoustic fingerprint to each of the approximately 900 trolleys** in the facility, despite the numerous background noises in the sorting center. **Changes in this fingerprint over time are a clear indication of damage**, reducing costly service interruptions and extensive maintenance...”

LeanBI: <https://leanbi.ch/en/solutions/>

3. Hands-on

Pumped Storage Hydropower Acoustic-sensing

Pumped Storage Hydroelectric Power Plants

Scenario

- The operation of hydroelectric power plants requires **precise monitoring** and preventive maintenance
- Predictive maintenance needs to be extremely accurate since downtime costs have **significant impacts**

Problem/Challenges

- Loud noises when operation changes from **generator** to **pump** mode
- Many reverberations and different machines operating simultaneously
- Imagine you feel your entire body vibrating when you are next to the machine



“Hearing” Problems



Opportunity

- Existing sensors observing mechanics/hydraulics do not see anomalies (e.g., vibration/pressure)
- Integrate acoustic sensors into the monitoring system

Two-step Approach

- **Anomaly detection**: profile baseline operation and find anomalies
- **Sound localization**: find the source of anomalies

Sound Event Localization and Detection of Overlapping Sources Using Convolutional Recurrent Neural Networks

Sharath Adavanne, *Member, IEEE*, Archontis Politis, *Member, IEEE*, Joonas Nikunen, *Member, IEEE*, and Tuomas Virtanen, *Member, IEEE*



Expert Systems with Applications
Volume 209, 15 December 2022, 118324



An anomalous sound detection methodology for predictive maintenance

Emanuele Di Fiore , Antonino Ferrara , Antonio Galli , Vincenzo Moscato ,
Giancarlo Sperli , 

Very good

A Novel Measurement Information Anomaly Detection Method for Cooperative Localization

Bo Xu , Shengxin Li , Asghar A. Razzaqi , Yu Guo , *Graduate Student Member, IEEE*,
and Lianzhao Wang 

Sound Event Detection: A Tutorial

Annamaria Mesaros¹, Toni Heittola¹, Tuomas Virtanen¹, Mark D. Plumbley²

¹ Tampere University, Finland

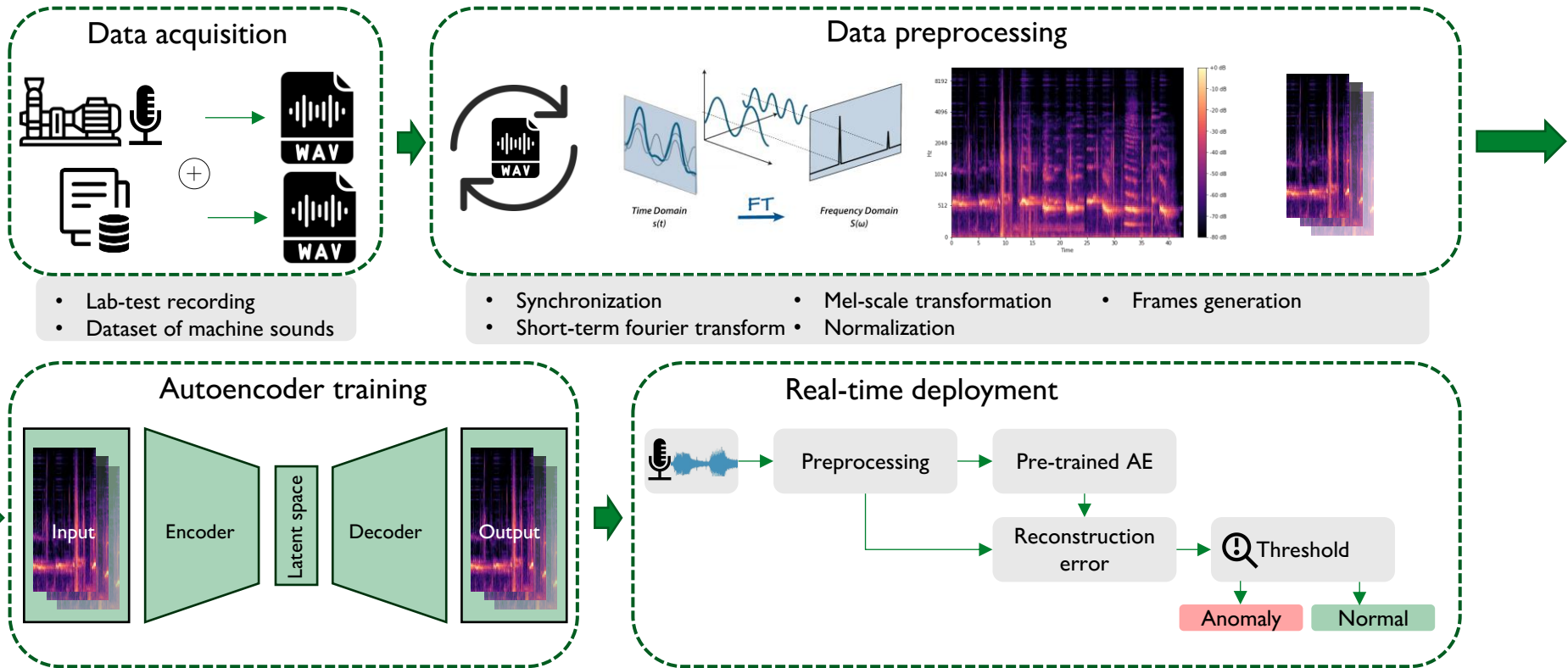
email: {annamaria.mesaros, toni.heittola, tuomas.virtanen}@tuni.fi

² University of Surrey, UK

email: m.plumbley@surrey.ac.uk

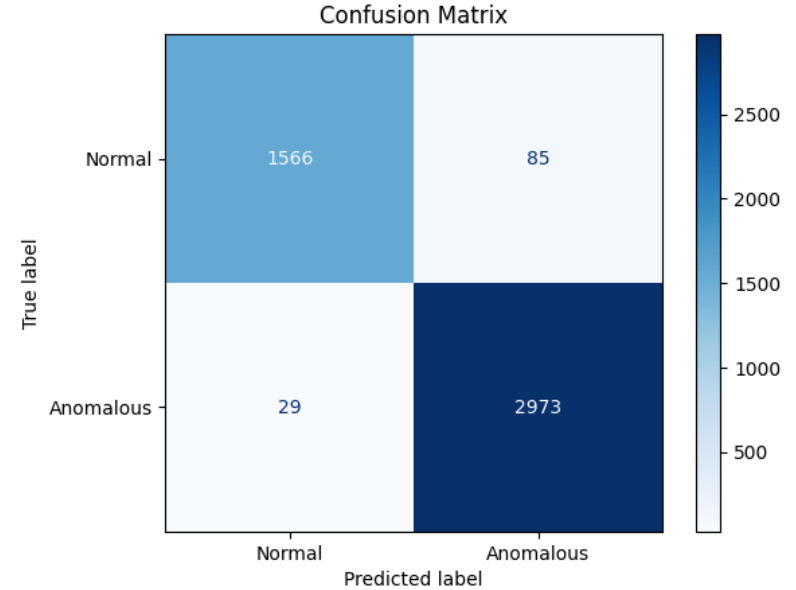
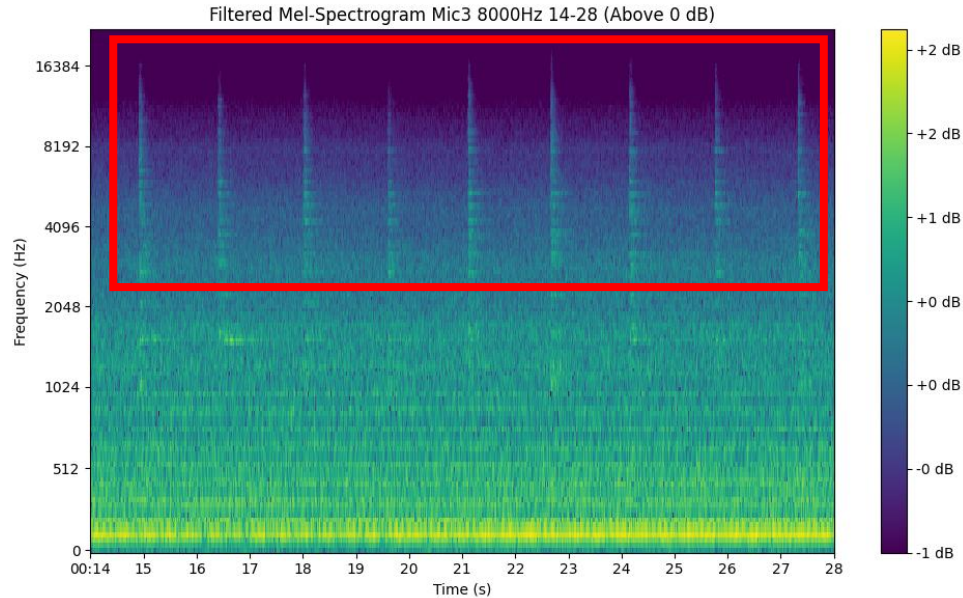
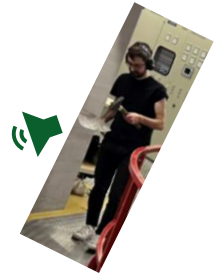
This one is amazing!

Design & Approach



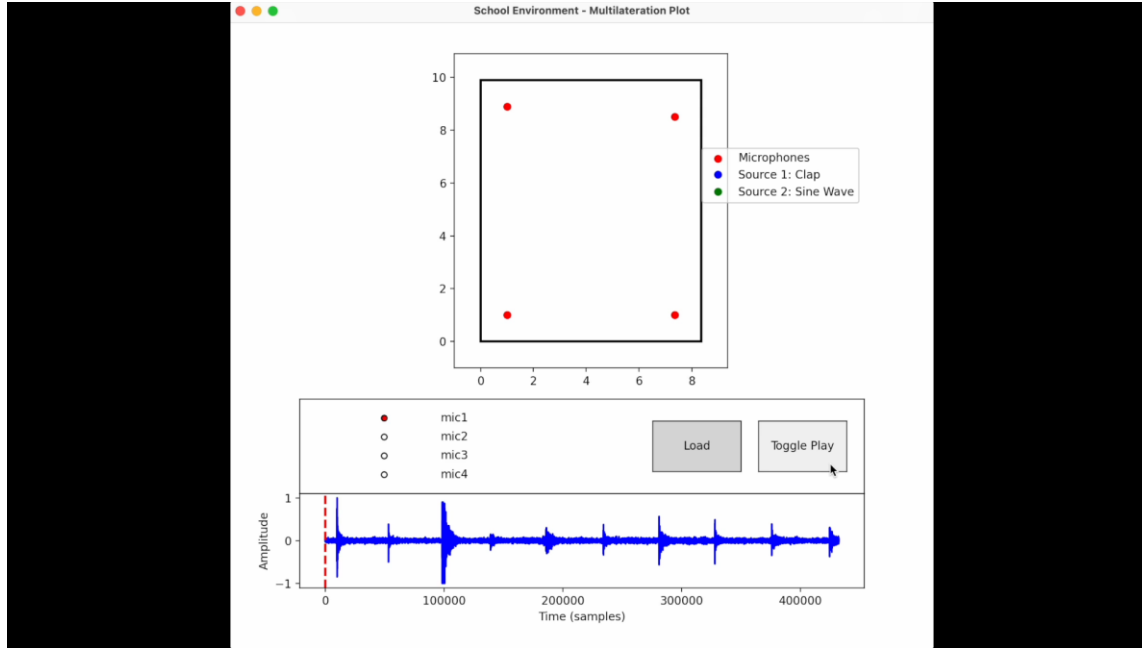


Preliminary Results – Induced Anomaly (Shovel+Hammer)

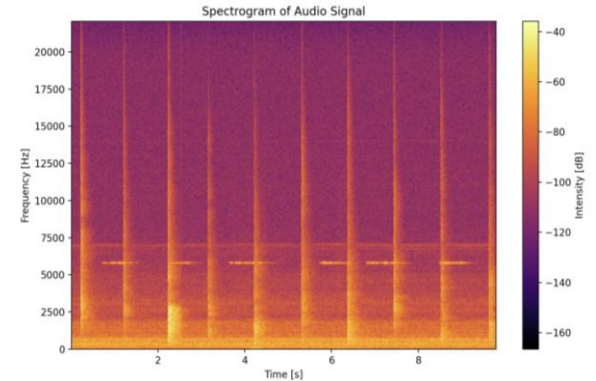


The shovel+hammer noise is straightforward to detect as anomalous

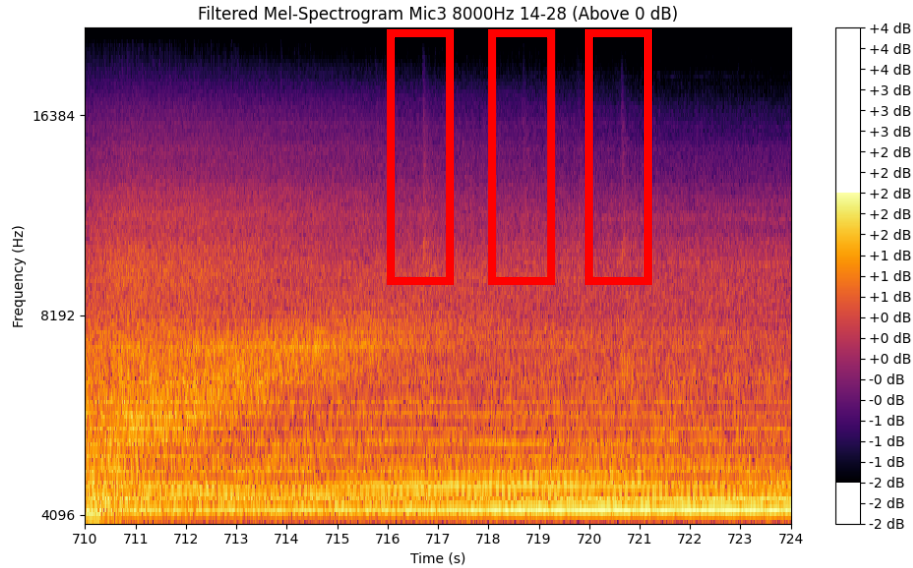
Preliminary Results – Sound Localization



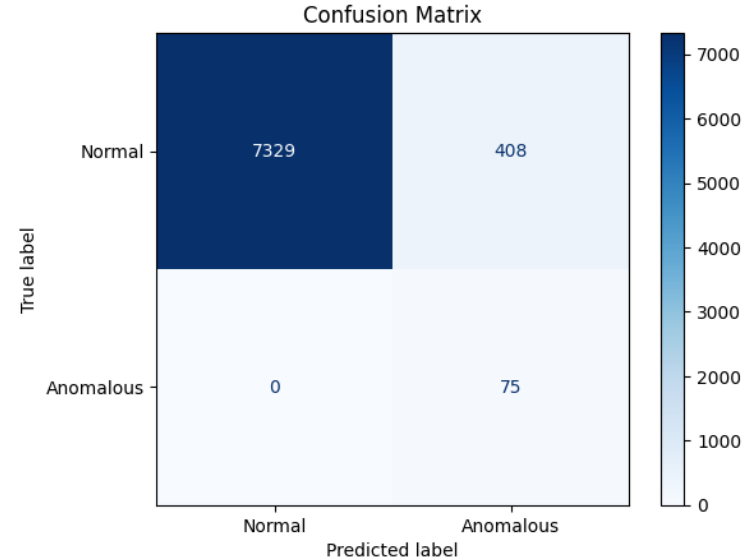
Clapping while walking in a room with background music



Preliminary Results – Real Anomaly



Over-prediction of anomalies



Model performs well
identifying “normal” operation

4. Closing

Summary and Takeaways

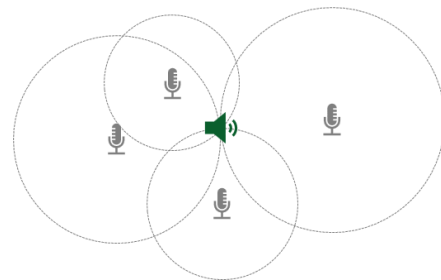
Major Takeaways

Pros

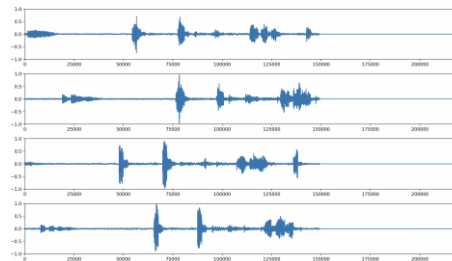
- State-of-the-art ultrasonic sensors can detect minimal changes in noise frequency patterns
- Especially effective when anomalous noises are human-perceptible
- Non-invasive and adaptable to a wide range of applications
 - From rotating equipment to leak detection.

Cons

- Relatively complex to model, which impact its cost benefit ratio over other sensors
- Sound localization is considerably more challenging than anomaly detection
- Performance may vary in noisy industrial environments, requiring advanced filtering and signal processing techniques.



*Acoustic sensing is a mature and reliable technology, being ideal for applied settings where **precision** and **reliability** are needed.*



Questions?



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***"From insight
to impact"*** 