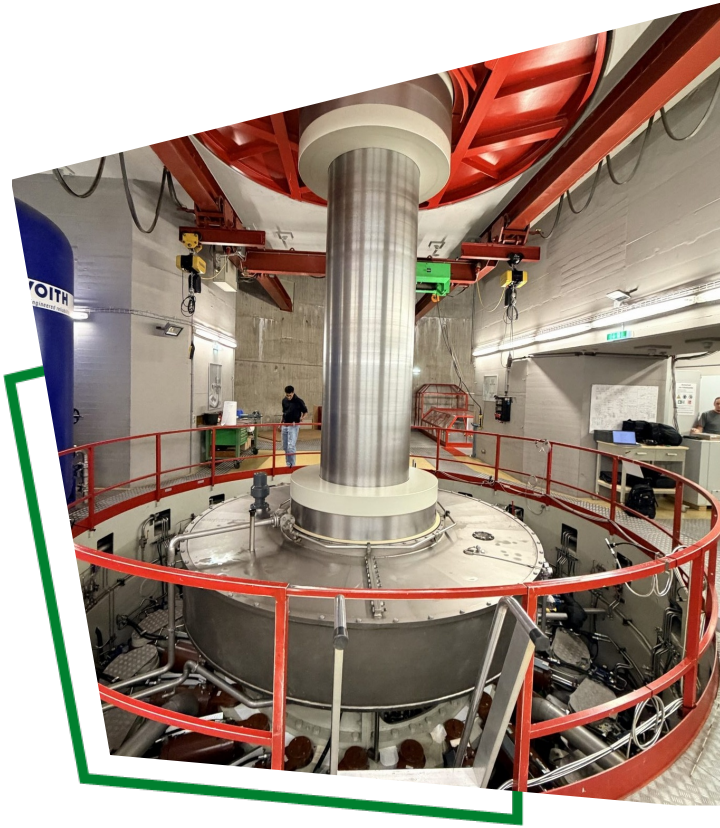
Universität St.Gallen
Institut für Computer Science
in Vorarlberg

Acoustic-Vibration Anomaly Detection and Localization at a Pump-Turbine



Jinyuan Zhang[1], Stefan Krummenacher[1], Zakaria Omarar[1], Arne Schacht[2], Bernhard Fässler[2], Bruno Rodrigues[1]

[1]Sensing Group, ICV-HSG, University of St. Gallen [2]illwerke vkw AG

From insight to impact

ViennaHydro 2026, Session 5.1, 19 November 2026, Laxenburg

Agenda

1. Motivation and objective
2. Approach: learning the healthy sound of a machine
3. Evaluation: five days at a 295 MW pump-turbine
4. Conclusions



The problem

Maintenance and downtime are costly

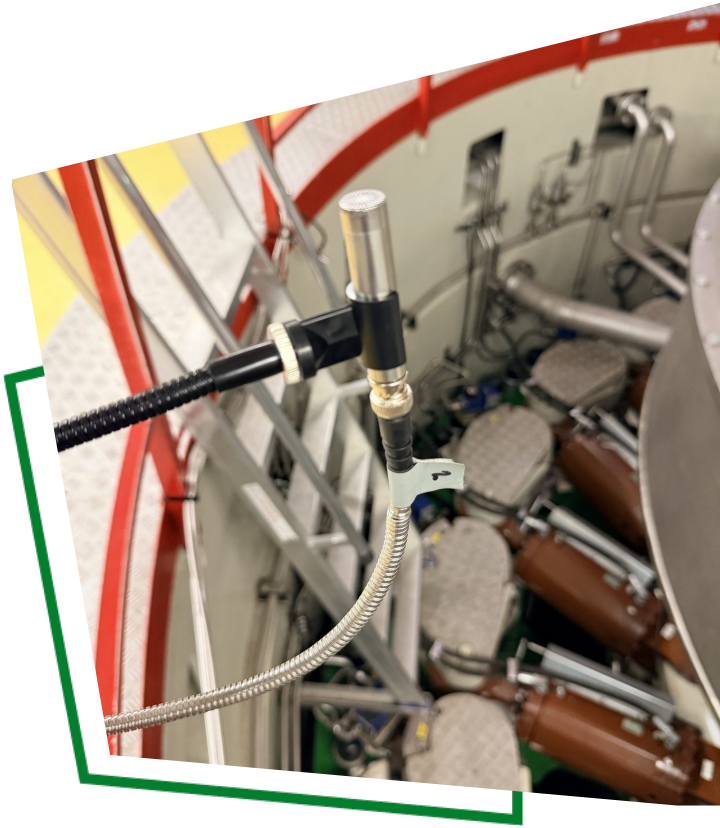
FLEXIBLE OPERATION

- Pumped storage balances wind and solar. The machines start, stop and reverse far more often than their design era assumed.
- Start-stop transients are a dominant consumer of Francis runner life [1, 2].

THE COST

- **Downtime comes at a very high cost:** a stopped unit cannot deliver the flexibility it is built for.
- **Unplanned outages** are highly costly and difficult to service [3].

Long-term goal: know the condition of the running machine, so that maintenance stops can become shorter and rarer.



[1] Trivedi et al., J. Hydraulic Research 51(2), 2013. [2] Gagnon et al., IOP Conf. Ser. EES 12, 2010.
[3] Khamaisi et al., LongevIoT Workshop at ACM IoT, 2025, arXiv:2509.22881.

State of the art

Airborne sound is missing from hydropower monitoring

1 The gap

No monitoring combines airborne sound and vibration to detect and locate anomalies.

2 Why it is hard

Many sources at once

Loud machine

Reverberant hall

3 Why now

Mature ML-based signal processing

Long-term fingerprints per operating mode

Plant data already collected

This work

Objective and contributions

Answer how airborne acoustics contributes over vibration and plant data, and determine its detectability limits, calibrated per feature and operating mode

To our knowledge, the first **multi-day**, **full-scale** airborne acoustic baseline of a pump-turbine across **every operating mode**.

1 Acoustics and localization

What airborne acoustics adds to vibration and plant data, with localization checked against 180 hammer strikes.

2 Detectability limits

The limits of an airborne array on a full-scale machine, which any fault-detection claim must exceed.

3 Drift of the healthy state

The main challenge to monitoring these machines, with candidate principles for when a baseline stays valid.

Learn the healthy state, flag deviations, locate the source

Microphones
9 channels, 50 kHz

Accelerometers
6 channels, 10 kHz

Per-second features
spectral lines, band energies, cross-channel quantities

1 Learn the baseline
One baseline per operating mode, from healthy data only (one-class SVM).

2 Flag a deviation
Conformal threshold per load range: 5 % false alarms by design.

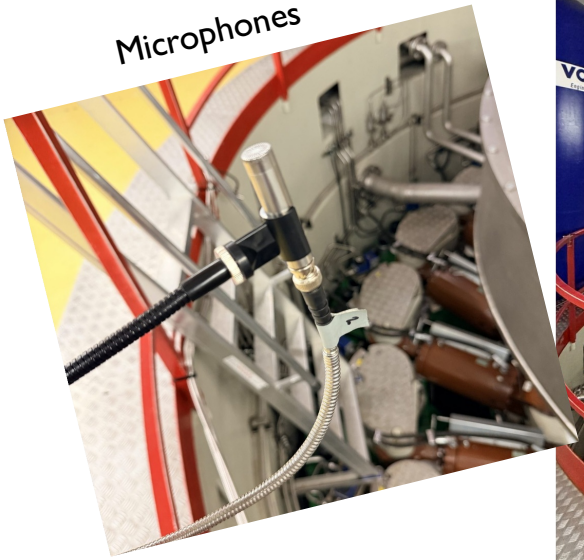
3 Locate the source
First demonstration: loudest microphone and arrival times (SRP-PHAT) give direction and height.

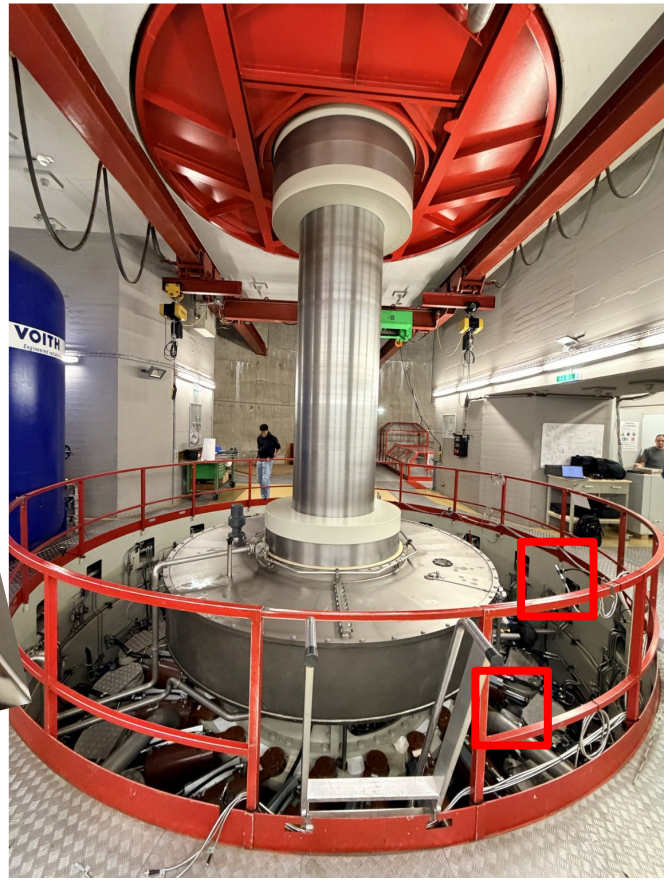
Plant data (SCADA) selects the mode and the load range. It is not an input to the alarm score.

A fault cannot be induced on a live machine, so we measure the healthy baseline and test with controlled sources.

Deployment

Microphones

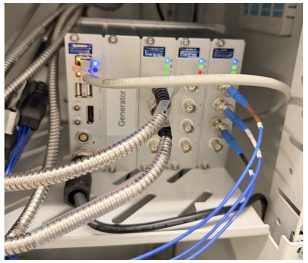




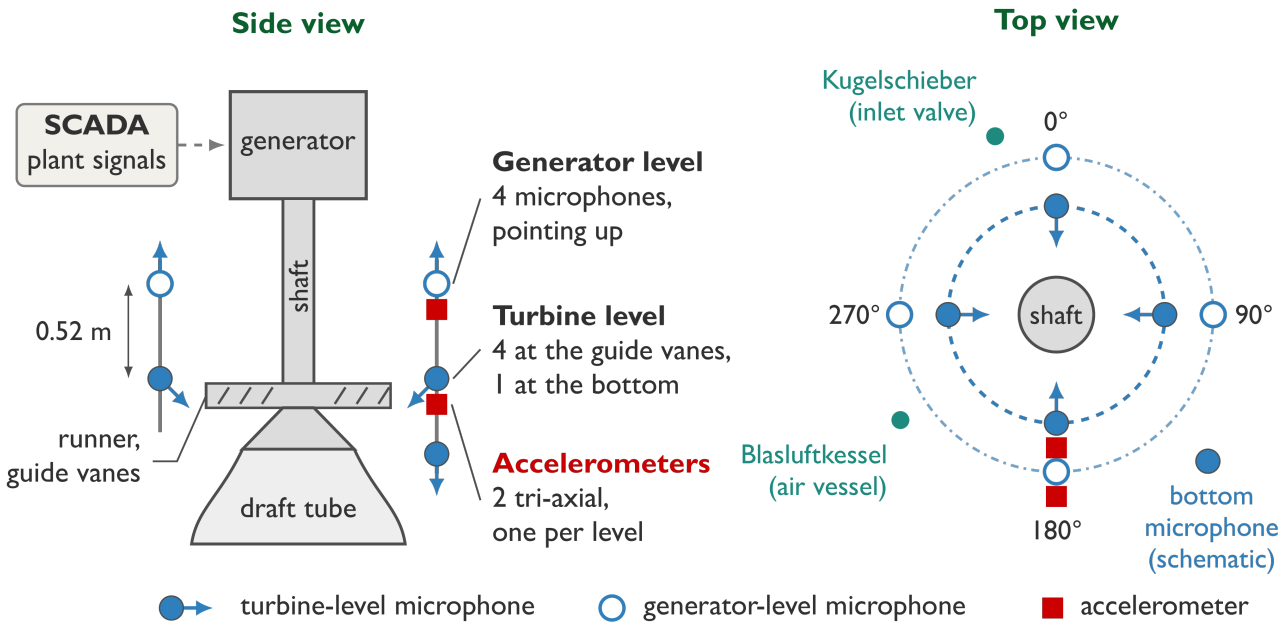
Accelerometers



All connected at the DAQ



A microphone array on a 295 MW pump-turbine



295 MW
reversible Francis, 354 m, 375 rpm

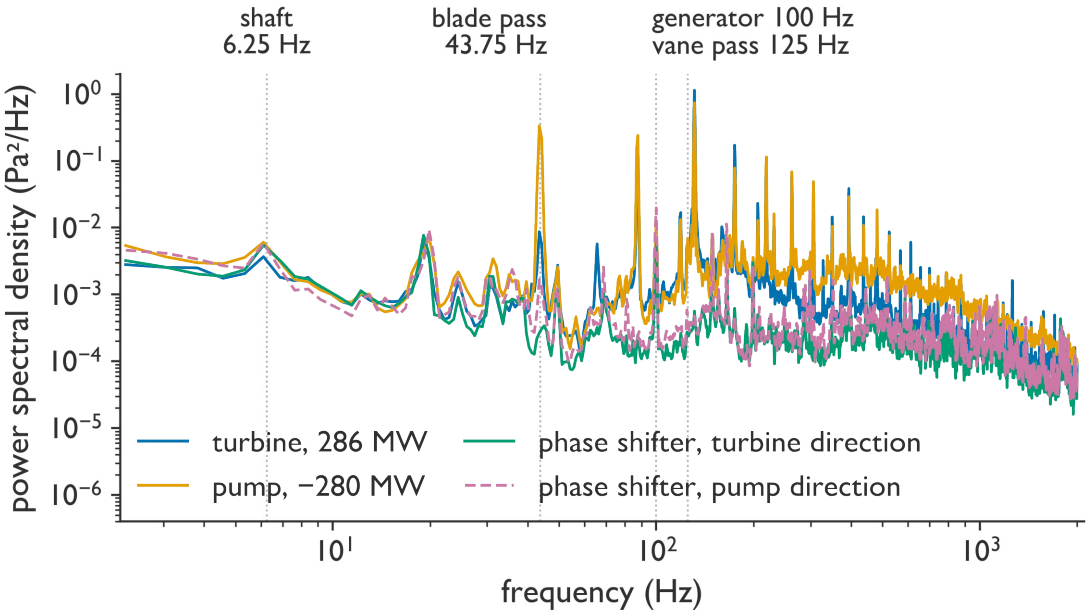
9 microphones
+ 2 tri-axial accelerometers

5 days
about 38 h, every operating mode

180 strikes
hammer test with logged positions

Rodundwerk II (illwerke vkw): 7 runner blades, 20 guide vanes, 16-pole generator. Audio at 50 kHz and vibration at 10 kHz, sample-synchronous. Plant data (SCADA) on four of the five days. Regular operation, all healthy.

Each operating mode has a distinct acoustic signature



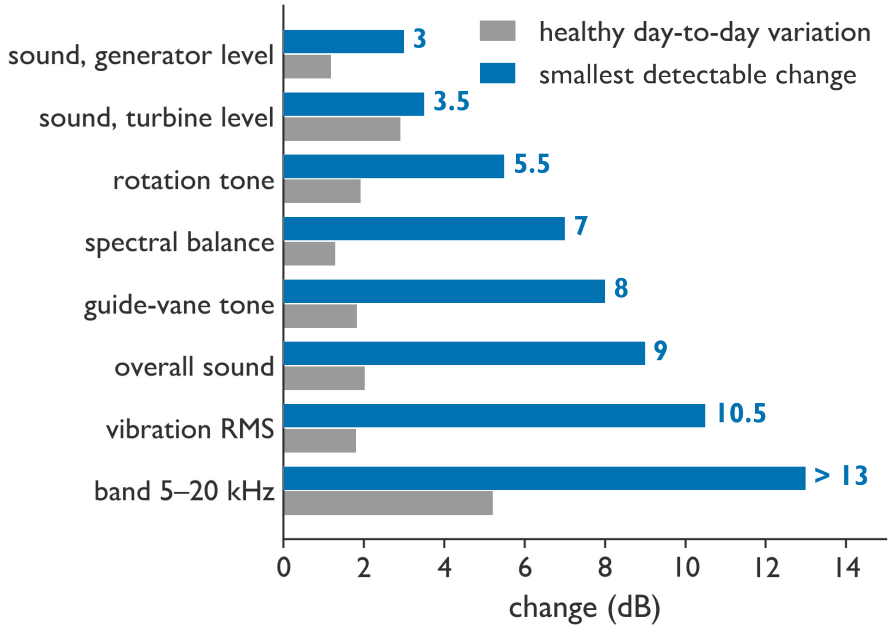
Microphone spectra of four operating modes on one day (29 June).

- **Pump blade-pass tone:** 27 to 28.5 dB above the floor on all five pump days.
- **Mode from sound alone:** one day without plant data was labeled to the minute from the microphones.

THE TONES FOLLOW THE MACHINE

Shaft, 375 rpm	**6.25 Hz**
7 runner blades	**43.75 Hz**
20 guide vanes	**125 Hz**
16-pole generator	**100 Hz**

Broadband changes of about 3 dB are detectable within one second



Turbine mode, one-minute averaging. Blue: smallest change detected in 90 % of the tests.

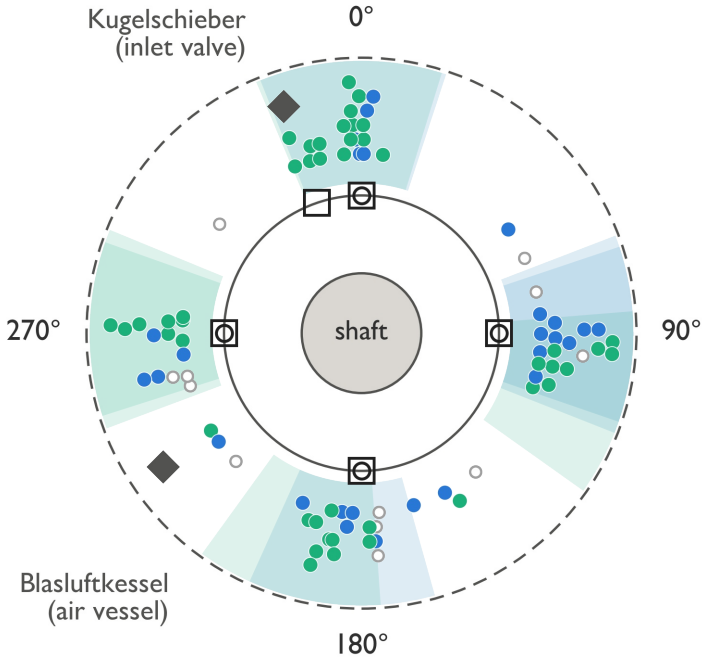
2.5–3.5 dB broadband sound per level, within one second

5.5–8 dB individual machine tones, with one-minute averaging

2–2.5 dB 5 to 20 kHz in the quiet phase shifter, a band only microphones reach

How: a known gain is added to one feature of healthy recordings. At one-minute averaging, every limit lies above the healthy day-to-day variation.

Hammer strikes are located within ±20°, also while pumping



The hall from above while pumping at −279 MW. Bottom microphone not shown.

- **Test:** 180 strikes on a plate at logged positions, at standstill and while pumping at −279 MW.
- **Direction:** median error 2.5° over 45 single strikes, all inside a ±20° sector.
- **Height:** correct level at 10 of 11 positions.
- **Under load:** all 27 ring strikes detected.



The controlled source

strike, generator level
strike, turbine level
below detection threshold
logged true position
microphone
plant landmarks
±20° reported sector

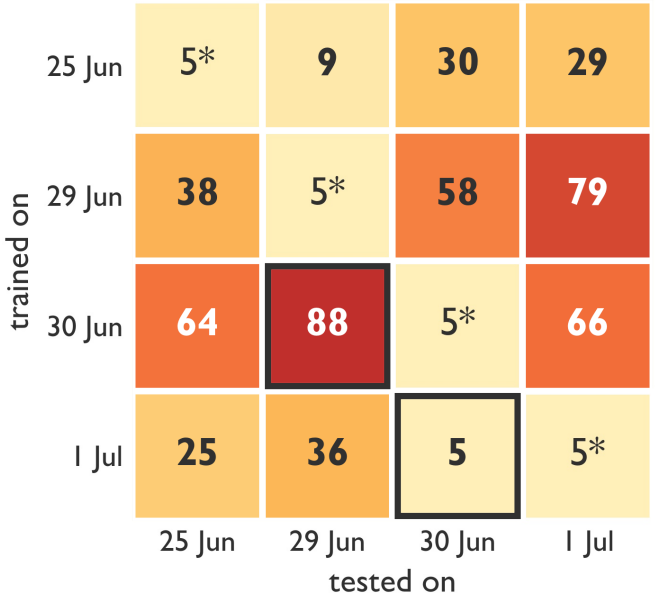
Demo video: https://www.youtube.com/watch?v=rneahOnLRUg

Sound and vibration are complementary

	SOUND	VIBRATION	PLANT DATA
Recognizes the operating mode	● near 95 %	● near 95 %	● by rule
Frequencies above 3.7 kHz	●	with contact microphones	–
Direction and height of a source	●	–	–
Structure-borne path	–	●	–
Plant efficiency index (slow degradation)	–	–	●

Recorded together, they separate an airborne source from one coupled to the machine.

The healthy baseline drifts within a run and between days



False alarms (%) on healthy turbine data. 5 is the design rate.*
Outlined: best and worst transfer.

- **Within one run:** false alarms rise from the 5 % target to 43 % in the second hour and 99 % by the fourth.
- **Between days:** a one-day baseline holds 5 % for one day pair and reaches up to 88 % for others.
- **Cause:** overall level, reservoir level, head and time of day do not explain the drift between days. Temperature is the open hypothesis.
- **What repeats:** the load response keeps its shape between days (median r = 0.90). Only its offset moves, by 1 to 8 dB.

Conclusions and next steps

1. First multi-day airborne acoustic baseline of a full-scale pump-turbine, in every operating mode.

2. Microphones recognize the mode, detect broadband changes of about 3 dB and locate hammer strikes within ±20°, without contact.

3. The measured detection limits and the drift define what a future fault-detection claim must exceed.

NEXT STEPS

- Compensate the day-to-day drift.
- Rebuild the same reference at a second, smaller plant.

A retrofit-friendly second sense for the machine hall, and a step toward condition-based maintenance.

Thank you!

Bruno Rodrigues

Sensing Group, ICV-HSG, University of St. Gallen

bruno.rodrigues@unisg.ch, sensing-group.com

Bernhard Fässler

Innovation Management, illwerke vkw AG

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We thank Jürgen Sutterlüti and Benoit Jouan (Gantner Instruments) and Bernhard Küng (illwerke vkw). Supported by Land Vorarlberg, illwerke vkw AG and Vorarlberg industry, with WKV and IV.