Structural Health Monitoring von Windenergieanlagen
Aktueller Stand und Perspektiven

TUM-Expertenforum 2024, München

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SHM

ZESS

VDI Fachausschuss 101 - Anwendungsnahe zerstörungsfreie Werkstoff- und Bauteilprüfung

Zerstörungsfreie Prüfung für die nachhaltige Energietechnik der Zukunft

SHM of rotor blades

Blades

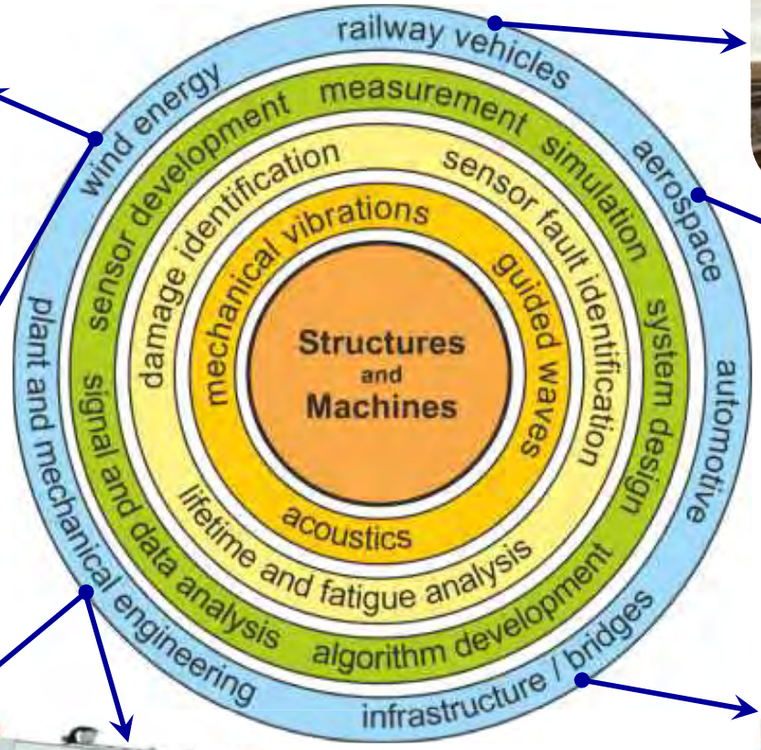
Fleet Monitoring

SHM of
- Grout
- Foundation
- Tower

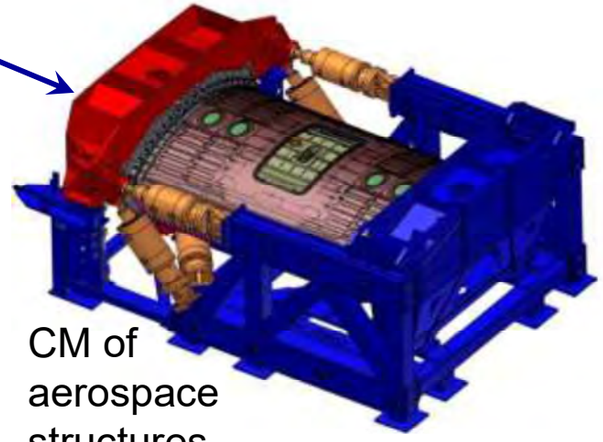
Control engineering for welding of tower segments

SHM

Mechanics with focus on Structural Health Monitoring

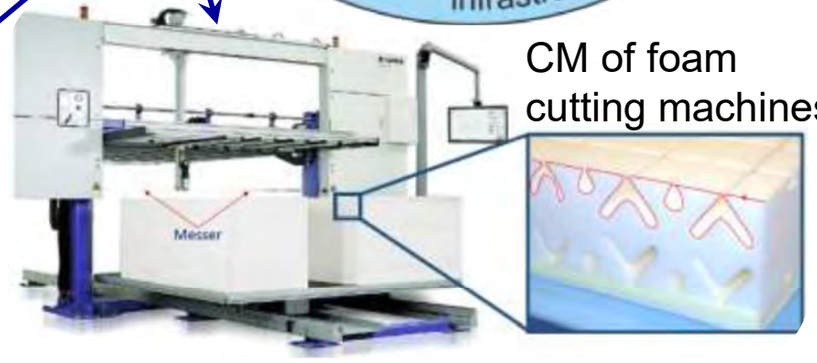


Sensors, automatic fault detection for rail vehicles

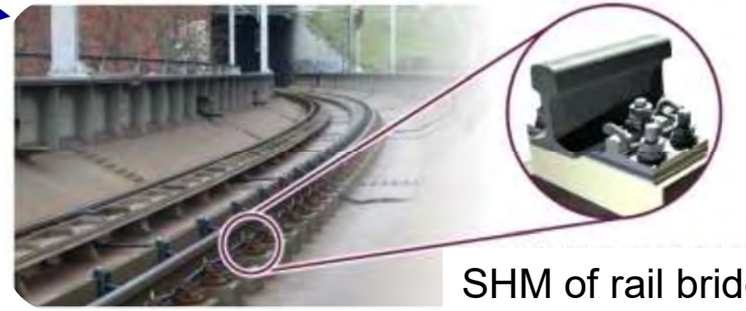


CM of aerospace structures

Condition Monitoring (CM) of drive trains

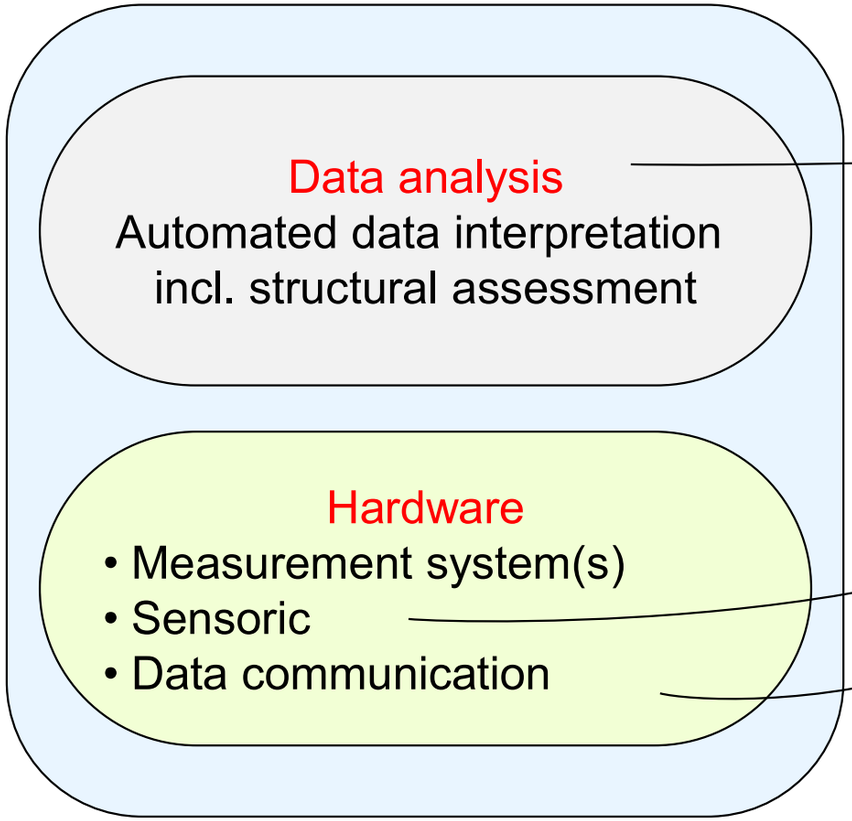


CM of foam cutting machines

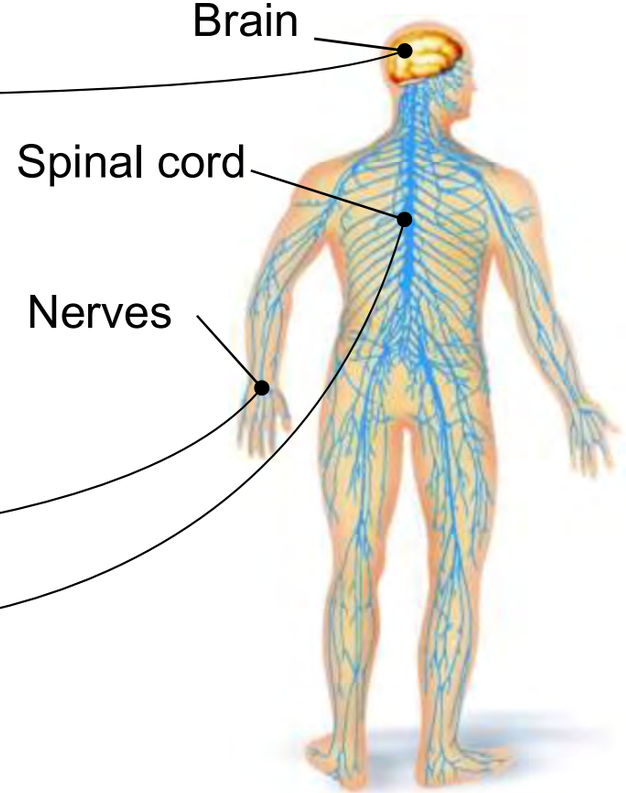


SHM of rail bridge components

Main components of a SHM-System



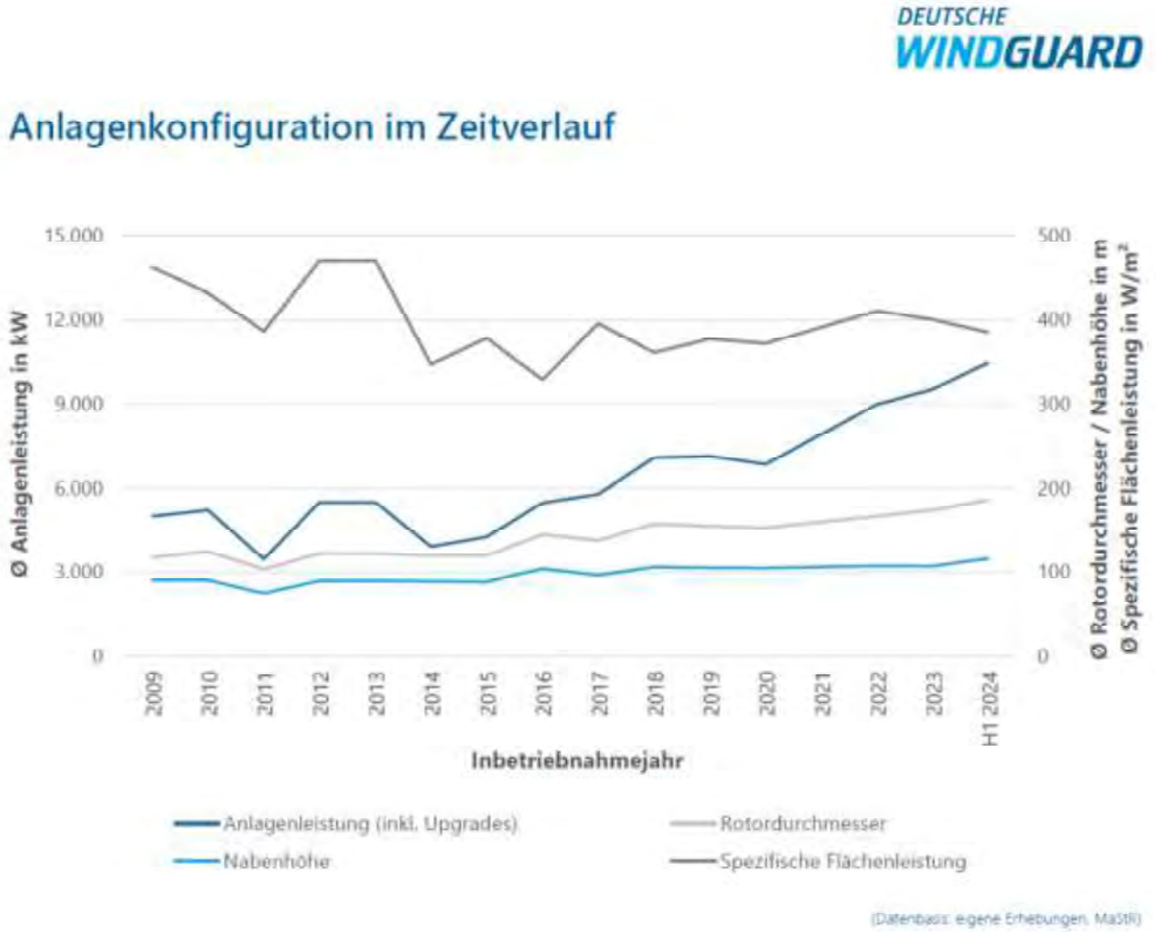
Analogy to the human being



Foundation of any CM/SHM-System

Depends on the measured physical principle:
- Vibration,
- Ultrasonic waves,
- Acoustic-Emissions, etc.

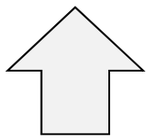
(Offshore) wind power capacity in Germany



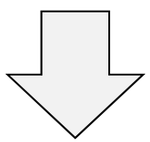
Source: Deutsche WINDGUARD, Status des Offshore-Windenergieausbaus in Deutschland, Ersten Halbjahr 2024
https://www.windguard.de/Statistik-1-Halbjahr-2024.html

Monitoring of wind turbines

Look into the past



How important is Structural Health Monitoring (early damage detection/location) for wind turbines today?



Look into the future

Projects with applications on Wind Turbines in last 5 years

In-Situ WIND (2019 – 2023): (03EE3023B)
- Monitoring of grout connections
- Synthesis of methods: Radar + Vibration

SmartRD (2021 – 2025): (03EE2034B)
- Vibration reduction and drift compensation in the production of large cylindrical steel components

IGF (2022 – 2025): (22867 N / P1656)
- Crack detection in bolts based on electromechanical impedance spectra

WEA-produktiv (2023 – 2025): (03EE3074B)
- Wind turbines with optimized productivity by fleet monitoring without additional sensors

NOAD (2024 – 2027): (03SX622D)
- Re-evaluation of offshore foundation structures through agile design for service life extension and repowering

Supported by:

Federal Ministry for Economic Affairs and Climate Action

on the basis of a decision by the German Bundestag

In-Situ WIND / Sensorics

T1 (LAT+76.40m)

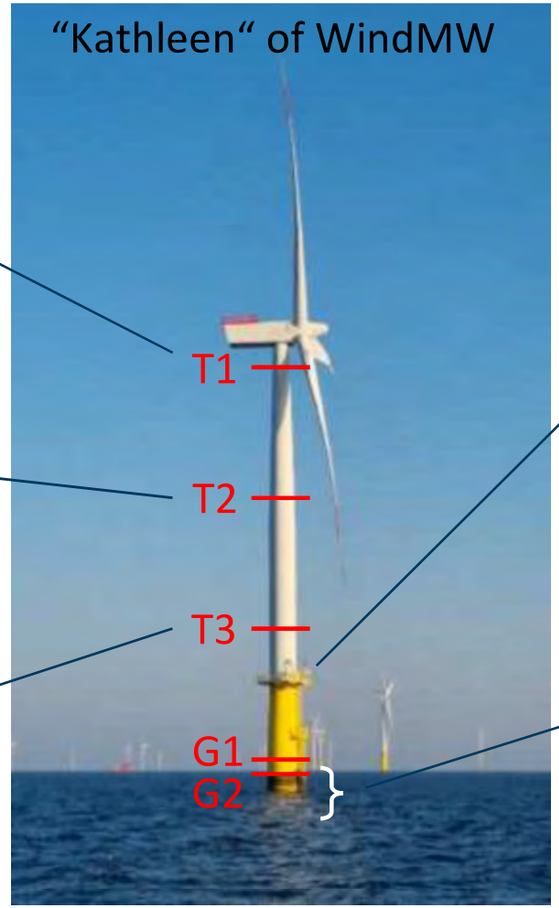
Acc
Pt100

T2 (LAT+50.30m)

DAQ
Acc
Pt100

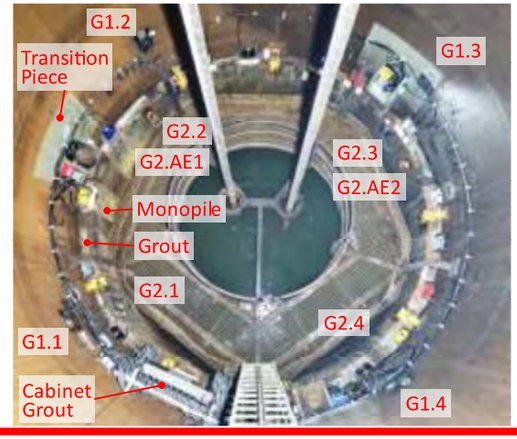
T3 (LAT+34.20m)

Acc
Pt100



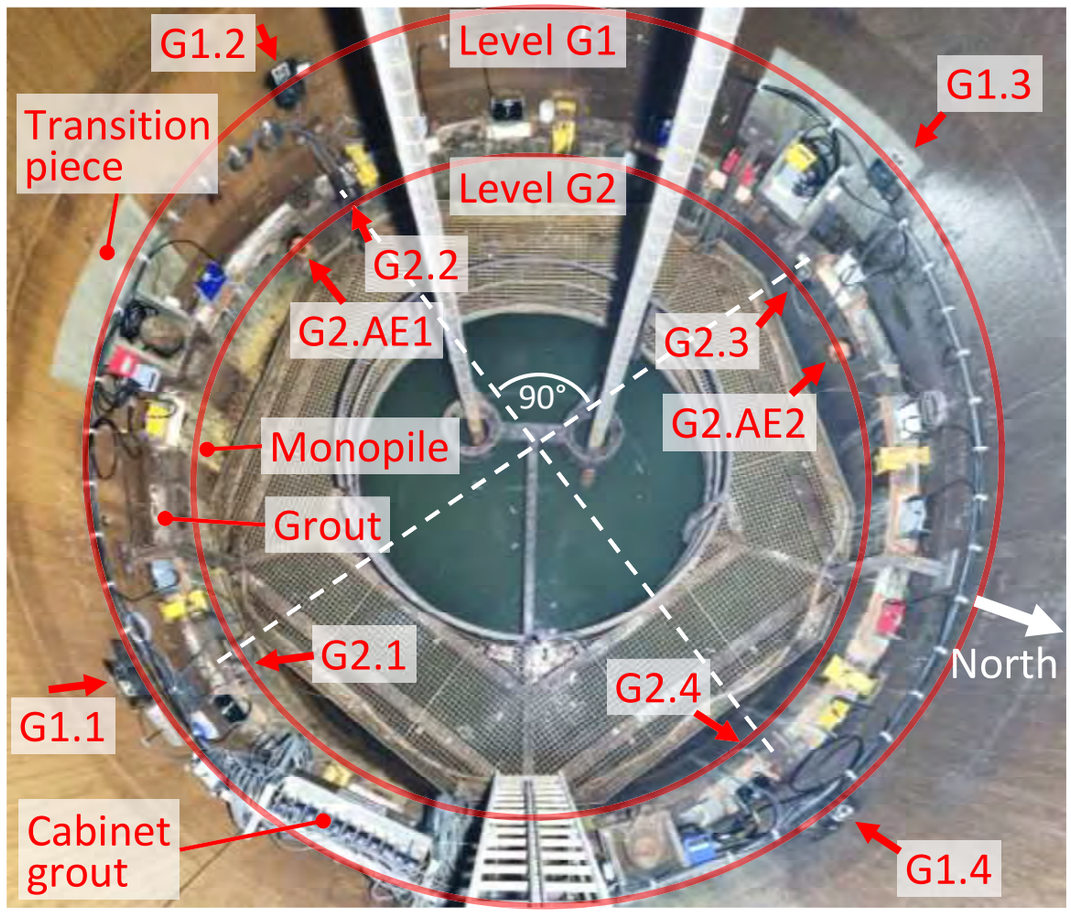
Entrance level: server cabinet

Grout area: G1+G2+DAQ

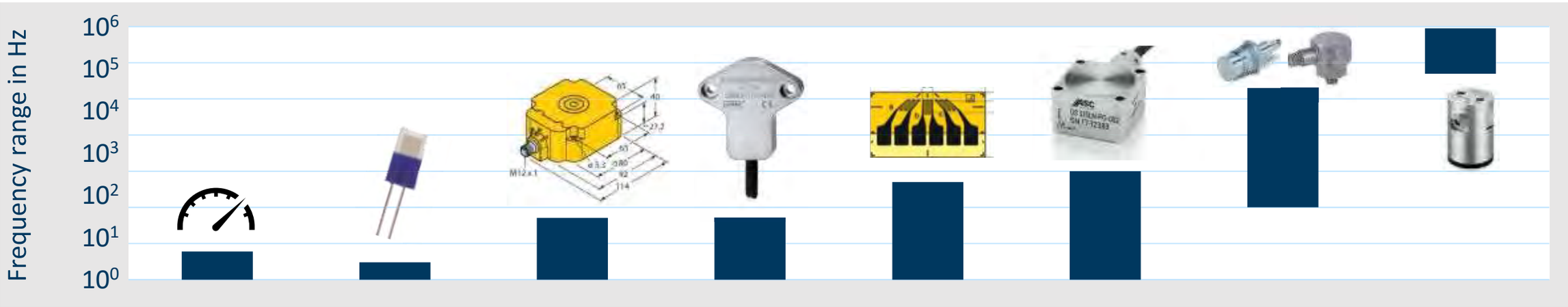


Offshore installation of 100 measurement channels and the entire measurement system was completed in **just 5 days by** Fraunhofer LBF and University of Siegen!

In-Situ WIND / Sensorics



In-Situ WIND / Sensorics

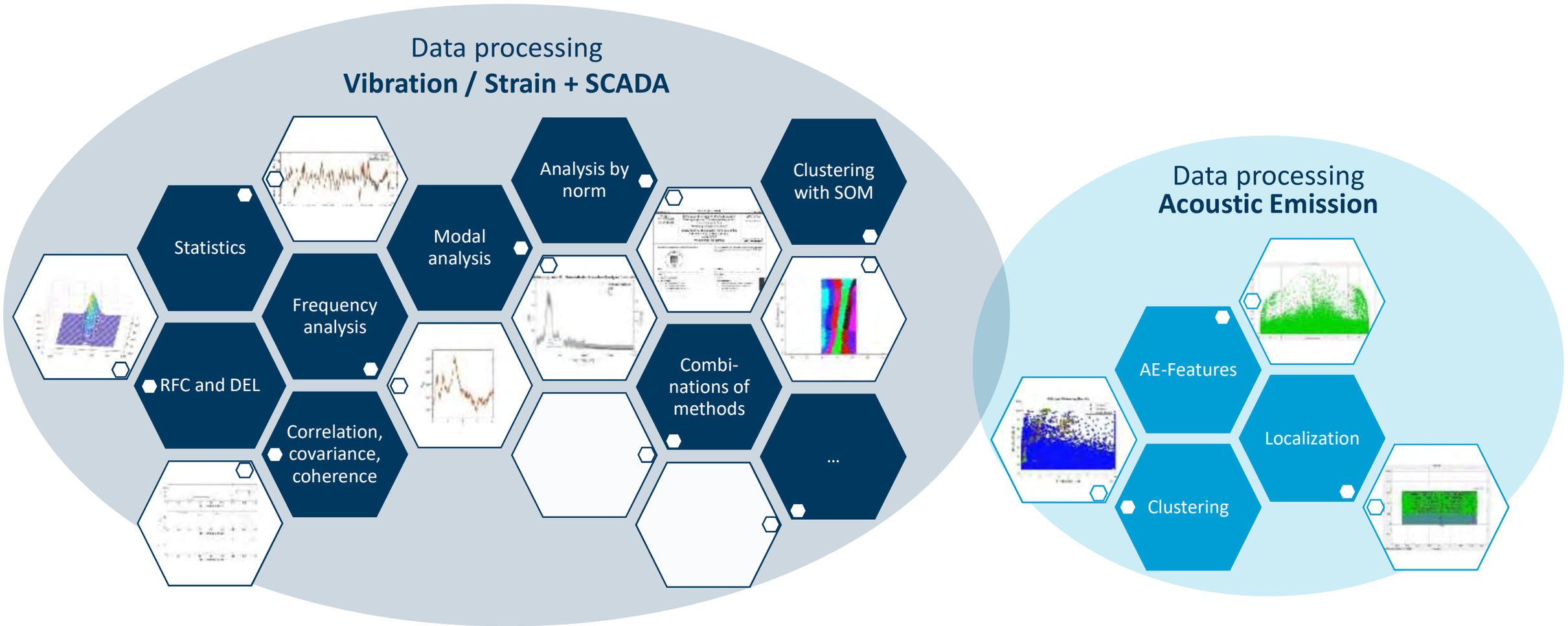


Sensors Channels (*) (n = 116)	SCADA	Pt 100	Distance sensors	Inclination sensors	Strain gauges	Acceleration sensors	Piezo sensors	AE sensors
	16	24	3	10	38	21	2	2

Analysis	
EOC / Compensation	
Structural dynamics	
Transient events	

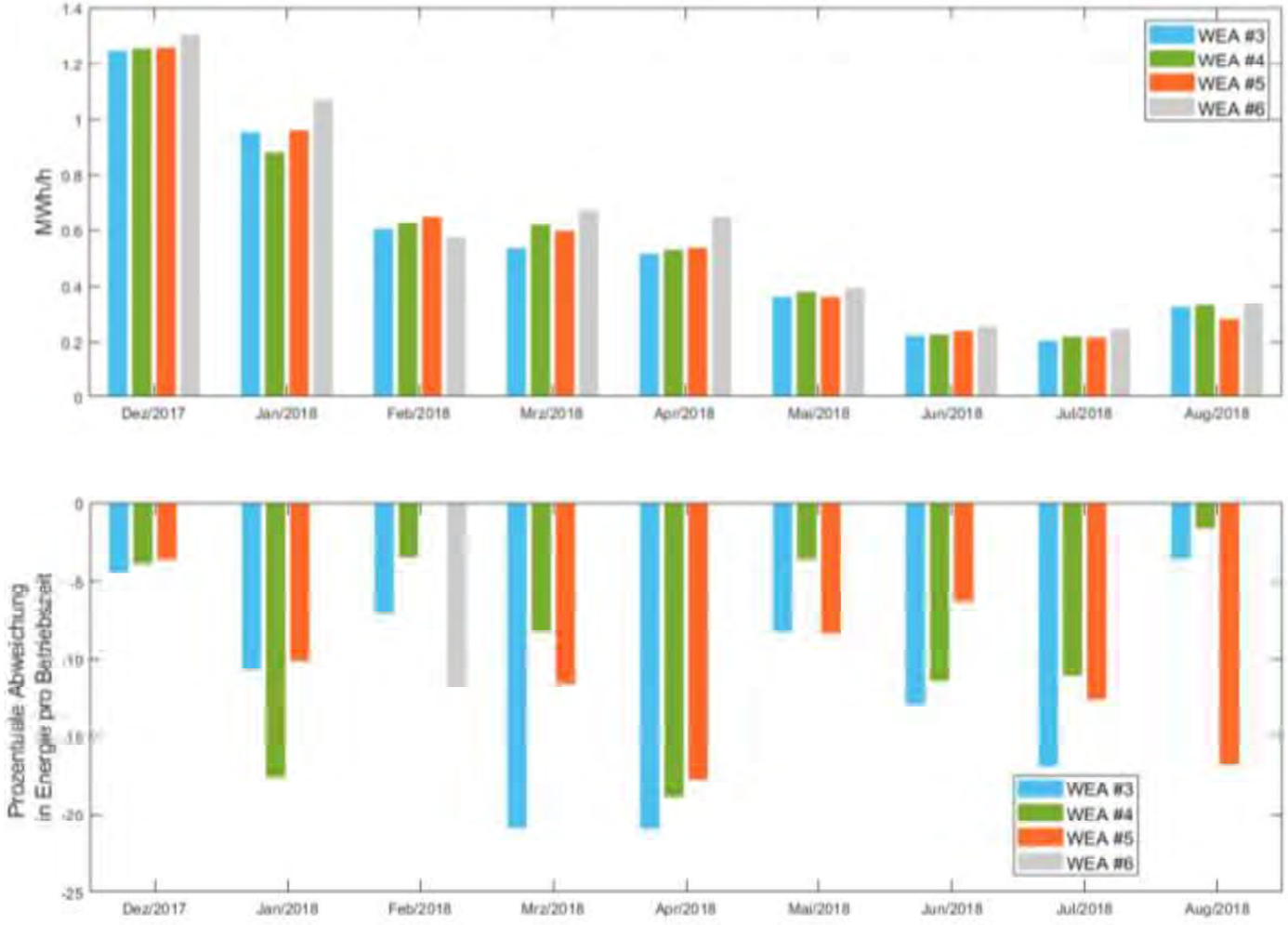
(*) University of Siegen + wind farm operator + SCADA

Feature extraction as a modular software package



WEA-produktiv / Power production in wind park (example)

- Energy produced per month in relation to the available operating time
- Significant differences between summer and winter
- Individual systems show different performance
- Starting point for population monitoring
  → Cause?



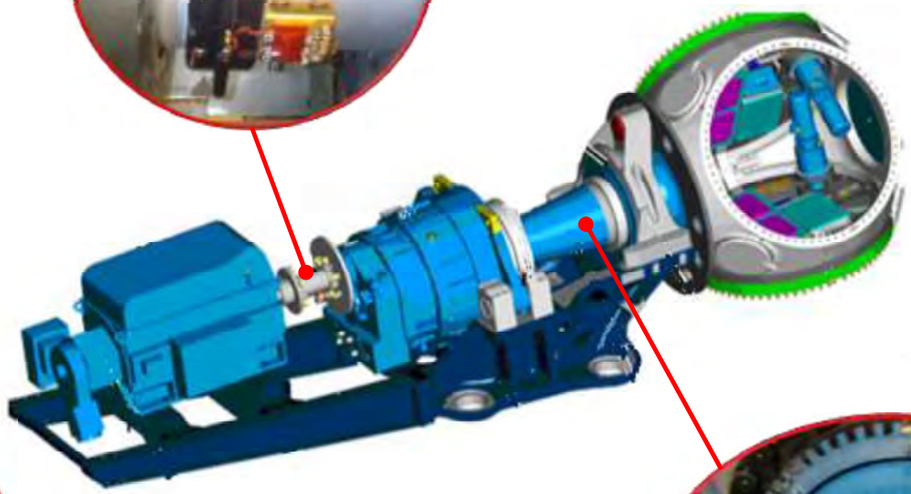
WEA-produktiv / Sensorics

Extensive drive train and nacelle instrumentation - integration and time synchronization of existing measurement systems and SCADA interfaces

Generator shaft
- Torque
- RPM

telemetric system

- Biaxial inclination
- 4 x 3-D ACC
- 2 x 1-D ACC



Weather station on the roof
- Camera
- 5G Antenna
- GPS time sychronisation

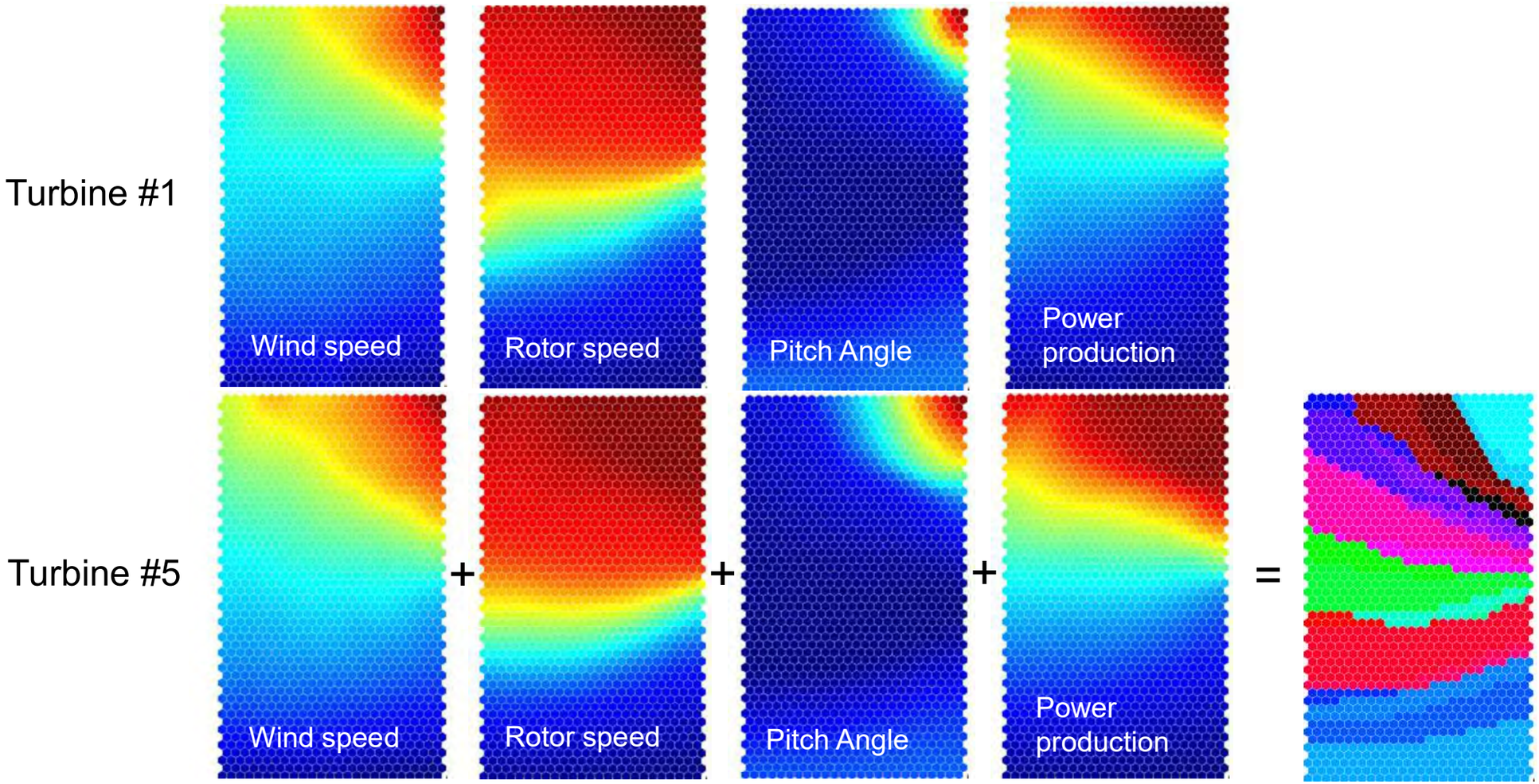
Rotor shaft
- Torque
- Bending X
- Bending Y
- Abs. position
- Orbit

Battery powered telemetric system

Data driven models (e.g. **S**elf **O**rganizing **M**aps for clustering and modelling of data)

E.g. of application cases:
- finding non linear correlations between vibration features and/or SCADA-data
- comparing a population of similar wind turbines
- clustering of data

WEA-produktiv



Conclusion

Lessons learned

- Understanding physical phenomena by means of measurements is very important
- It is hard to obtain reliable measurement data from plants in-situ → sensor installations, data organization, feature extraction, understanding of overlapping phenomena are very time consuming
- Data analysis and algorithm development is more effective with measurements from self-installed sensors
- SHM without compensation of Environmental and Operational Conditions effects is impossible
- Population Monitoring can bring benefits → limited number of sensors, comparison between features of plants can make the detection of anomalies more efficient
- Actual trends: monitoring for life time extension, power production optimization, …

Open questions for the future

- Use of simulated data incl. of EOC for algorithm development? Isolated consideration of effects? Later: algorithm optimization with measured data
- Can we trust the source of the data? (sensors, measurement systems?). Aging of the structure or aging of the sensors and sensor connections?
- Future significance of sensor fault identification, sensor signal reconstruction, information redundancy? Especially if accurate signal amplitudes are needed (e.g. RFC for Remaining Life Time).

Thank you for your attention !

MSHM Universität Siegen
Arbeitsgruppe bei Universität Siegen

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