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Optical Through-Silicon Waveguides for Chip-to-Chip Interconnections

Abstract

Optical interconnections are a promising step forward to overcome the intrinsic limitations of electrical interconnections between integrated circuits. A dielectric waveguide etched through the full thickness of a silicon substrate and mechanically stabilized by a bridging structure can pave the way for 2.5D and 3D photonic architectures. This research deals with the design, modelling and realization of the **optical through-silicon waveguide (OTSW).** The influence of the waveguide **sidewalls tapering angle and roughness** on the beam propagation is part of the study. Such bridged optical through-silicon waveguides are **monolithically integrated** and can provide effective **mode size conversion** and favour the **coupling** of external light sources to photonic integrated circuits.

Concept and Motivation

Data centers and high-performance computers need to process a **constantly increasing amount of information**.

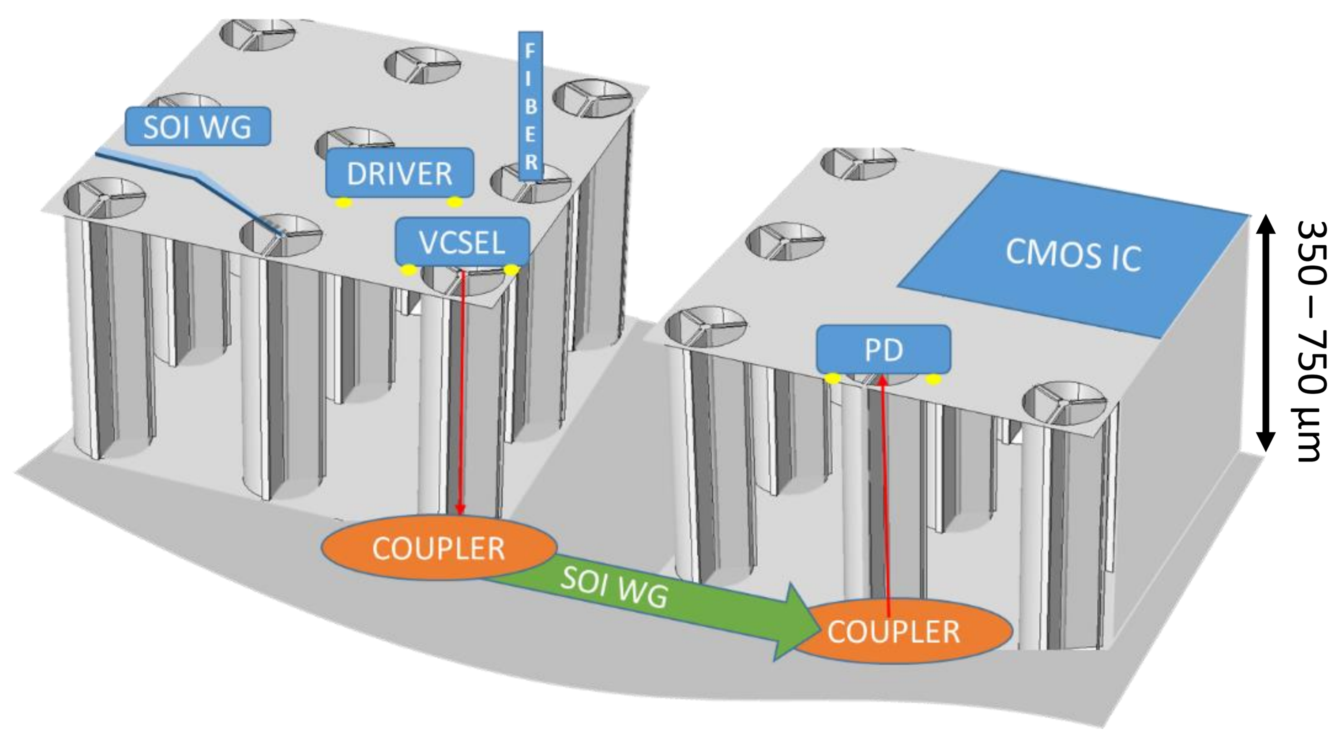
The current chip generation is interconnected by **metal** channels.

~20% of the power is **lost** in long interconnections (>1 mm).

Transistors scale, interconnects DON'T!

These electrical connections are intrinsically limited in their performance by **dissipative wave propagation and line charging, crosstalk, and relatively high latency.**

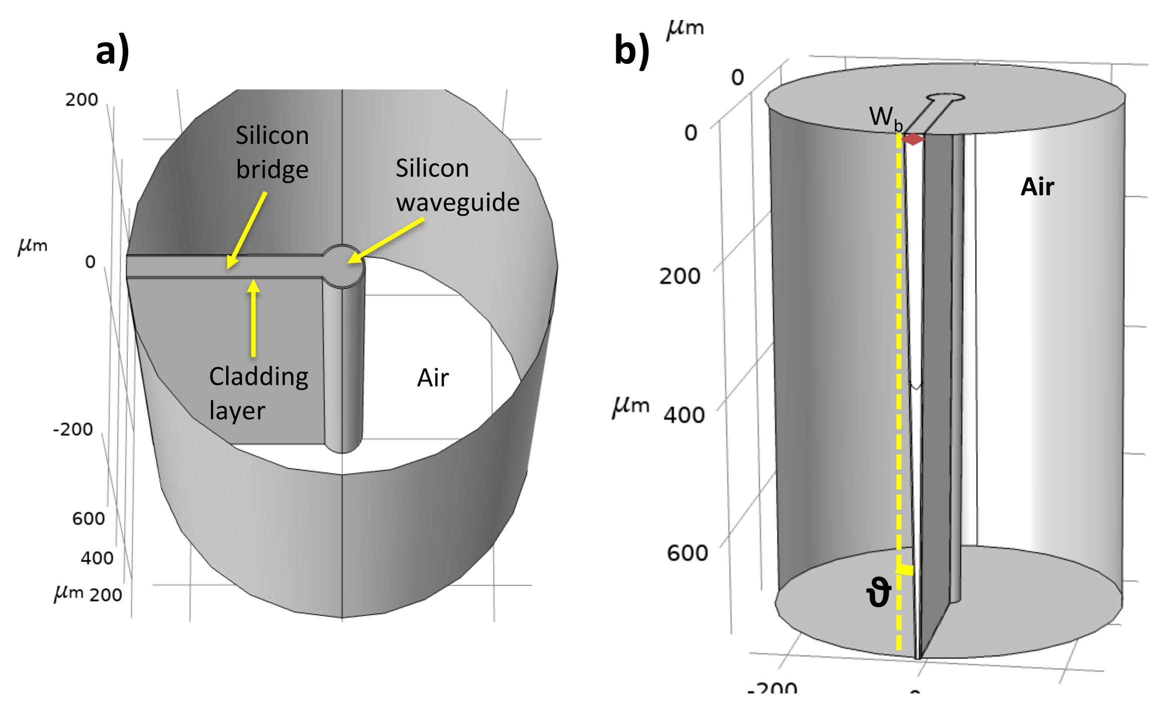
Light as information carrier strongly **reduces power dissipation** in long interconnections and provides **ultra-high bandwidth**.



Scheme of the Optical through-Silicon Waveguide interposer and its foreseen integration in a 2.5D architecture. Long chip-to-chip optical interconnections are made possible.

Model and Design

- The waveguide is composed of a **silicon core** and a **cladding** (of lower refractive index) that can be made of **air, SiO_2, Si_3N_4, polymers** or other suitable materials.
- The operational wavelength region spans ranges **from 1260 nm to 1625 nm**. Most of the photonic integrated circuits and optical fibers operate at **1550 nm**.
- The core is supported by a one or more silicon slabs, defined as **"bridges"**, which provide mechanical stability.
- **Sidewalls tapering angle ϑ** and **bridge-to-core size ratio** play a fundamental role for mode-size conversion, integration and coupling.



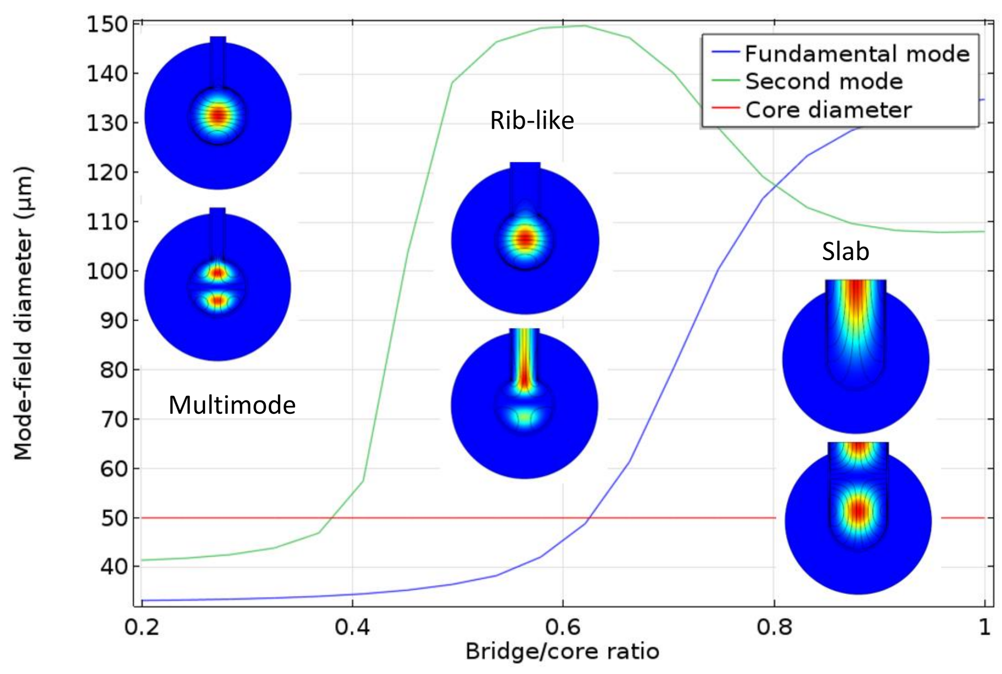
(a)Top and (b)side view of the Optical Through-Silicon Waveguide

Simulation

Finite element method (FEM) simulations using COMSOL Multiphysics:

2D Finite Difference Frequency Domain

- To evaluate an acceptable **bridge-to-core size ratio**



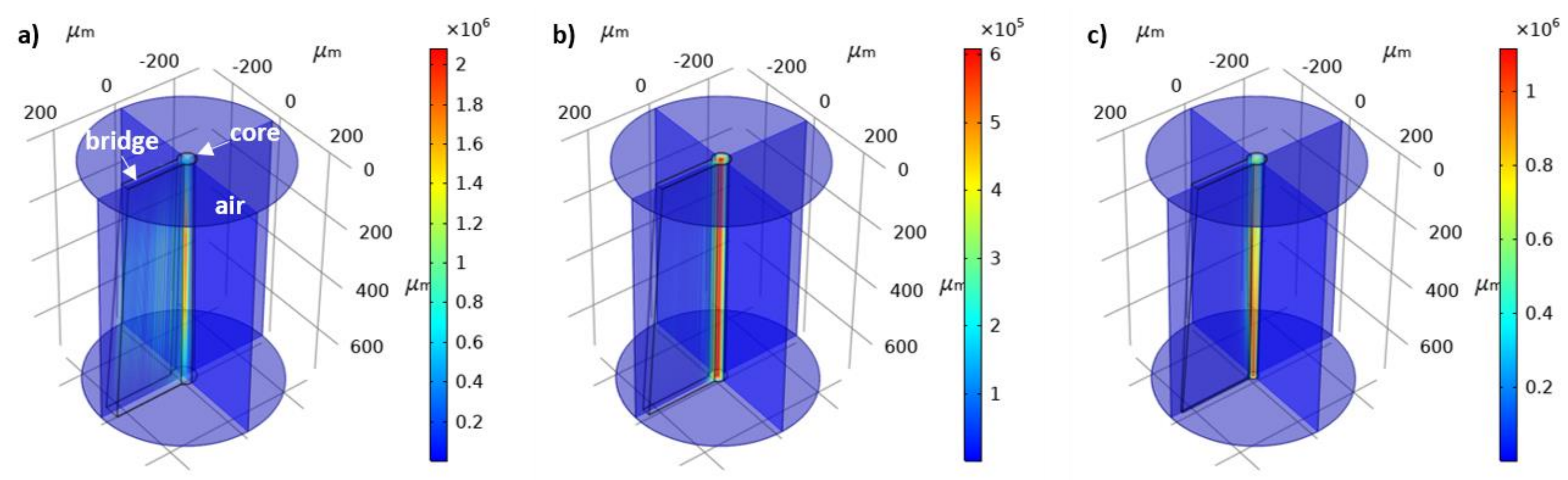
STUDY PARAMETERS:

- λ = 1550 nm
- Core radius R_C = 50 µm (n_{Si} = 3.48)
- Cladding thickness t_c = 2 µm SiO_2 (n_{SiO2} = 1.53)
- Surrounding: Air (n_{air} = 1)
- Bridge width: parametric sweep 10 to 50 µm ⇔ bridge-to-core size ratio 0.2 to 1

2D cross-section simulation of the first two supported modes of a bridged optical through-silicon waveguide. The mode-field diameter of the fundamental and the second supported modes are plotted versus the bridge-to-core size ratio. In addition, the normalized electrical field for the first two modes in the three different regions is shown.

3D Beam Envelope Method

- To investigate the **beam propagation** characteristics depending on the **tapering angle ϑ**



3D beam propagation simulation of a bridged optical through-silicon waveguide with a tapering angle of a) -0.9°, b) 0° and c) 0.9°. The surrounding substrate is hidden, and the electric field values are represented on the x, y and z planes.

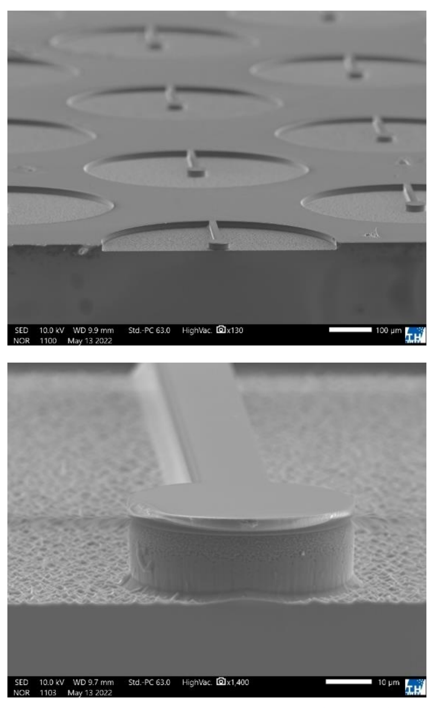
Materials and Methods

The waveguides can be fabricated using **deep reactive ion etching** (DRIE) processes:

- **Cryoetching** ➡ experimental, smooth sidewalls, tunable taper, slow etch rate
- **Bosch etching** ➡ robust, high roughness, steep sidewalls, high etch rate

The **cladding** and an **anti-reflection layer** can be deposited by **plasma-enhanced chemical vapor deposition** (PECVD) or thermal oxidation.

The optical characterization exploits a **1550 nm laser**.



OTSW patterns on (100)-Si

Key-points

- Monolithically integrated
- Tapered sidewalls
- CMOS compatible
- High bandwidth (>1 Tb/s)
- Integration with Photonic Integrated Circuits
- No crosstalk, no latency
- Mode-size conversion
- Passive waveguiding or sensing applications
- Under development

Literature

- Pending PCT patent: https://www.inventionstore.de/angebot/6059/
- F. Villasmunta, P. Steglich, S. Schrader, H. Schenk and A. Mai, "Numerical Simulation of Optical Through-Silicon Waveguide for 3D Photonic Interconnections," 2021 International Conference on Numerical Simulation of Optoelectronic Devices (NUSOD), 2021, pp. 115-116, doi: 10.1109/NUSOD52207.2021.9541464.

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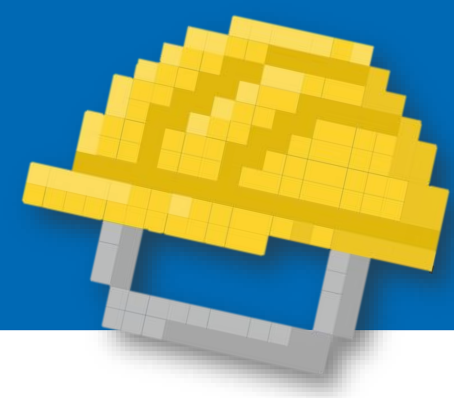
Innovation im Handwerk

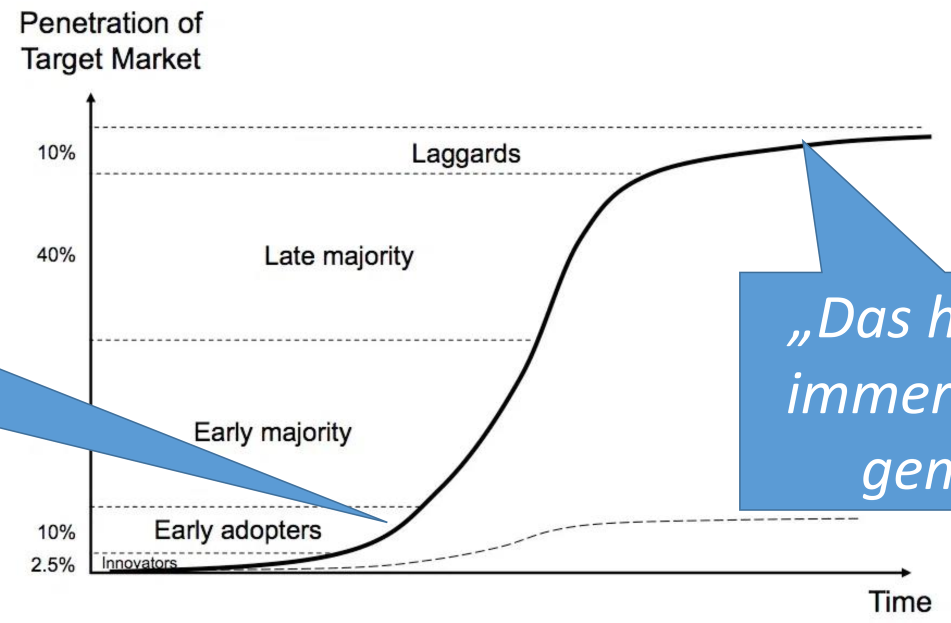


Einleitung

Was ist Innovation?

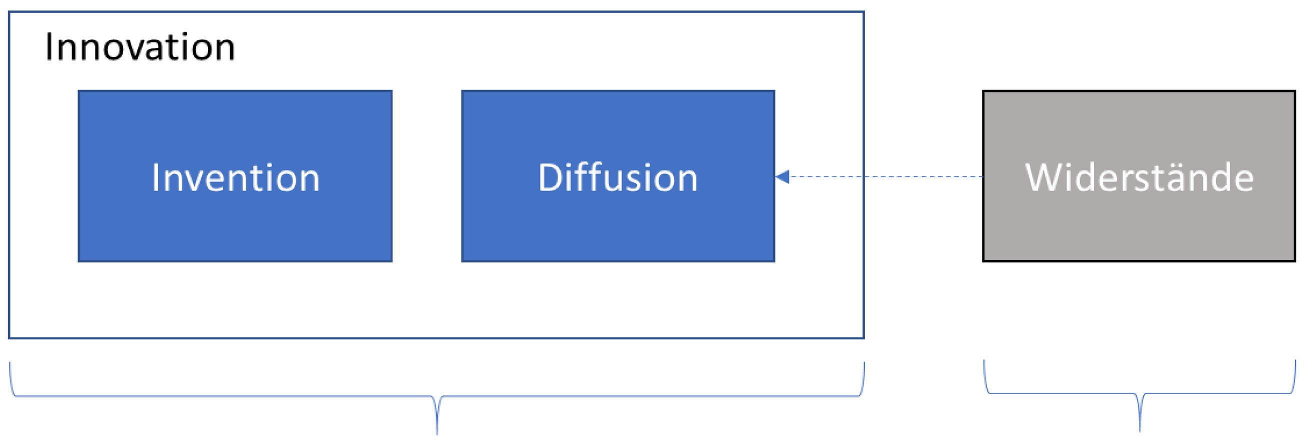
Eine Innovation kann modellhaft als eine Erfindung (Invention) bezeichnet werden, die immer mehr Anwendung findet, bspw. weil sie verschiedene Aufgaben stark erleichtert (diffundiert).
Nicht alle Menschen nehmen sich Neuerungen gleich schnell an.

„Hast du auch schon das neue …“



„Das haben wir immer schon so gemacht“

[1]



Rollen/Typen/Diffusionskanäle

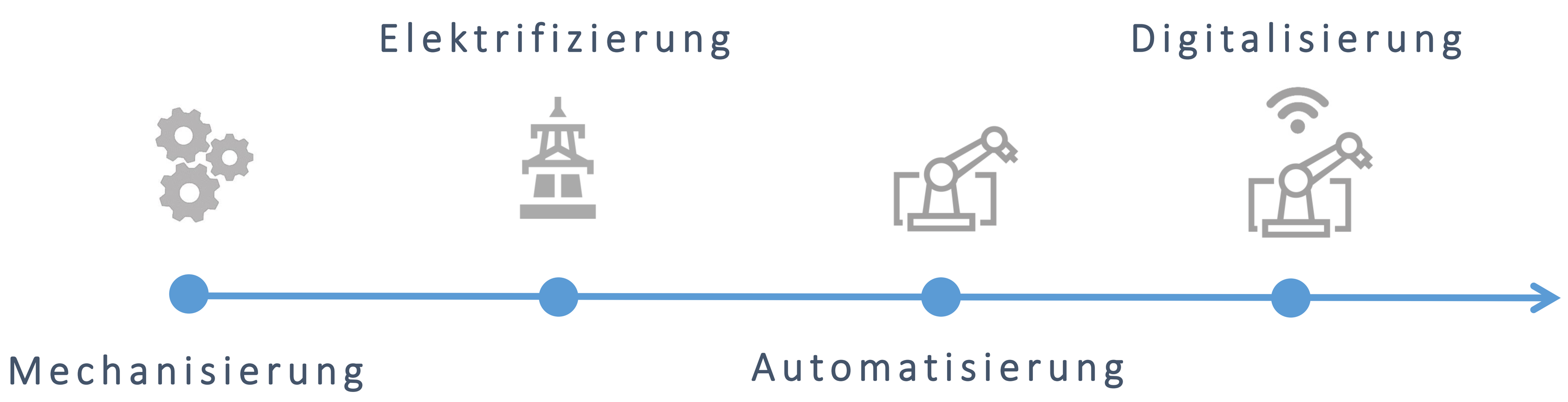
Spezifische Akzeptanz

Die Frage, wann Innovationen gelingen, Technologien angenommen und genutzt werden und schließlich diffundieren hängt nicht allein vom technologischen Reifegrad ab: Das Gesellschaftliche Umfeld, persönliche Vorlieben und viele weitere Aspekte spielen hierbei eine große Rolle.

Stand der Technik

Handwerk 4.0

Innovationen im fertigenden Sektor haben zu den industriellen Revolutionen geführt:



Neben der Industrie gibt es noch die handwerkliche Fertigung. Während die Zusammenhänge zwischen Innovation, also technischer Entwicklung und Diffusion für die industrielle Anwendung gut erforscht sind, ist dies beim Handwerk ein blinder Flick [2].

Das führt zu folgenden Forschungsfragen:
Welche Unterschiede gibt es bei der Innovationsbereitschaft zwischen Industrie und Handwerk?
Unter welchen Umständen werden Technologien im Handwerk adaptiert?
Welche Spezifischen Anforderungen lassen sich daraus für das Handwerk formulieren?

Innovationsradar

Die Prozessgliederung nach Porter verdeutlicht, dass sich die Prozessschritte vor und nach der eigentlichen Leistungserstellung im Handwerk, nicht sonderlich von denen der Industrie unterscheiden.

Spracherkennung, Bilderkennung, Remoteassistenz, 3D-Scans, Diebstahlschutz, Drohnen, Chat Bots, …

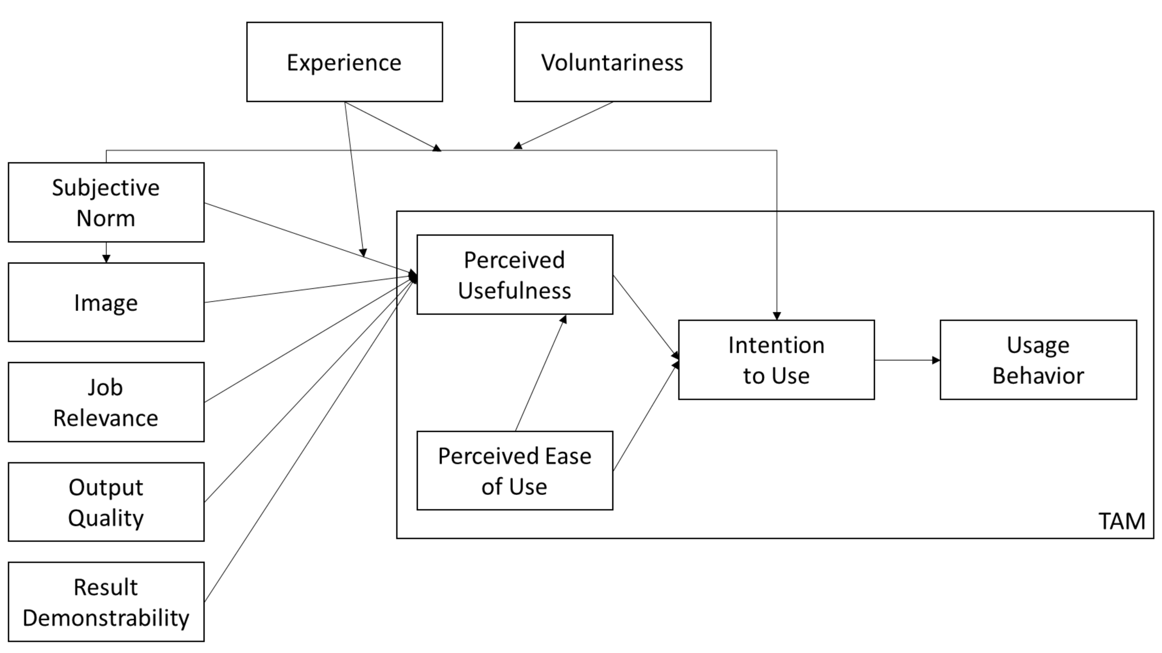
Welche Erkenntnisse lassen sich aus der Industrie übertragen?

Industrie — Transfer — Handwerk

Forschungsansatz

Akzeptanzmodell

Ob Technologien Anwendung findet, hängt neben Verfügbarkeiten auch von der Akzeptanz der Anwender ab. Das Technologieakzeptanzmodell (TAM) hat sich an der Schnittstelle zwischen Technologien und Menschen, die diese nutzen sollen, etabliert. Es wird herangezogen, um bisherige Widerstände zu identifizieren und Unterschiede zur Industrie aufzudecken [3].



Fallstudien

Eine Reihe von Fallstudien, bei denen Handwerksunternehmen mit digitalen bzw. industriellen Methoden konfrontiert werden und diese ausprobieren können, dient als Grundlage für darauf aufbauende Beobachtungen und *Conversational Interviews* [3]. Diese Interviews dienen dazu Hypothesen zu formen, wie Innovationen in das Handwerk hineingetragen werde oder entstehen, wann sie sich durchsetzen und sich innerhalb des Handwerkssektors verbreiten.


Exoskelett beim Radwechsel (KFZ)


AR Fern-assistenz im SHK-Handwerk


Reihenfolgeplanung mit VR & Simulation (Tischlerei)


5S Prozesse mit Lego (Bautischler)

Jede Fallstudie betrachtet eine Technologie oder Methode in verschiedenen Handwerksbetrieben einer Branche und bezieht ebenfalls den Hersteller der Technologie mit ein. Die so erstellten Hypothesen werden dann anschließend mit quantitativen Methoden untersucht.

[1] Lurin, P.A.: Business Planning for Managers and Entrepreneurs (2014). ISBN: 3981373421
[2] Prell, B., Günther, N., Reiff-Stephan, J.: Cyber-Physical Production Systems in Settings with Limited Infrastructure. TH Wildau Eng. Nat. Sci. Proc. 1, (2021). https://doi.org/10.52825/thwildauensp.v1i.6.
[3] Davis, F.D.: Perceived Usefulness, Perceived Ease of Use, and User Acceptance of Information Technology. MIS Q. 13, 319 (1989). https://doi.org/10.2307/249008.
[4] Glaser, B.G., Strauss, A.L.: The Discovery of Grounded Theory: Strategies for Qualitative Research. Aldine Transaction (1967).

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New measurement approach for the wheel pass-by noise of freight wagons

Robert Kamenzky, Robin Pianowski, Prof. Dr.-Ing. Ennes Sarradj, Prof. Dr. Peter Blaschke

Train noise and wheel / rail interface

figure 1: pass-by noise of trains

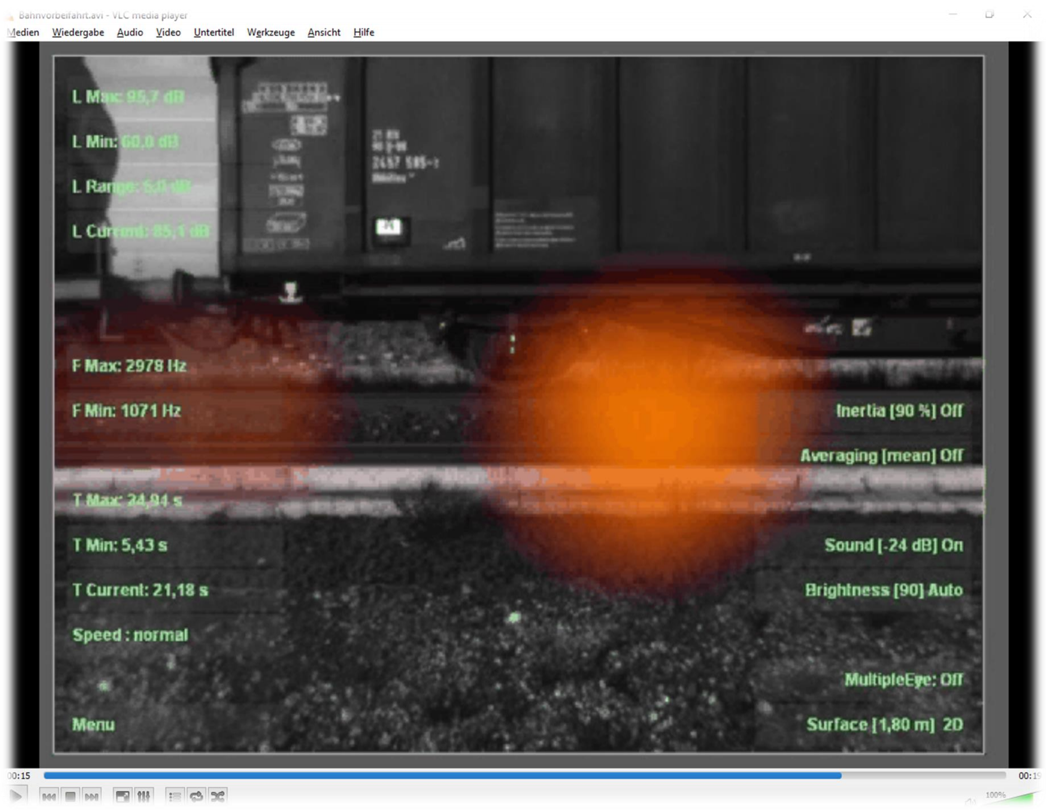

figure 2: acoustic camera – main noise contribution by wheel-Rail interaction

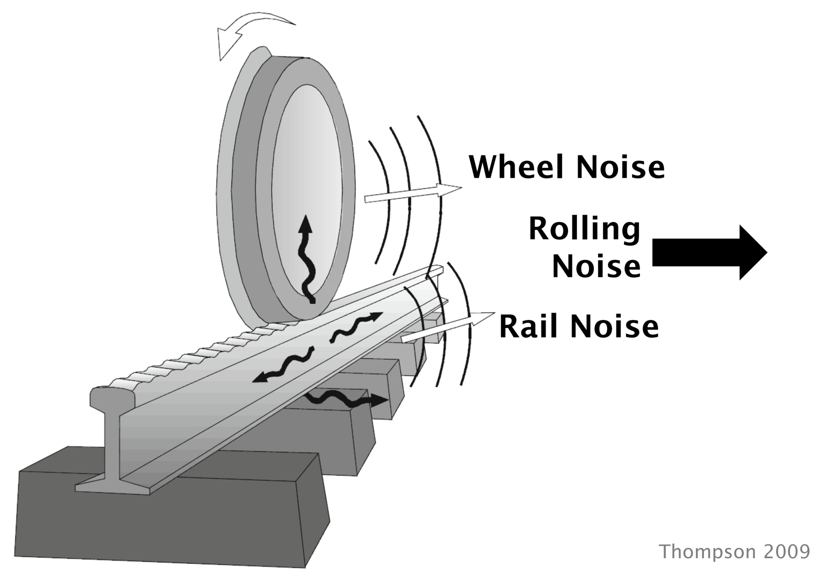

figure 3: S noise emission of the wheel/rail system

The main noise mechanism of freight wagons is the wheel / rail interface. Due to surface roughness the rolling wheel impacts on the rail, inducing vibrations in wheel and rail which radiate as acoustic noise.

The scope of this work is the development of a new measurement approach for **assessing the pass-by noise of freight wagon wheels**. To avoid the immanent disadvantages of microphone measurements, i.e. interfering noise due to other vehicles, weather, etc., the acoustic emission is derived from vibration measurements at the rail contemporaneous to the train pass-by.

The procedure has a two-tiered approach. First the transfer functions (TF) of a static reference vehicle on the track are measured via impact measurement. All TFs are measured from the wheel/rail interface to a wayside microphone and a transfer path model is derived.

In a second stage the pass-by of different freight carriages is measured with vibration sensors on the track. Only the immediate transit of the wheel passing the sensor position is triggered, ensuring quasi stationary conditions. Measured vibration data is linked to the transfer path model. As a result synthesized sound pressure levels of the freight carriages wheels pass-by are obtained.

Laboratory experimental set-up and results

A experimental set-up, consisting of a handcar wheelset in a semi anechoic chamber was build. Ten pass-by measurements with rail acceleration in y and z and sound pressure of a reference microphone were conducted (measurement time 300 ms, band width 300 – 6000 Hz).

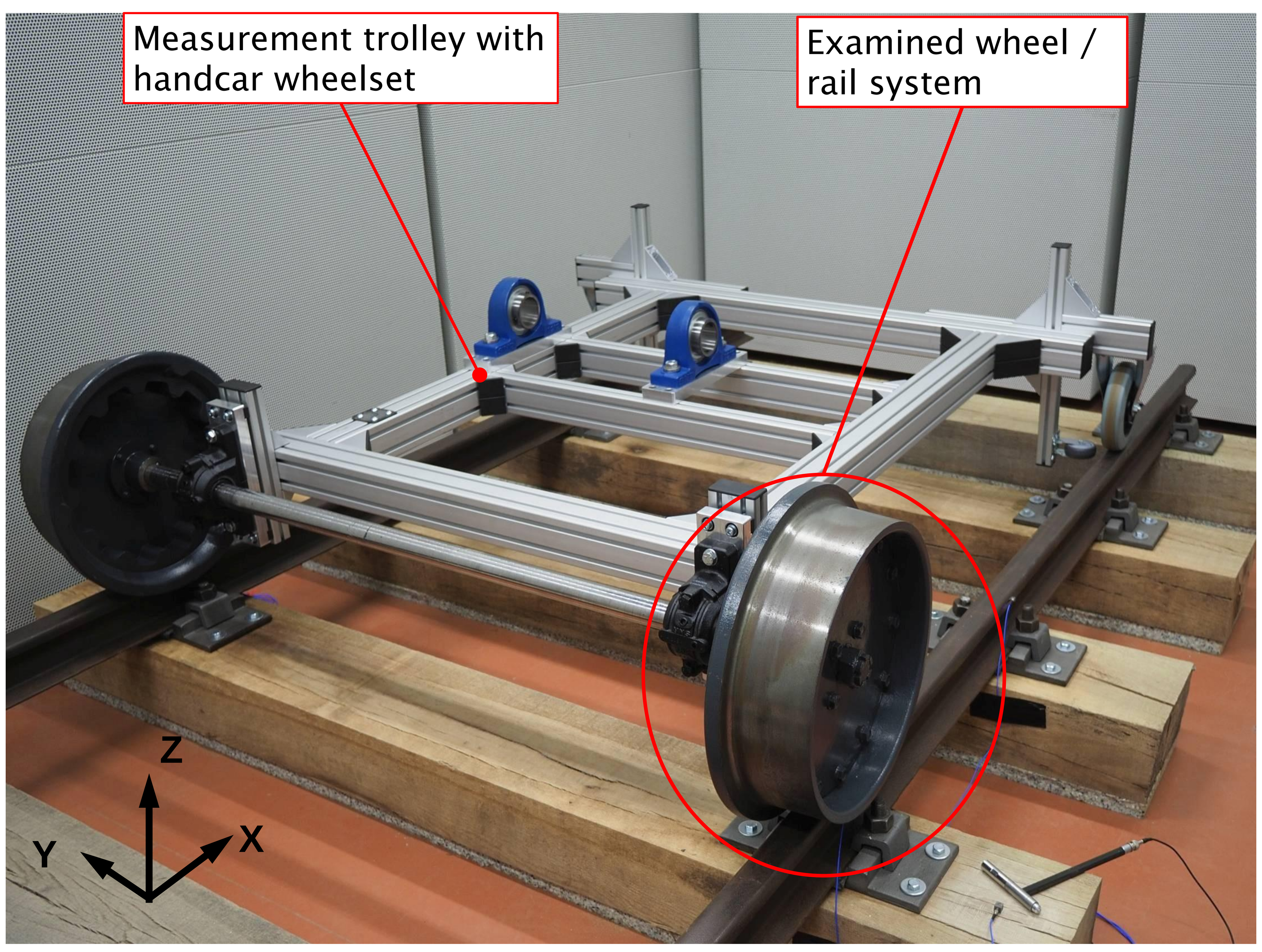

figure 4: front view of laboratory set-up. The handcar wheelset is a loan from the Erlebnisbahn Zossen GmbH and has standard gauge.

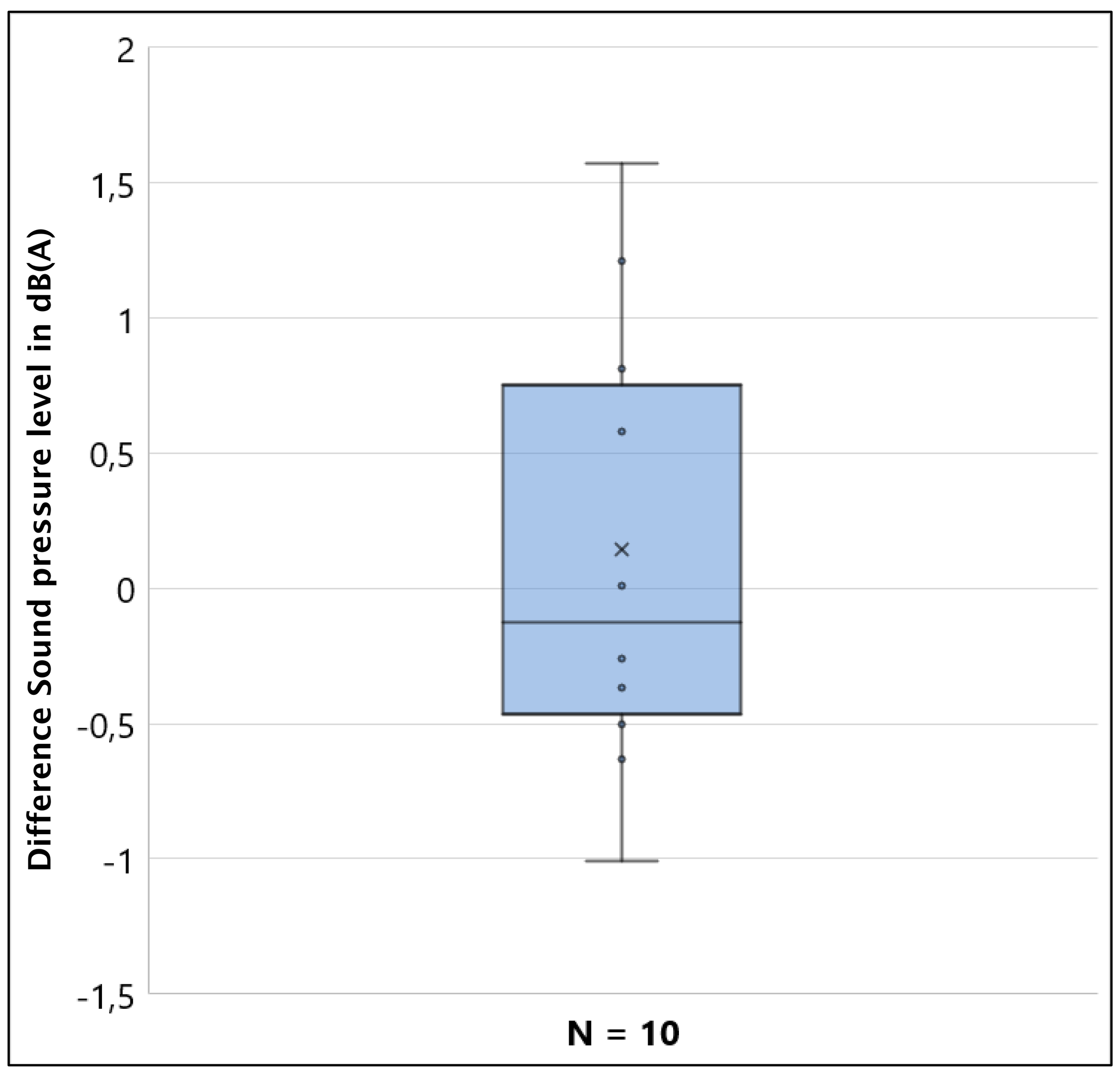

Figure 5: Difference in A-weighted sound pressure levels of Synthesis from rail vibration versus reference microphone

Mean:
0,41 dB(A)
Standard deviation:
0,81 dB(A)
Peak to peak:
2,5 dB(A)

Synthetized A-weighted sound pressure levels and reference microphone measurements match with a mean difference of less than one dB(A). Variation is still high with a peak to peak span of 2,5 dB(A). No crosstalk compensation for transfer function measurements and pass-by measurements was implemented. Minimizing crosstalk will yield better results for the synthesized sound pressure levels.

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In Situ Wheel Tire Damage Detection - RiESE

Robin Pianowski, Robert Kamenzky, Prof. Dr. Peter Blaschke

Description

Railway wheel tires are subjected to wear (fig.1) due to high stress. For a secure operation and to avoid accidents, knowledge about the wear status and damage is required. Therefore a stationary maintenance is performed. This leads to periodic out of service time for trains that decreases transportation capacity.

To improve the knowledge of the wear-status this research project focuses on proactive damage and wear detection that is capable to identify a wheel tire damage on a wayside measuring station during train passage.

With a detection system working during operation, critical damages and wear can be repaired faster. It gives the possibility to individually plan the maintenance intervals and to reduce unexpected failures that lead to transportation delays.

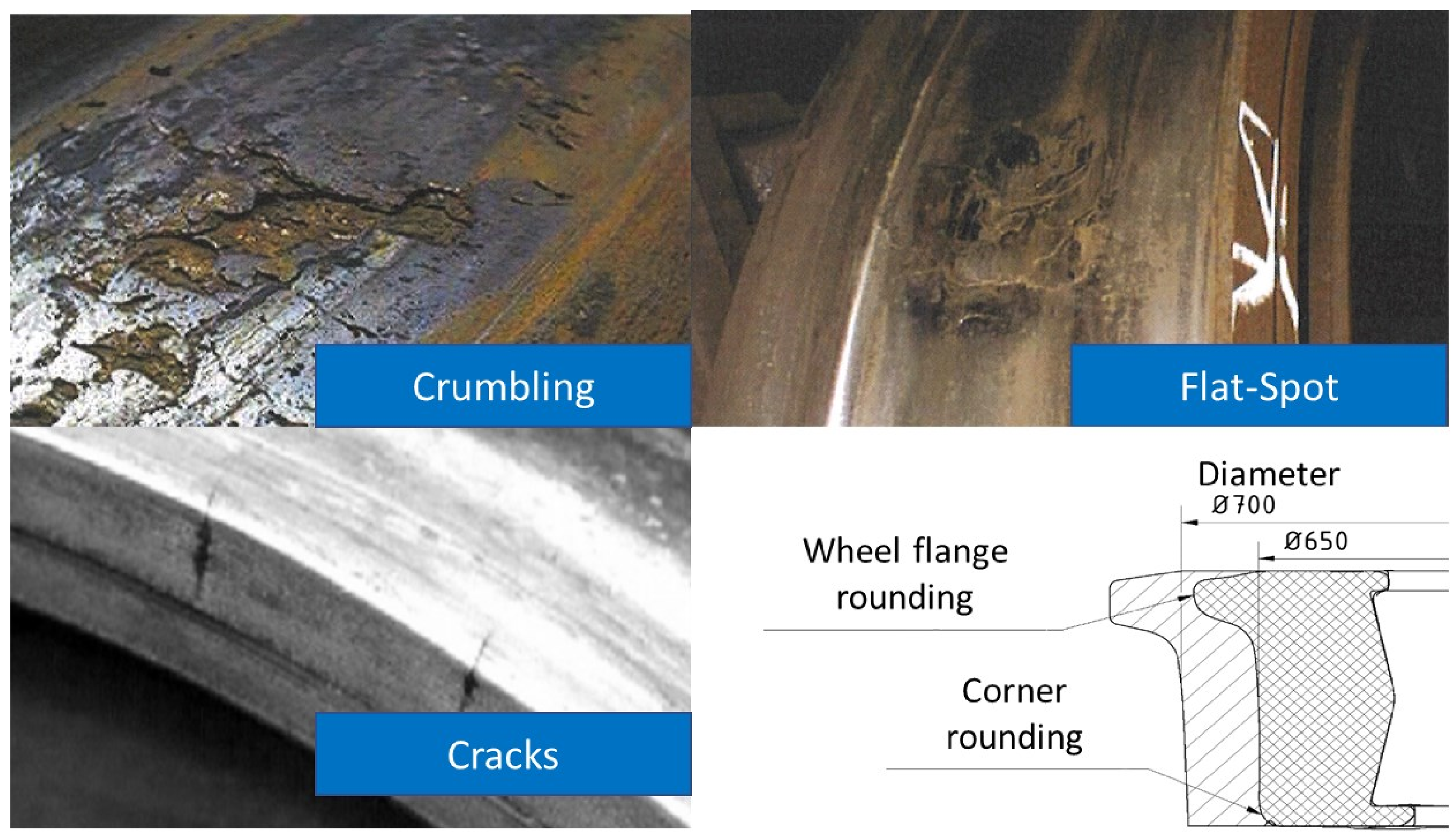

Fig. 1 Exemplary wheel tire damage and typical wear process

Approach

The approach bases on structural dynamic recognition of wheel tire damages. Is there a damaged or worn out wheel tire its modal parameters should differ from an intact tire. This approach may give information about the condition. To capture the tire signal out of a train passage over the measuring station the transfer path analysis and synthesis is utilized.

The first step is to determine modal differences of intact and damaged wheel tires. Therefore a numerical modal analysis is executed. The appearing mode shapes are clustered and named after Chladni-figures regarding nodal lines and rings (fig.2). This ensures a comparability with later experiments.

After the classification an experimental modal analysis of factory new and worn out wheel tires is performed. The mode shapes from the numerical analysis are paired to the experimental. Therefore each eigenfrequency with its mode shape can be compared.

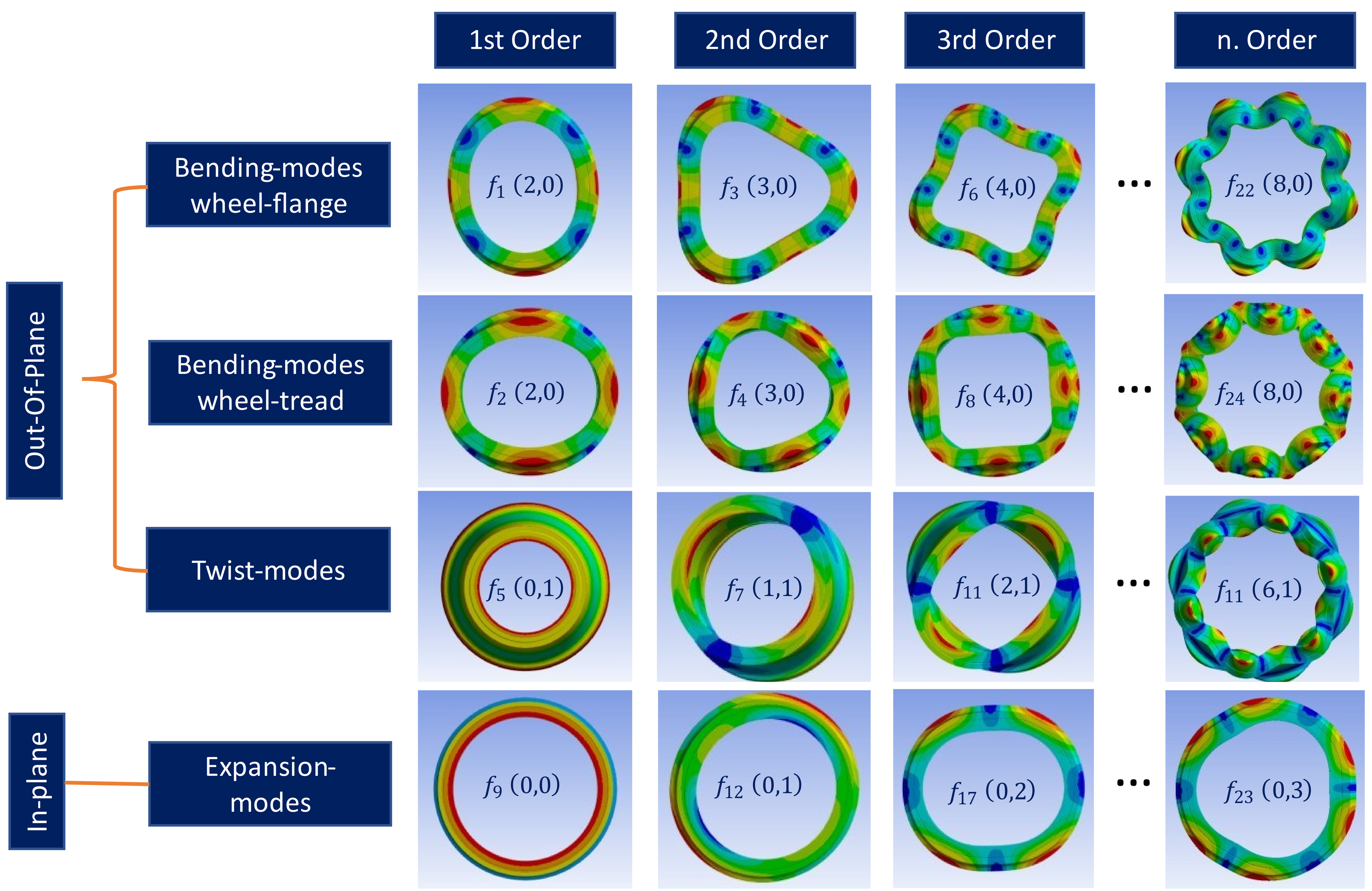

Fig. 2 Clustered mode shapes due to shape and order of wheel tire numerical modal analysis

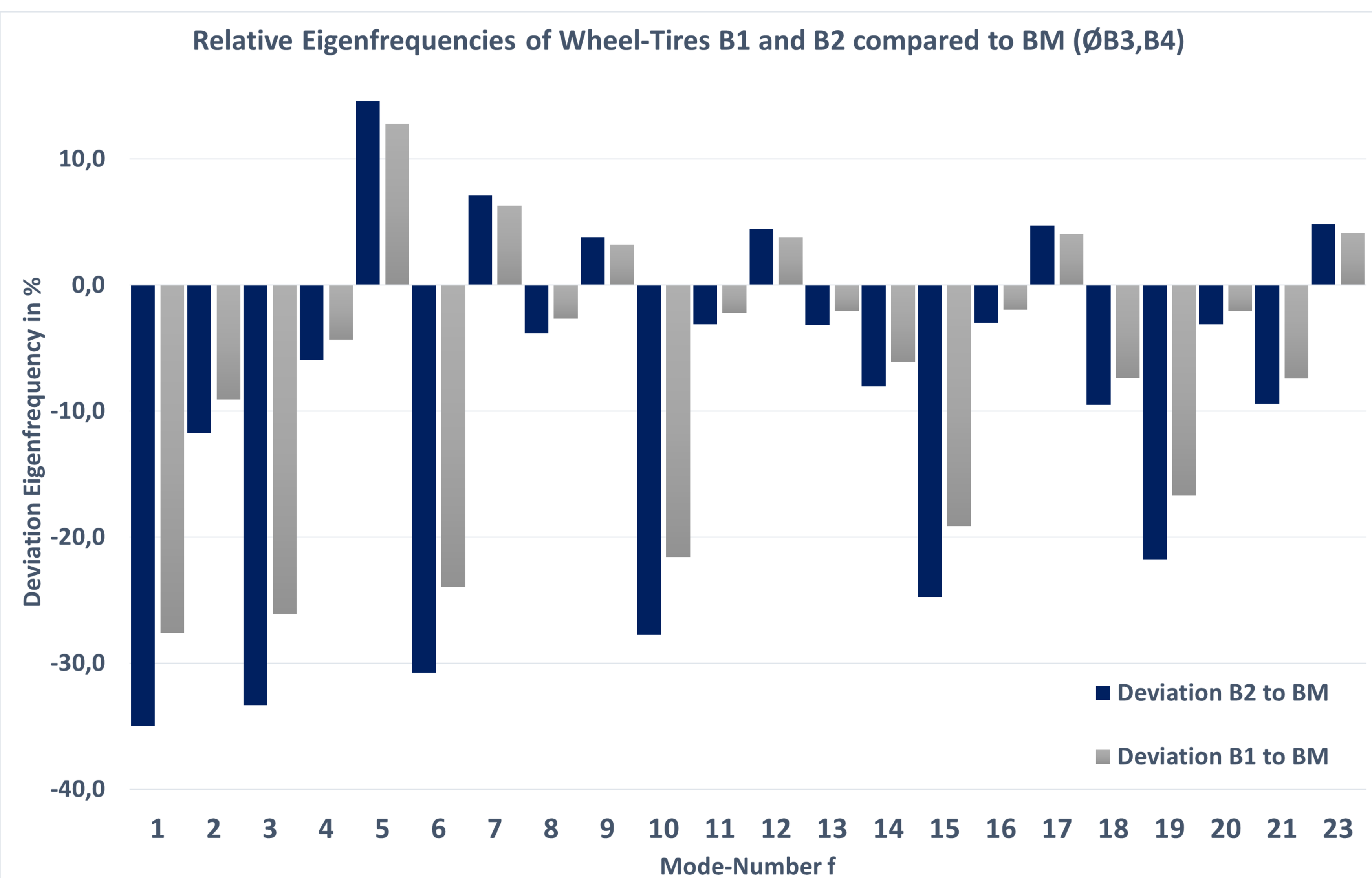

Fig. 3 Relative comparison of mode shape eigenfrequencies of worn out (B1,B2) and factory new (BM) wheel tires indicate significant deviations

In fig. 3 the results are plotted. The eigenfrequencies of worn out wheel tires B1 and B2 are compared to BM which is the average of two factory new wheel tires whose eigenfrequencies barely differ. The deviations in eigenfrequencies are significant in a range from 2 to 35%. Referring to the mode shapes a consequent pattern can be identified. Bending modes at the wheel flange are deviating consequently higher then any other mode cluster. Furthermore most frequencies are lower compared to the factory new state except for in-plane modes as well as the first twist-modes with in-plane character.

The change in eigenfrequency is not linear over all mode shape categories. Even the two worn out tires B1 and B2 differ by 5% in wheel flange bending-modes. Further investigation priories the geometrical influence of wear and damage on wheel tires in numerical parameter studies. The aim is to determine defects or wear that leads to a specific and repeatable change in eigenfrequency.

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