TECHNISCHE UNIVERSITÄT DRESDEN

COMP-ECO

DRESDEN concept

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Function Integrative Lightweight Structures: Introduction to Function Integration

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Institut für Leichtbau und Kunststofftechnik

Industrial revolutions

Transition from hand production methods to machines
- Steam and water power
- New chemical and iron production processes
- Development of machine tools
- Mechanised factory systems
- Starting in textile industry
- Iron industry, agriculture and mining

Technological Revolution
- Scientific discovery
- Standardisation
- Mass production
- Industrialisation
- Rail and telegraph
- Electric power and telephones
- Electrification
- Globalisation

Digital Revolution
- After 1st and 2nd world war
- Slow down of industrialisation and technological advancement
- Digital development
- Supercomputer
- Production process – use of communication technologies

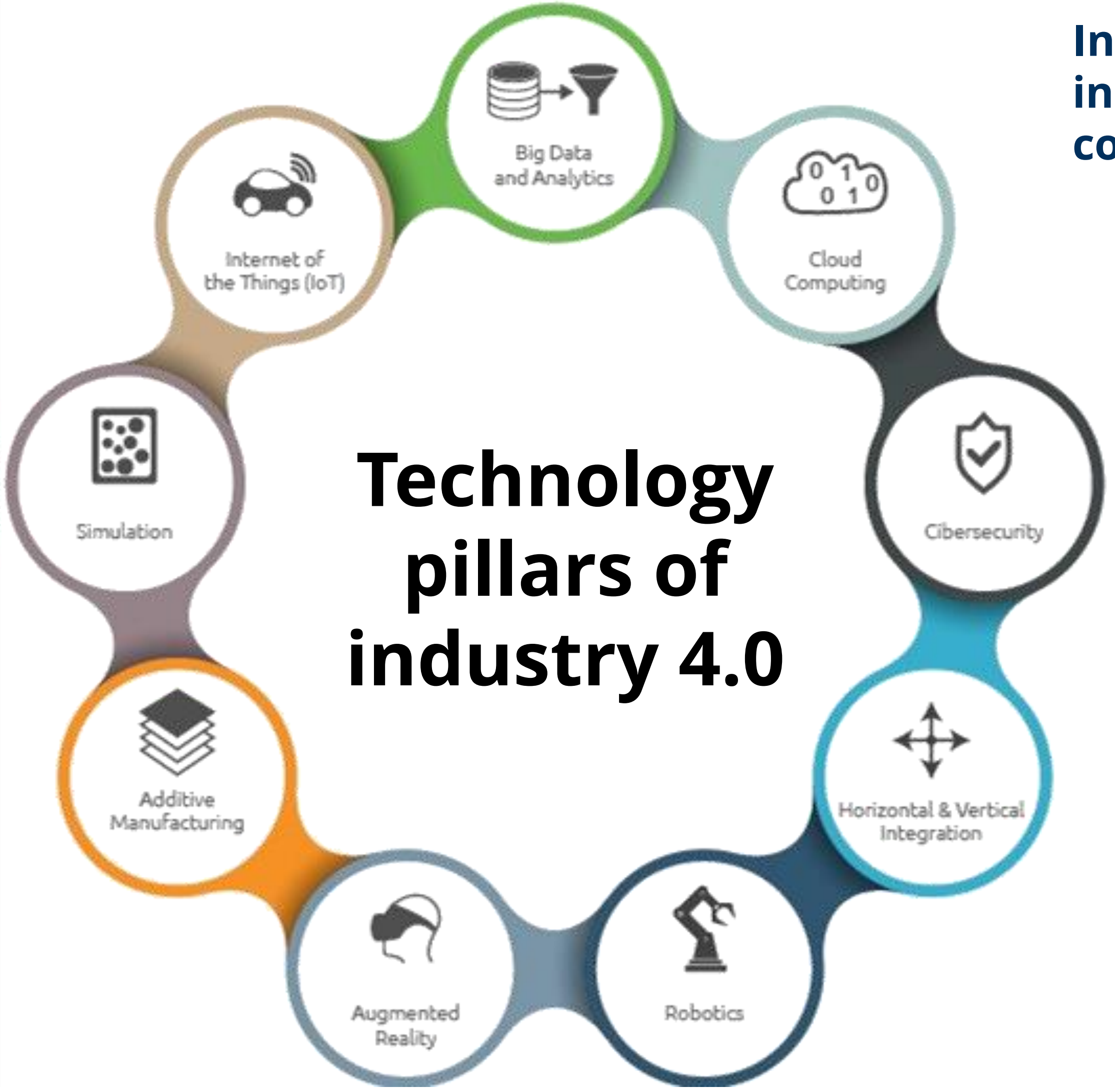
Industry 4.0
- Change of processes, technologies, industries and social patterns
- Artificial intelligence
- Gene editing
- Robotics
- Automatization
- Machine to machine communication
- Internet of things (ioT)

Customisation and Collabo-ration
- Human-machine collaboration for substitution of human weaknesses
- Human factors
- Well-being

1st	2nd	3rd	4th	5th
Mechanisation	Electrification	Automation	Digitalisation	Personalisation
~1750 - 1850	~1850 -1930	~1930 – 2000	~2000 - 2020	Future

Today

Industry 4.0



https://industry40marketresearch.com/blog/industry_4-0_technologies/

Intelligent networking of machines and processes for industry with the help of information and communication technology

- **Flexible production** –digitally networked processes
- **Convertible factory** – modular product lines, improved productivity and efficiency, individualized products, in small quantities at affordable prices
- **Customer-oriented solutions** –customized, digitalized solutions and products
- **Optimised logistics** – evaluation and control algorithms, smart networking
- **Use of data** – production and life time data, continuous development and operation by data evaluation and adjustment
- **Resource-efficient circular economy** – life cycle, design and recycling

Industry 4.0 and Global Megatrends (2023)

Gender shift
traditional gender roles are losing their social obligations

Health
Importance of health – high quality of life

Globalisation
Merging the world's population
Increasingly close and free exchange of ideas, talents and goods

Connectivity
Networking based on digital infrastructure
Connected communication technologies

Individualisation
Self-realisation within a uniquely designed individuality
Personal freedoms and individual self-determination

Security
Fundamentally renegotiation of Safety meaning
Resilience

New Work
New working models

Neo-Ecology
new values in all aspects, as sustainability fundamentally realigns society, economy and companies

Knowledge Culture
Digitalisation of education
Cooperative and decentralised knowledge generation

Urbanisation
Rising number of people living in cities
Cities are more than just places

Silver Society
Demographic change
New social and economic conditions

Mobility
Mobile world culture
New products and services
Future use of transportation

https://www.zukunftsinstitut.de/dossier/megatrends-en/

Function-integration

Design

Design Catalogue
Functional integration
Integral Construction
Hybrid Construction
Mounting elements
Stiffening elements
Increased material utilization
Integral function exploitation

Materials

Technologies

3D-MID
Multicomponent injection moulding
Back Injection
In mould decoration
Combined Processes
Integral processes

As few components and as many technical functions as possible
Multifunctionality

FUNCTION-INTEGRATION

Electromobility
Enhancement of reliability
Increased Customer Benefit

Integrated lighting and control elements
Reliability
Actuators
Sensors
Condition Monitoring
Structural Health Monitoring
Structural Electronics/ Adaptronic
Vibroacoustics
Vibration Damping

Linking of Softwaresystems
Consistent process processing
Data integration
Computer-integrated Information Processing
Business and economic technical tasks
Computer integrated manufacturing (CIM)

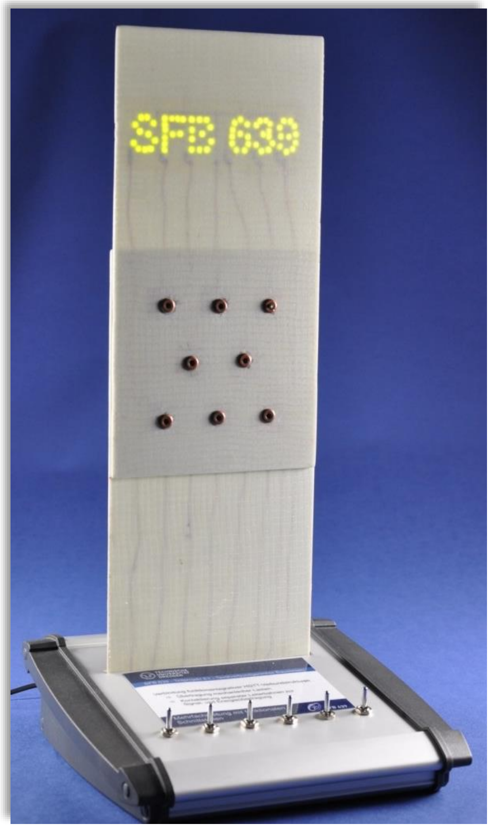
Introduction – motivation for function-integration

General Demands

- Increase of functional density
- Safety aspects
- Reliability and maintenance
- Costs
- Installation space
- Resource efficiency
- Light-weight potential/mass
- Condition monitoring – insufficient knowledge of the long term behaviour
- Additional functionalities

New possibilities

- ➢ Integral production processes enable an increased complexity of fibre reinforced composites
- ➢ The layer-wise built up of fibre reinforced composites the insertion of additional functional elements
- ➢ Detection of physical measurands not detectable by conventional systems
- ➢ novel miniaturised evaluation electronic



Integrated conductors and lighting elements in fibre-reinforced polymer

Motivation for function-integration

Demands on novel design and mobility concepts

- Safety
- Installation space
- Comfort
- Adaptive

www.manager-magazin.de

2013

www.digitaltrends.com

2015

Future

Function-integrative light-weight structures/systems

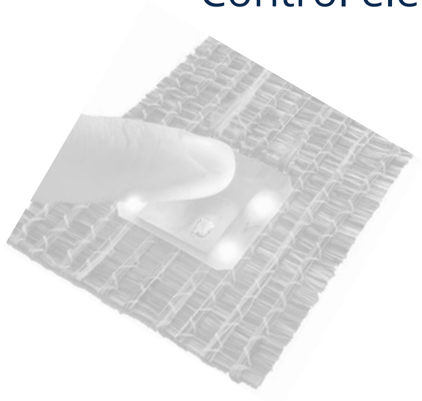
- Structural integration of functional elements
- Reduction of the required installation space
- Reduction of maintenance intervals

Motivation for function-integration

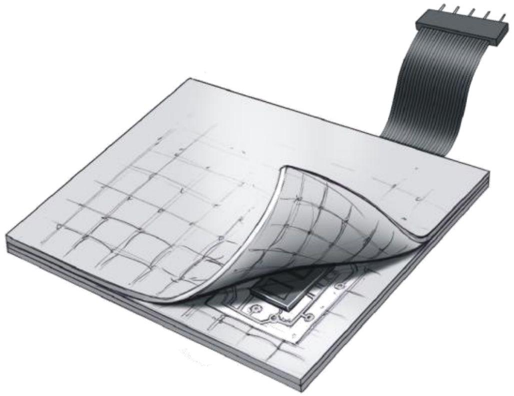
Function-integrative vehicle carrier (FiF)

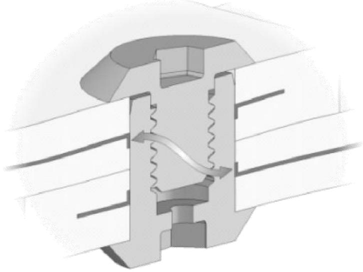
Design rules for textile reinforced composites

Control elements

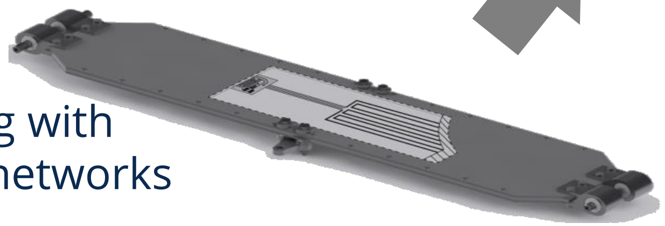


Integrated sensor networks and actuator systems



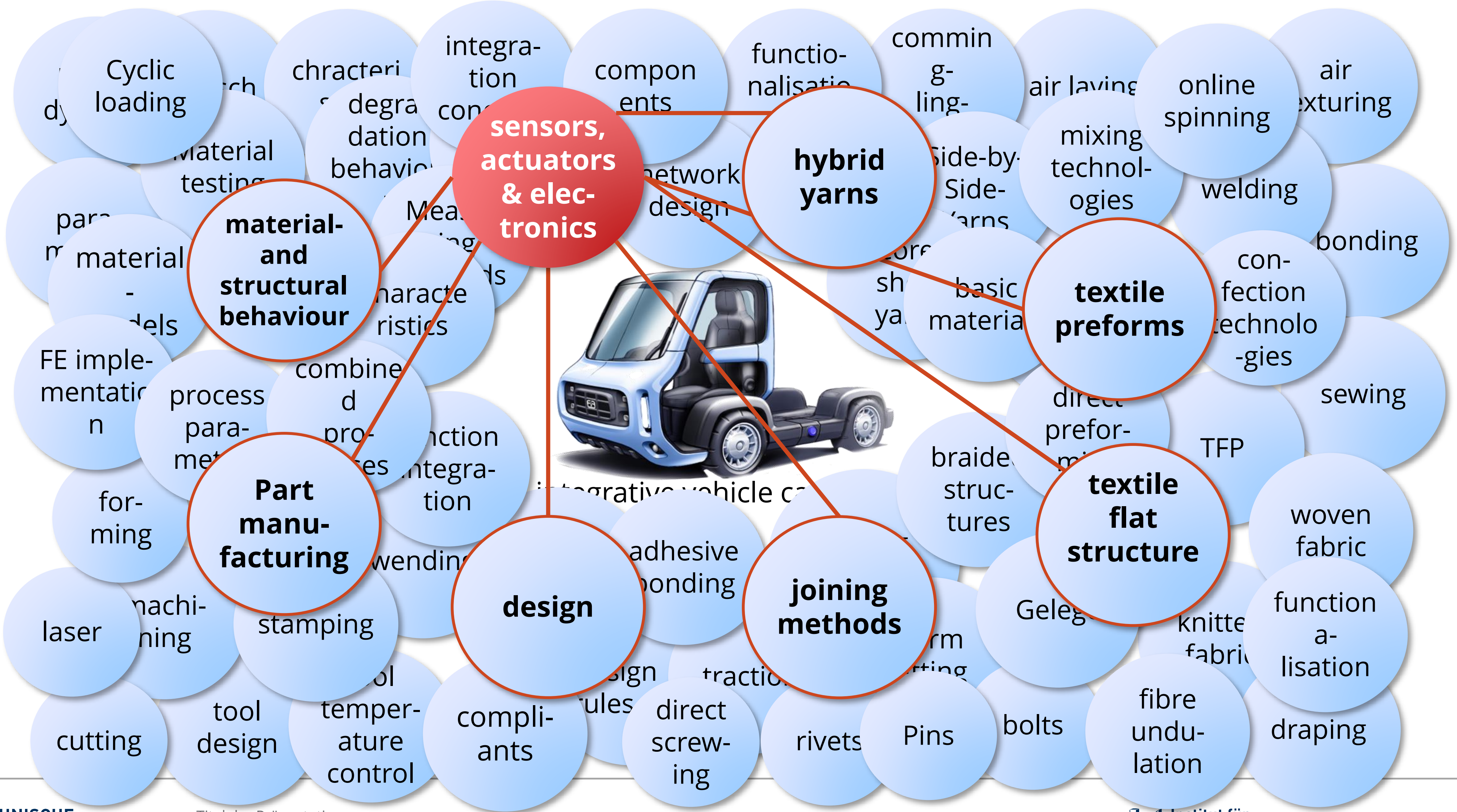


Functional interfaces

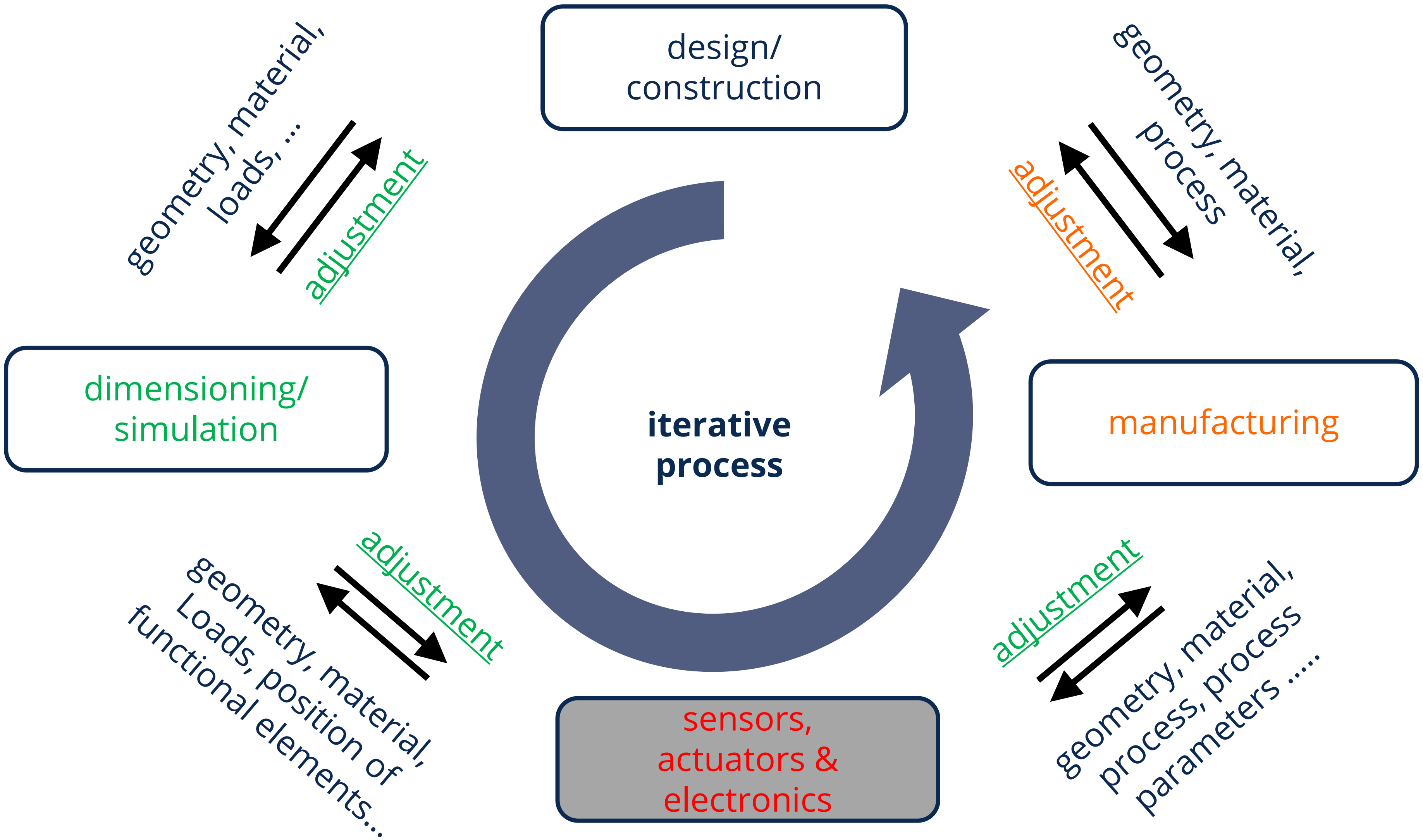


Adaptive flex spring with integrated sensor networks

Motivation for function-integration



Extension of the iterative design process



Function as an inherent contradiction of the system

Design in an **iterative process** to **solving contradicting goals** and taking into account

- **Contradictions** of mechanical and functional properties
- **Boundary Conditions**, e.g. geometry, mass
- **Constraints**, e.g. costs

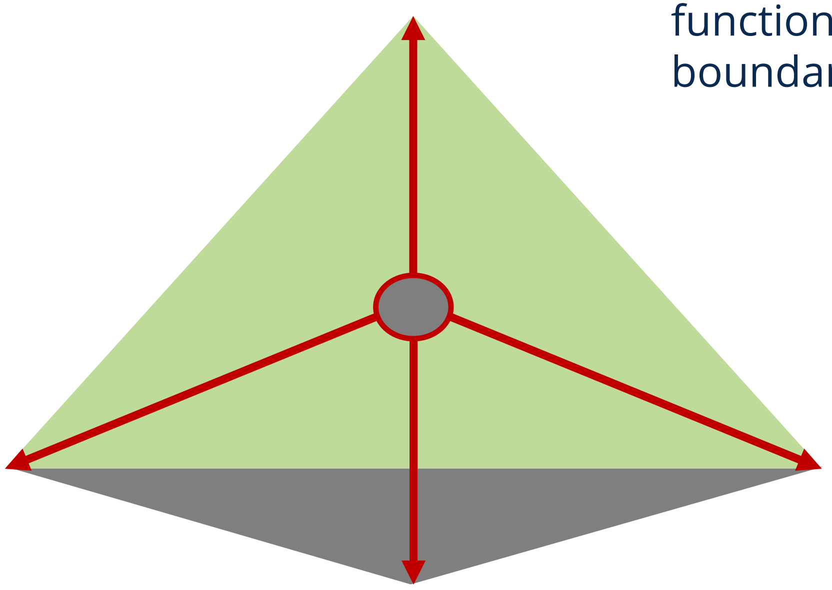
⇨ **Trade-off between contradictions**

Mass - Materials

Dependent on fulfilment of primary function, compliance with acceptable boundary conditions

Functional properties

No significant reduction in mechanical properties & primary component function



Costs - Resources

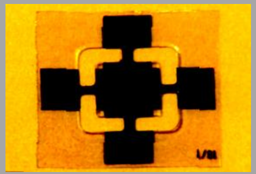
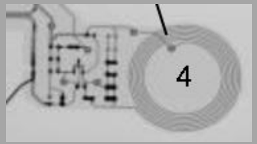
Extra Function

Design of function-integrative light-weight structures is carried out in an iterative process taking into account mechanical, physical and functional properties as well as costs.

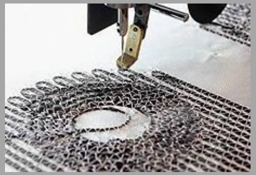
Function-integration – Functionalities and methods

Enabling methods
e.g. interfaces , simulation methods, energy supply and transmission, data analysis methods (KI, ML …)

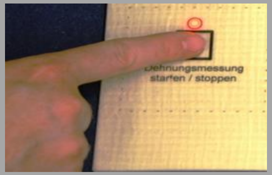
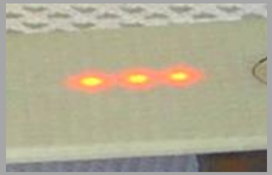
Sensory functionalities

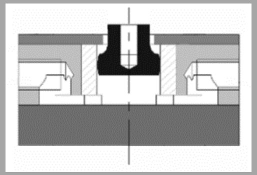
Structural functionalities



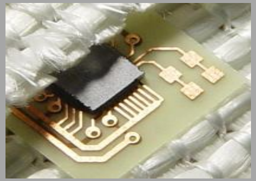

Complex functionalities

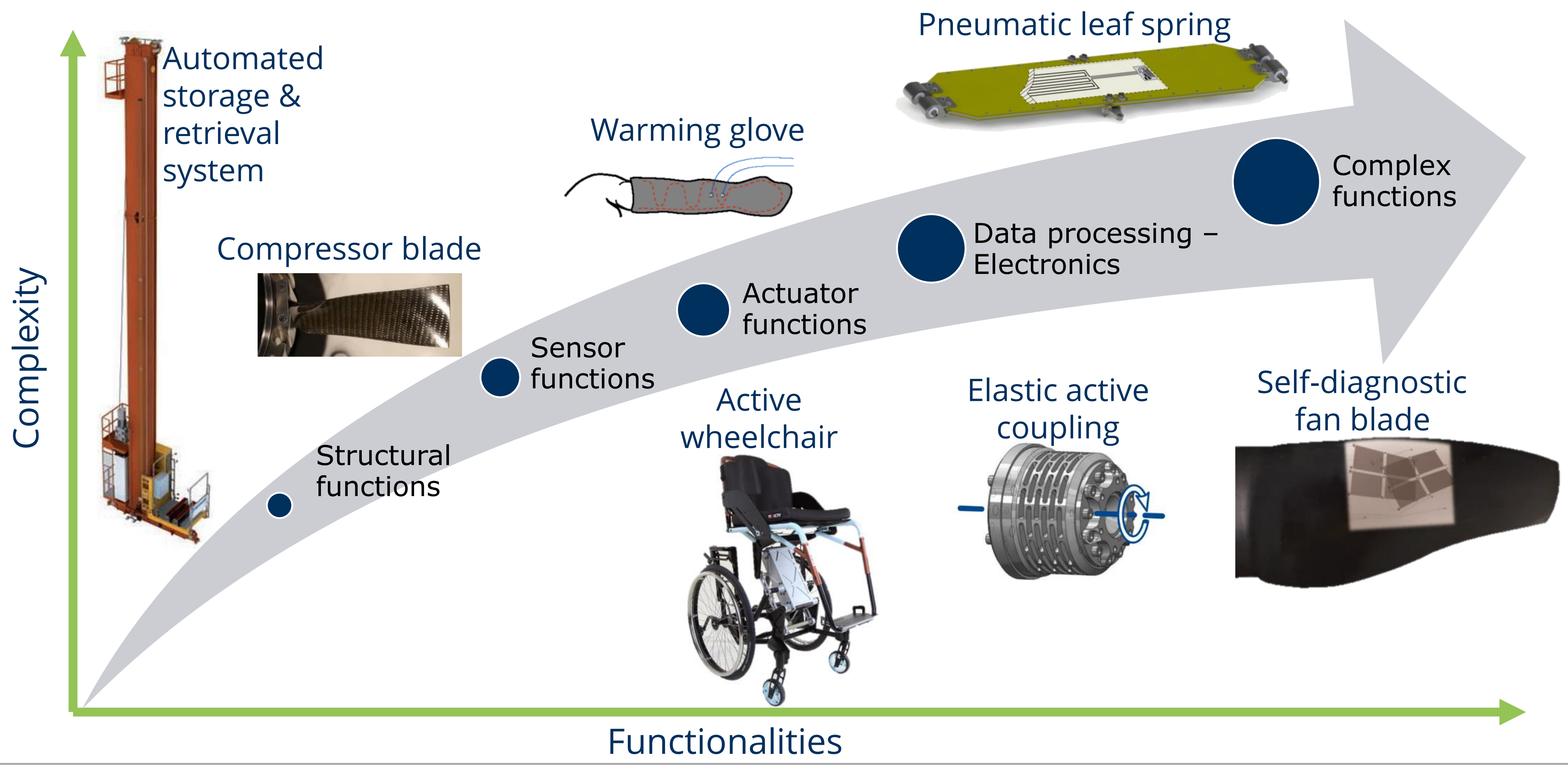
Actuator functionalities

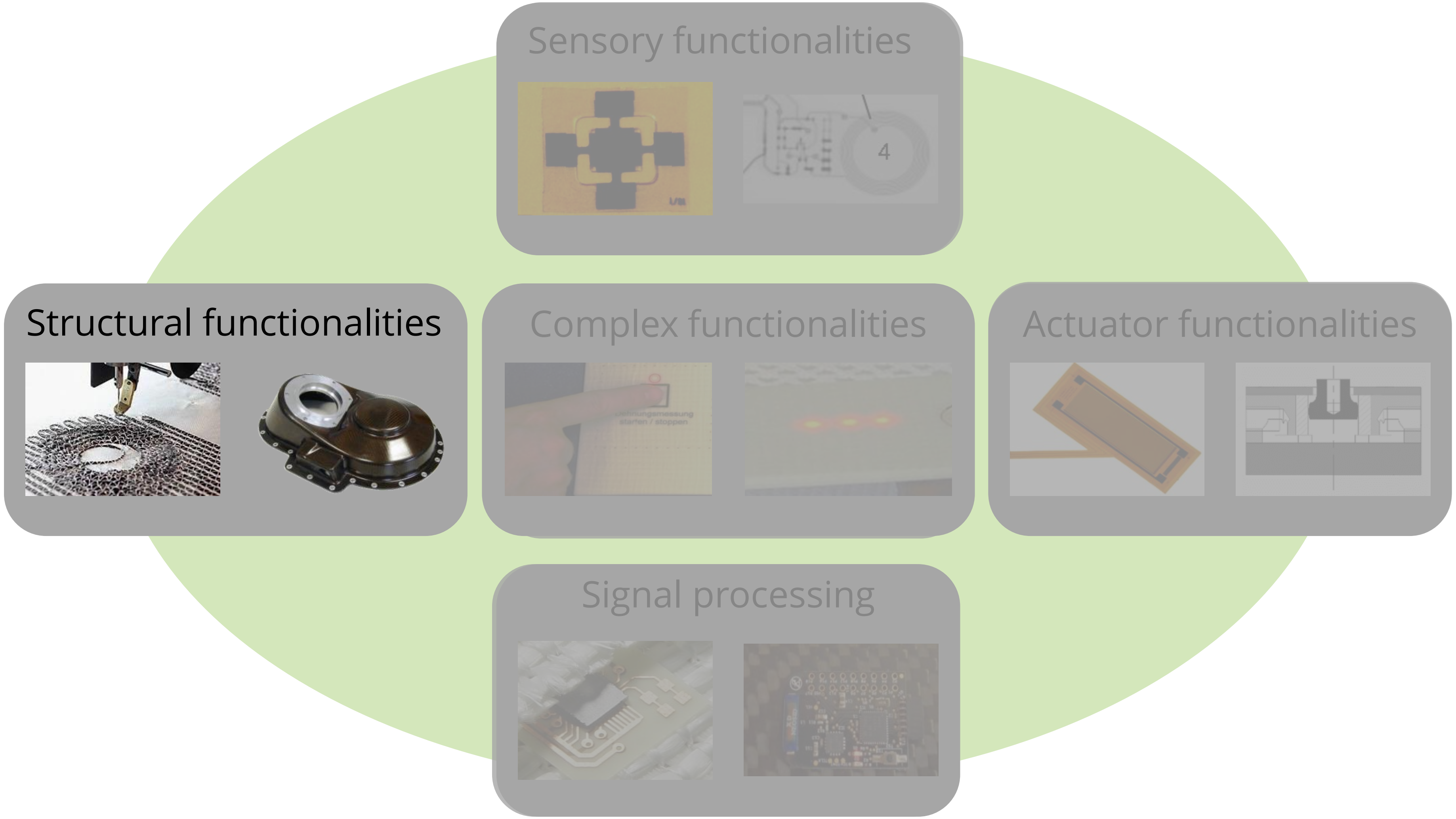
Signal processing




Complexity of Functionalities



Examples - Structural Functionalities



Innovation transfer in applications

Fast pragmatic realisation and verification of SFB results (“proof of principle”)

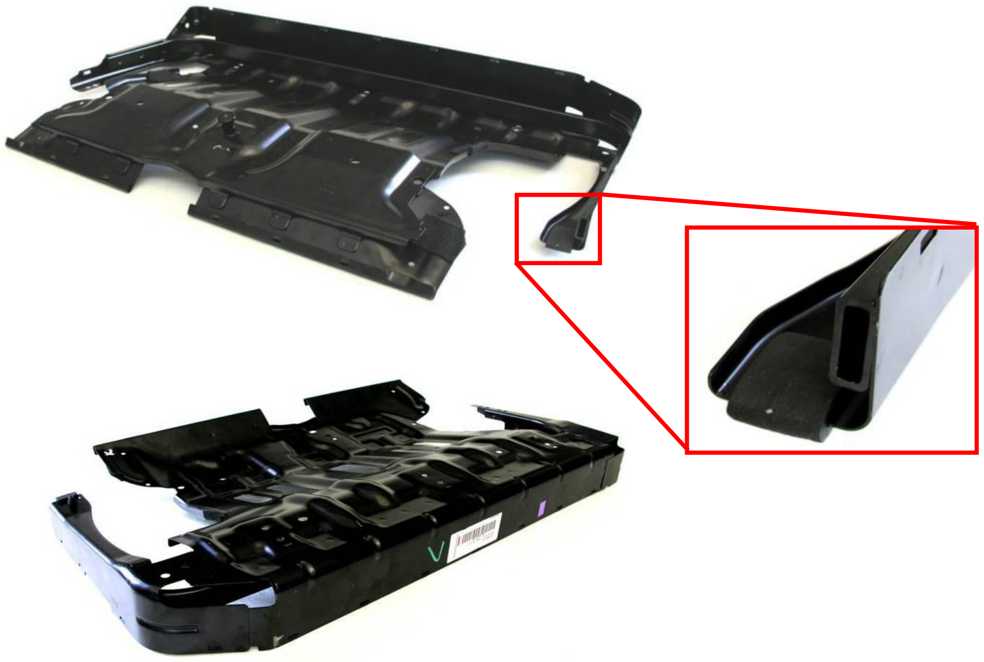
Example: Thermoplastic seat pan of the VW-Tiguan

2/3 rear seat pan made of fibre-reinforced plastic (FRP)
for a longitudinally adjustable rear seat system

Design of the seat pan made of fibre-reinforced plastics (FRP)

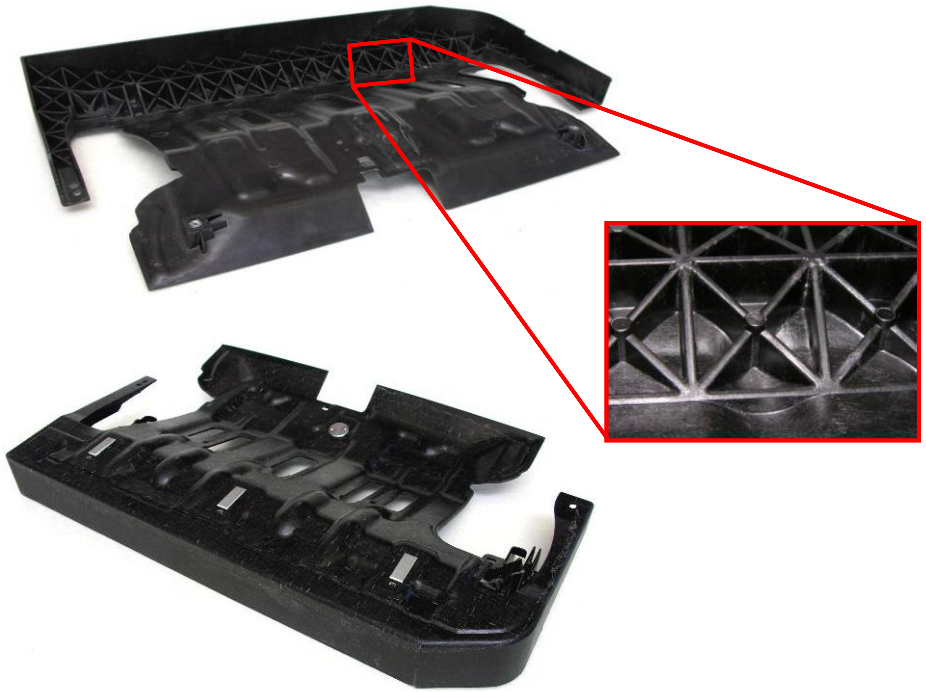
Series part made of steel

- 5 single parts are joined in an additional assembling process
- Using an additional steel tube for structural rigidity of the part



Thermoplastic seat pan with fabric reinforcement

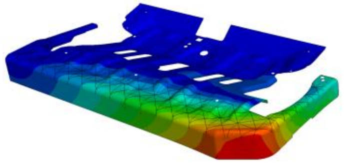
- Integral construction, manufactured in one step
- Load-driven design of rib geometry



Continuous development process

Composite seat pan prototype

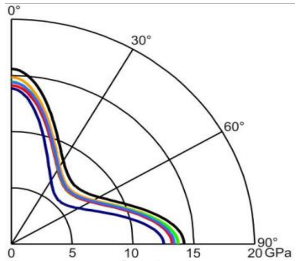
Design



Simulation models and calculation

Development of manufacturing process

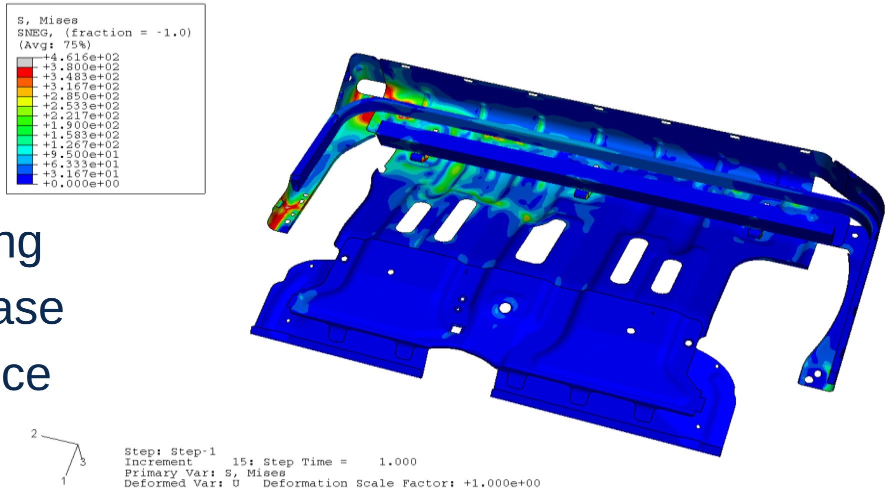
Material development and characterization



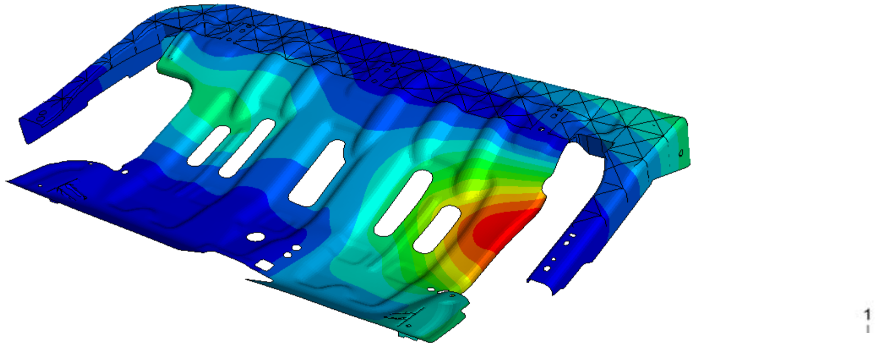
Prototype test

Numerical simulation of components

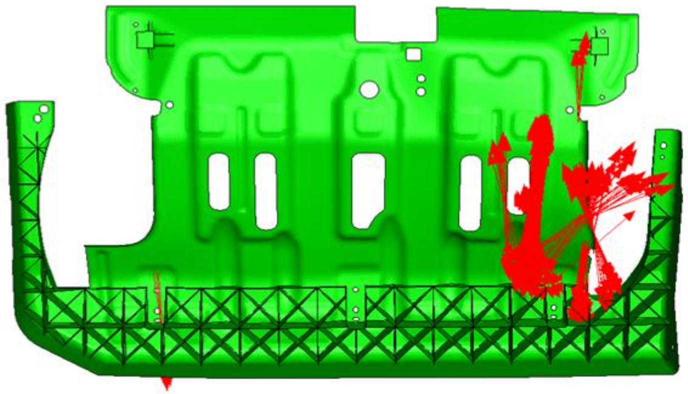
- Static load cases - misuse test
- Dynamic load cases
  - 56 km/h front crash with dummies
  - Crash with child car seat and Isofix mounting
- Mechanical properties from the SFB 639 database
- Comparison of composite seat pan with reference part (classical steel construction)



Stress of steel seat pan in crash load case



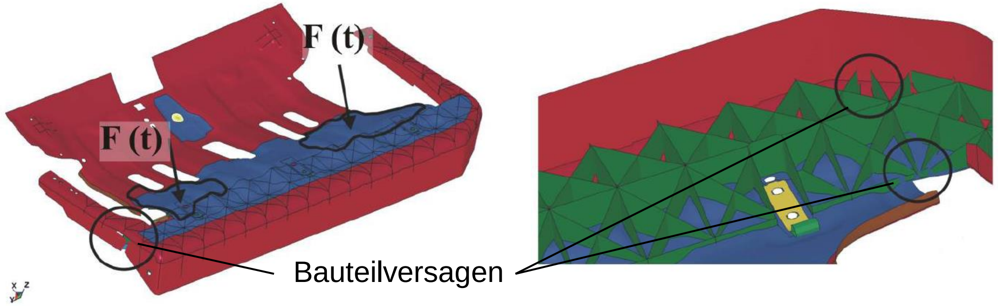
Deformation of composite seat pan in crash load case



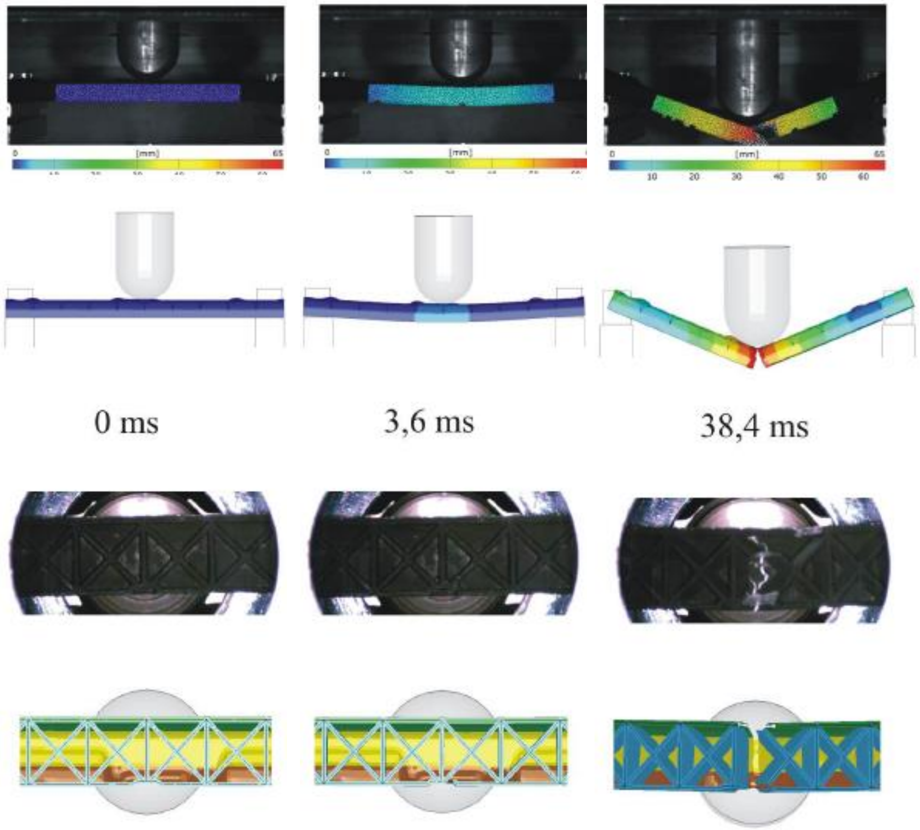
Adjustment of fibre orientation by analysing the principle stresses

Highly dynamic component simulation

- Verification of explicit simulation models using basic structures
- Calibration of the simulation using impact tests
- Crash simulation of seat pan structure with LS-DYNA

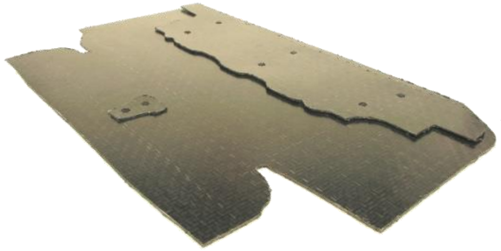


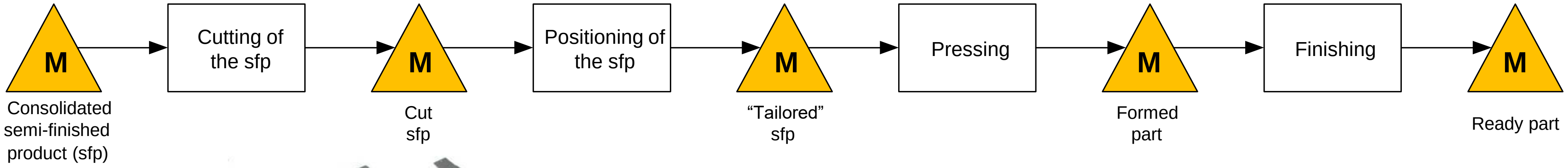
Failure analysis from crash simulation



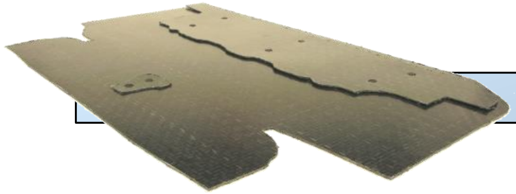
Impact tests for calibration the simulation

Process analysis of the seat pan manufacturing

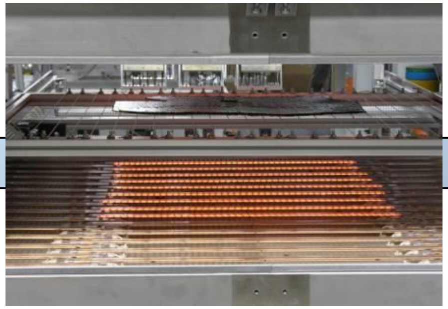




Details to the automated seat pan production

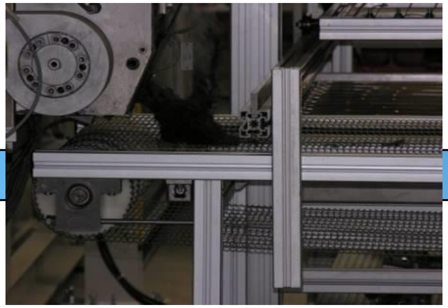


GF/PP textile reinforcements

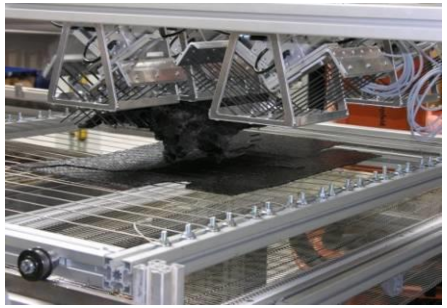


Heating the reinforcement in an infrared radiator

Pellets made of long glass fibres and PP



Extrusion of the polymer melt

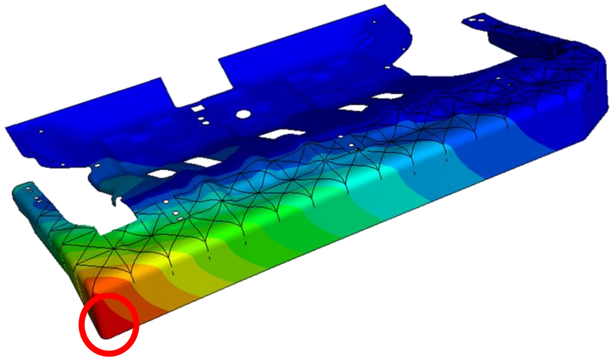


Automated transfer of the semi-finished product

Integral press process

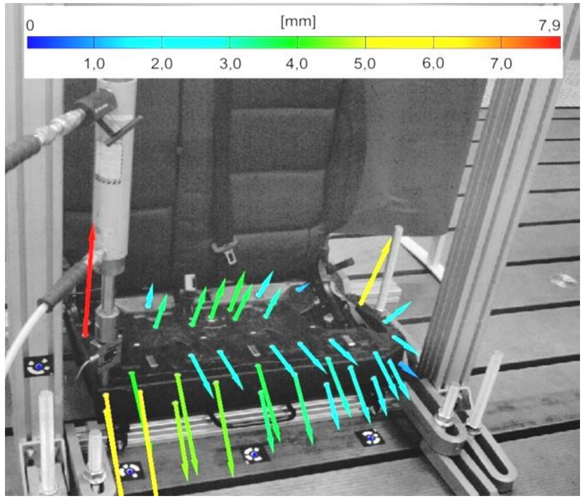
Static component tests

- Test force: 1000 N
- Deformation analysis with optical measurement system
- Verification of simulation results with static misuse load cases



u_{max}=7.5 mm

Simulation load case: “misuse left”



Measurement load case: “misuse left”

Test facility

Static component tests

Test configuration: frontal impact simulation with crash dummies

Test conditions

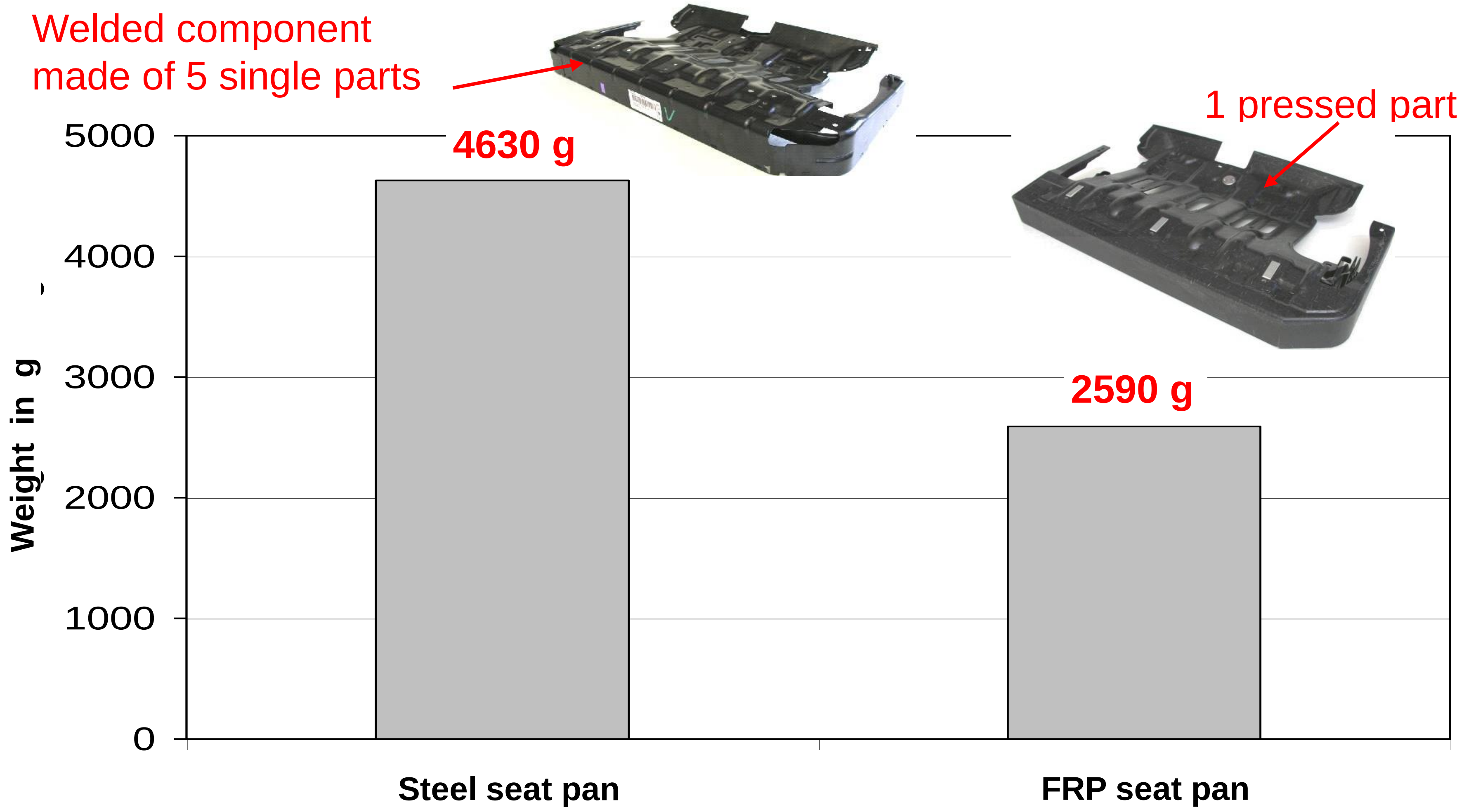
- Frontal vehicle impulse 0°, 56 km/h
- Dummy occupancy: Pos. 04,05 -> 50%
  Pos. 06 -> 90%

FRP seat pan after passed sled test

Result

- Rear seat structure and all locking mechanisms and anchors satisfy the test specifications
- Passengers were restrained by the restraint system and remained on the rear seat
- Thermoplastic seat pan resists the loading

Weight comparison

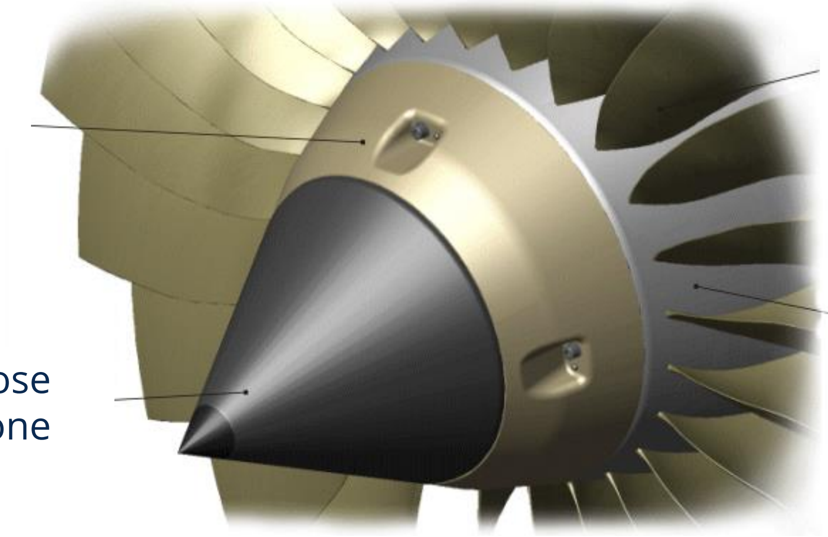


→ **Weight reduction: 2 kg** → **Complete rear seat: 3.3 kg**

Examples - Structural Functionalities

Single Piece Nose Cone

Conventional design [1)]



Novel single piece design
(standard for all novel RR aircraft engines)

Rolls Royce aircraft engine with Single Piece Nose Cone made of carbon fibre-reinforced composite [2)]

Sources:
[1)] Junghannß, Stefan: *Konzeption und Auslegung eines Composite Spinners für die Rolls-Royce BR700 Triebwerksserie.* Diploma thesis, TU Dresden, 2004
[2)] Rolls-Royce plc (https://tu-dresden.de)

The novel „Nose cone“ is lighter, cheaper and more robust than the conventional multi-part version.

Examples - Structural Functionalities

Vibration-optimised fibre-composite radial shaft for the drive of auxiliary aggregates of the engine

Design

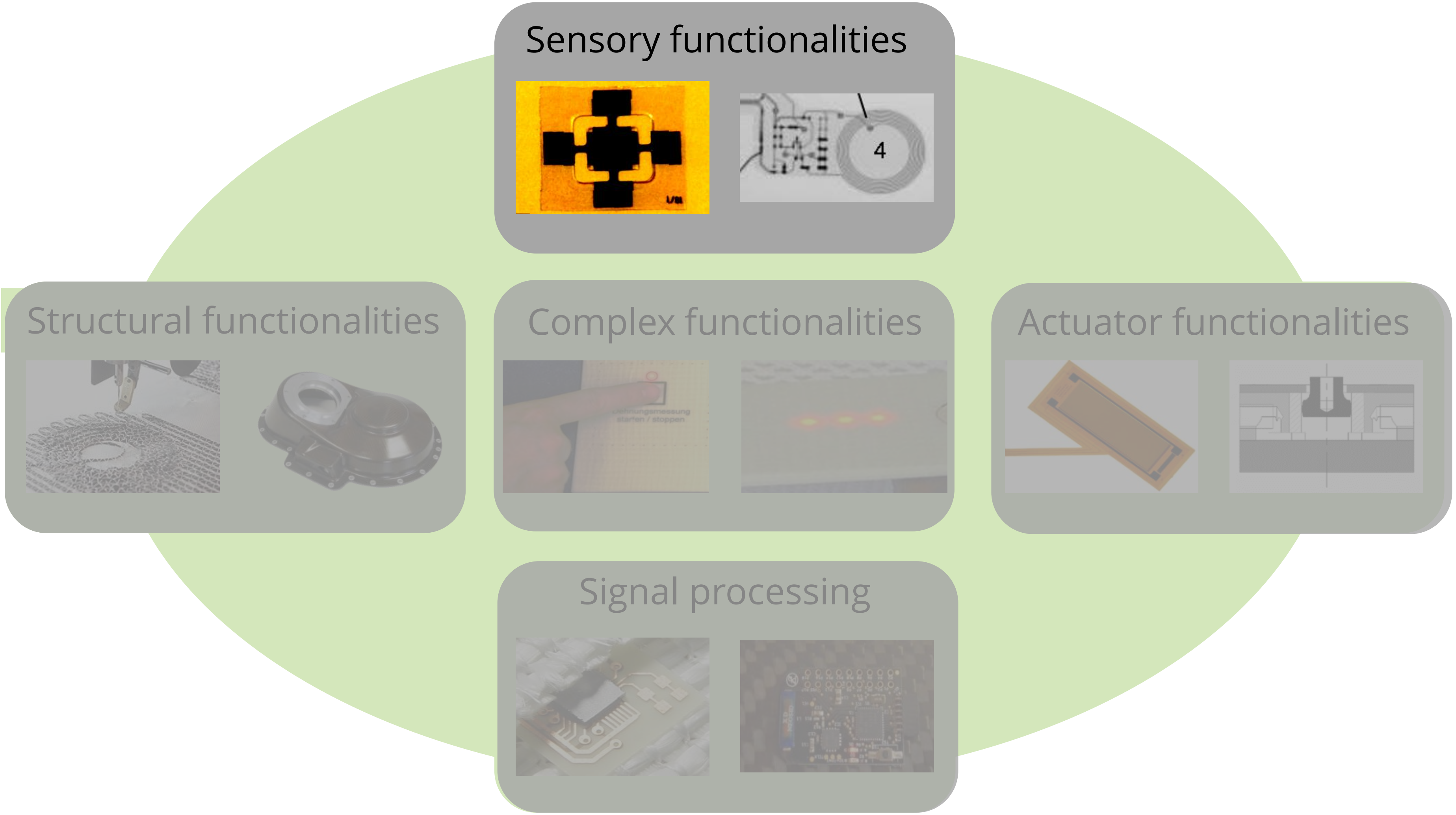
- Hybrid part (metal-CFRP)
- Positive force transfer supported by profiled shaft cross-sections

Benefit

- Realisation of a 30 percent higher speed compared to a conventional steel shaft and 20 percent weight reduction
- Considerable kerosene savings possible during operation

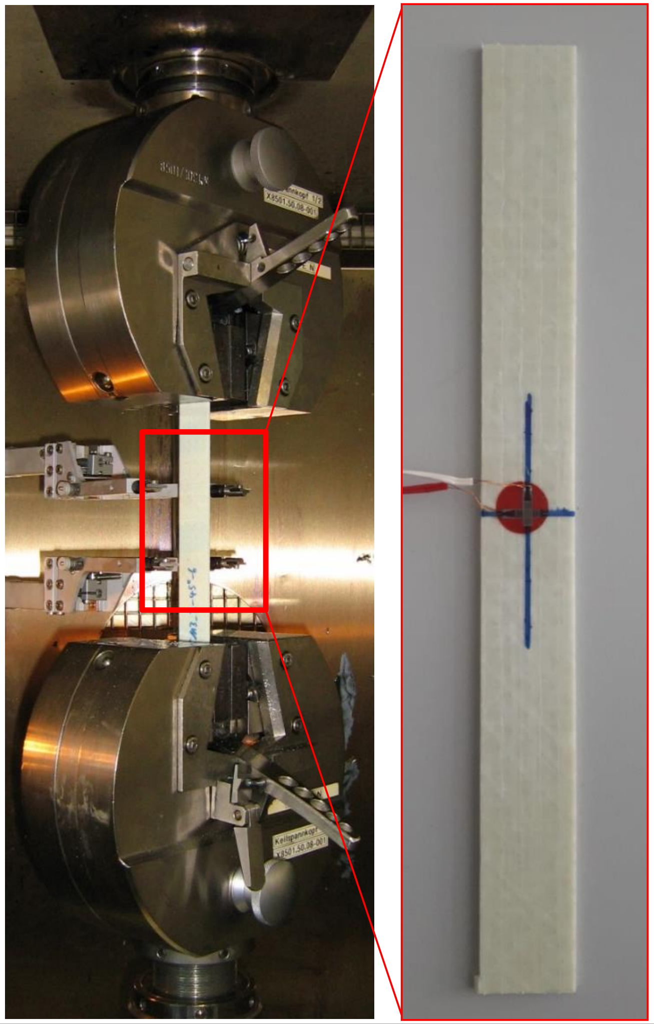
source: Sebastian Spitzer (https://tu-dresden.de)

Examples - Sensory Functionalities

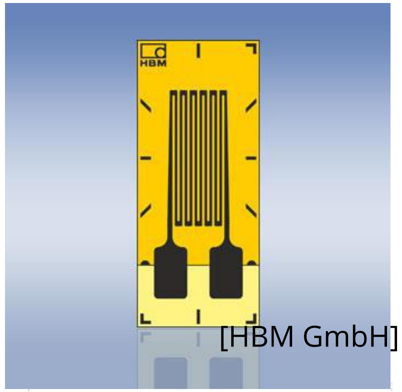


Examples - Sensory Functionalities

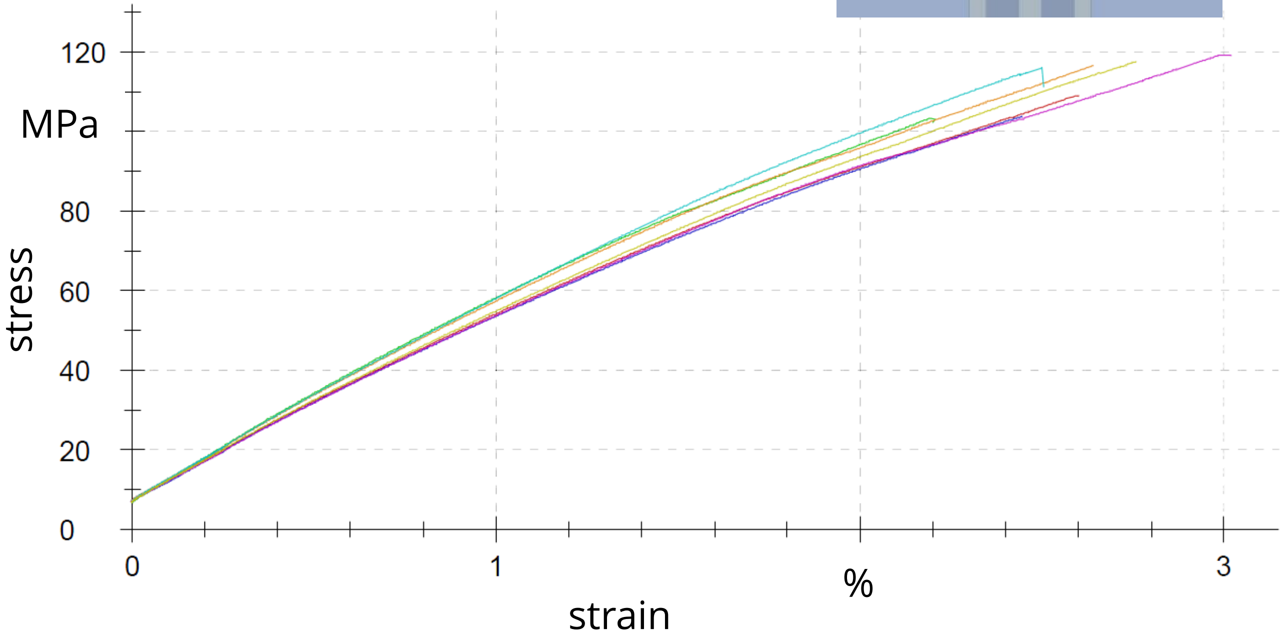
Determination of strain



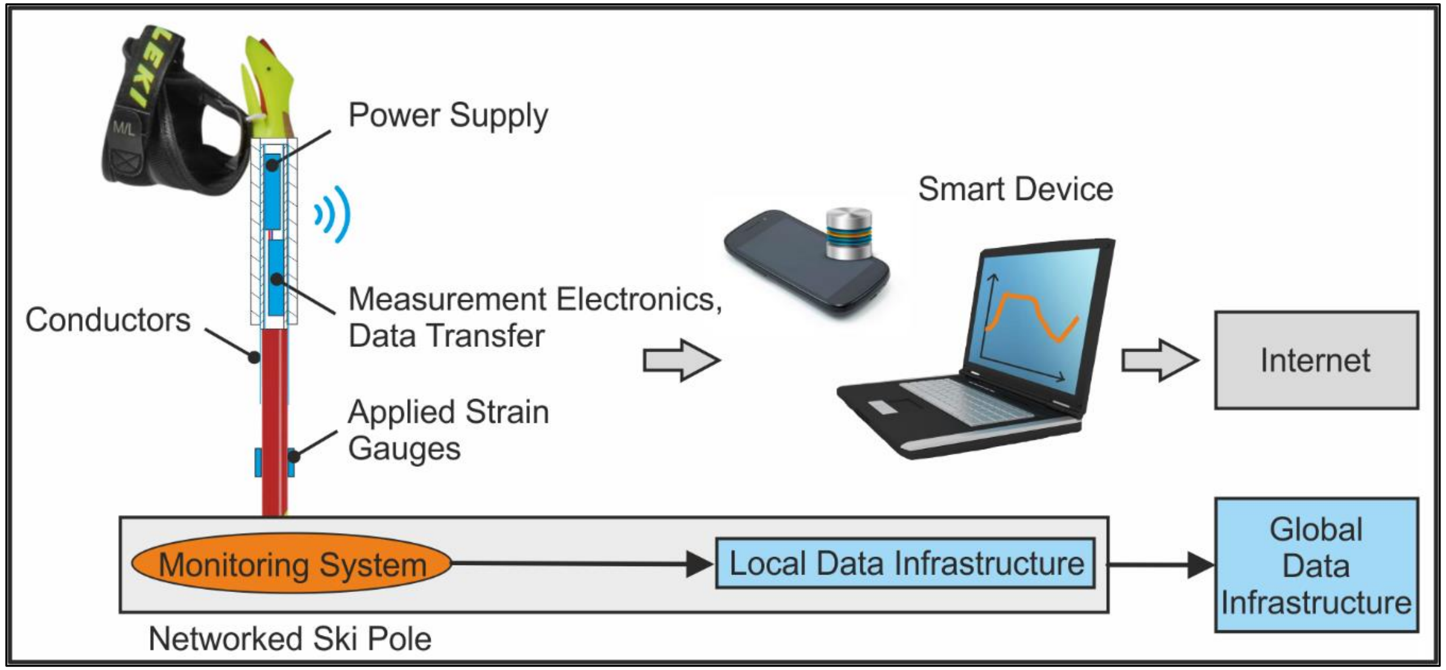
Utilisation of **strain gauges** for the determination of strains e.g. for material characterisation or condition monitoring

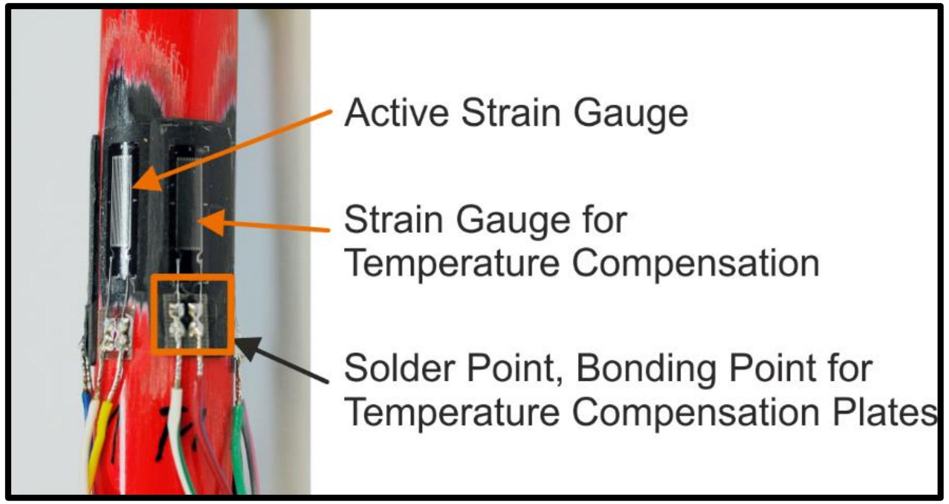


[HBM GmbH]



Examples - Sensory Functionalities





Determination of axial loades and bending on the Ski pole

6 Strain gauges

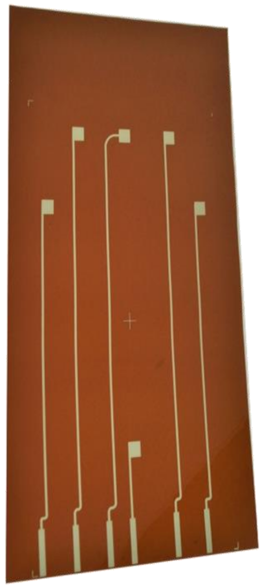
- 3 active strain gauges
- 3 passive ones used for temperature compensation

Transmission of the signals via bluetooth to smartphone

approx. 32 g additional mass

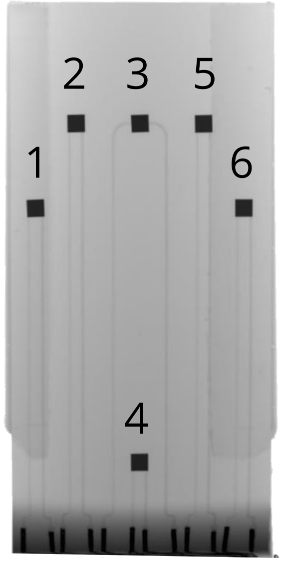
Examples - Sensory Functionalities

Impact determination



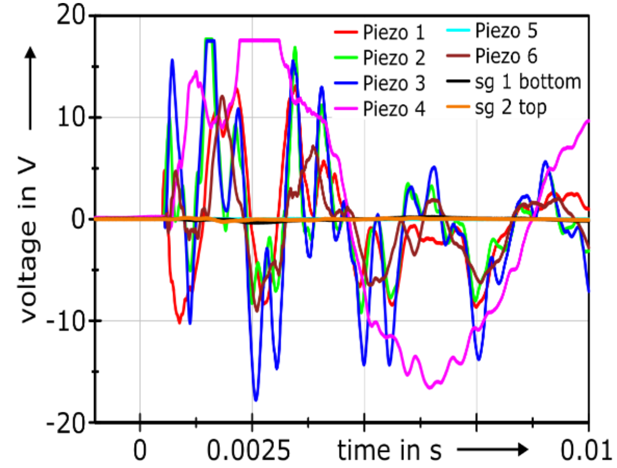
Sensor layer (TemSal) (piezoceramic actuators and strain gauges)

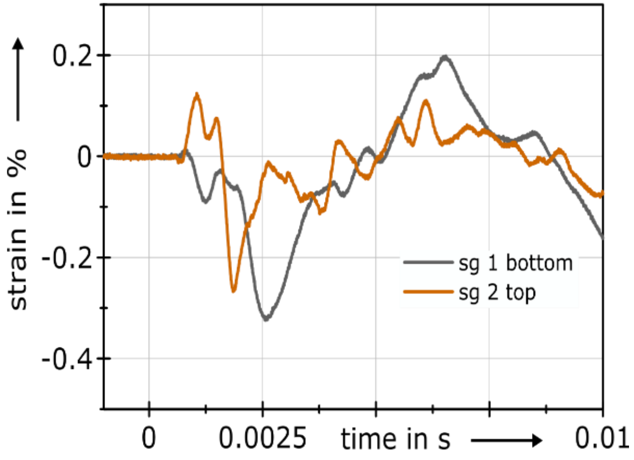
Blade with integrated sensor layer



CT-Scan Showing the integrated elements

Sensor signals under highly dynamic loading



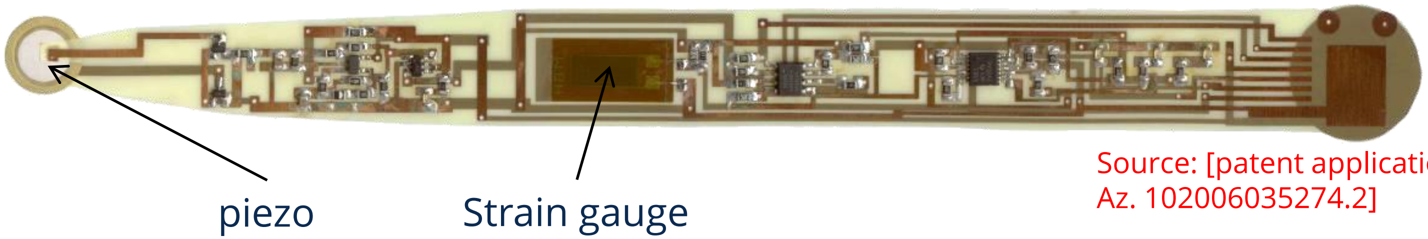


Examples - Sensory Functionalities

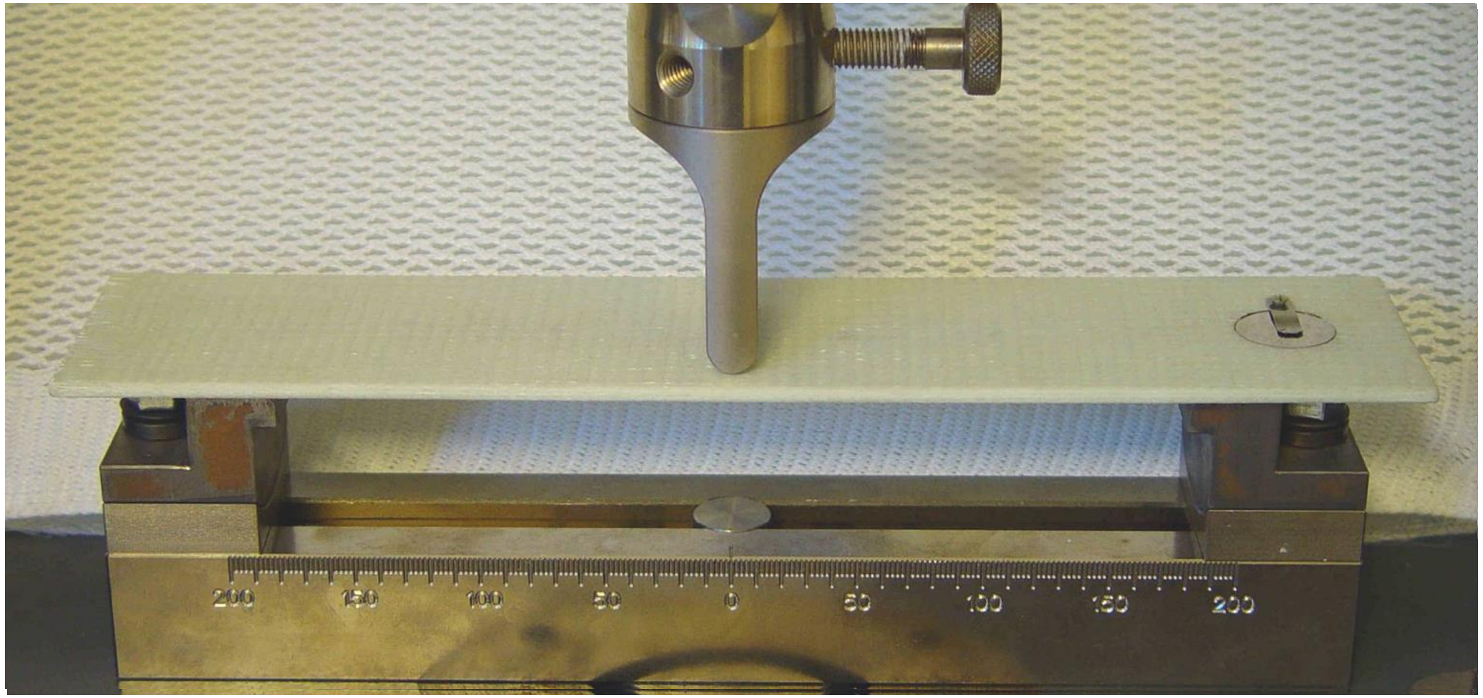
Bending beam with different integrated sensory functionalities

for example

- strain gauges
- capacitive sensors
- piezoceramic sensors

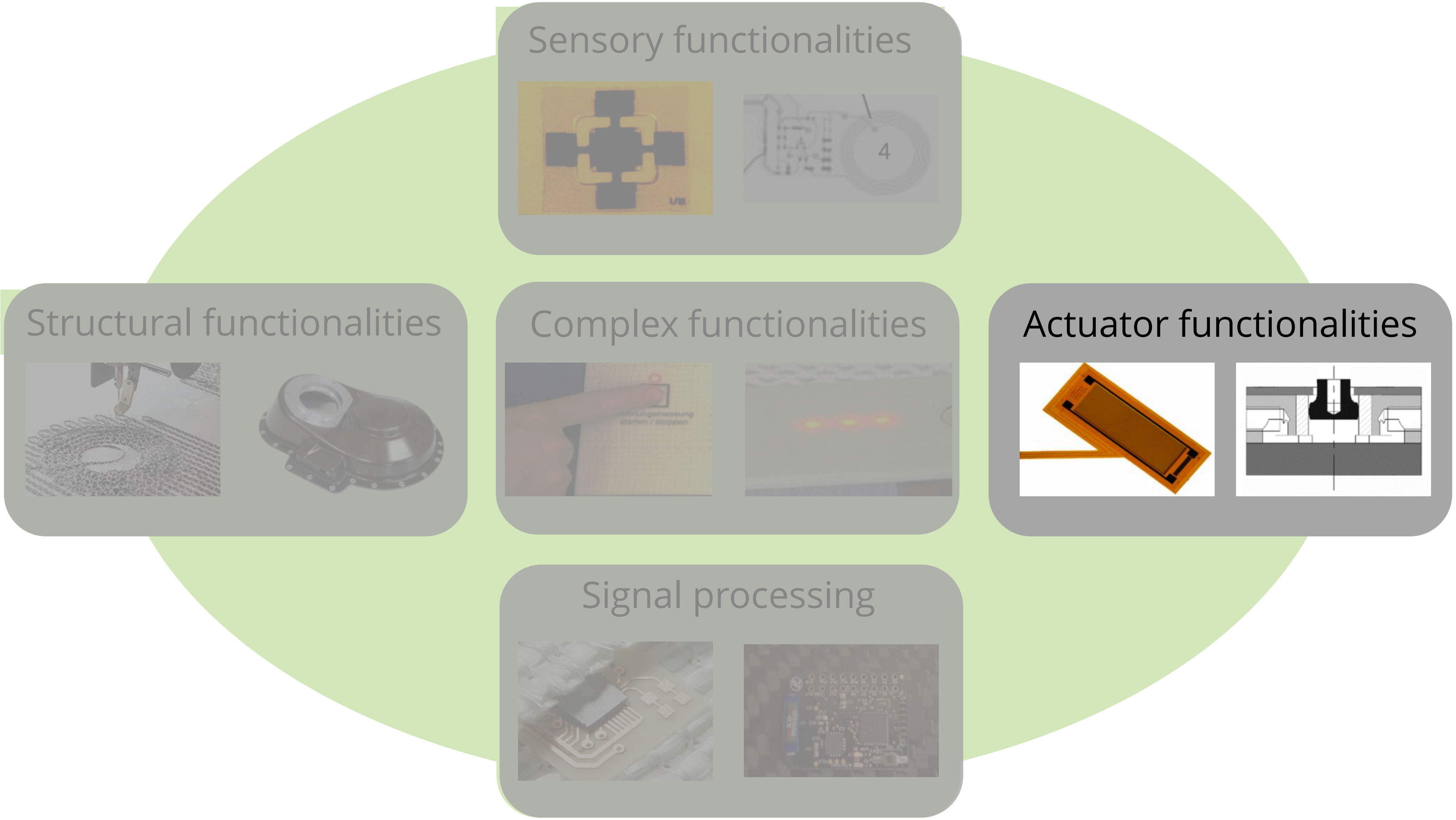


Source: [patent application Az. 102006035274.2]



SFB 639

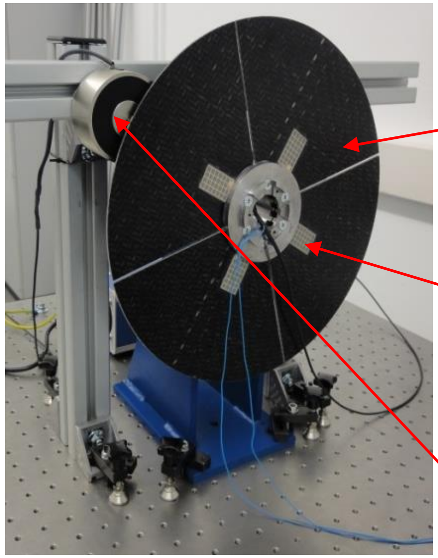
Examples - Actuator Functionalities



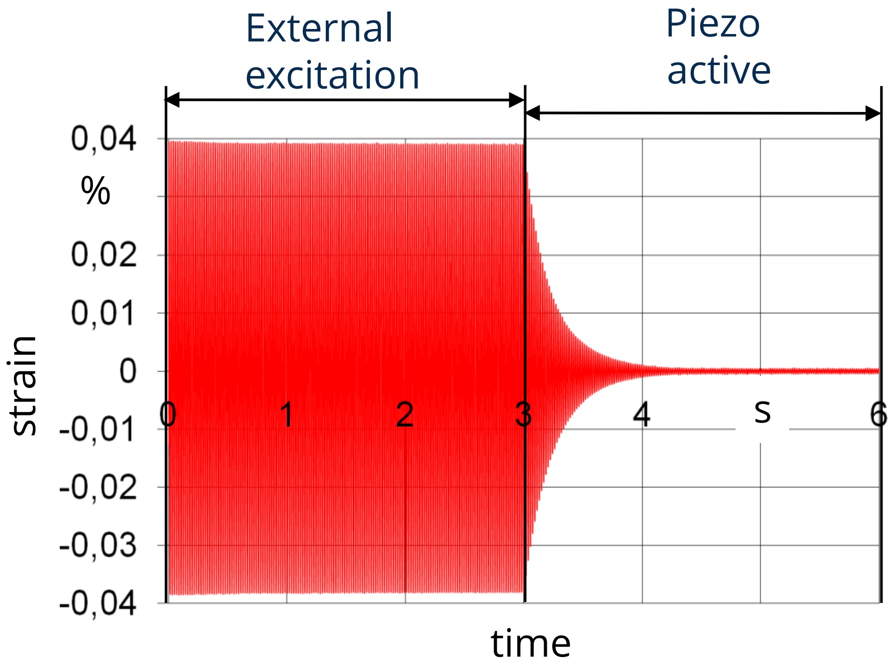
Examples - Actuator Functionalities

Possible appliations for actuator functionalities

- active vibration damping
- energy harvesting
- structural health monitoring
- energy or signal transmission



Active fibre-reinforced rotor with interated piezoceramic elements and additional strain gauges



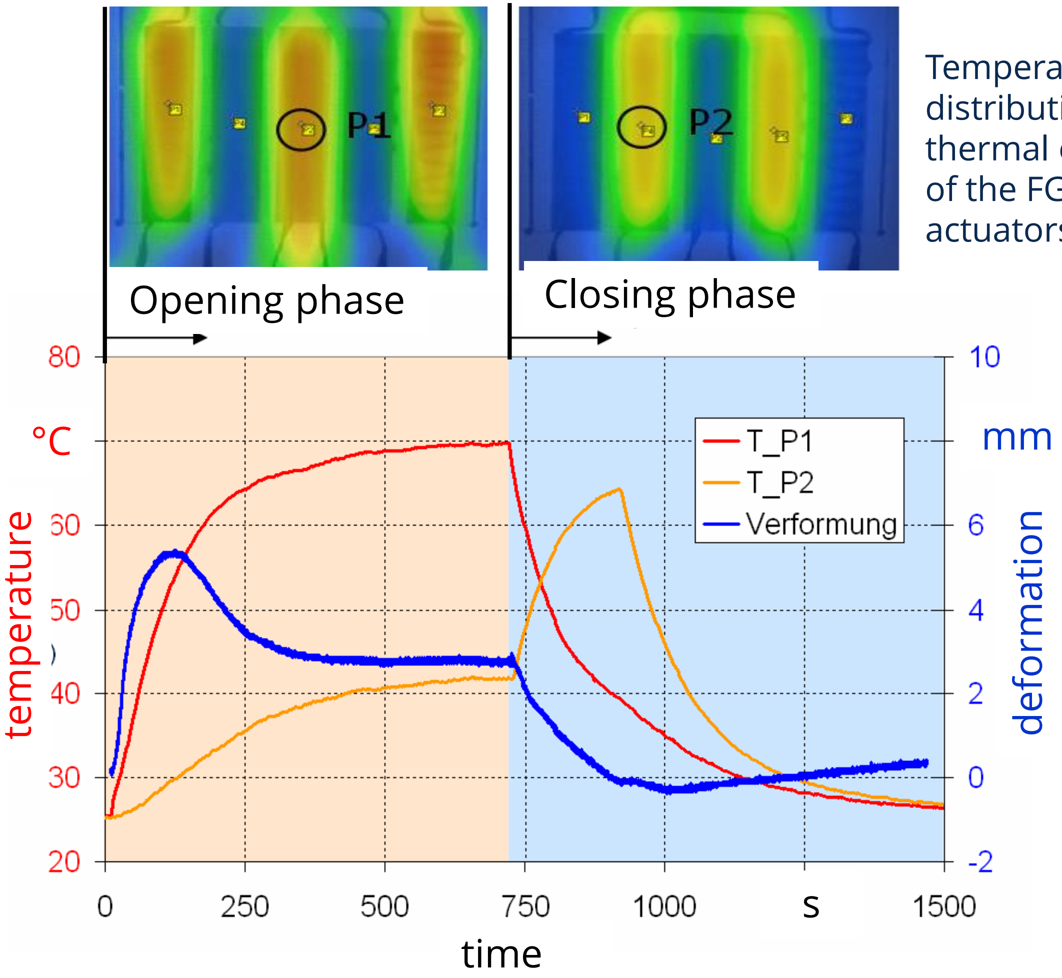
Measured strain during electro-dynamic excitation and damping by an integrated piezo

Examples - Actuator Functionalities

Fibre-reinforced plates with embedded shape memory alloys (SMA)

Example: active mechanisms

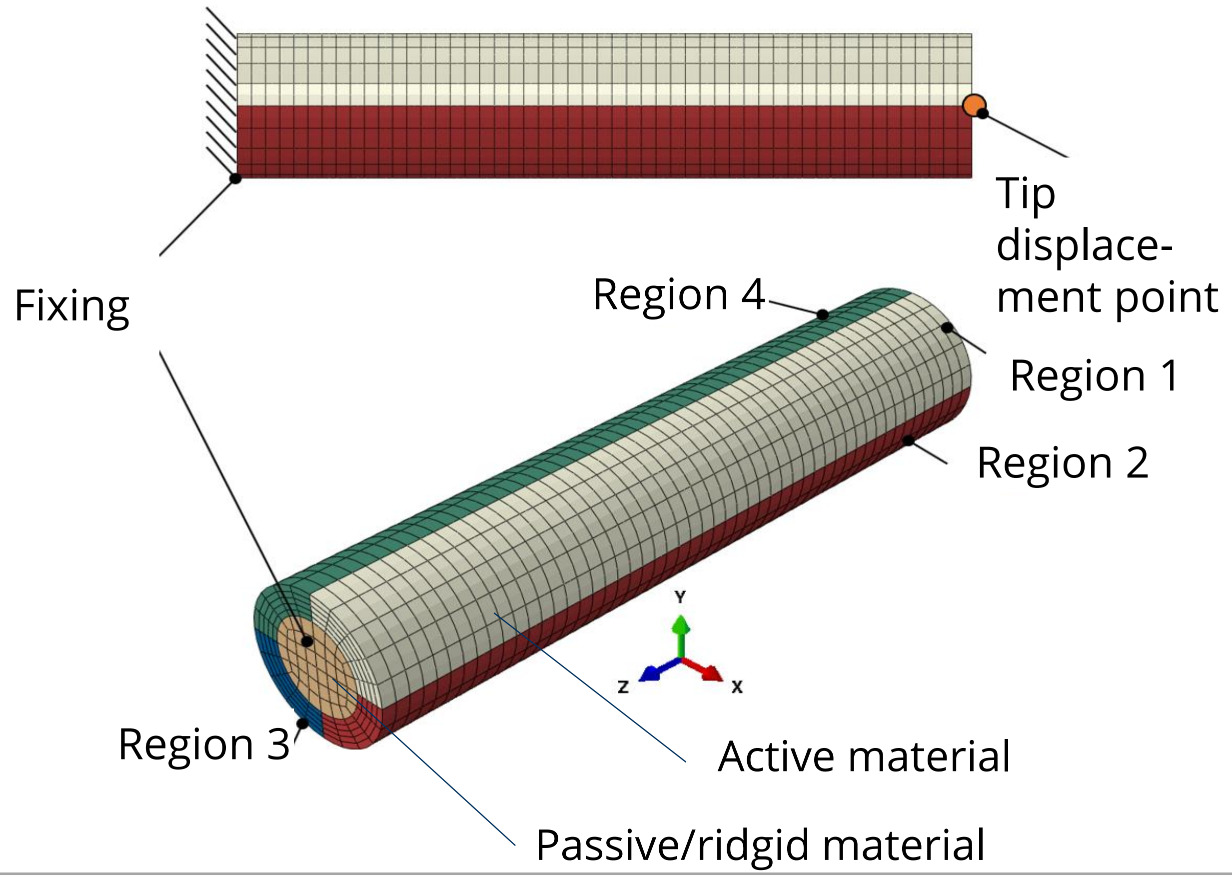
Glass fibre-reinforced sheet with embedded SMA actuators

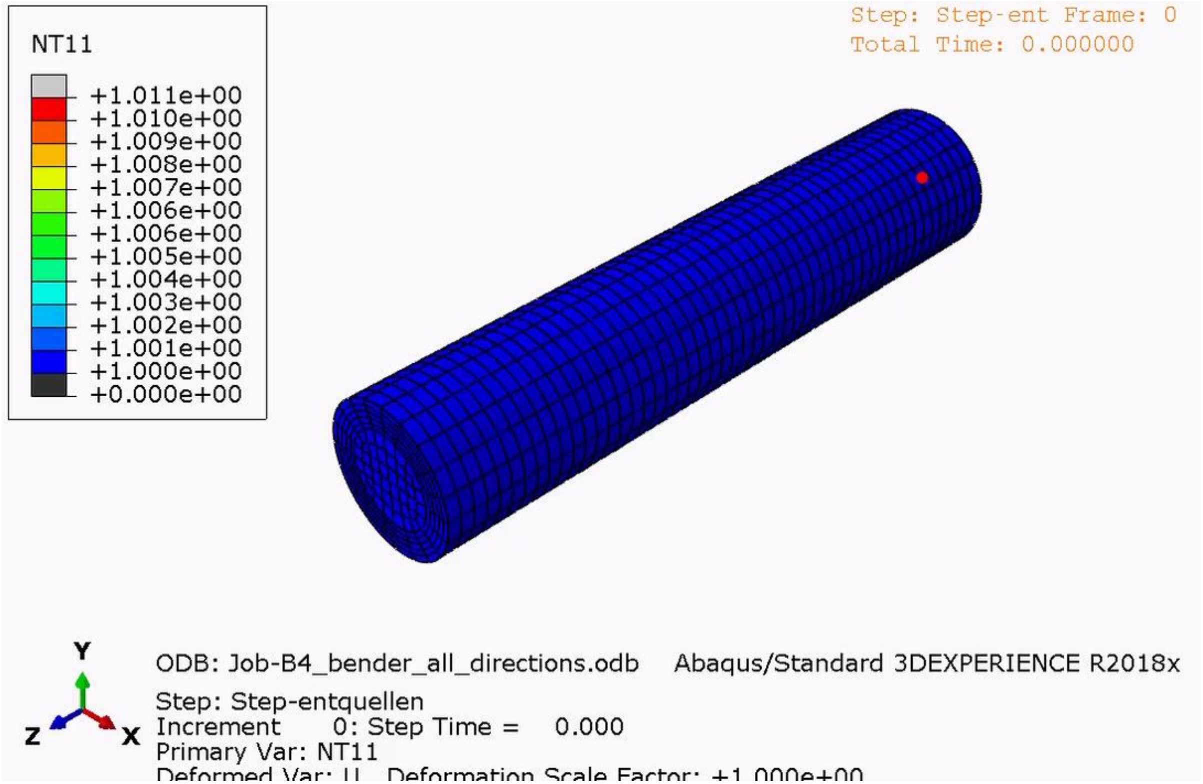


Temperature distribution during thermal excitation of the FGL actuators

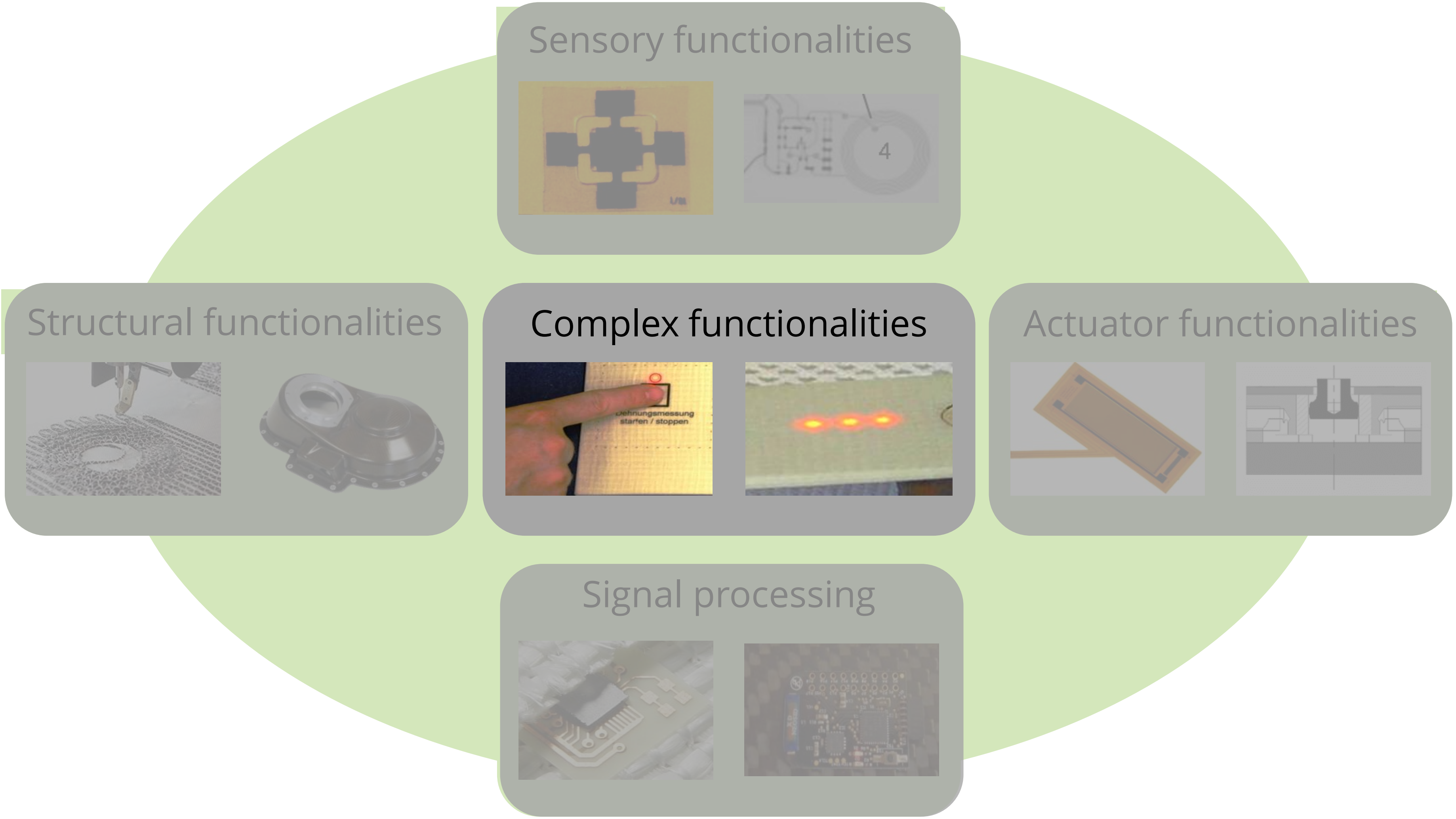
Examples - Actuator Functionalities

Actuation by active structure materials





Examples – Complex Functionalities



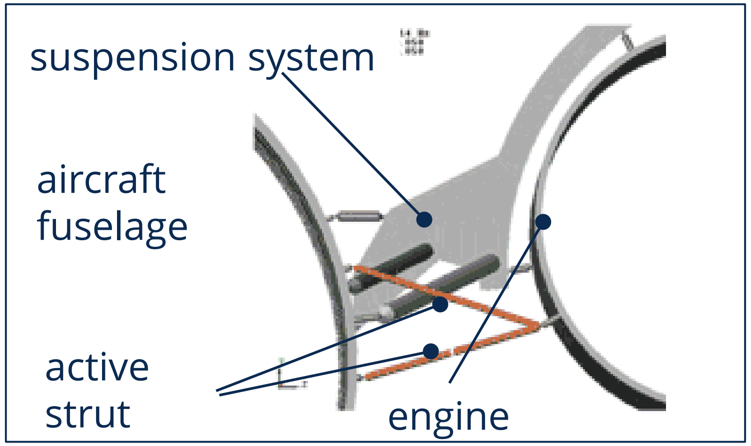
Examples – Complex Functionalities

Active suspension system for aircraft engines

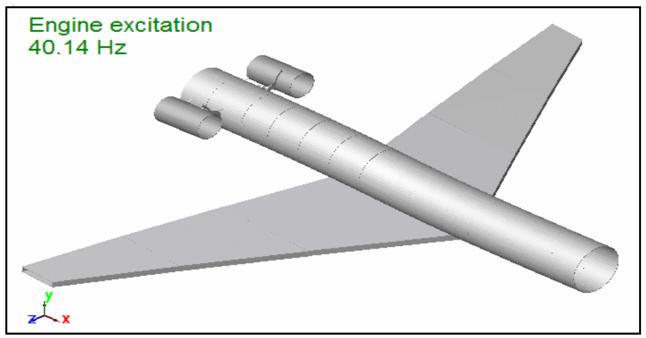
Noise and vibrations are disturbing even in areas remote from the engine

Reduction of the vibration transmission by substitution of individual by active struts

problem



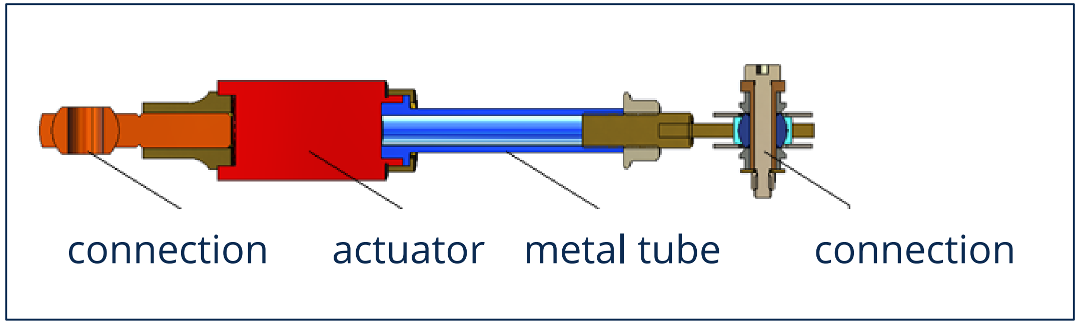
vibrations in the suspension system



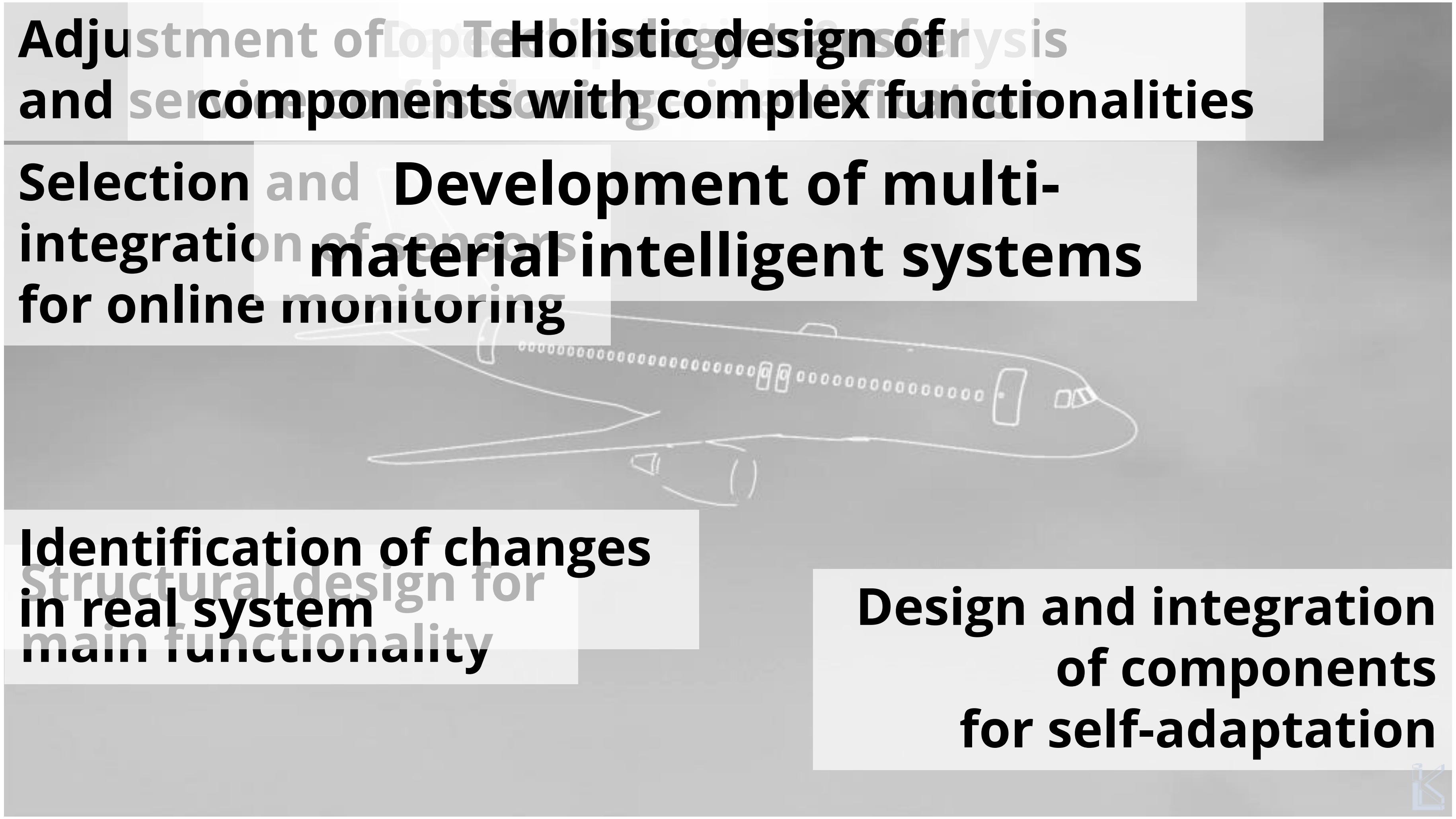
vibrations in the aircraft

solution

concept of an active strut



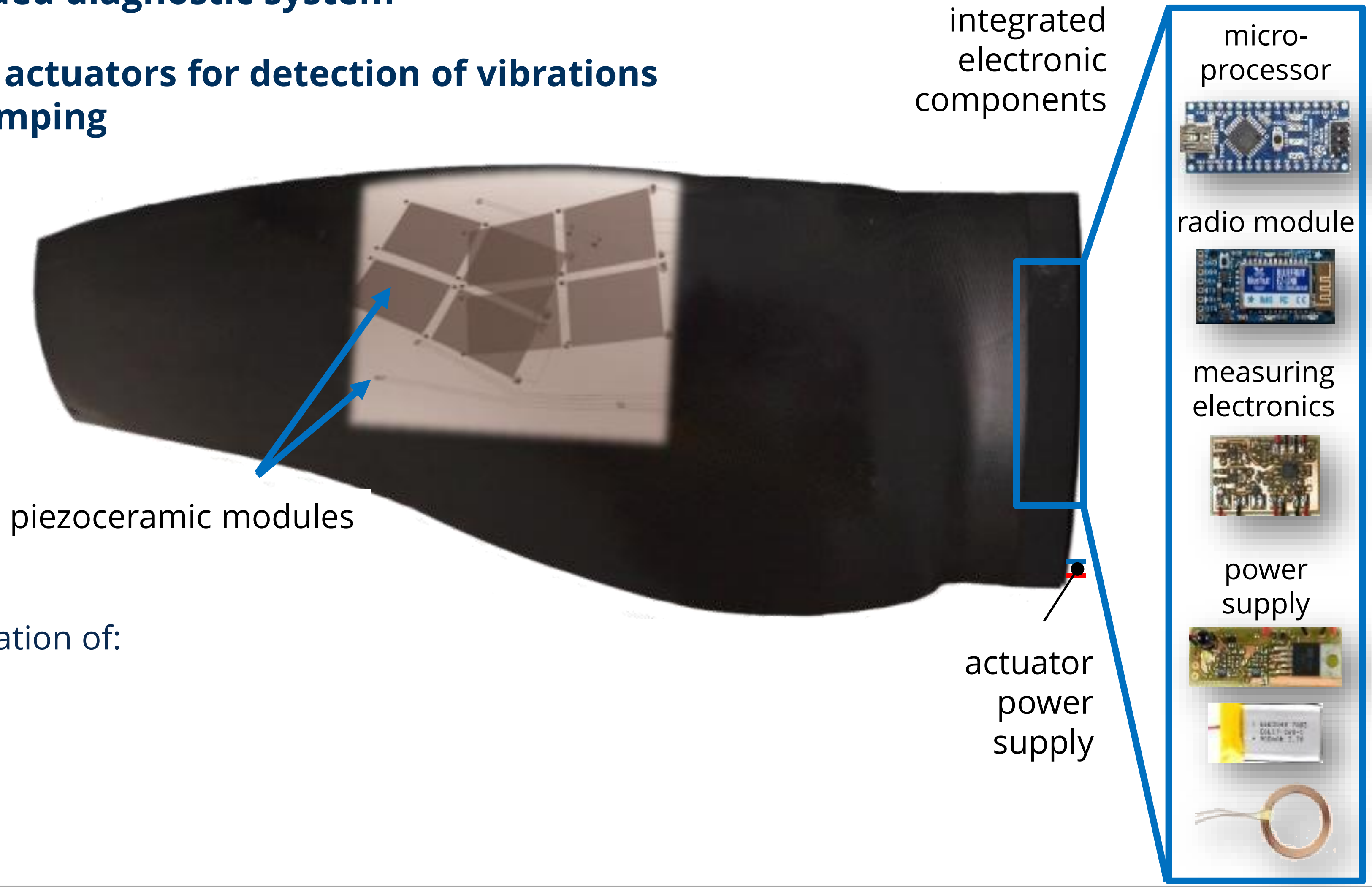
Examples – Complex Functionalities



Examples – Complex Functionalities

Fan blade with embedded diagnostic system

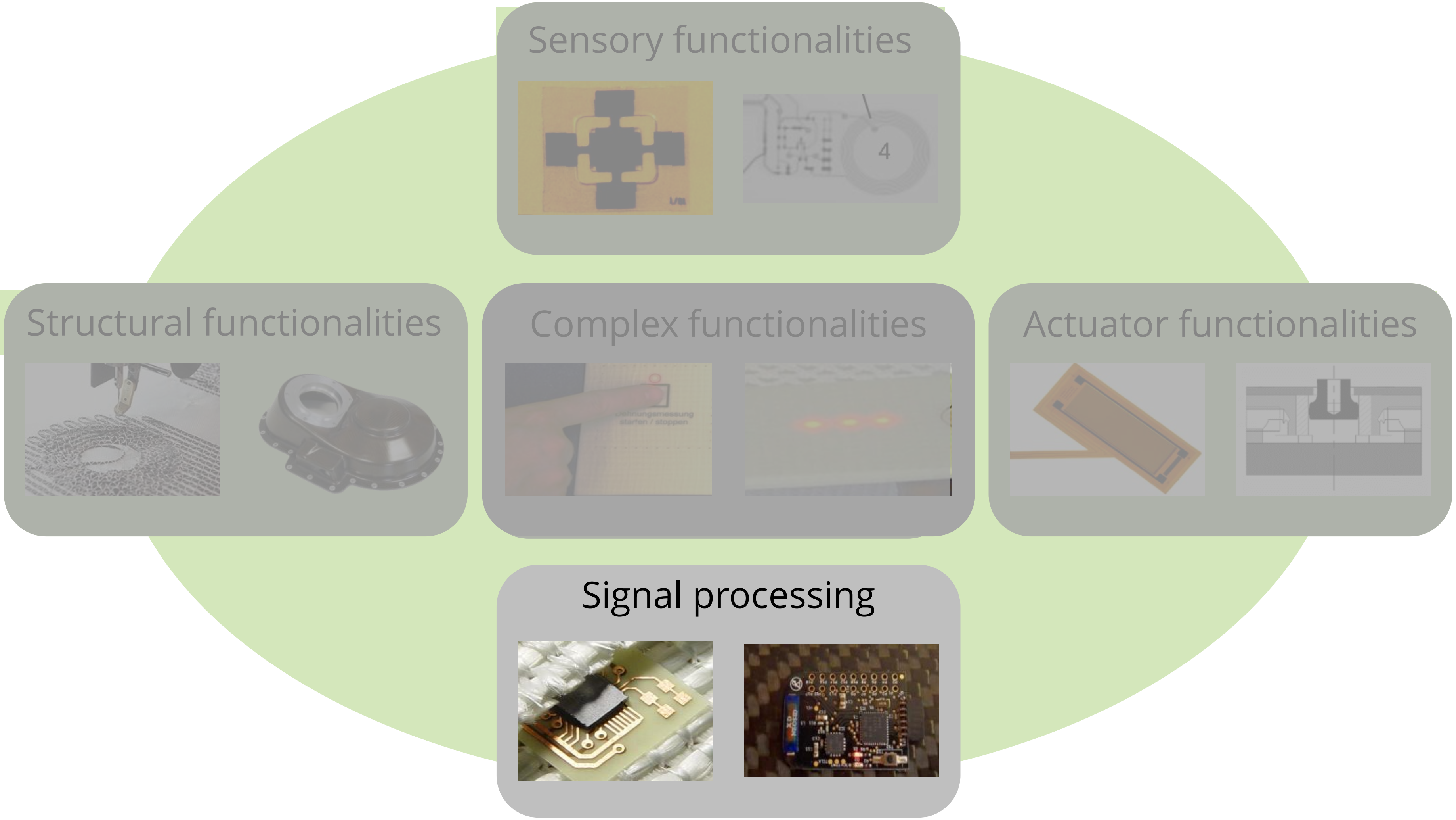
Integrated sensors and actuators for detection of vibrations and active vibration damping



location resolved determination of:

- damage in-plane
- delamination
- deformation

Signal Processing/Evaluation



Signal Processing/Evaluation

Huge variety for the processing and evaluation of signals

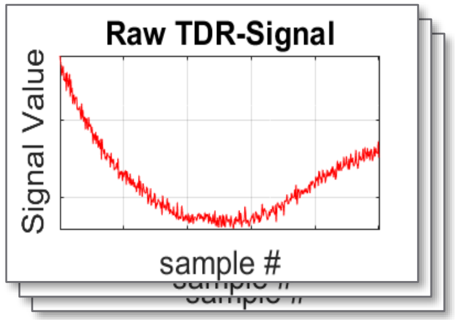
- Transforming (analogue/digital)
- Filtering
- Clustering
- Smoothening
- Analytical evaluation
- Indication of a limit value transgression

Current trends

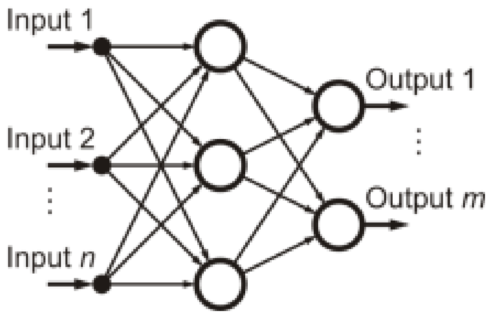
New methods (Artificial Intelligence/ Machine Learning/Neural Networks/ Deep Learning …) used for the determination of complex relationships

→ Huge database necessary for training and validation

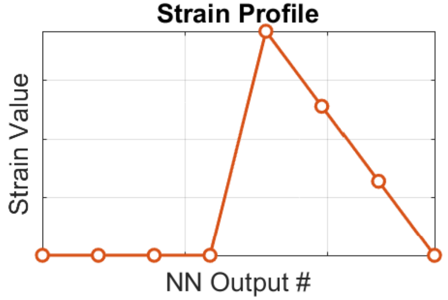
→ Self-learning systems



Raw sensor signal



Training and validation of a neural network



Information about systems condition/ behaviour

Introduction – function-integration - Evaluation

Integration of functional elements

Advantages

- Functionality of the part surface remains
- Combination of several single components in one part
- Part protects elements against external disturbances and media
- Improved data collection quality, consistency and repeatability

Disadvantages

- More complex components/ manufacturing
- Limited repair possibilities
- Possible failure of the active function
- Functional elements represent mechanical disturbances

Challenges

- Positioning and fixing of the functional elements
- Implementation of more complex tool concepts and manufacturing processes
- Functional elements have to withstand process parameters during the manufacturing process
- Contacting the functional elements
- Electrical insulation of the functional elements is required for integration into electrically conductive composite structures (e.g. CFRP structures).