Collaborative Research Centre 1261

Magnetoelectric Sensors:
From Composite Materials to Biomagnetic Diagnostics

Magnetoelectric Sensors for (Bio-) Medical Applications

Agenda

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Agenda

Motivation

- For the CRC
- My own one

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Agenda

biomagnetic sensing SFB 1261

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Magneto-electric sensing

- Basic principle
- First results

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Applica-tions

- Heart
- …

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Outlook on school activities

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biomagnetic sensing SFB 1261

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- Basic principle
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Pause

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Outlook on school activities

Discussion

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Motivation – What if …

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Problem:

- >100.000 catheter-based electrophysiological examinations/ablations per year in Germany
- Bleeding risk
- Exposure to radiation

What if …

… it would be possible to find the origin of arrythmias without catheter examinations?

- Avoidance of invasive procedures
- Improved planning of ablation procedures

Motivation

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- **My own one**

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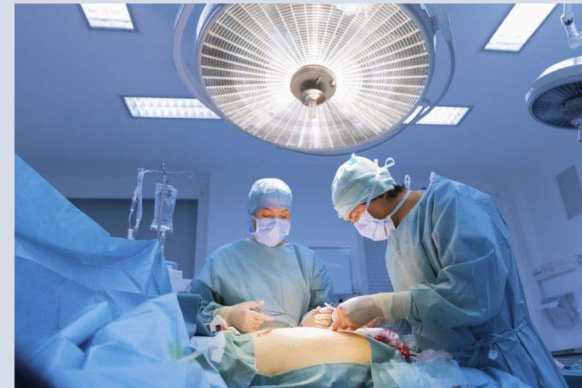

Problem:

- 175 000 operations for colorectal disease in Germany per year
- In 3-20 % leaks of the connecting suture occur
- Increased hospitalization, morbidity & mortality

What if …

… complications after intestinal surgery can be detected via noninvasive bedside detection?

- Early intervention in the event of a leak
- Earlier hospital discharge with negative result

Motivation – What if …

Four further "what ifs"

- Movement analysis
- Localization of medical devices
- Capsule tracking
- Interface for robot-assisted surgery

All of them …

- have high medical relevance
- can be potentially solved with magnetic sensor technology
- might lead to major improvements in patient treatment

General Objectives of the CRC

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Main research objectives

Sensor aspects

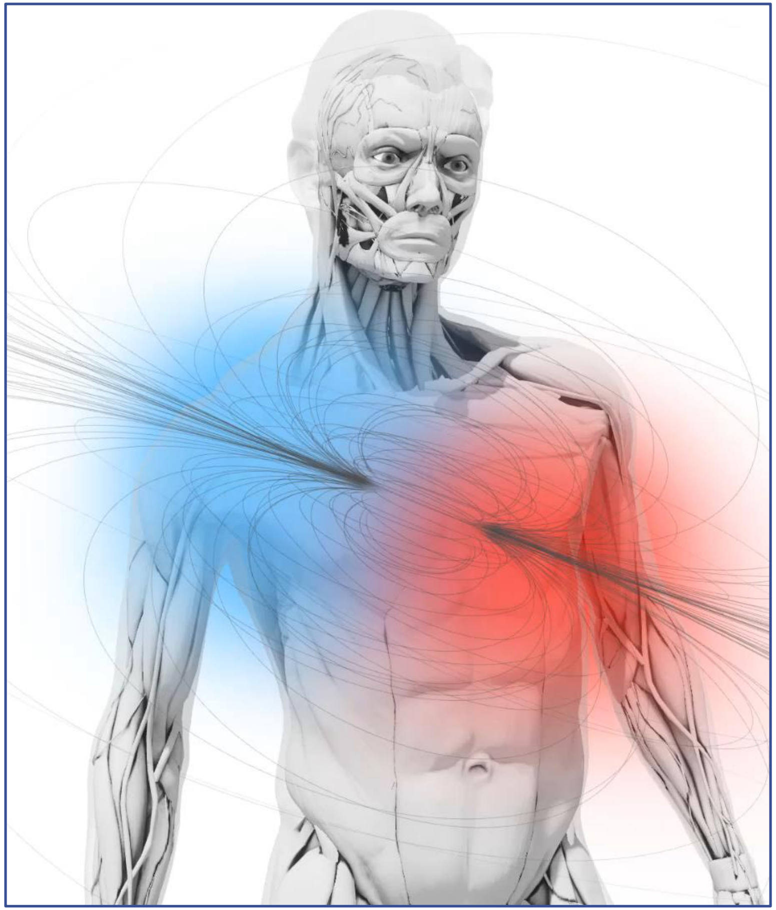
- Magnetic field sensor approaches based on magnetoelectric composites
- Detection limits in the pT/Hz$^{1/2}$ range
- Frequency range from 1 Hz to 10 kHz

System aspects

- Medical applications
- Uncooled and (magnetically) unshielded operation

Research team

- Interdisciplinary team, able to excellently cooperate with background in physics, materials science, electrical engineering, and medicine



Research Team

Principal Investigators (23)

- 15 professors
- 2 associate professors
- 6 “junior” group leaders

Research team

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Physics (1) and Materials Science (11)

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Physics (1) and Materials Science (11)

Electrical Engineering (4)

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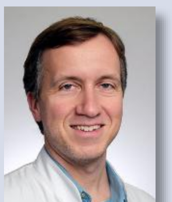
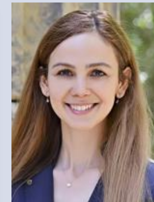
Medicine (5)





Physics (1) and Materials Science (11)









Electrical Engineering (4)

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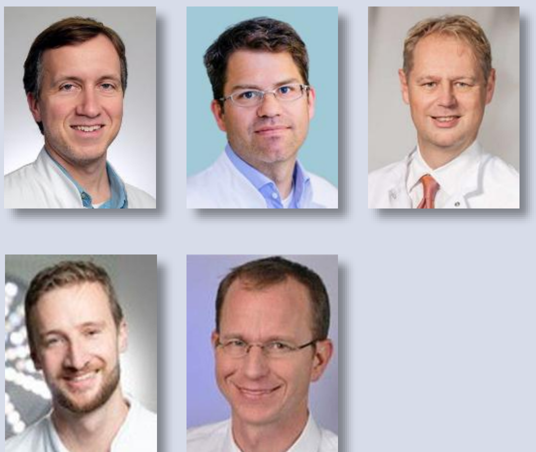
Medicine (5)



Physics (1) and Materials Science (11)

Electrical Engineering (4)

Outreach (2)

Research Team

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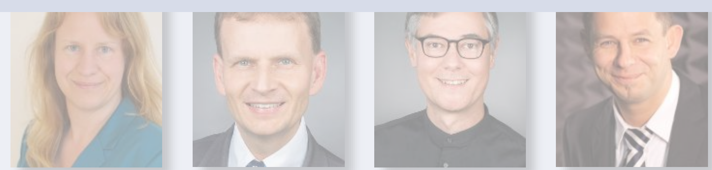
Principal Investigators

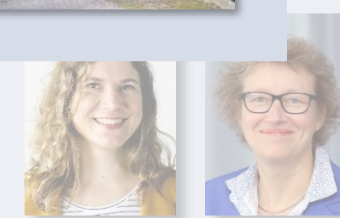
- 15 professors

Physic (1) and Materials Science (11)

Me

Doctoral Researchers (25) and Postdocs (5)





Research Periods

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Now

Period 3 (2024 – 2028)

Focus on sensor systems

- Research on the most sensitive sensor principles
- Focus on sensitivity, bandwidth and robustness
- 3D sensor arrays
- Application specific inverse solutions
- Six medical applications

Period 2 (2020 – 2024)

Focus on sensors

- New sensing principle (surface acoustic wave)
- Focus on sensitivity and bandwidth
- Sensor arrays
- Global inverse solutions
- Four medical applications

Period 1 (2016 – 2020)

Focus on measurement principles

- Single sensors
- Focus on effect size
- Four medical applications

Research Periods

Now

Period 3 (2024 – 2028)

Speaker change (2021)

E. Quandt → G. Schmidt

Phase 1

Noise level at 10 Hz (e.g. converse sensor)[1]:

70 pT/Hz$^{0.5}$

Phase 2

Noise level at 10 Hz (e.g. converse sensor)[2]:

7.5 pT/Hz$^{0.5}$

Prediction for Phase 3

Noise level at 10 Hz (e.g. converse sensor):

1 pT/Hz$^{0.5}$

principles

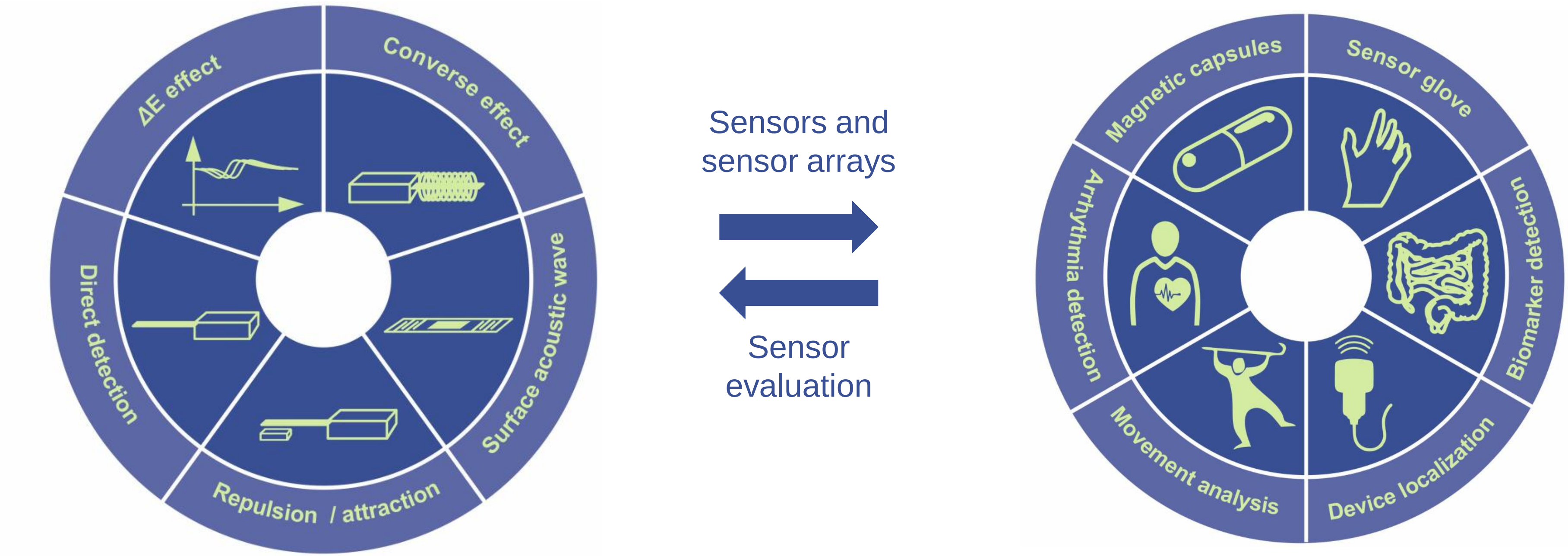
- Single sensors
- Focus on sensitivity
- Four medical applications

- Global inverse solutions
- Four medical applications

- Six medical applications

[1] Hayes, P., Jovičević Klug, M., Toxværd, S., Durdaut, P., Schell, V., Teplyuk, A., Burdin, D., Winkler, A., Weser, R., Fetisov, Y., **Höft, M.**, Knöchel, R., **McCord, J.**, **Quandt, E.** (2019). Converse Magnetoelectric Composite Resonator for Sensing Small Magnetic Fields *Scientific reports*, 9(1), 16355. doi: 10.1038/s41598-019-52657-w, open access.
[2] Measurement from November 2023, paper currently under review.

General Objectives of the CRC



Sensor concepts

- Research focus on five most promising sensor concepts
- Tailoring the concepts to the medical applications

Medical applications

- Two projects are not continued
- Four new applications (often focused on magnetic localization and/or detection of or within the human body)

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Magneto-electric sensing

- Basic principle
- First results

Applica-tions

- Heart
- …

Outlook on school activities

SFB 1261

My Own Motivation

Spatial versus temporal analyses

- ❑ *CT* and *MRI*

Motivation

- For the CRC
- **My own one**

My Own Motivation

biomagnetic sensing SFB 1261

Spatial versus temporal analyses

- *CT* and *MRI*

My Own Motivation

biomagnetic sensing SFB 1261

Spatial versus temporal analyses

- ❑ ***CT*** and ***MRI***
- ❑ ***EEG*** (ECG, …)

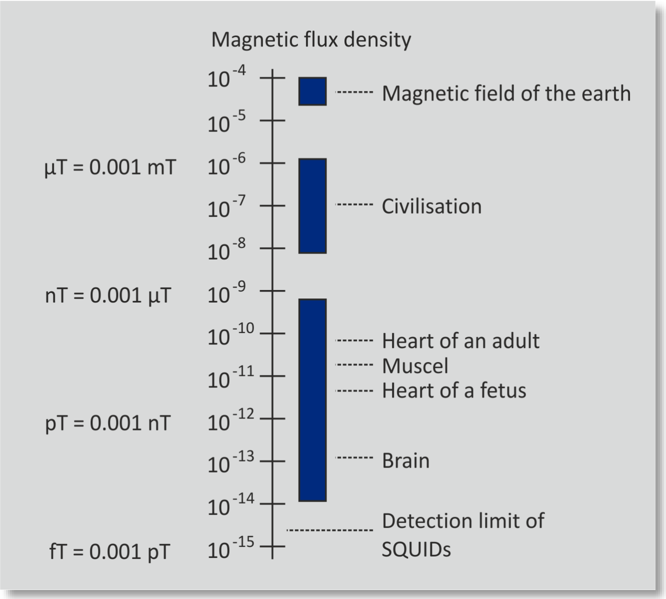
Motivation – Understanding the Problems

Medical applications

- Heart analyses (in various ways)
- Movement analysis
- Colon analyses

Motivation – Understanding the Problems

Problems of magnetic analyses



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- Movement analysis
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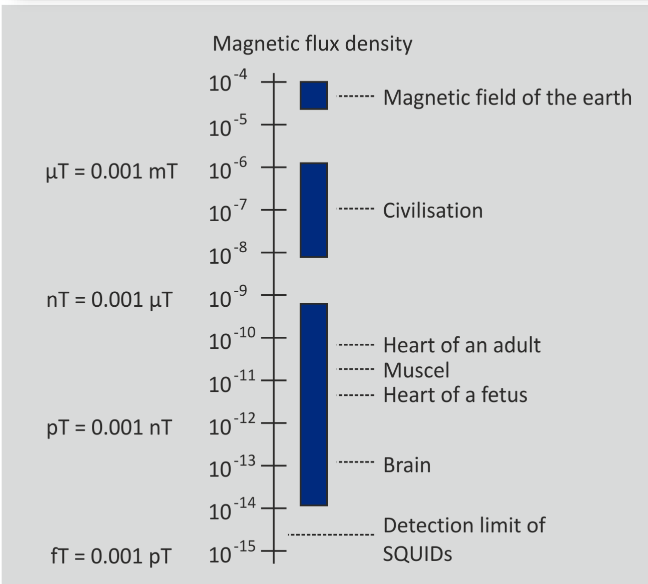
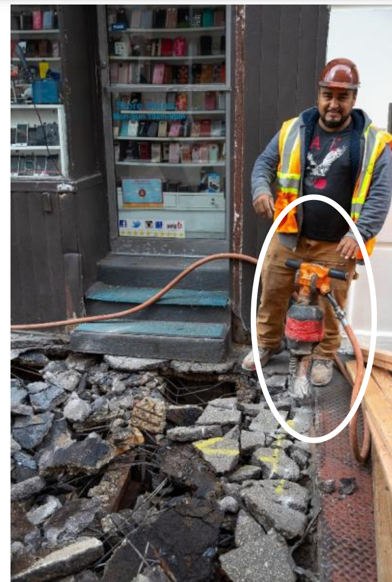
Motivation – Understanding the Problems

- ❑ Problems of magnetic analyses

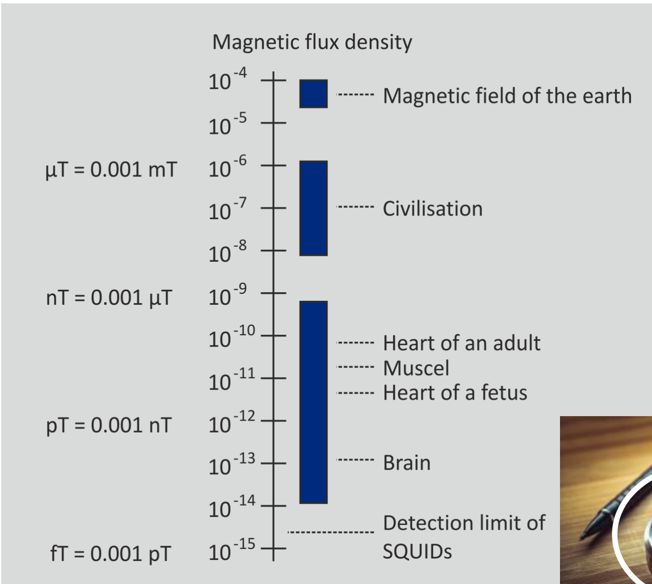


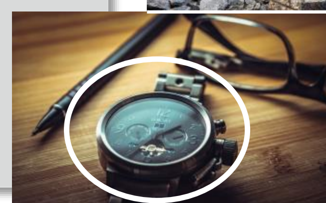


- ❑ Jackhammer, about 100 dBA, 2 Pa

Motivation – Understanding the Problems

Problems of magnetic analyses



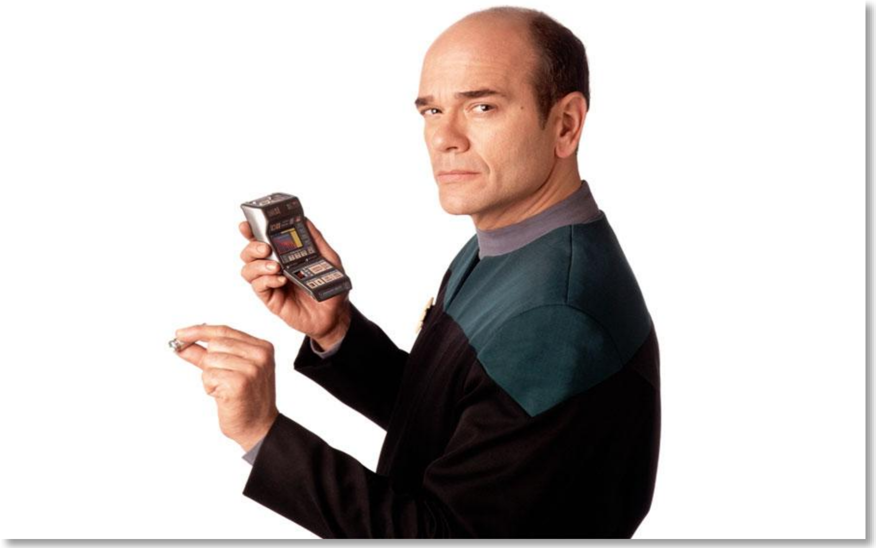


- ❑ Jackhammer, about 100 dBA, 2 Pa
- ❑ Watch ticking, about 20 dBA, 2 10-4 Pa

My Own Motivation

Research Hypothesis

- ***Magnetic sensor technology*** could be able to replace or supplement previous ***electrical analyses***.



My Own Motivation

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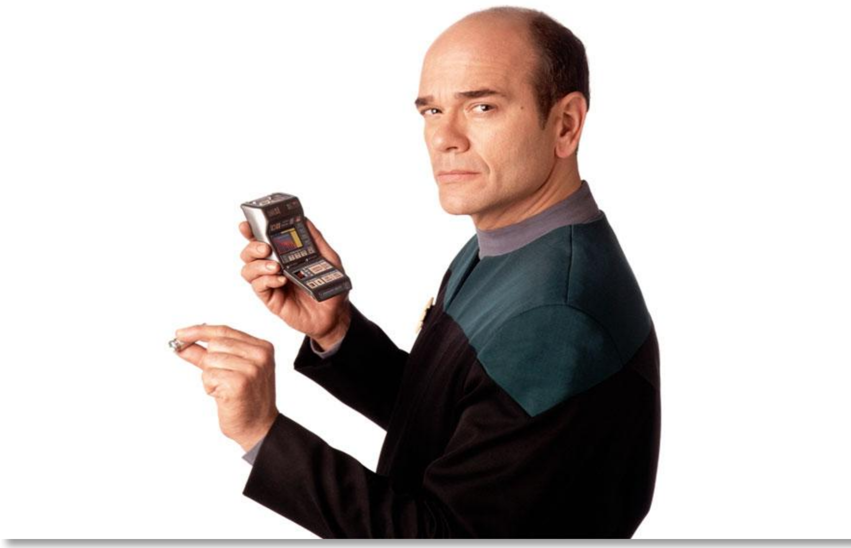
Research Hypothesis

- ***Magnetic sensor technology*** could be able to replace or supplement previous ***electrical analyses***.

Research questions / details:

- ***Why*** should we use magnetic sensors?
- Which ***medical analyses*** does this concern?
- What does it take to ***make this work***?
- Are there new ***applications*** that could benefit from the new sensor technology?



My Own Motivation

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Prediction of Steering Movements

- Contactless measurement of brain, heart, and muscle activities.
- Here first only a prediction of steering movements while driving a car.

My Own Motivation

Prediction of Steering Movements

- Contactless measurement of brain, heart, and muscle activities.
- Here first only a prediction of steering movements while driving a car.

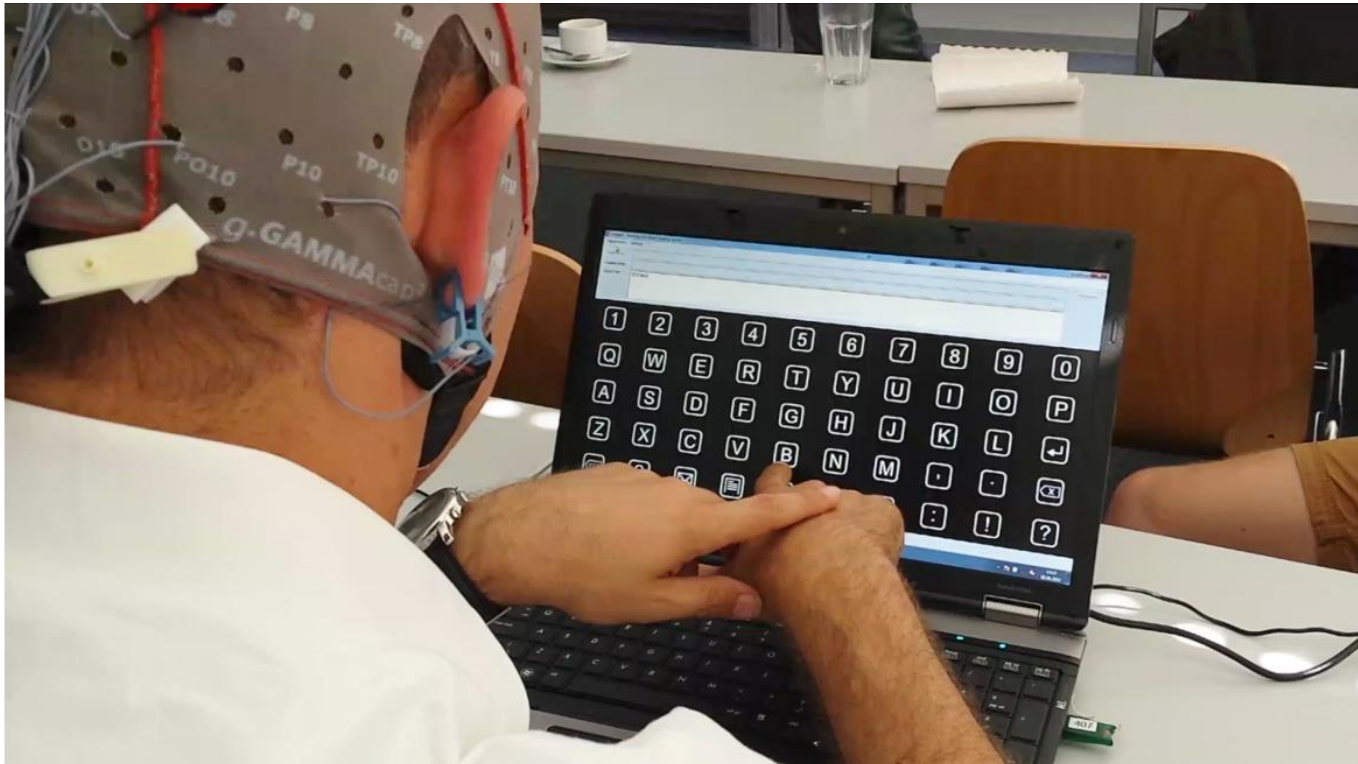
Solution

- Recording of brain signals (and pattern recognition).

My Own Motivation

Basic idea

- Usage of brain-computer interfaces (BCIs).



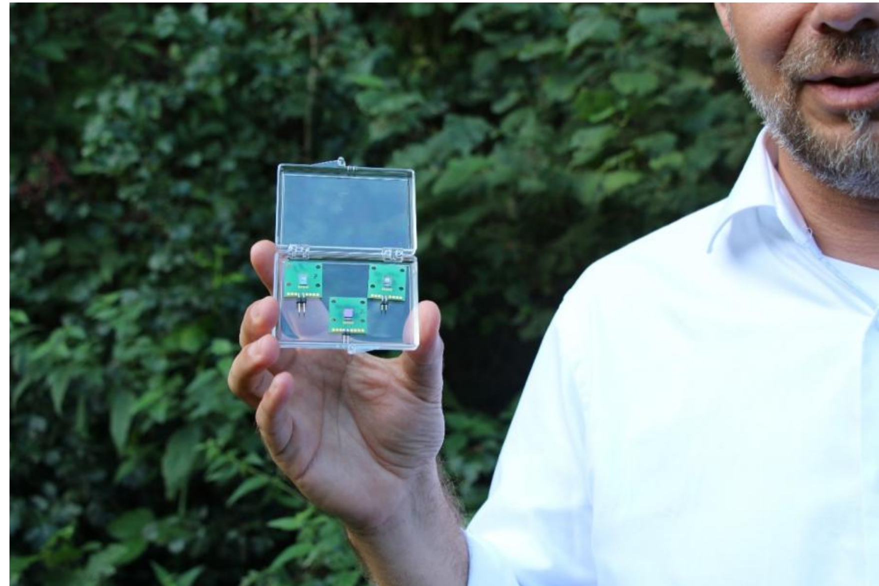
My Own Motivation

Prediction of steering movements

- Contactless measurement of brain, heart, and muscle activities.
- Here first only a prediction of steering movements while driving a car.

Solution

- Recording of brain signals (and pattern recognition) …
- … not electrically, but magnetically.



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- Basic principle
- First results

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Basics of Magnetoelectric Sensors

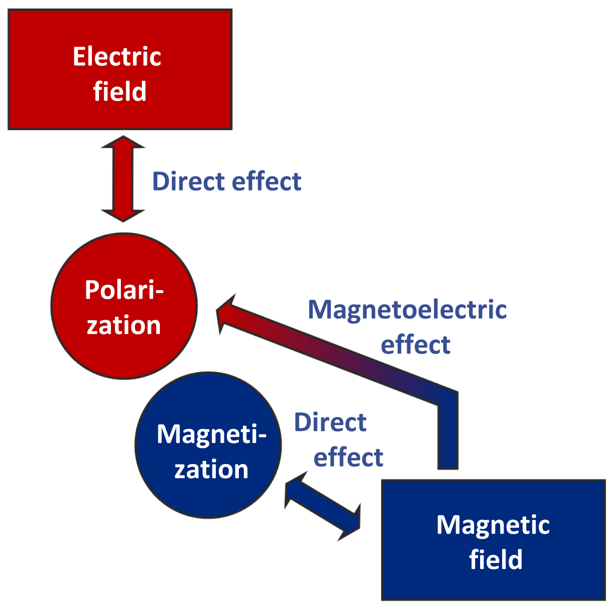
Membran was yesterday …

… today is piezo

Basics of Magnetoelectric Sensors

Idea

- Basic goal: ***Non-cooled*** magnetic measurements in ***unshielded*** environments for bio-medical applications
- Usage of "non-direct" conversion principles



Magneto-electric sensing

- **Basic principle**
- First results

Basics of Magnetoelectric Sensors

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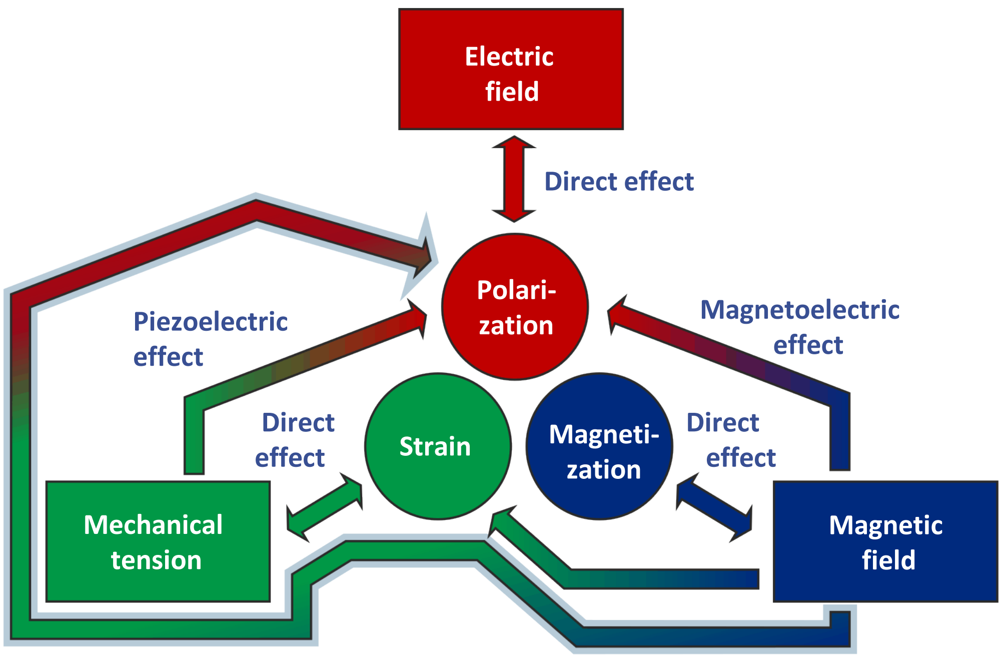

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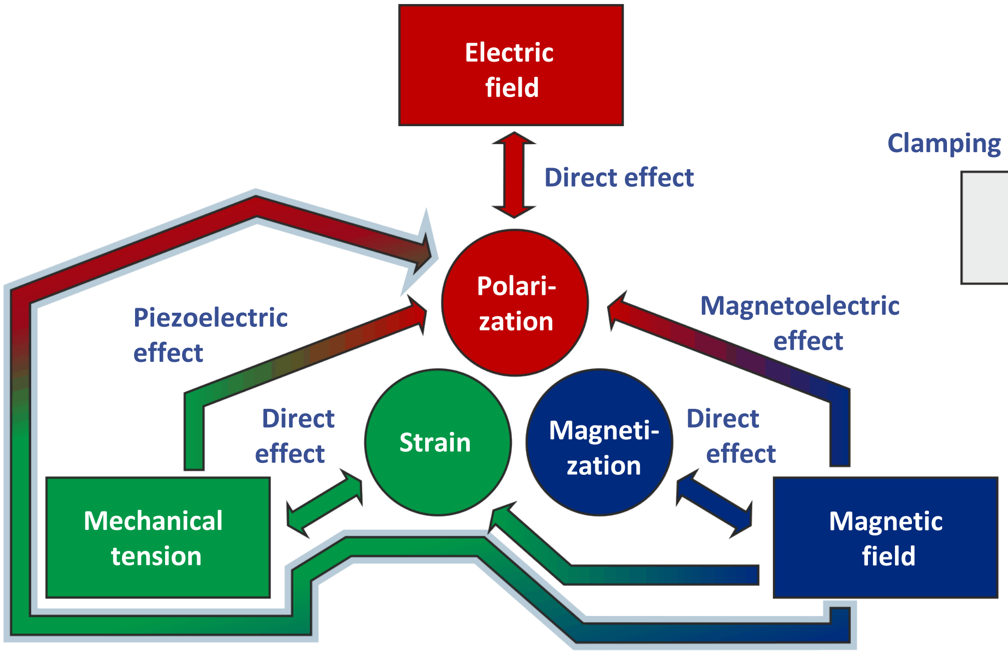

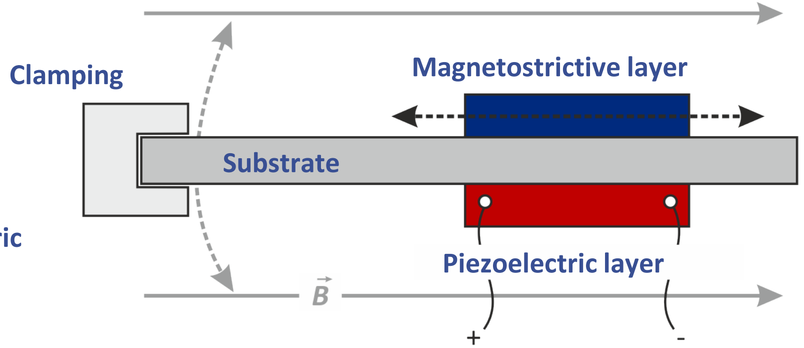

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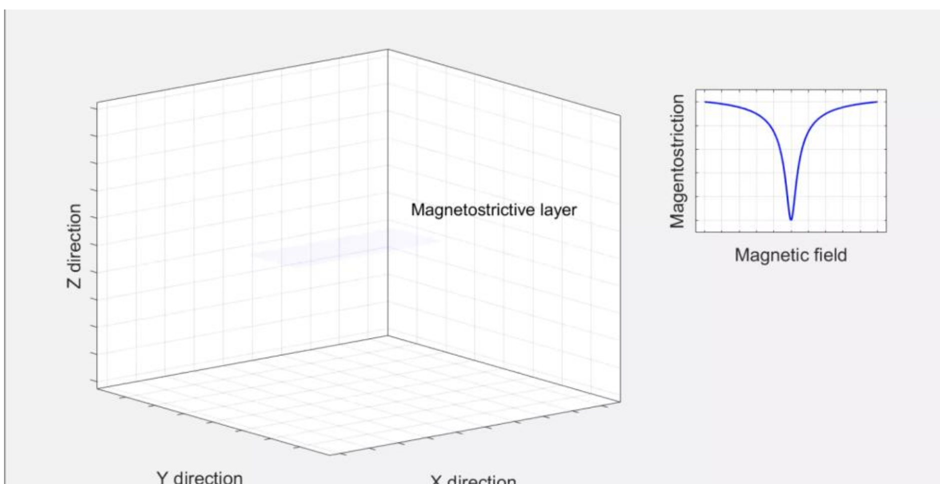
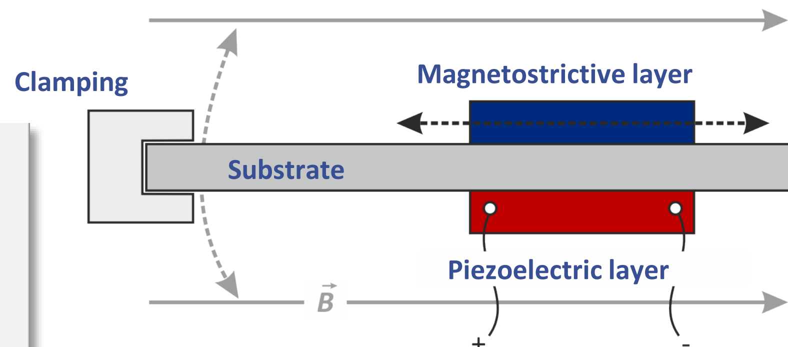
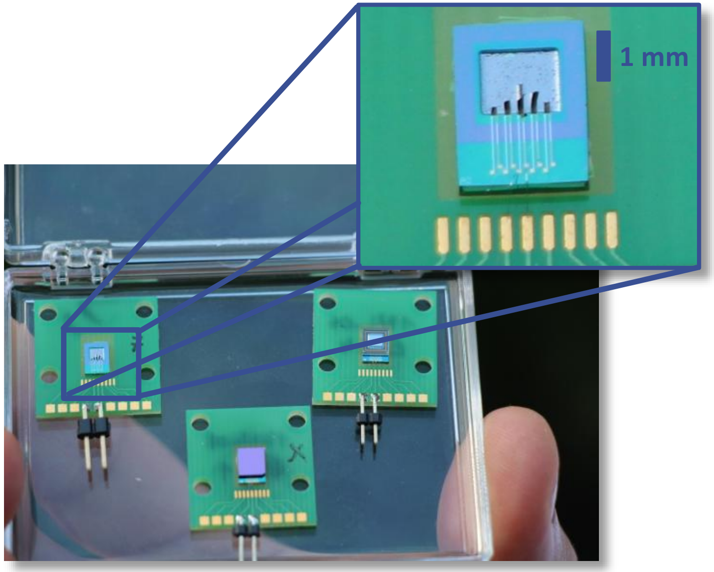




Basics of Magnetoelectric Sensors

Idea

- Basic goal: ***Non-cooled*** magnetic measurements in ***unshielded*** environments for bio-medical applications
- Usage of “non-direct” conversion principles
- Several read-out principles (as well as additional sensor principles)

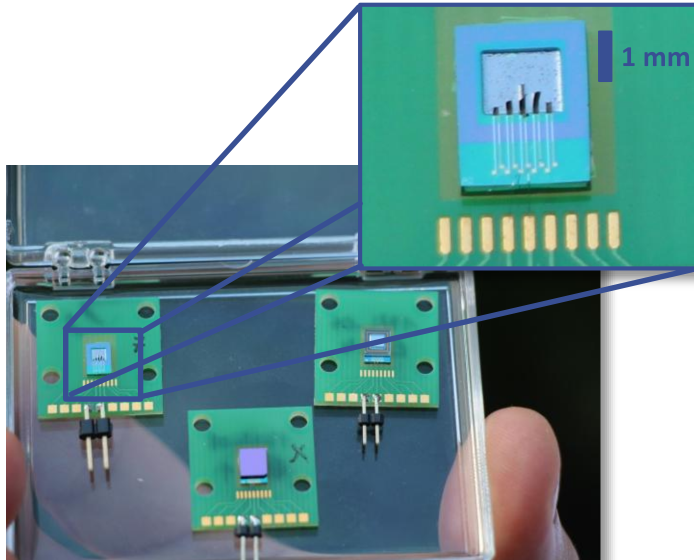


Basics of Magnetoelectric Sensors

Sensor / readout principles

Direct detection sensors

- Resonant e.g. at 7 kHz and at 49 kHz



Basics of Magnetoelectric Sensors

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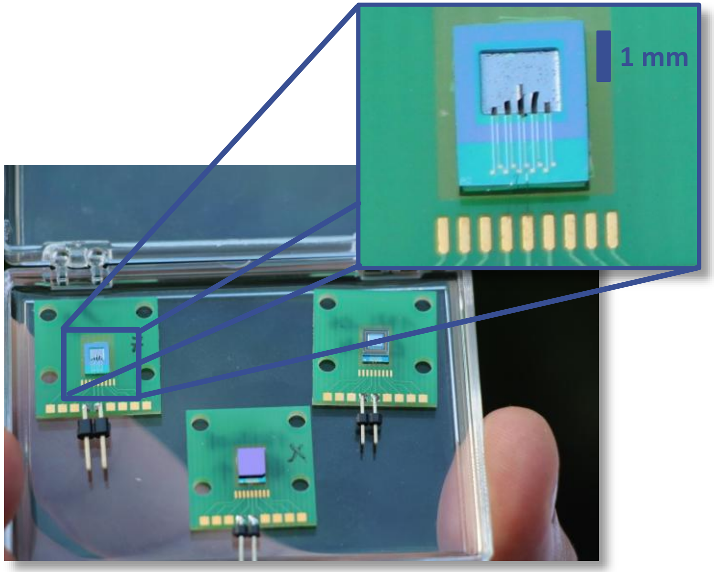
Sensor / readout principles

Direct detection sensors

- Resonant e.g. at 7 kHz and at 49 kHz

Delta-E sensor/readout

- Basic principle:
  - Excite the cantilever electrically at a resonance frequency
  - The magnetic field changes the E module of the cantilever
  - This leads to an amplitude an phase modulation of the electric signal
- Frequency range:
  - 0 to 10 kHz (adjustable via e.g. the geometrical shape of the cantilever)
  - Readout at e.g. 50 kHz



Basics of Magnetoelectric Sensors

Sensor / readout principles

Direct detection sensors

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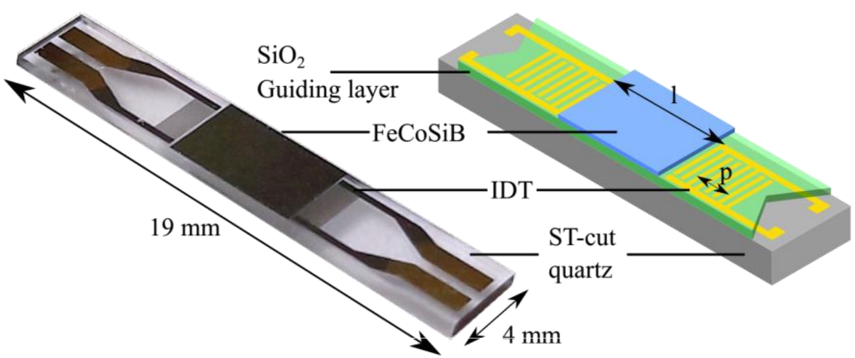
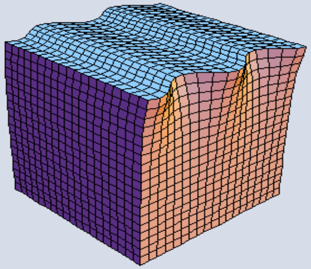
Delta-E sensor/readout

- Magnetic field changes the E module of the cantilever



Surface acoustic wave (SAW) sensor/readout

- Basic principle:
  - Excite Love waves (Shear waves with guiding layer) on a magnetostrictive material
  - The magnetic field modifies the wave velocity (Delta-E effect)
  - Delay/phase variations can be exploited to measure the magnetic field
- Frequency range:
  - 0 to 1 MHz (adjustable)
  - Readout at around 100 MHz



Basics of Magnetoelectric Sensors

Sensor / readout principles

Direct detection sensors

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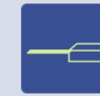
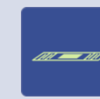


Delta-E sensor/readout

- Magnetic field changes the E module of the cantilever

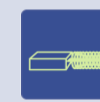
Surface acoustic wave (SAW) sensor/readout

- Delay/phase variations can be exploited to measure the magnetic field



Converse effect sensor/readout

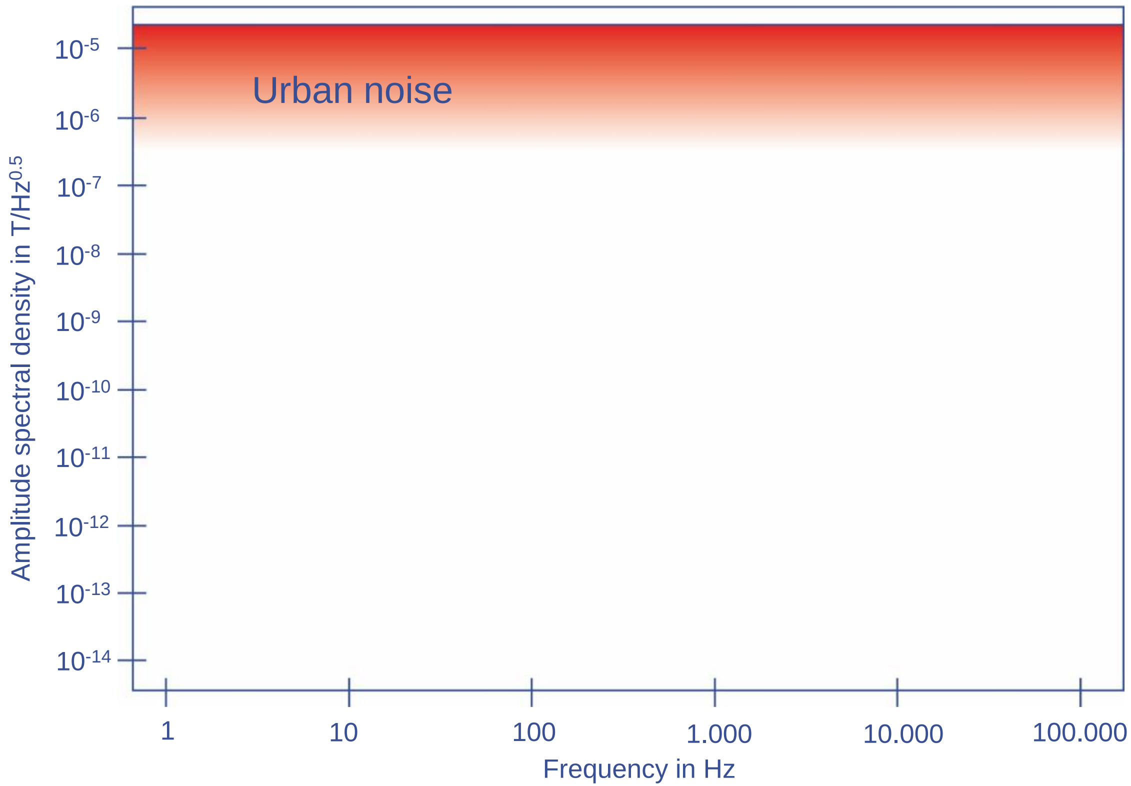
- Electric excitation and magnetic readout



Repulsion / attraction-based readout

- Extra magnet creates a low-noise external field

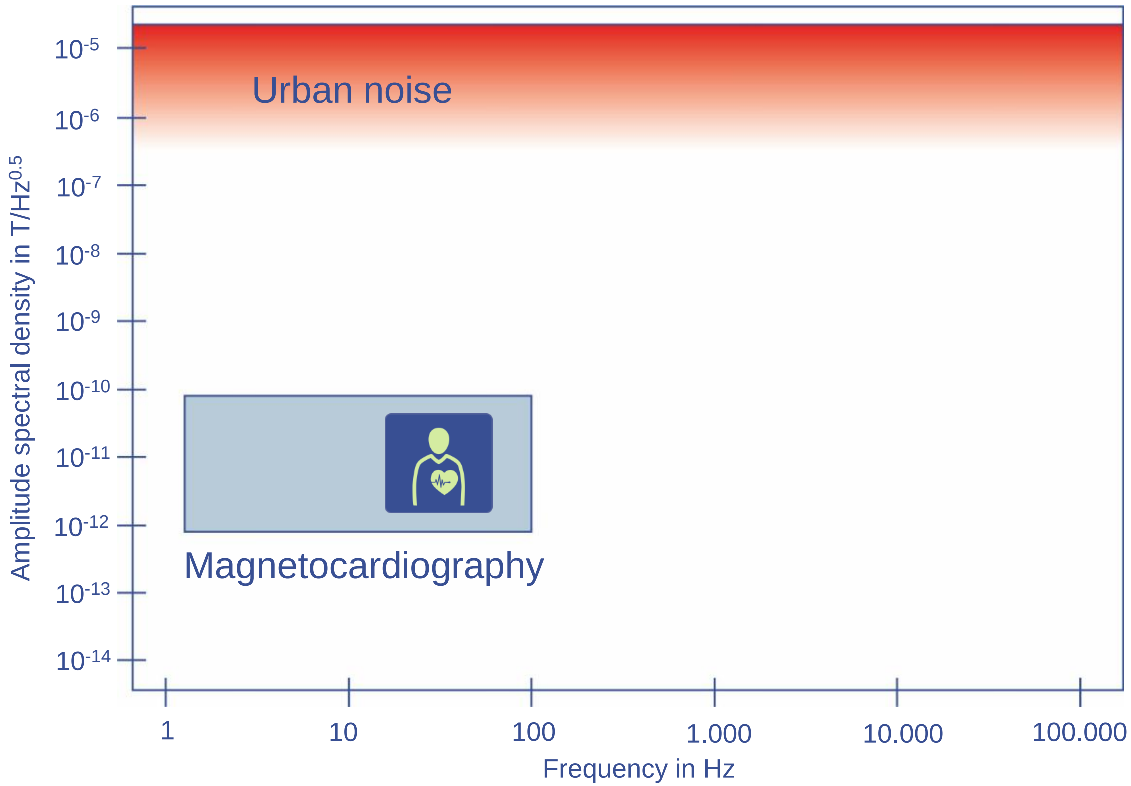
Biomagnetic Fields Addressed in the CRC



Challenges for the magnetic field sensors

- Small signals
- Large noise level
- No cooling
- No shielding

Biomagnetic Fields Addressed in the CRC



Challenges for the magnetic field sensors

- Small signals
- Large noise level
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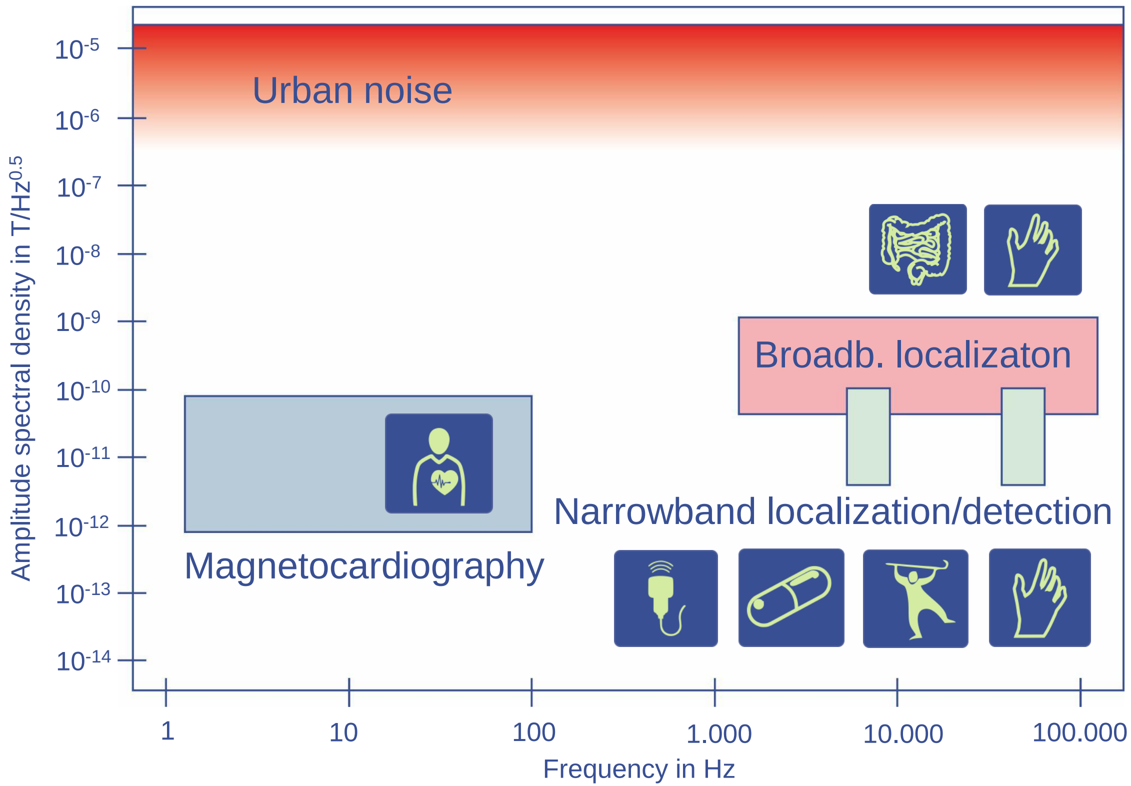
Applications

- Magnetocardiography (MCG)

Biomagnetic Fields Addressed in the CRC



Challenges for the magnetic field sensors

- Small signals
- Large noise level
- No cooling
- No shielding

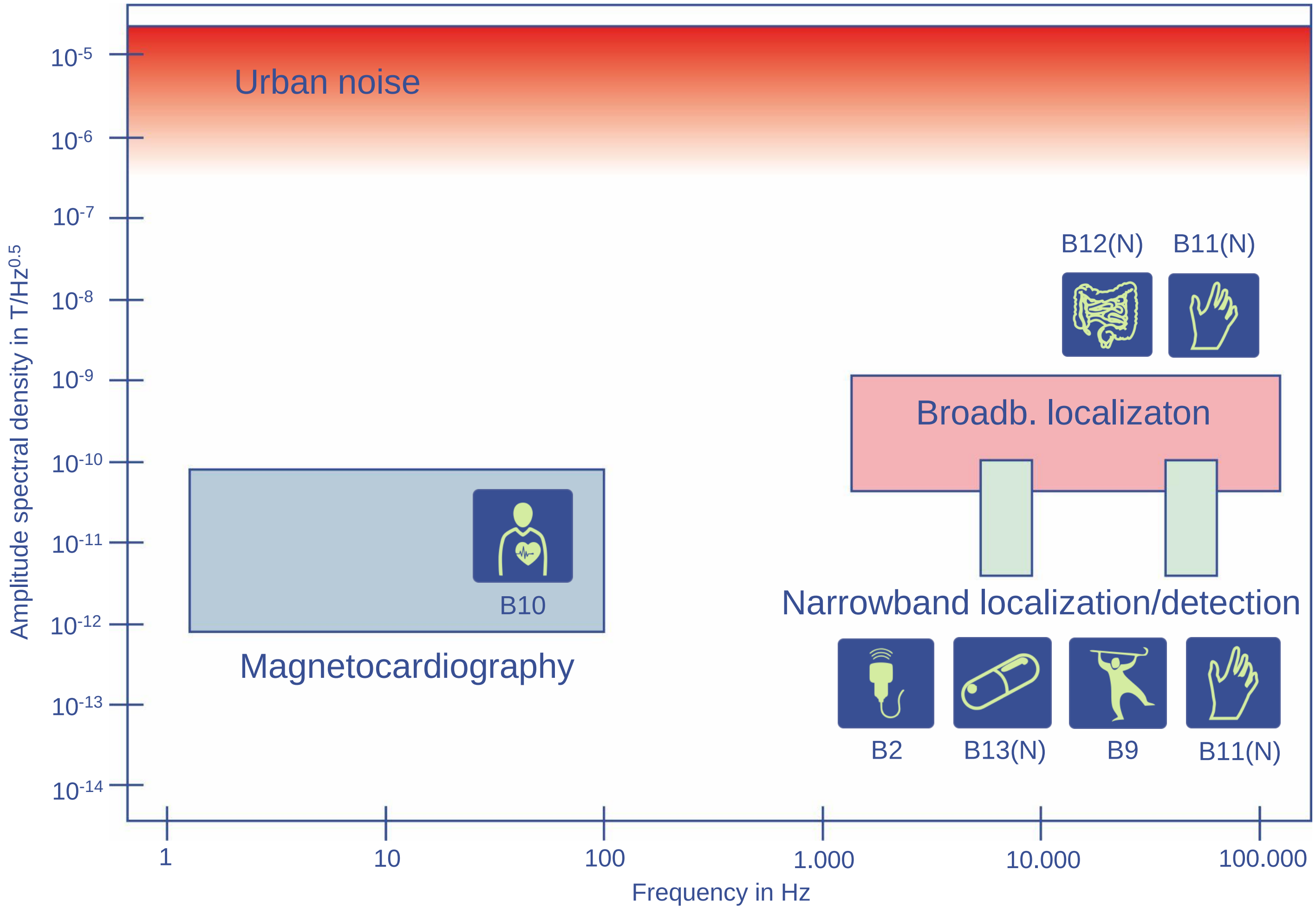
Three kinds of sensors needed

- Broad band
- Single frequency
- Low frequency

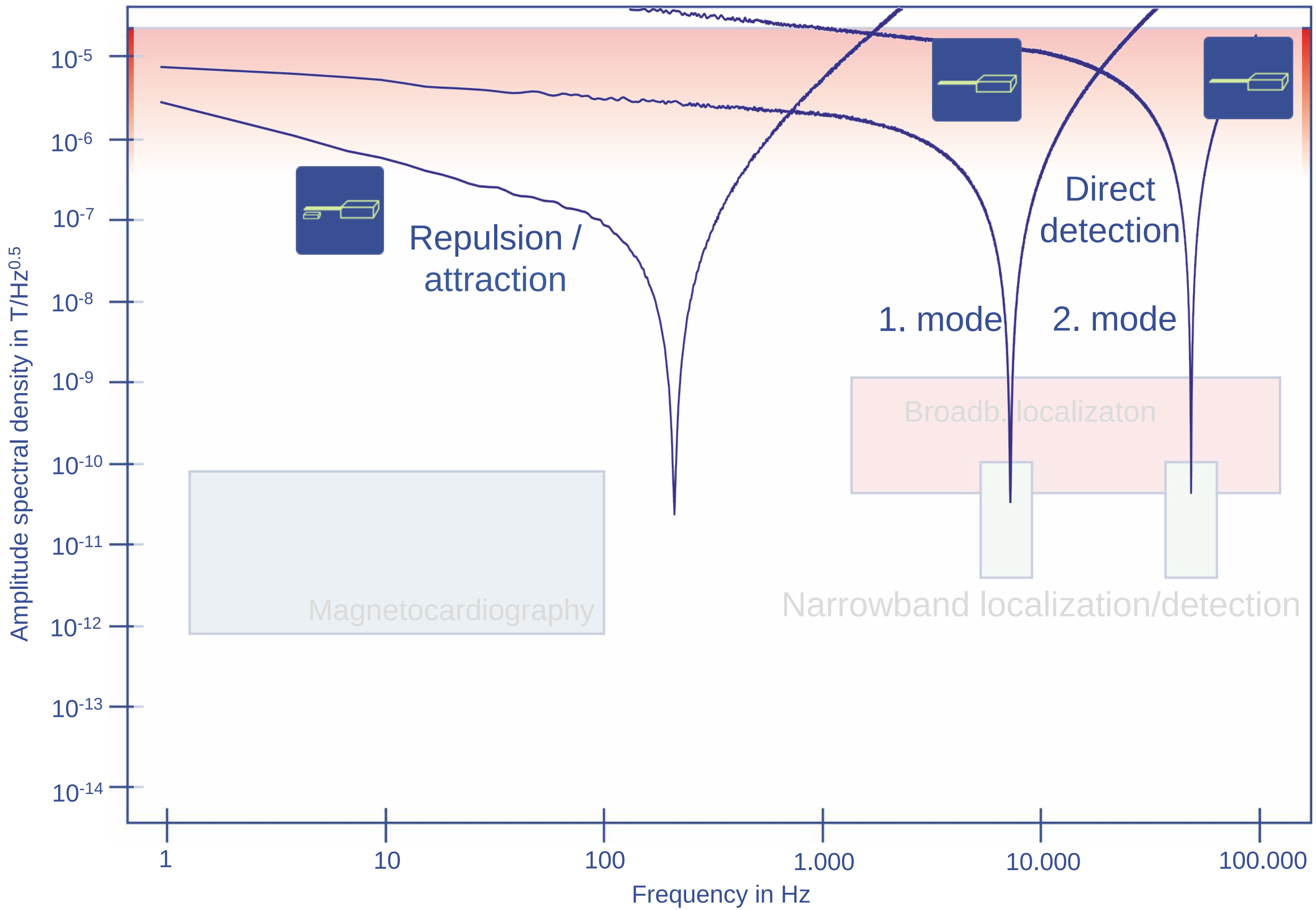
Applications

- Magnetocardiography (MCG)
- Capsule localization (CL)
- Magnetic localization (ML) including movement analysis and device localization
- Magnetic particle detection (MPD)

Biomagnetic Fields Addressed in the CRC



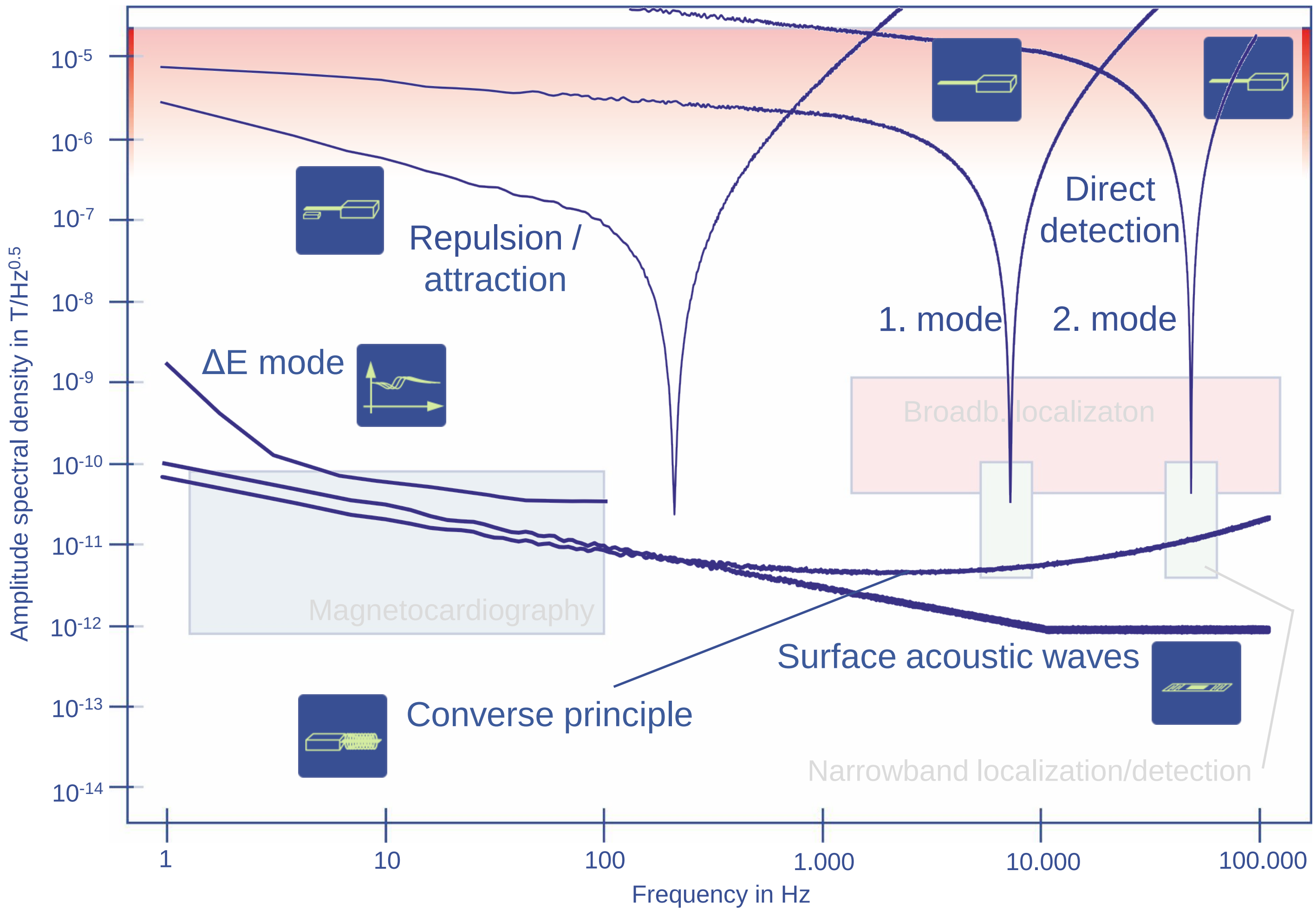
Performance of ME Sensor Systems (End of 2023)



Single-frequency sensors

- Direct detection (Z1)
- Repulsion / attraction (A2)

Performance of ME Sensor Systems (End of 2023)



Single-frequency sensors

- Direct detection (Z1)
- Repulsion / attraction (A2)

Broad-band sensors

- ΔE mode (A4)
- Converse principle (A7)
- Surface acoustic waves (A9)

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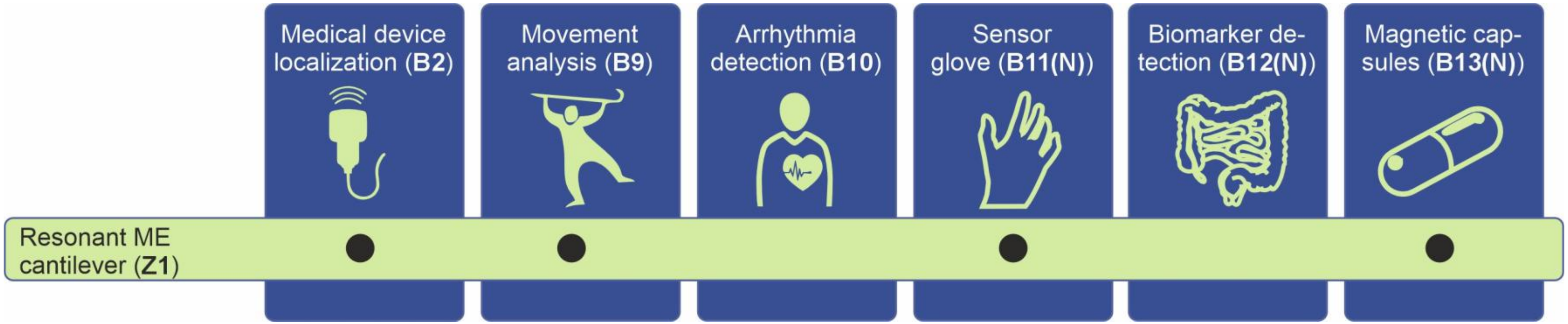
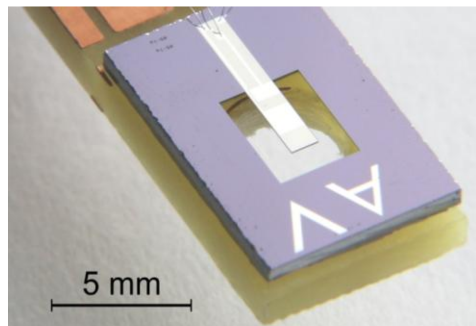
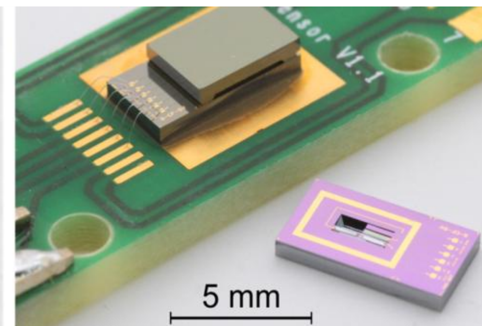
Sensor Principles and Applications



Sensor Advantages (Resonant ME Cantilever in Direct Detection Mode)

- Very sensitive only at a few frequencies (modes)
- Very small readout hardware
- Very power/energy efficient





Applications

- Five applications are funded by the DFG
- One is funded by the university (sensor glove)

Sensor Principles and Applications

biomagnetic sensing SFB 1261

	Medical device localization (**B2**)	Movement analysis (**B9**)	Arrhythmia detection (**B10**)	Sensor glove (**B11(N)**)	Biomarker detection (**B12(N)**)	Magnetic capsules (**B13(N)**)
Resonant ME cantilever (**Z1**)	●	●		●		●
ΔE-effect sensor (**A4**)	●	●		●	●	
Converse-effect ME sensor (**A7**)	●		●	●	●	●
Surface acoustic wave sensor (**A9**)	●		●	●	●	●
Permanent magnet composite sensor (**A2**)		●		●		

Applications

- Five applications are funded by the DFG
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Can we?

Sensor fabrication

Sensor evaluation

Sensor application

Research Facilities

Can we? … Yes, we can!

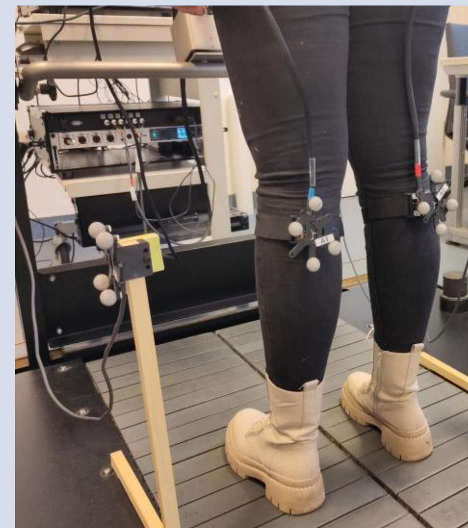
Sensor fabrication

Excellent clean rooms in Kiel and Itzehoe

Sensor evaluation

Magnetically shielded chamber, TEM, …

Sensor application



Patient/control measurements in Kiel and Heidelberg

(Bio-) Medical Applications

Six selected fields of application

- Cardiologic applications
- Movement analysis
- Localization of medical devices
- Biomarker detection (in the human body)
- Sensor gloves for robot-assisted surgery
- Tracking of „smart pills“

All applications have cleared ethics and are investigated with medical partners on selected patient groups / in (bio-) medically important fields.

Applications – Cardiologic Analyses

Research hypothesis

- Magnetic sensor systems can support their electric counterparts in a positive manner when (the origin of) cardiologic diseases (e.g. arrythmias) should be detected

Applications – Cardiologic Analyses

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- Magnetic sensor systems can support their electric counterparts in a positive manner when (the origin of) cardiologic diseases (e.g. arrythmias) should be detected

Basic idea / plan

- Investigate so-called state-space approaches for spatio-temporal modelling of the human heart
- Estimate the time-varying spatial current density within the human heart based on magnetic (and electric) sensor systems
- Explore a priori knowledge by means of CT and MRI scans as startup conditions
- Estimate the “system properties” of a heart (conduction velocities and directions) for localizing the origins of arrythmias

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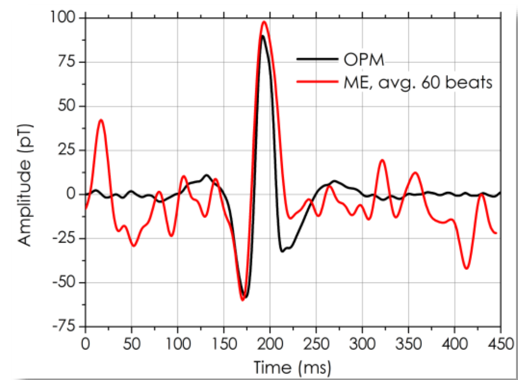

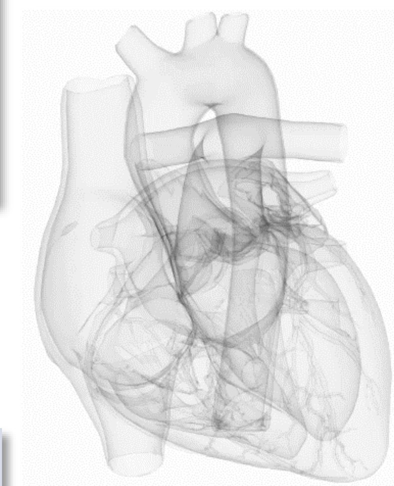

First results

Applications – Magnetic Movement Analysis

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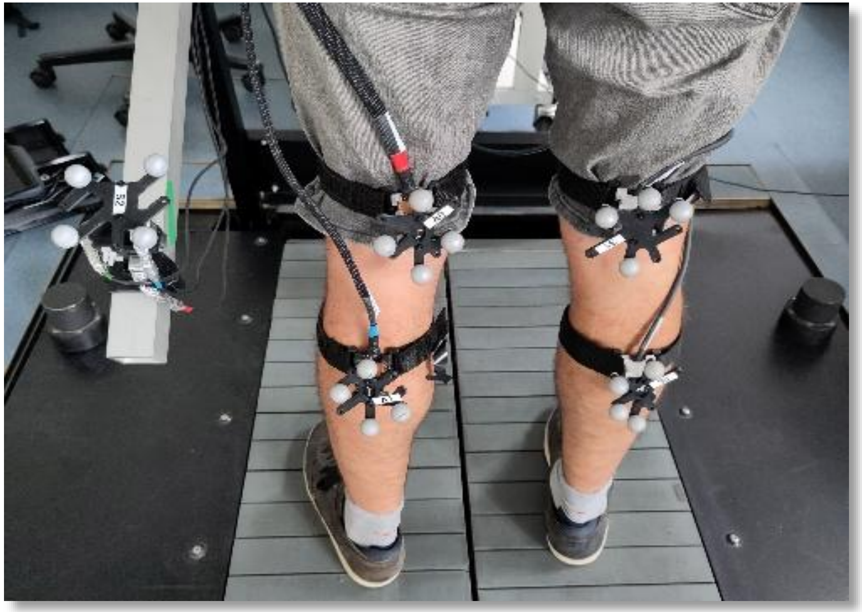
Research hypothesis

- Magnetic sensor systems can support their IMU-based counterparts for home assessment to improve personalized patient care.



Applications – Magnetic Movement Analysis

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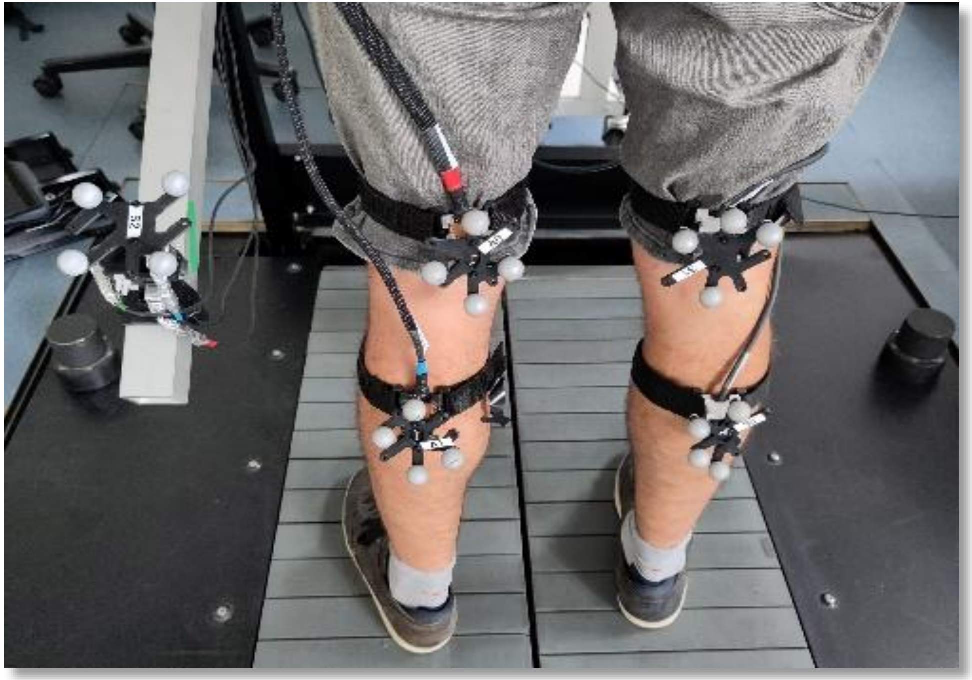
Research hypothesis

- Magnetic sensor systems can support their IMU-based counterparts for home assessment to improve personalized patient care.

Basic idea / plan

- Equip clothes (trousers, shirts) with magnetic sensors and actuators
- Use a priori knowledge about the human walking (for healthy subjects and patients of selected diseases)
- Investigate the potential of magnetic movement analysis to support other approaches (IMU-based)
- Compare magnetic approaches with the gold standard (camera-based)



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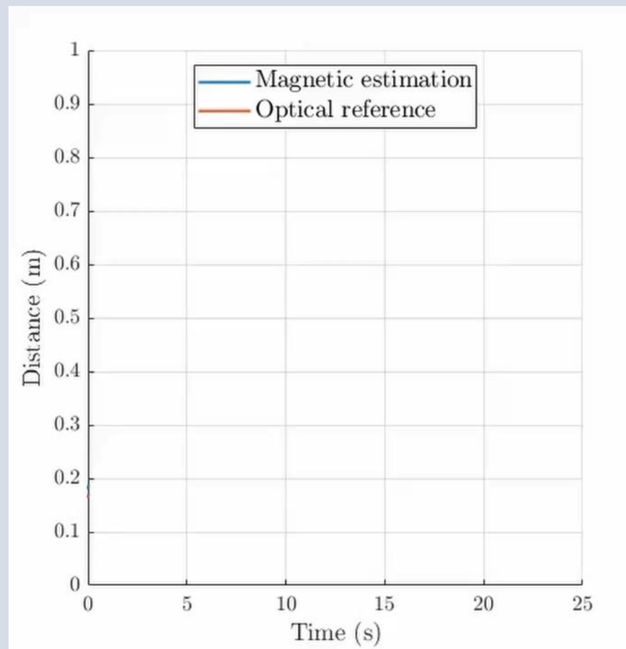
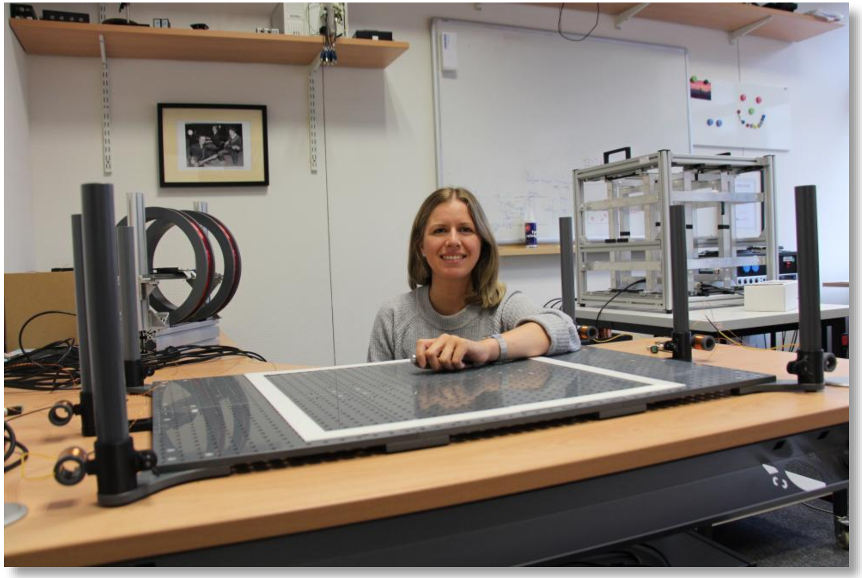


First results

Applications – Magnetic Device Localization

Research hypothesis

- Magnetic localization approaches can support or replace optical counterparts for improving patient care.



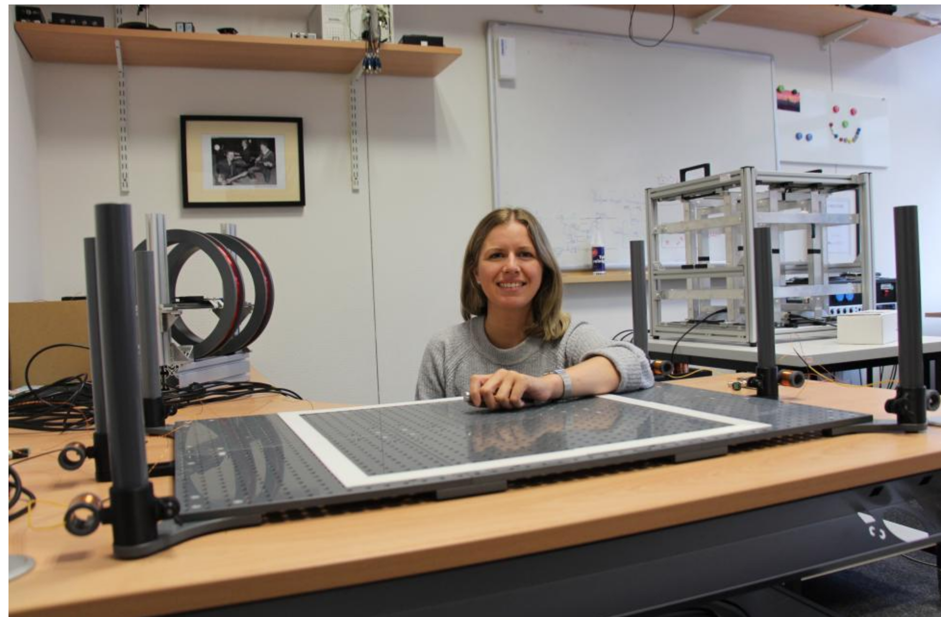
Applications – Magnetic Device Localization

Research hypothesis

- Magnetic localization approaches can support or replace optical counterparts for improving patient care.

Basic idea / plan

- Equip medical devices (e.g. ultrasound scanners) with magnetic sensors and localize the sensor position relative to coils that emit predefined signals.
- Fuse the information gathered from magnetic and auxiliary (e.g. ultrasound) sensing devices.
- Alternatively, localize magnetic sources (coils or cantilevers with magnetic powder) outside or inside the human body.



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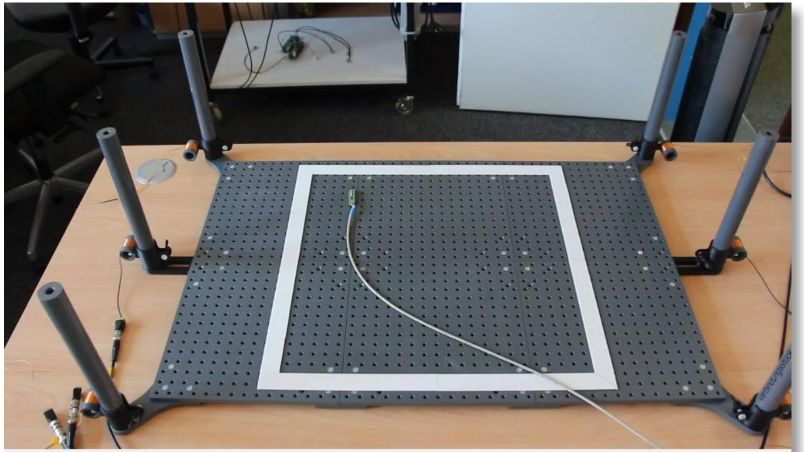
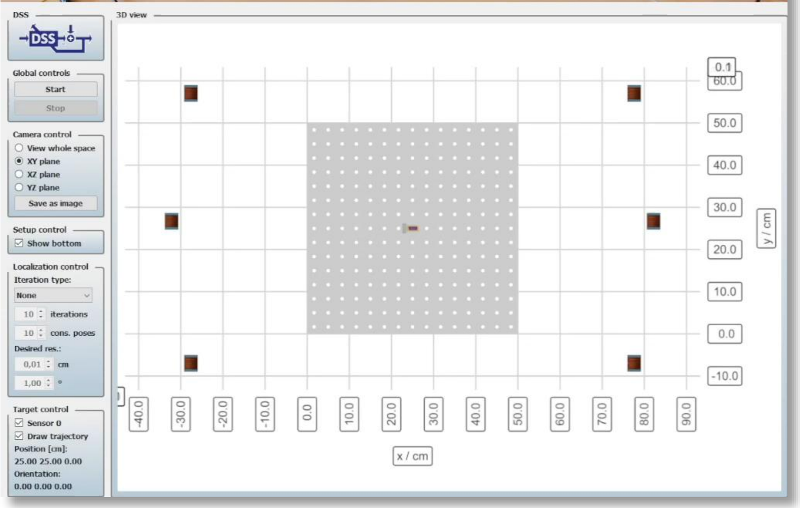




First results

Applications – Magnetic Biomarker Detection

Research hypothesis

- Magnetic nano particles can be combined with MIPS (molecularly imprinted polymers) to dectect medical biomarkers in vivo

Applications – Magnetic Biomarker Detection

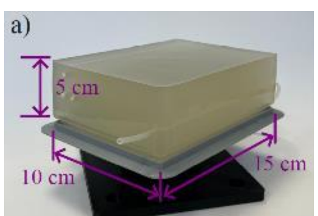
Research hypothesis

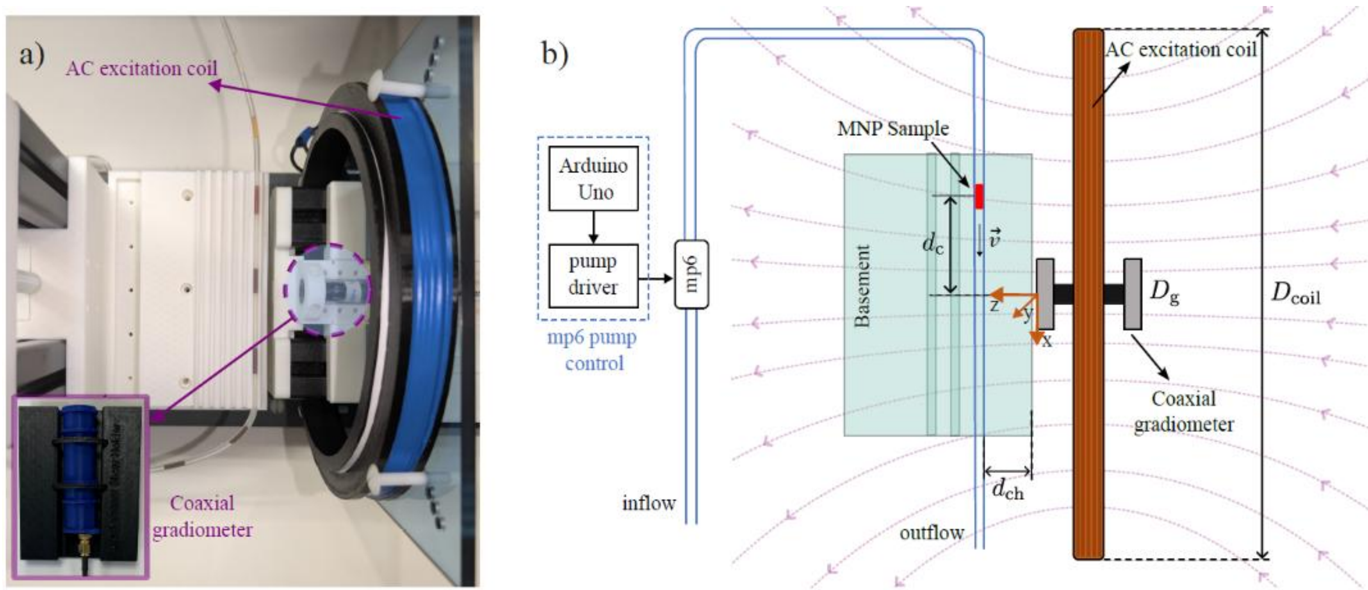
- Magnetic nano particles can be combined with MIPS (molecularly imprinted polymers) to detect medical biomarkers in vivo

Basic idea / plan

- Investigate sensor systems suitable for in vivo measurements

First results





Applications – Magnetic Biomarker Detection

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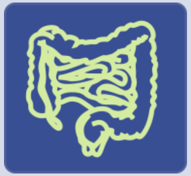
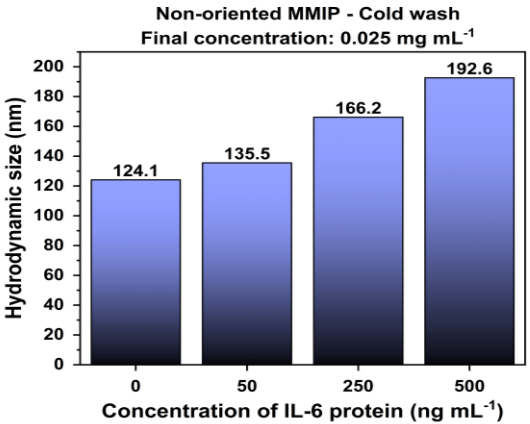
Basic idea / plan



- Establish the process for “connecting” medically relevant biomarkers via MIPS to magnetic nano particles in vivo
- Investigate magnetic detection mechanisms that exploit differences of size and weight of the functionalized nano particles
- Find out if this helps to solve problems that appear in colon surgeries

First results

Fluid that contains the functionalized magnetic nano particles



The more biomarkers are binding, the larger the nano particles get

Applications – Magnetic Sensor Glove

Research hypothesis

- Magnetic localization approaches can help to improve haptic interfaces of robot-assisted surgery systems.

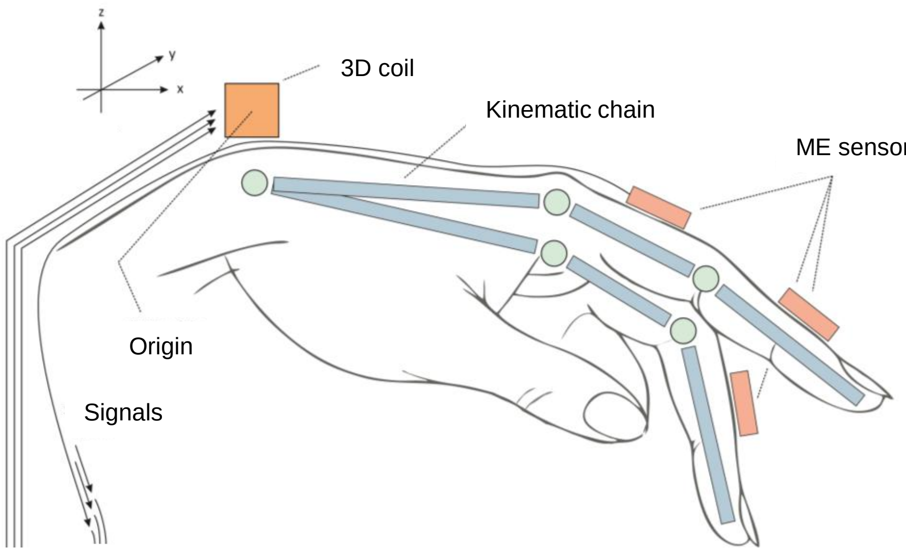
Application – Magnetic Sensor Glove

Research hypothesis

- Magnetic localization approaches can help to improve haptic interfaces of robot-assisted surgery systems.

Basic idea / plan

- Equip a sensor glove with magnetic sensors and actuators
- Use a priori knowledge about the hands, fingers, movements to build appropriate models
- Compare the potential of magnetic detection to support other approaches (IMU- or camera-based)



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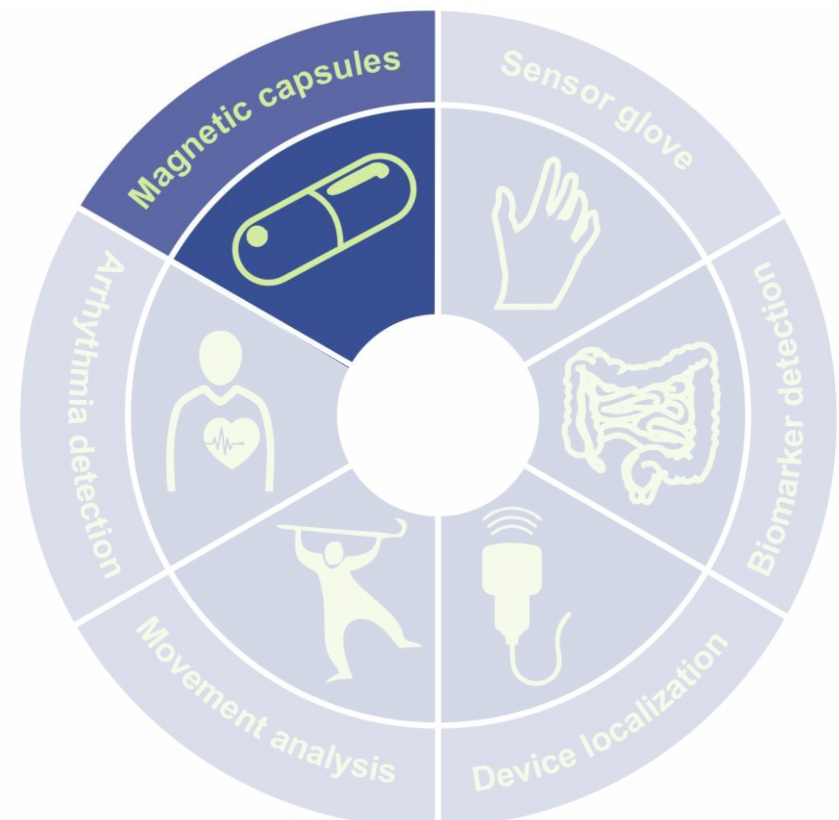
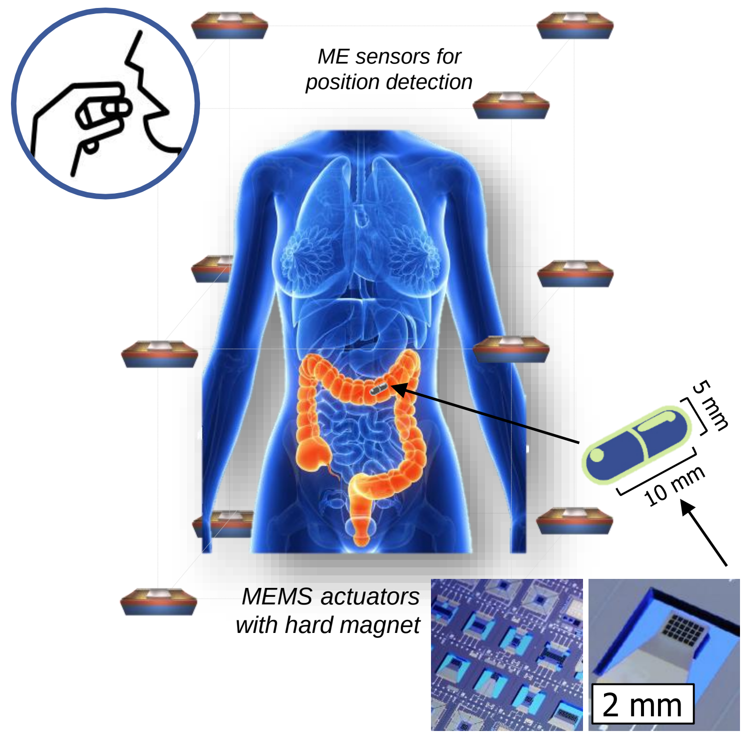
First results

Applications – Localization of Capsules



Research hypothesis

- A cantilever with magnet powder will swing sufficiently long after excitation to be localized by magnetic sensors



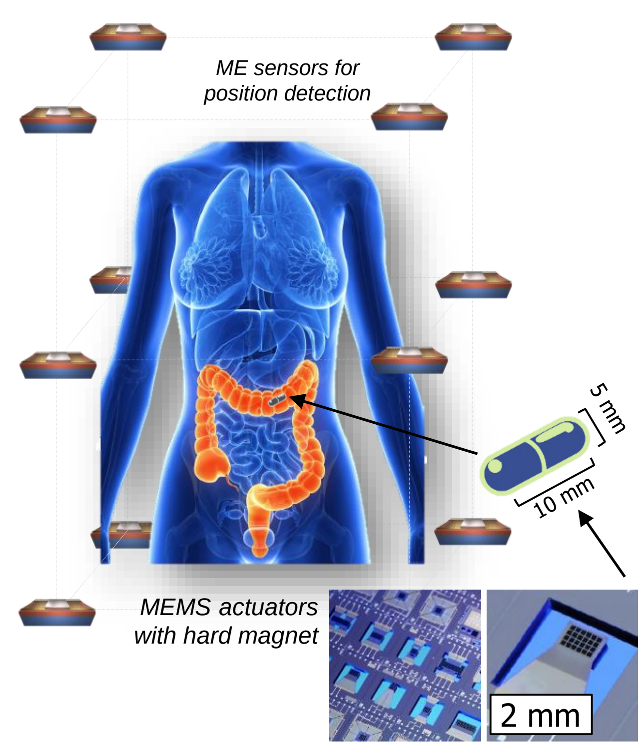
Applications – Localization of Capsules

Research hypothesis

- A cantilever with magnet powder will swing sufficiently long after excitation to be localized by magnetic sensors

Basic idea / plan

- Build a cantilever with magnet powder using MEMS technology
- Explore if the sensor can be localized with a small amount of magnetic sensors
- Find out if this principle can be used to investigate the gastrointestinal motility (e.g., Parkinson's disease, inflammatory bowel disease, ...)



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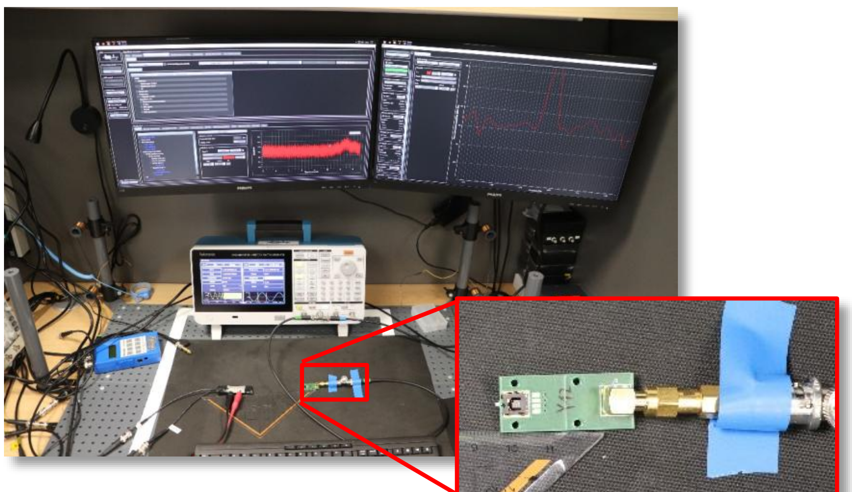

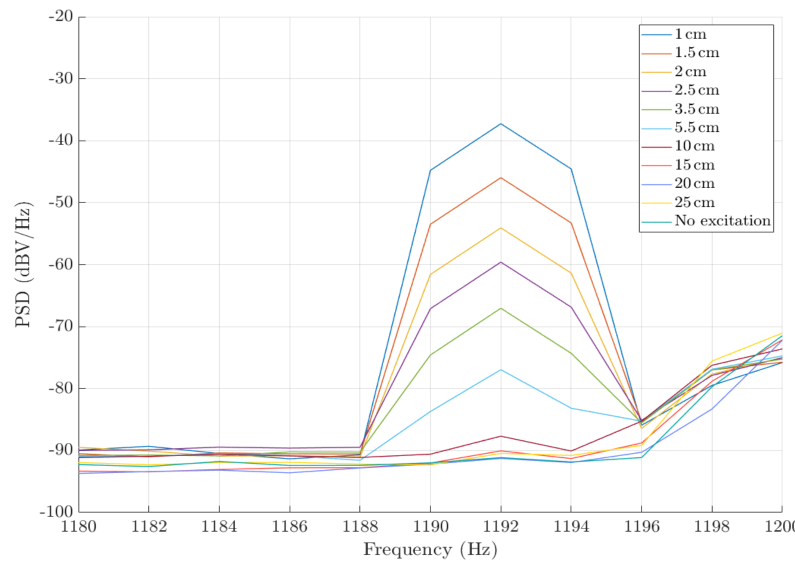

First results

Agenda

biomagnetic sensing SFB 1261

Motivation

- For the CRC
- My own one

Applica-tions

- Heart
- …

Magneto-electric sensing

- Basic principle
- First results

SFB 1261

Agenda

biomagnetic sensing SFB 1261

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Outlook on school activities

SFB 1261

Science Outreach

Enhancing science communication on biomagnetic sensing through events, materials, training, and research

- ❑ Three groups of addressees

Public

Schools

Researchers of the CRC

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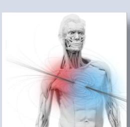
Public

- ❑ Podcast with nine „double-features“ available via www.biomagmentic-sensing.de



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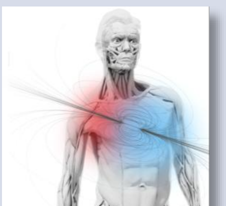
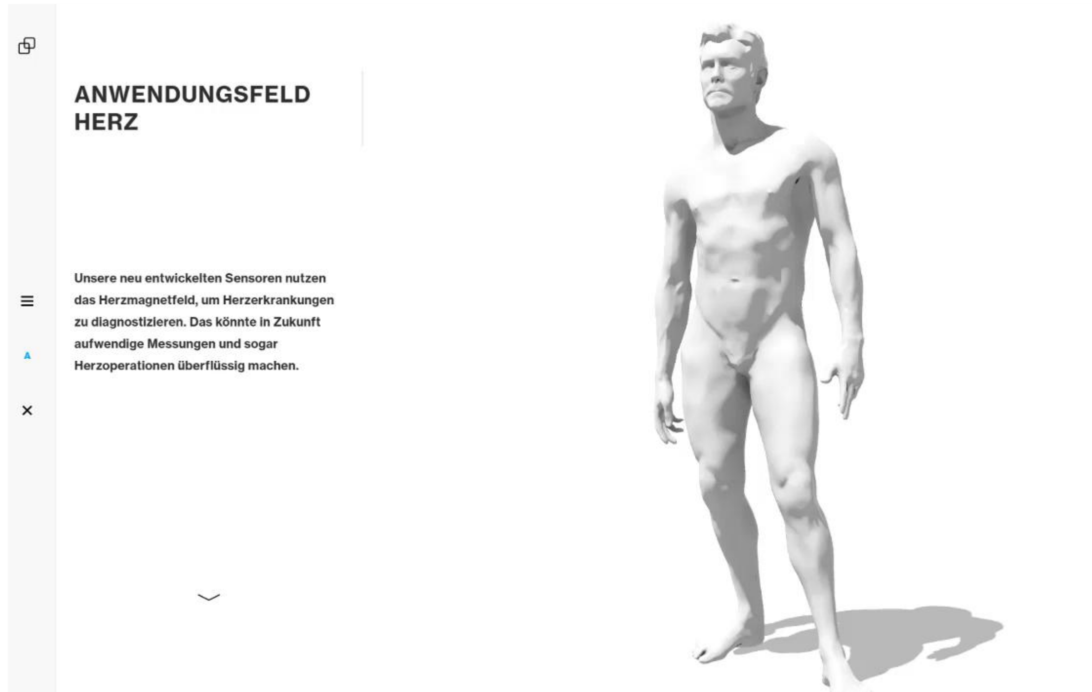


- ❑ Interactive visualization of selected applications and sensor principles



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Schools


Biomagnetic Sensing - Übersicht
https://biomagnetic-sensing.de/index.php/uebersicht-outreach

biomagnetic sensing für alle

science visualization

Home | Übersicht | Forschungseinblicke | Für Schulen | Unterrichtsmaterialien | Vorträge und Aktionen | Podcast | Unsere "Mikroseite"

Wissenschaftskommunikation im Bereich der biomagnetischen Sensorik

Der SFB 1261 setzt sich für interaktive und ansprechende Wissenschaftskommunikation und in diesem Zuge für die Verbreitung von Wissen über biomagnetische Sensorik ein. Aus diesem Grund existiert innerhalb des SFBs eine **Projektgruppe für Öffentlichkeitsarbeit**. Sie entwickelt in Zusammenarbeit mit anderen Forschenden des SFBs ein vielfältiges Angebot an Outreach-Angeboten wie Vorträge, interaktive Ausstellungen, Laborführungen, Schulbesuche, Schülerlabortage und viele andere.

Unser Ziel

Unser Ziel ist es, die Forschung des SFBs transparent und der Öffentlichkeit zugänglich zu machen und zusätzlich jungen Menschen authentische Einblicke in die Welt von Naturwissenschaften und Ingenieurswissenschaften zu bieten. Zusätzlich dazu bietet unser Outreach-Programm Nachwuchswissenschaftler/innen die Möglichkeit, ihre Fähigkeiten im Bereich der Wissenschaftskommunikation auszubauen. Mehr Informationen zu unserem Outreach-Ansatz finden sich **hier**.

Unser Angebot

In den folgenden Abschnitten sind die einzelnen Outreach-Angebote ausführlicher dargestellt:

- **Digitale Medien**
- **Interviews**
- **Öffentliche Vorträge und Aktionen**
- **Für Schulen**
- **Unterrichtsmaterialien**

Science Outreach

Enhancing science communication on biomagnetic sensing through events, materials, training, and research

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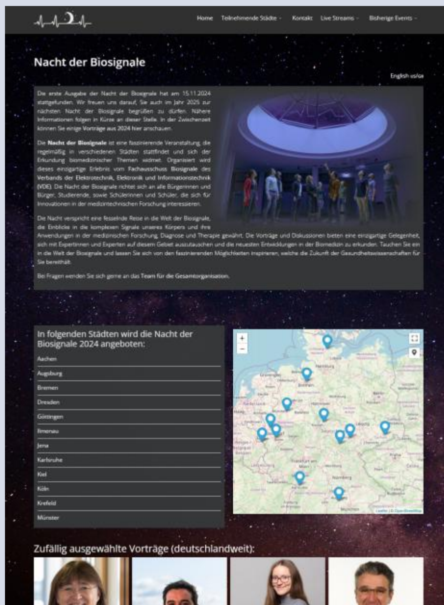
Schools

Events



Night of the Biosignals

Science Outreach

Enhancing science communication on biomagnetic sensing through events, materials, training, and research

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Schools

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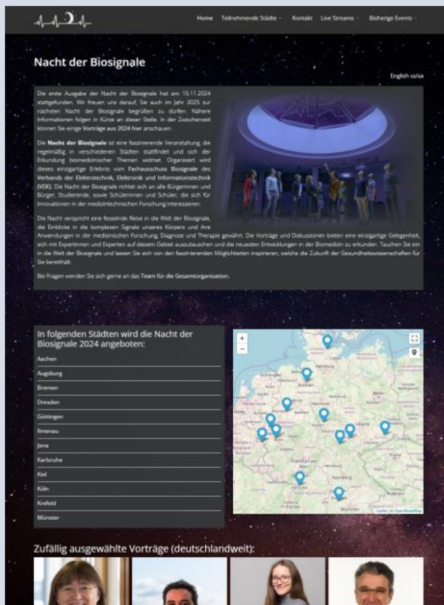
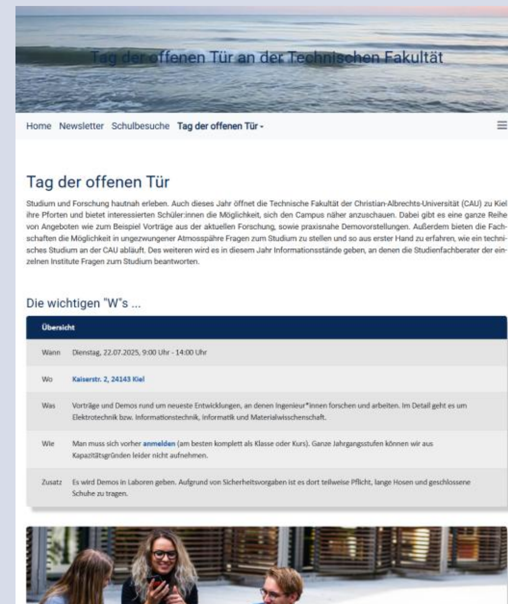


Tag der offenen Tür

22.07.2027
9 Uhr – 14 Uhr



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biomagnetic sensing SFB 1261

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- Basic principle
- First results

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Outlook on school activities

Discussion

SFB 1261

Collaborative Research Centre 1261

Magnetoelectric Sensors:
From Composite Materials to Biomagnetic Diagnostics

Kiel University
Christian-Albrechts-Universität zu Kiel
UNIVERSITÄTSKLINIKUM Schleswig-Holstein
UNIVERSITÄTS KLINIKUM HEIDELBERG
Fraunhofer ISIT
IPN