Medical Information Technology

Faculty of Electrical Engineering and Information Technology

Smart Solutions for Advanced Healthcare

Director

Univ.-Prof. Dr.-Ing. Dr. med. Dr. h.c. (CTU Prague)
Steffen Leonhardt, M.S. (Suny at Buffalo)

Chair for Medical Information Technology,
Helmholtz-Institute for Biomedical Engineering
Pauwelsstr. 20, 52074 Aachen

Phone: +49 (0) 241 80-23211 (office)
Email: medit@hia.rwth-aachen.de
Web : http://www.medit.hia.rwth-aachen.de

Staff (Full time equivalents)

Executive Team
Priv.-Doz. Dr.-Ing. Walter, Marian
Dr.-Ing. Lüken, Markus
Clever-Offermanns, Bettina, Secretary
Glöckner, Daniele, Secretary
Dipl.-Ing. von den Driesch, Patrick, Laboratory Engineer
Thomas, Theo, IT Administrator
Dupont, Felix, Electronics Technician

Senior Advisor/ Emeritus
Prof. Dr.-Ing. Dr. h. c. (CTU Prague) Vladimir Blazek

Associate Lecturer
Priv.-Doz. Dr.-Ing. Misgeld, Berno

Research Associates
Baarlink, Immo, M. Sc.
Blase, Daniel, M. Sc.
Blaß, Nico, M. Sc.
Hoffmann, Raphael, M. Sc.
Hülkenberg, Alfred, M. Sc.
Urban Jacobs, M. Sc.
Khosravi, Nika, M. Sc.
Linschmann, Onno, M. Sc.
Lohse, Arnhold, M. Sc.
Lyu, Chenglin, M. Sc.
Michael, Lorenz, M. Sc.
Prüßmann, Jannik, M. Sc.
Rixen, Jören, M. Sc.
Röhren, Felix, M. Sc.
Salehi, Forouzan, M. Sc.
Silva, Diogo, M. Sc.
Voss, Daniel, M. Sc.

Apprentices
Beaujean, Oskar, Software Developer
Leonel Tchuente, Electronics Technician
Poschen, Alina, Software Developer
Triebe, Tim, Software Developer
Warkentin, Astrid, Software Developer

Guests
09.01.2025 till 31.07.2025
Mahendar Guguloth, B. Sc.(IIT Madras, India)
01.09.2023 till 29.02.2024
Ján Šeleng, M. Sc. (University of Zilina, Slovakia)
17. & 18.11.2025
Prof. Jan Havlík and a group of students from the CTU Prague

PhD Defenses
16.05.2025: Simon Lyra
13.11.2025: Florian Voss
12.12.2025: Jöran Rixen

Highlights, Delegations and Events
- April 2025: New Lecture "Quantitative Physiology"
- June 2025: Field trip to Dräger, Lübeck
- July 2025: Visit of the EMBC in Copenhagen, Denmark
- September 2025: Visit of the BMT in Muttenz, Switzerland
- October 2025: New CAD and 3D printing
- course
- October 2025: Hosting of "Nacht der Biosignale"
- by the VDE
- November 2025: Visit of the "Workshop on Assistive Technologies and Robots in Healthcare, Rehabilitation and Assistance at Work" in Tokyo, Japan
- November 2025: Visit of the IUPESM World Congress on Medical Physics and Biomedical Engineering in Adelaide, Australia
- November 2025: Visit of the A+A trade fair
- in Düsseldorf, Germany
- December 2025: Visit of the MEDICA trade fair in Düsseldorf, Germany with students

Introduction

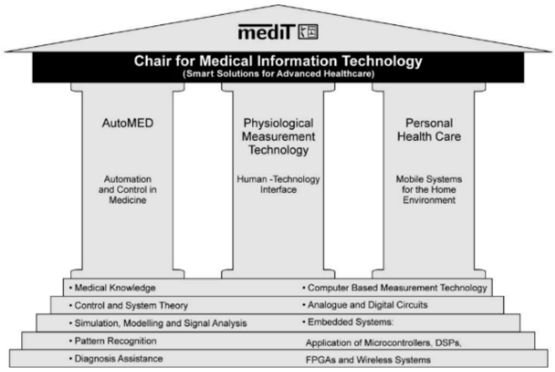

Fig. 1: Research profile of MedIT.

The Chair for Medical Information Technology is particularly concerned with research problems in the fields of “Unobtrusive Measurement Technologies”, “Personal Health Care”, and “Automation and Control in Medicine”. For an illustration of the interaction of these concepts, see Fig.1.

Personal Health Care encompasses wearable medical devices; particularly diagnostic devices designed for use at home. Current technological developments are in the fields of „Intelligent Textiles“ and „Body Area Networks“ (BAN), related basic research areas (e.g., signal processing and motion artifact rejection), and sensor fusion. Due to demographic trends, especially in developed nations, our chair also focuses on the needs of the elderly (e.g., enabling greater autonomy at home).

Automation and Control in Medicine are involved in the modeling of medical and physiological systems and the implementation of feedback-controlled therapy techniques. Research topics include tools and methods for the modeling of disturbed physiological systems, sensor-supported artificial respiration, active brain pressure regulation, and dialysis regulation and optimization.

Where necessary and sensible, unobstrusive measurement technologies (sensors and electronics) are developed. Examples include non-contact sensing techniques (e.g., magnetic bioimpedance), bioimpedance spectroscopy, and inductive plethysmography. Currently, active research is being conducted on the use of biomechatronics.

Ongoing Research – Selected Projects

Admittance-Based Hemodynamic Monitoring

Cardiovascular diseases remain the leading cause of death in the developed world. Owing to conditions such as high blood pressure, atherosclerosis, genetic risk factors, and unhealthy lifestyles in an aging society, more than 400 million people worldwide suffered from cardiovascular disease in 2022, resulting in approximately 18 million deaths. Reduced perfusion of heart muscle tissue, for example, due to coronary artery obstruction, impairs the pumping performance of the heart. The standard of care for these patients consists of drug therapy or support with a heart pump, such as a left ventricular assist device. In both cases, careful monitoring of the patient’s heart function is required. Currently, there is no satisfactory method for determining cardiac function and measuring cardiac output continuously; available techniques are either inaccurate, complex, or unsuitable for continuous monitoring. For implants or temporary applications, one promising new method is based on measuring electrical conductance with an electrode catheter from inside the ventricle, as shown in Fig. 2.

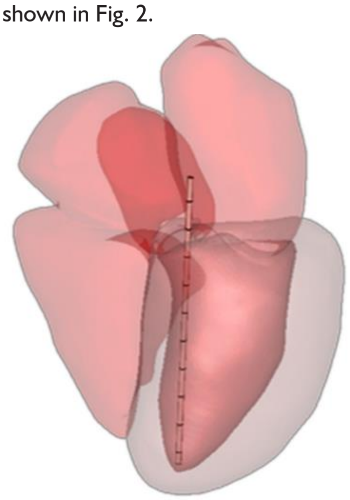

Fig. 2: Simulation model of an admittance measurent in the left heart ventricle.

As blood has a higher electrical conductivity than the surrounding tissues, the conductance correlates with the ventricular volume. Employing appropriate algorithms, it is therefore possible to calculate the volume of the ventricle. From the ventricular volumes in systole and diastole, the stroke volume can be determined and thus the volume of blood pumped into the aorta. At present, the available algorithms require elaborate calibration for accurate measurements, which limits their practicability. The aim of this project is to develop a new algorithm that avoids manual (re-)calibration and thus enables automated continuous monitoring of cardiac function. To this end, we are improving admittance measurement instrumentation using a multichannel setup to perform numerous admittance measurements, supported by computer simulations of the electrical fields and simulated admittance measurements in the heart.

Funded by: German Research Foundation (DFG)

Patient-exoskeleton Synergistic Control with Variable Impedance Actuators

Gait impairments of the lower extremities commonly arise from neurological conditions such as stroke, spinal cord injury, multiple sclerosis, and age-related degeneration. These impairments significantly reduce mobility, independence, and quality of life and are often accompanied by secondary effects, including muscle atrophy. When neuromuscular and skeletal deficits are severe, conventional rehabilitation approaches and orthotic devices provide limited functional support, motivating the use of powered lower limb exoskeletons in medical rehabilitation. Such devices offer the potential to restore functional mobility beyond what is achievable with passive orthoses alone. Powered exoskeletons enable patients to practice standing and walking movements by providing physical assistance, repetitive motion, and sensory feedback, thereby promoting motor recovery through neuroplastic mechanisms. By facilitating high-intensity and task-specific training, these systems can support the reorganization of neural pathways associated with locomotion. However, the clinical effectiveness and user acceptance of such systems strongly depend on how naturally and safely the exoskeleton interacts with the patient. Rigid control strategies with fixed assistance levels often fail to account for patient variability, limit active patient participation, and may compromise gait stability. As a consequence, patients may become passive recipients of motion rather than active contributors to the rehabilitation process. This highlights the need for adaptive control concepts that treat the patient and exoskeleton as a coupled system rather than as independent entities. This project proposes a patient–exoskeleton synergistic control framework based on Variable Impedance Actuators (VIAs) to achieve adaptive, cooperative, and safe gait assistance. The proposed framework explicitly integrates the patient into the control loop, enabling continuous adaptation to changing physical capabilities and rehabilitation progress. As illustrated in Fig. 3, the overall patient–exoskeleton synergistic approach focuses on continuously measuring or estimating human–exoskeleton interaction torques, monitoring the patient's condition and fatigue, and adapting both the control strategy and the level of assistance online according to the patient's current capabilities. By actively regulating actuator stiffness, the system ensures smooth and stable mechanical coupling between the human and the exoskeleton during bipedal gait while maintaining compliance and comfort. In addition, gait stability is continuously analyzed while accounting for human–robot interaction dynamics, enabling the implementation of a fall prevention strategy. Through this integrated patient- in-the-loop concept, the exoskeleton evolves from a rigid assistive device into an intelligent and cooperative partner that enhances patient engagement, improves gait safety, and supports effective and individualized robot-assisted rehabilitation.

Funded by: German Academic Exchange Service (DAAD)

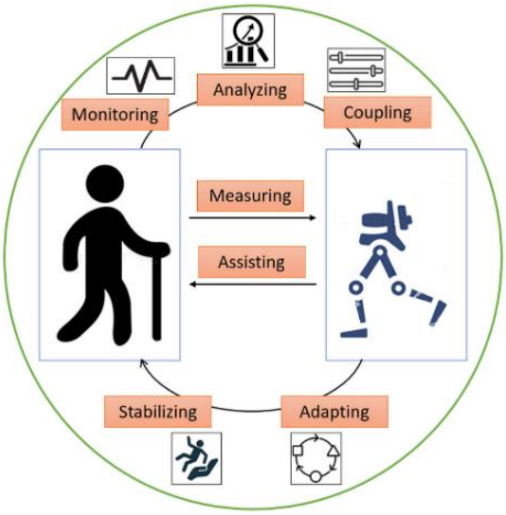

Fig. 3: Patient-Exoskeleton Synergy Concept.

Modelling and Removal of Physiological Motion Artifacts in Capacitive ECG: A cECG Test Bench

Capacitive ECG (cECG) applications have gained momentum in the last two decades, as they can extend cardiac monitoring to everyday life and mighteven replace classical ECG in some instances. However, with every new application scenario proposed for cECG, the limitations of this modality are becoming more evident. In the literature, various improvements and modifications in the sensor design can be found. Similarly, numerous signal processing techniques have been proposed to tackle the biggest challenge of cECG, namely motion artifacts. So far, most solutions revolve around increasing signal coverage so that cECG can be used to monitor the heart rate and the heart rate variability while ignoring the full potential of capacitive ECG. An electrocardiogram is an essential tool for diagnosing arrhythmia, and its waveform is of utmost importance for medical diagnosis. However, the deformation processes of the cECG signal are not well understood yet. Our research group has been trying to explain the deformation of cECG by identifying the origin of these artifacts. By identifying the mechanical vibrations of cardiac and respiratory activity, a distortion in the coupling impedance of cECG measurement can be observed even when there is no active movement of a limb or the torso. This interference from the cardiomechanical signals into the cECG has been called "physiological motion artifacts" to distinguish them from the classical motion artifacts that do not share the same origin as the cECG signal. As mechanocardiography (MCG) signals are time-lagged synchronous with the cECG signal, their artifacts appear as a part of the cECG, likely deteriorating the identification of essential features. This project aims to model and quantify physiological motion artifacts by better understanding of the interaction of cECG and MCG. Therefore, a test bench is designed to mimic the cECG measurement scenario under influence of physiological motion artifacts. Furthermore, the test bench can be used to evaluate different experimental designs of cECG frontends under constant pressure conditions. By modeling the interaction of different cardiac signals in multimodal sensors, the deformation in cECG could be reduced with the goal of regaining some diagnostic power of cECG. Such an improvement would enhance the quality of cECG recordings, e.g., a future home monitoring system or standardized cECG screening in a patient chair during anamnesis.

Funded by: German Research Foundation (DFG)

Fig. 4: Scheme of the cECG test bench. Using two voice coil actuators, the contact pressure of both elec-trode-skin interfaces can be controlled individually. This allows testing with impedance mismatches between the electrodes as well as the modulation of dynamic contact pressures, as induced by cardio-mechanical activity.

Unobtrusive Monitoring of Cardiovascular Parameters

This project investigates unobtrusive, multimodal sensing concepts for the continuous assessment of cardiovascular parameters in everyday environments. Motivated by the high prevalence of cardiovascular diseases and the limitations of conventional, contact-based monitoring technologies, this project aims to enable long-term, unobtrusive observation of cardiac dynamics without compromising user comfort or compliance.

The project is based on a multimodal sensor architecture (cf. Fig. 5) that integrates capacitive electrocardiography (cECG), reflective photoplethysmography (rPPG), and ballistocardiography (BCG). These complementary modalities allow for a robust acquisition of electrical, optical and mechanical signatures of cardiac activity. From the fused signals, a set of physiologically relevant cardiovascular parameters is derived, including heart rate, heart rate variability (HRV), pulse arrival time (PAT), pulse transit time (PTT), and pre-ejection period (PEP). In combination, these parameters provide insight into cardiac timing, vascular properties, stress indications and short-term cardiovascular dynamics beyond isolated vital sign measurements. A key methodological contribution of the project is the explicit integration of BCG sensing into the cECG electrode structure (cf. Fig. 5), enabling the independent estimation of PEP and therefore provide a second stress-related parameter besides standard HRV parameters. Two primary application scenarios are addressed. First, the sensing system was integrated into a patient bed, allowing continuous cardiovascular monitoring during rest and sleep without direct skin contact or attached electrodes. This scenario targets clinical and geriatric care settings, where unobtrusive monitoring can reduce sleep disruption, motion constraints, and measurement-induced bias while enabling extended observation periods and therefore improved diagnostic value (cf. Fig. 6). Second, the project explores integration into an automotive driver seat, transferring the same sensing principles to the mobility domain. Here, cardiovascular parameters are acquired through seat-embedded sensors, enabling continuous assessment of driver state and physiological stress without active user interaction (cf. Fig. 7). This application demonstrates the adaptability of the sensing concept across domains with markedly different boundary conditions.

The project will advance unobtrusive cardiovascular monitoring by combining multimodal sensor fusion, physiological modeling, and application-driven system integration. The results contribute to the development of scalable monitoring technologies suitable for both clinical environments and everyday life, and form the basis for future translational research and field studies at RWTH Aachen University.

Funded by: Daimler and Benz Foundation

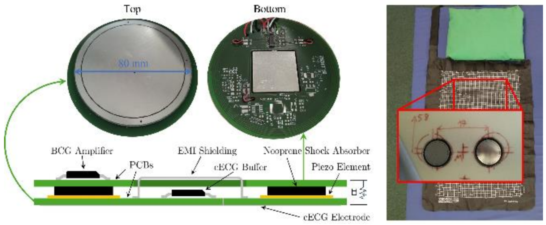

Fig. 5: Implemented measurement system integrating cECG and BCG into a combined measurement system for integration into the everyday environment such as a mattress (right).

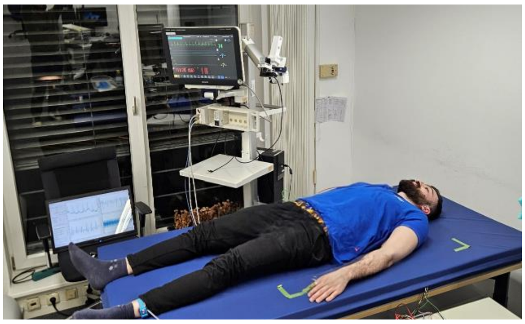

Fig. 6: Unobtrusive monitoring system including cECG, PPG and BCG integrated in the mattress and a subject being attached to a patient monitor for obtaining reference ECG, PPG and blood pressure.

Fig. 7: Unobtrusive measurement of cardiovascular parameters on the driver's seat. Left: Our colleague, Daniel Blase, sitting on the integrated sensor system, and Markus Lüken in the back seat recording cardiac signals. Right: Integrated sensing system on the driver's seat.Fusion of Electrical Impedance Tomography & Ultrasound Tomography

Fusion of Electrical Impedance Tomography & Ultrasound Tomography

Electrical Impedance Tomography (EIT) and Ultrasound Tomography (UST) are both lesser-known, but already clinically used tomography techniques. UST basically works similarly to the well-known CT, just with ultrasound instead of X-ray. A slight difference is that you can not only take the transmission into account, but also the reflected part of the injected ultrasound (see Fig. 8).

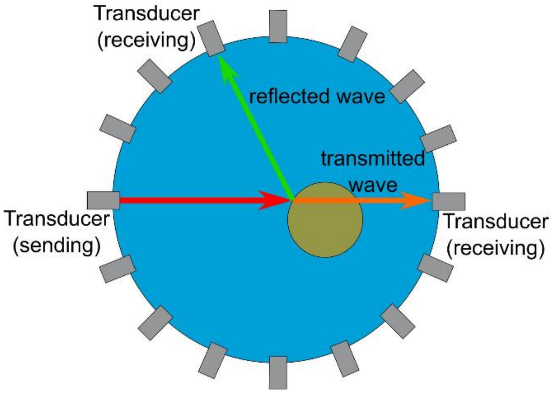

Fig. 8: Functional principle of UST

In EIT, a harmless alternating current is applied to the surface of the patient's body, which leads to a potential distribution on the surface that depends on the body's inner composition. The current injection, as well as the voltage measurements, are normally done using an electrode belt, with the current being fed in from different positions so that as many linearly independent measurements as possible are obtained. Finally, a tomogram of the body can be calculated from this series of measurements (see Fig. 9).

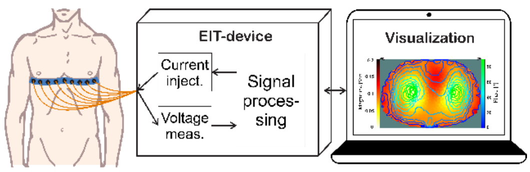

Fig. 9: Typical EIT arrangement.

Both modalities have a considerably lower spatial resolution than CT or MRI, but are characterized by portable, inexpensive hardware and the fact that they work without ionizing radiation. In addition, they offer a temporal resolution sufficient for live images. These properties make them attractive, especially for constant patient monitoring at bedside, in cases where the low spatial resolution is sufficient. For instance, one of the main applications of EIT is determining how well the different regions of the lung are ventilated.

From a diagnostic point of view, the distinction or – even better – the identification of tissue types is particularly interesting, as it would enable, e.g., identifying the reason for non-ventilated lung areas. That's why multi-frequency EIT (mfEIT) is an ongoing research topic, where currents with different frequencies are applied, and the responses are compared. As the electrical impedance of the respective tissues has a characteristic frequency dependence, this method makes it possible to distinguish different types of tissue. Bringing mfEIT and UST together probably has the potential of further improving the tissue recognition, as it enables a finer analysis that takes both electrical and acoustic properties of the tissue into account.

Additionally, for current medical ultrasound, the lung is said to be inaccessible, since the great change in impedance between body tissue and air leads to total reflection. However, more recent research suggests that lower frequencies (than the ones commonly used in medical US) are capable of penetrating the lung. Here, further research is needed to fully understand the underlying mechanism and to assess the diagnostic potential lying in this approach.

An FPGA-based multi-frequency electrical impedance tomograph has already been built. Currently, a low-frequency ultrasound tomography system is under construction. In the long term, it is planned to fuse both modalities. As a patient interface, a belt featuring alternatingly arranged EIT electrodes and US transducers will serve. An early prototype of this is shown in Fig. 10.

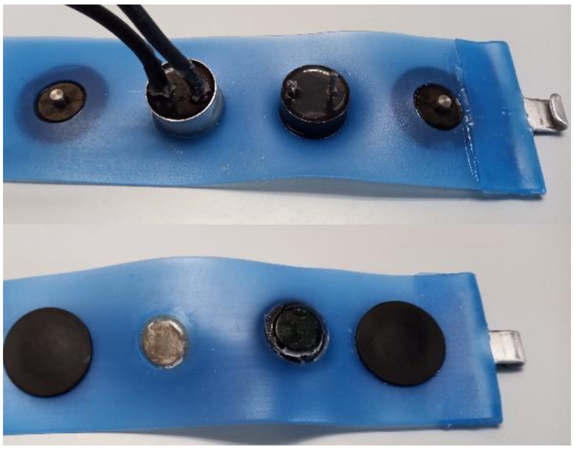

Fig. 10: Belt prototype for combined EIT and UST. EIT electrodes outside, ultrasonic transmitter and receiver inside

Funded by: German Research Foundation (DFG)

Selected References in 2025

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PhD Theses and Honors in 2025

Prizes and Awards

1. March 2025:
   Grant from Daimler and Benz Foundation for Dr.-Ing. Markus Lüken
2. May 2025 :
   POSTER in Prague
   Session Bio- medical Engineering:
   1st place: Nika Khosravi: "State of the Art in Pulsed-Dose Oxygen Delivery for Mechanical Ventilation"
   Session Communications:
   2nd place: Urban Jacobs, Nathan Kühr, Lukas Mardak: "Pulse to Tone Dialling Converter"
   Session History of Science and Technology:
   4th place: Jannik Prüßmann, Immo Baarlink: "A Historical Overview of Electrocardiography: From Early Discoveries to Modern Advances"
3. June 2025:
   DGBMT sponsorship award from the „Klee Family Foundation" for Dr.-Ing. Lukas Bergmann
4. November 2025:
   Announcement that Prof. Leonhardt will be elevated to IEEE Fellow in 2026.

Fig. 11: Dr.-Ing Lyra (May 16th, 2025)

Fig. 12: Dr.-Ing Voss (Nov. 13th, 2025)

Fig. 13: Dr.-Ing Rixen (Dec. 12th, 2025)