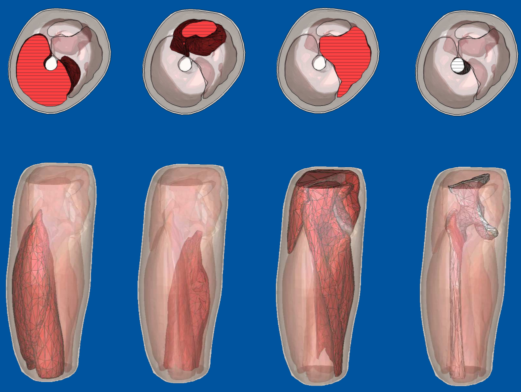
Medical Information Technology

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, D-52074 Aachen

Phone: +49 (0) 241 80-23211 (office)
Fax: +49 (0) 241 80-623211
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
von Platen, Philip, M. Sc.
Clever-Offermanns, Bettina, Secretary
Glöckner, Daniele, Secretary
Dipl.-Ing. von den Driesch, Patrick, Laboratory Engineer
Thomas, Theo, IT Administrator

Senior Advisor/ Emeritus

Prof. Dr.-Ing. Dr. h.c. (CTU Prague) Blazek, Vladimir

Asociate lecturer

Priv.-Doz. Dr. Misgeld, Berno

Research Associates

Badiola, Idoia, M. Sc.
Bergmann, Lukas, M. Sc.
Blase, Daniel, M. Sc.
Blaß, Nico, M. Sc.
Borchers, Patrick, M. Sc.
Hoffmann, Raphael, M. Sc.
Hülkenberg, Alfred, M. Sc.
Jacobs, Urban, M. Sc.
Khosravi, Nika, M. Sc.
Linschmann, Onno, M. Sc.
Lohse, Arnhold, M. Sc.
Lyu, Chenglin, M. Sc.
Prüßmann, Jannik, M. Sc.
Rixen, Jören, M. Sc.
Röhren, Felix, M. Sc.
Salehi, Forouzan
Silva, Diogo, M. Sc.
Voß, Florian, M. Sc.
Voss, Daniel, M. Sc.

Apprentices

Beaujean, Oskar, Software Developer
Dupont, Felix, Electronics Technician
Leonel Tchuente, Electronics Technician
Trödel, Cedric, Software Developer
Warkentin, Astrid, Software Developer

Promotionen

18.04.2024: von Platen, Philip
31.10.2024: Bergmann, Lukas

Guests

01.09.2023 till 29.02.2024
Dr. Kazi Jabed Akram (IIT Madras, India)

Delegations and events

- In Mai 2024, the MedIT team and almost 20 students visited Inomed and Stryker.
- On June 27 2024, Prof. Leonhardt provided a presentation at the InCabin Sensing event: "Unlocking the Secrets of Vital Signs in Your Car Seat - A Journey into Unseen Monitoring Techniques".
- On July 15 2024, the MedIT team participated in a Mini-Symposium titled "Recent Advances in Bioimpedance as a Tool for the Assessment of Muscle Condition" at the IEEE EMBC in Orlando.
- From September 8th to 12th 2024, a MedIT delgation attended the "Computing in Cardiology 2024" in Karlsruhe.
- In November 2024, a MedIT delgation and interested students visited the MEDICA in Düsseldorf.
- From November 11th to 12th 2024, a student delegation from CTU Pragug led by Prof. Jan Havlik visited our department to learn about activities in the field of medical technology.

Introduction

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 intection of these concepts, see Fig. 1.

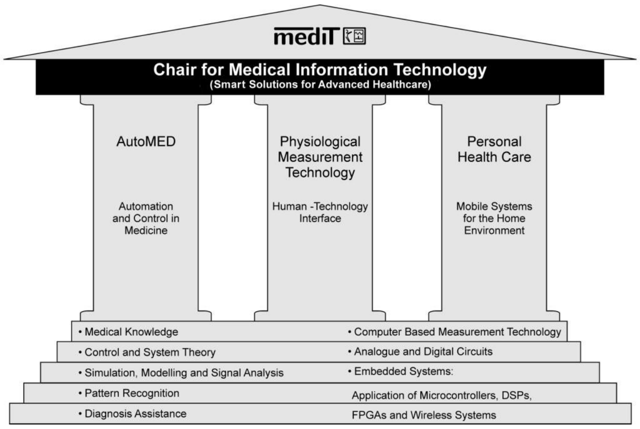


Fig. 1: Research profile of MedIT.

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

Ergonomic mobility assist for older adults using exoskeletons

Demographic changes in Germany will fundamentally change the way we deal with aging and mobility in the coming years. One in three people in Germany will soon be over 65 years old, with the number of over-85s in particular set to rise disproportionately. This will have a significant impact on social systems, which will face the major challenge of supporting a growing number of older adults with increasing age-related and illness-related limitations. One of the main functional limitations of old age is the geriatric syndrome of frailty. A decrease in muscle mass and muscle strength (sarcopenia), degenerative diseases such as rheumatism and arthritis, and other age-related processes mean that an increasing number of movements and actions relevant to everyday life can no longer be performed adequately. A reduction in everyday movements due to age-related processes leads to a self-reinforcing downward spiral, which means that more aspects of life can only be managed with external help. Although the purely passive aids currently available (e.g., walking sticks, rollators, and hand grips) can provide support, they cannot interact actively. To counteract this downward spiral, active exoskeletons can be used on the lower extremities. Such an exoskeleton can help to compensate for these functional limitations by providing targeted support for movement sequences. To provide support, they most often use electric motors to apply torque to the joints of the wearer. In contrast, passive exoskeletons only assist movement using elements such as springs, which do not allow torque adaption according to the movement sequences.

When using exoskeletons to support movement, various key aspects must be fulfilled by the exoskeleton. These include an age-appropriate application and operating concept as well as gender-adaptive support and adjustability of the exoskeleton. In addition, the use of Inertia Measurement Units and the measurement of ground reaction forces can be used to draw conclusions about the stability of the movement and to counteract an impending fall. The measurement of vital parameters also makes it possible to provide support adapted to the patient’s state of health and diagnose health problems. Finally, the exoskeleton can be combined with other assistance systems, such as rollators, to further increase the stability of locomotion. Fig. 2 shows an example scenario of how an exoskeleton can be used in the daily lives of older adults.

Fig. 2: Usecase scenario of an exoskeleton for older adults.

Need-based muscle assessment in an aging society

In wealthy countries, a constant increase in life expectancy has created new challenges for today’s health care systems. Age-related loss of muscle mass, strength, and function, referred to as sarcopenia, appears to be a key driver of the physical frailty phenotype. This phenotype results in a significant decrease in independence and quality of life. Therefore, non-invasive measurement modalities to assess muscle condition and performance for therapy planning are in high demand.

The combination of Electrical Impedance Myography (EIM) and Electromyography (EMG) has shown to be a promising tool to analyze geometric, physiological, and metabolic properties of muscles. Both approaches are highly sensitive to the applied electrode placement, which requires accurate and comprehensive Finite Element Method (FEM) simulations to address questions such as the definition of an optimal electrode placement along specific muscle groups. We created an anatomically correct model of the human thigh, consisting of anterior, posterior, and medial muscle compartments, to simulate the effects of movements of the lower leg. The model is complemented by the femur, subcutaneous fat, and surrounding skin layer, see Fig. 3.

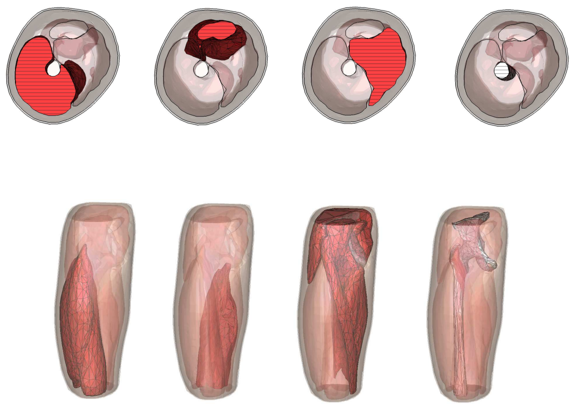


Fig. 3: Visualization of the developed thigh model, anterior, posterior, and medial muscle compartment in cross-sectional (top) and frontal view (bottom).

To analyze the impact of leg extension and flexion exercises on the thigh muscles, we created a motor controlled testing environment. The environment enables continuous monitoring of EMG, EIM, torque, and angle signals during leg extension exercise, see Fig. 4. The setting enables to analyses the impact of either quasi-stationary muscle state, meaning maintaining either a constant angle or torque during measurement, or dynamic muscle activation, as for instance rotating the leg within the knee joint's range of motion.

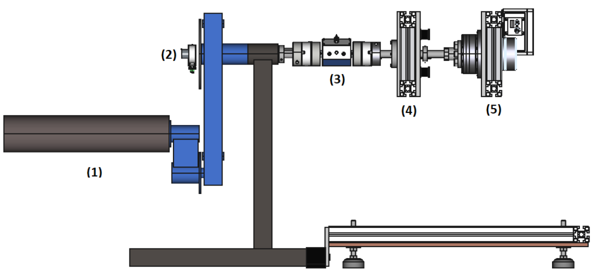


Fig. 4: Schematic of the assembled test-bench, consisting of (1) leg extension training device, angle sensor (2), torque sensor (3) angle limiter (4), and motor-gear combination (5).

In combination, the fine tuning of electrode placement and the performance of guided movements in a limiting environment should provide deeper insights into the superimposed geometrical and physiological processes shaping EIM and EMG signals and their relation to the dynamic process of muscle contraction and relaxation. In the future, this may pave the way for new types of muscle function tests.

Funded by: German Research Foundation (DFG)

Contactless Monitoring of Vital Signs Using a Bedside System

According to the WHO, cardiovascular diseases (CVDs) are the leading cause of death worldwide. Although personal risk factors, such as unhealthy diet, lack of physical activity, and smoking, are well known, the incidence of CVDs is still increasing. Typically, screening for CVDs is performed only if patients already have symptoms or during widespread checkups. However, the ability to detect CVDs in at early stage is crucial for intervention as soon as possible and for enhancing patients' chances of survival. Conventional methods, such as electrocardiography (ECG), require direct skin contact via electrodes, making them unsuitable for continuous home monitoring. In contrast, contactless monitoring techniques have the potential to overcome these limitations by eliminating the need for direct contact. These methods can be integrated into objects of everyday life, such as beds, car seats or desk chairs. An example of a bedside system is shown in Fig. 5.

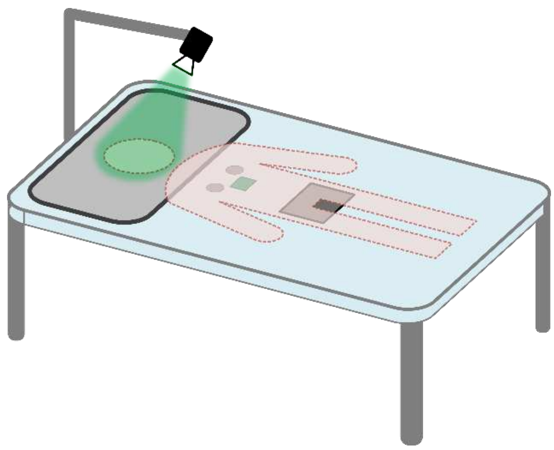


Fig. 5: Schema of a contactless bedside monitoring system.

Our system comprises four bed-integrated sensors and two cameras. The sensors, implemented into the mattress, can measure heart and lung activity using various approaches, including capacitive, inductive, mechanical, and optical measurement techniques. Furthermore, an RGB camera enables tracking of the patient's position and movements. In addition, it allows the extraction of heart activity from the facial region. The second camera is an infrared camera, which is primarily used to monitor a patient's temperature but can also be utilized for movement tracking in low-light conditions, where the quality of the RGB camera is insufficient.

Each of these sensors has unique strengths and limitations, but they share a common challenge. Because they operate without direct skin contact, they tend to suffer from significantly reduced signal quality compared with traditional methods. In addition, if a patient moves during a measurement, it is nearly impossible to accurately extract vital signs from a single sensor reading. Therefore, our system includes a large number of different sensors whose data are fused in the data processing step. If one sensor does not measure sufficient data or only measures motion artifacts, others can compensate for this.

Once validated, this setup will be further expanded to automatically detect various CVDs and advise patients to visit doctors.

Funded by: German research foundation (DFG)

Contactless and Multi-modal Analysis of Wounds using Deep Learning

The term "chronic wound" refers to a breach of our protective barrier, the skin. Here, the orderly wound healing process somehow stagnates, often during the inflammatory stage. To timely treat or even prevent such wounds, early detection and close supervision of conclusive wound parameters are desired, such as dimensions, oxygenation, and temperature distribution. This procedure could not only improve the treatment but also reduce the costs and stress for patients. Therefore, this project envisions the relief of healthcare professionals in hospitals or outpatient care from paper forms, disposable rulers, and subjective, educated guesses during (chronic) wound evaluation by developing a small, mobile, AI-based and contact-less 1-Click-Solution. With this in mind, multiple camera-based measurement techniques have been employed, such as infrared thermography, hyperspectral imaging, depth vision, and color vision.

To interpret the measurement results, simulations were conducted to form and test the hypotheses. Fig. 6 shows a Monte Carlo simulation of the light tissue interaction in a multi-layer skin model.

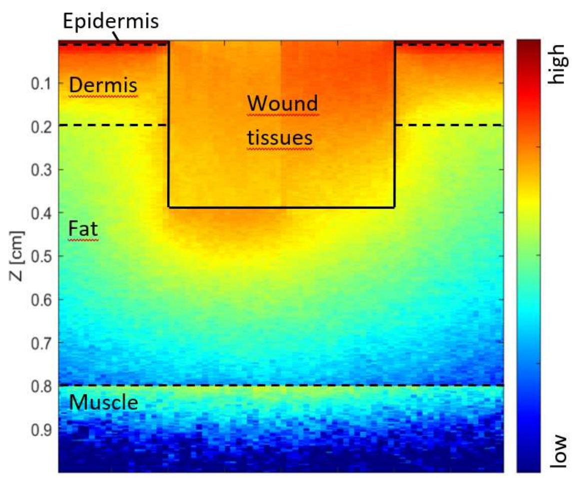


Fig. 6: Light-tissue interaction as absorbed power in a stage 2 pressure ulcer.

A few impressions of the thermal conductivity simulations in wounded human tissue are shown in Fig. 7. Where appropriate, machine-learning algorithms are trained to assist with the automated wound analysis by segmenting the wound from the background, classifying the wound stage, or determining the affected body part. AI can also be used for data generation. To run these algorithms on a mobile device, energy-efficient yet powerful hardware must be used. As conventional GPUs will not suffice in this regard, this project is embedded into the future cluster NeuroSys. Together with over 30 academic and industrial project partners, this cluster aims to establish a leading local industry for the development, production, and mastering of neuromorphic chips specifically designed for AI applications.

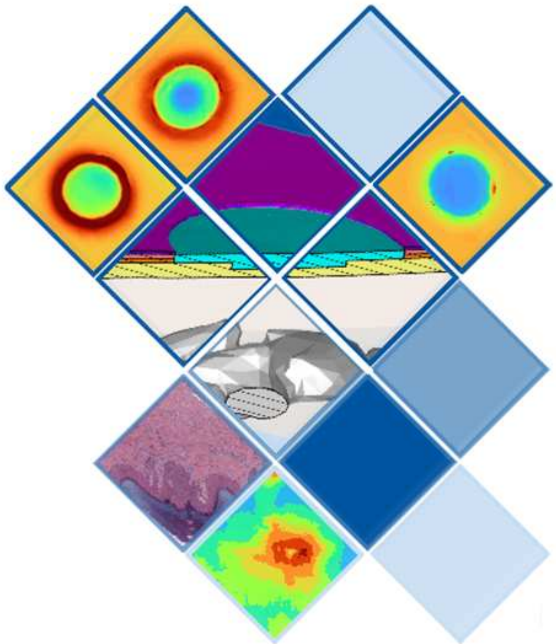


Fig. 7: Thermal simulations of different stages of pressure ulcers (image by J. Monissen).

Funded by: German Federal Ministry of Education and Research (BMBF).

Modeling of High Pressure Solenoid Valves

The COVID-19 pandemic has resulted in a significant shortage of ventilators, and the re-production rate was limited by insufficient supply chains. Following common topologies, proportional high pressure solenoid valves (HPSV) based on magnetic actuation are widely used for the dosage of inspiratory flow to the patient. Its control is therefore crucial for precision and safety but also challenging as the system behaviour is strongly non-linear (hysteresis). A model-based approach for control tuning including a toolchain for system identification would be beneficial to enable incorporation of a variety of arbitrary valves. Instead of focusing on the separate electrical, mechanical or pneumatic domains to establish a circuit diagram of the valve, it is desired to examine the overall system behavior.

Therefore, this research focuses on different models of hysteresis and their precision when being applied to actual measurement data of high pressure solenoid valves as a foundation for a following model-based control approach which can be either feedback or feedforward based on the inverse model. As as example, Fig. 8

shows the fitted hysteresis loops of the Prandtl-Ishlinskii (PI) model. The input signal is chosen as quasi-static with a slow variation above the opening duty cycle of the valve.

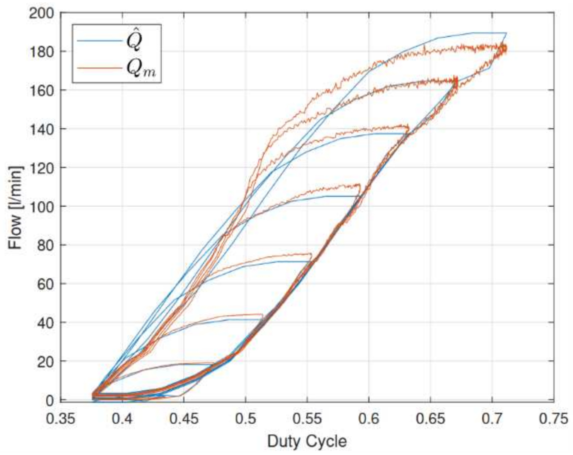


Fig. 8: Fitted hysteresis curve of the Prandtl-Ishlinskii model $\hat{Q}$ which maps the flow as a function of the duty cycle, compared to measured data Q_m.

The hardware setup for flow measurement was arranged as follows: A proportional solenoid control valve type 2873 (Bürkert Fluid Control Systems, Ingelfingen, Germany) was supplied by a pressure of 3 bar and driven by an amplified 24 V pulse width modulated (PWM) signal resulting in an operational flow range of 0 to 200 L/min. A single flow sensor (SFM3300, Sensirion, Stäfa, Switzerland) was attached to obtain the data against atmospheric pressure. The PI model performed with an mean average error (MAE) of less than 2.5 L/min.

In upcoming projects the dynamic and its influencing factors are to be identified and combined with the quasitstatic behavior. After validating the overall model different control approaches will be applied.

Selected References in 2024

[1] G. Scaramuzzo, B. Pavlovsky, A. Adler, et al. (2024), "Electrical impedance tomography monitoring in adult ICU patients: state-of-the-art, recommendations for standardized acquisition, processing, and clinical use, and future directions.", Critical Care, doi: https://doi.org/10.1186/s13054-024-05173-x

[2] M.M. Deininger, D. Ziles, A. Borleis, et al. (2024), "Breath-by-breath comparison of a novel percutaneous phrenic nerve stimulation approach with mechanical ventilation in juvenile pigs: a pilot study.", Scientific Reports, doi: https://doi.org/10.1038/s41598-024-61103-5

[3] F. Voss, P. Grünter, J. Wolski, S. Leonhardt, and M. Lüken, "Hardware-in-the-loop setup for contactless skin servo control of neonatal incubators", Biomedical Signal Processing and Control, doi: https://doi.org/10.1016/j.bspc.2023.105628

[4] A. C. Hülkenberg, C. Ngo, R. Lau, and S. Leonhardt, "Separation of ventilation and perfusion of electrical impedance tomography image streams using multidimensional ensemble empirical mode decomposition", Physiological Measurement, doi: https://doi.org/10.1088/1361-6579/ad5c39

[5] A. Lohse, P. Von Platen, S. Leonhardt, and M. Walter, "Robust control of oxygen saturation during mechanical ventilation", Lékař a technika-Clinician and Technology, doi: https://doi.org/https://doi.org/10.14311/CTJ.2024.1.01

[6] L. J. Reichelt, I. Badiola, V. Blazek, S. Leonhardt, and M. Lüken, "Development of a Ring-Shaped Pulse Oximeter to Analyse Angle Dependency in SpO2 Estimation", Proceedings of the 51st international Computing in Cardiology conference, doi: https://cinc.org/archives/2024/pdf/CinC2024-260.pdf

[7] R. Bayford, R. Sadleir, I. Frerichs, T. I. Oh, and S. Leonhardt, "Progress in electrical impedance tomography and bioimpedance", Physiological Measurement, doi: https://doi.org/10.1088/1361-6579/ad68c1

[8] A. Lohse, M. M. Deininger, J. Loeser, et al., "A physiological model of phrenic nerve excitation by electrical stimulation", Biomedical Physics & Engineering Express, https://doi.org/10.1088/2057-1976/ad1fa3

[9] P. Borchers, S. Leonhardt, and M. Walter, "Modeling and Control of an Automated Hemolysis Test Bench", IFAC-PapersOnLine, doi: https://doi.org/10.1016/j.ifacol.2024.11.012

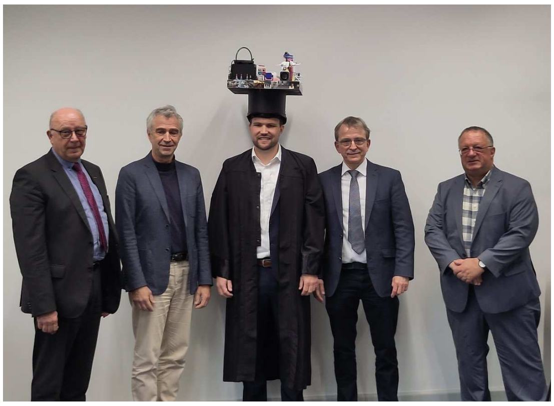
[10] P. von Platen, A. Abdelsamed, A. Lohse, et. al., "Robust closed-loop control of systemic oxygenation in acute lung injury", Biomedical Signal Processing and Control, doi: https://doi.org/10.1016/j.bspc.2023.105532

Prizes and Awards

1. During the Workshop Biosignals in Göttingen, the MedIT team has been rewarded with the 1st (I. Badiola) and 3rd (F. Voß) price for the best oral presentation.
2. Prof. Leonhardt has been elected as a member of the DFG Review Board 407 "Systems Engineering", subject area 4.41-06 "Biomedical Systems Technology" (for the period 2024-2027).
3. During the 28th International Student Conference on Electrical Engineering POSTER, the MedIT team has been rewarded with the 1st (D. Blase and P. Xie), 3rd (J. Prüßmann) in the session Biomedical Engineering and the 3rd (N. Blass and F. Voss) price in the session History of Science and Technology.
4. Dr. Tobias Menden has been awarded with the 2nd "Klee-Price" by the German Society for Biomedical Engineering in the VDE (DGBMT).
5. Simon Lyra and co-authors have been awarded with the Nightingale Award 2022, for their article "Camera fusion for real-time temperature monitoring of neonates using deep learning", which has been published in the journal Medical & Biological Engineering & Computing.
6. Prof. Leonhardt has been elected a Fellow of Asia-Pacific Artificial Intelligence Association (AAIA)
7. At this year's AUTOMED Symposium in Villingen-Schwenningen, Prof. Leonhardt was honored with the VDI Plaque of Honour for his many years of commitment to the Society of Measurement and Automation Engineering (GMA).
8. Prof Leonhardt has been elected to the German Academy of Science and Engineering (acatech), a prestigious private not-for-profit scientific academy.

The MedIT Team

Promotionen and received awards in 20204



von Platen, Philip (Apr. 18, 2024)

Bergmann, Lukas (Oct. 31, 2024)

Election as acatech member (Oct. 15, 2024)

VDI Plaque of Honour (Nov. 09, 2024)