mediT

Medical Information Technology

Faculty of Electrical Engineering
and Information Technology

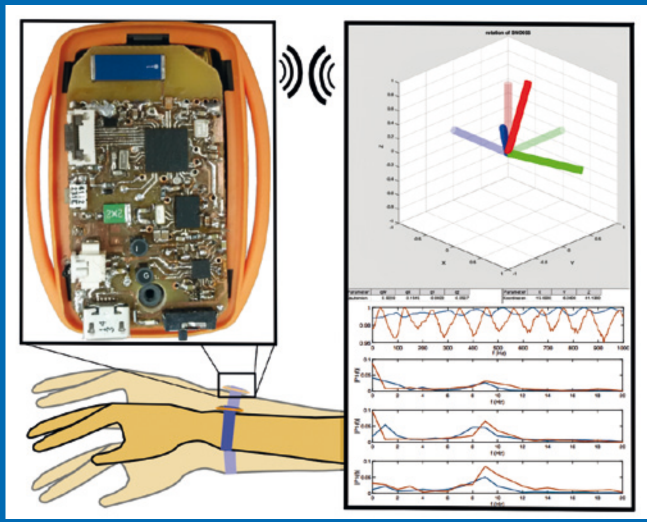
# Smart Solutions for Advanced Healthcare

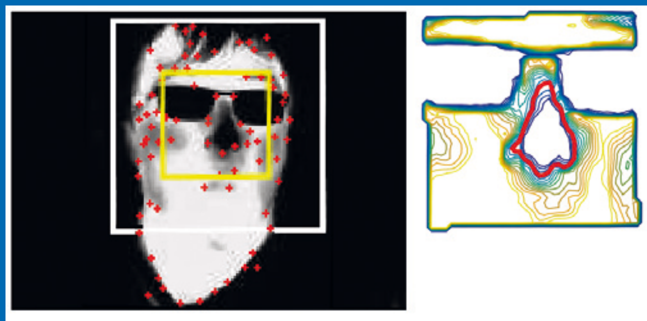
## Director

Univ.-Prof. Dr.–Ing. Dr. med.
Steffen Leonhardt, M.S.

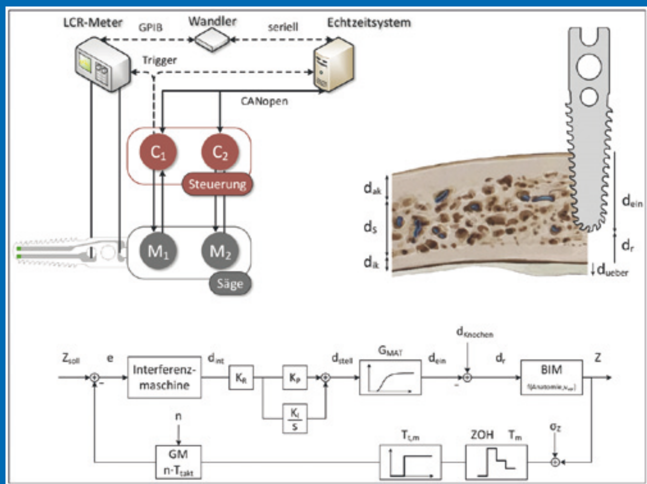
Philips Chair for Medical Information Technology
Helmholtz-Institute for Biomedical Engineering
Pauwelsstrasse 20
52074 Aachen

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





(a) Face detection and tracking (b) Nose detection




## Staff (Full time equivalents)

Walter, Marian, Dr.-Ing., Senior Scientist
Misgeld, Berno, Dr.-Ing., Senior Scientist
Teichmann, Daniel, Dr.-Ing., Senior Scientist
Venema, Boudewijn, Dr.-Ing., Senior Scientist

Blazek, Vladimir, Prof. Dr.-Ing., Senior Advisor/Emeritus

Balzer-Sy, Heidi, Admin. Assistant
Clever-Offermanns, Bettina, Admin. Assistant
Tholen, Toni, Dipl.-Ing., Laboratory Engineer
Wrobel, Walter, Dipl.-Ing., Laboratory Engineer
Thomas, Theo, IT Administrator
Fischer, Marc (apprenticeship)
Friedeheim, Gustav (apprenticeship)
Windeln, Fabian (apprenticeship)

Aguiar Santos, Susana, M.Sc.
Barbosa Pereira, Carina, M.Sc.
Böhm, Anna, Dipl.-Ing.
Castelar Wembers, Carloas Emilio, M.Sc.
Hentze, Benjamin, Dipl.-Ing.
Hochhausen, Nadine, Dr. med.
Hoog Antink, Christoph, Dipl.-Ing.
Ismail, Abdul Hamid, M.Sc.
Korn, Leonie, M.Sc.
Leicht, Lennart, Dipl.-Ing.
Liu, Lin, M.Sc.
Lüken, Markus, M.Sc.
Menden, Tobias, M.Sc.
Ngo, Chuong,, Dipl.-Ing.
Orschulik, Jakob, M.Sc.
Paul, Michael, M.Sc.
Penzlin, Bernhard, Dipl.-Ing.
Pomprapa, Anake, Dr.-Ing.
Rüschen, Daniel, M.Sc.
Vetter, Pascal, M.Sc.
Weyer, Sören, Dipl.-Ing.
Yu, Xinchi, M.Sc.

## Guests

Ismail, Abdul Samad, Dr. (UTM, Malaysia)
Ahmad, Nor Bahiah, Dr. (UTM)
Wan Kadir, Wan Nasir, Dr. (UTM)
Mustaffa, Noorfa Haszlinna, Dr. (UTM)
Isnin, Ismail Fauzi, Dr. (UTM)
Jamaludin, Najeb bin, Dr. (UTM)
Thangavelu, Ir.Sasikala Devi (UTM)
Hariyanti, Murni (UTM)
Ma, Qingchuan (Tsinghua University, China)

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## Introduction

The Philips Chair for Medical Information Technology is especially concerned with research problems in the **field of "Unobtrusive Measurement Technologies", "Personal Health Care",** and **"Automation and Control in Medicine".**

The topic *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, the laboratory also focuses on the needs of the elderly (e.g. enabling greater autonomy at home).

Automation and Control in Medicine is involved with 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, sensors and measurement electronics are developed, for example, in the areas of non-contact sensing techniques (e.g. magnetic bioimpedance), bioimpedance spectroscopy and inductive plethysmography. Active research is currently conducted in biomechatronics.

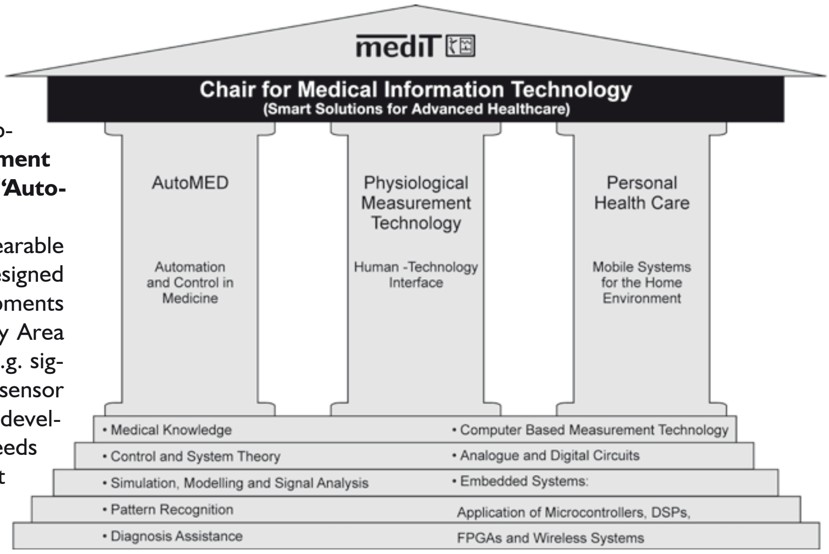


*Fig. 1: Research profile of MedIT.*

## Selected Ongoing Research Projects

### Monitoring of Respiratory Rate in Newborn Infants using Thermal Imaging

Respiration is one of the most important physiological processes. Principally, respiratory rate (RR) can be used as an early and solid predictor of cardiopulmonary arrest, intensive care admission or death. However, it is one of the most frequently undocumented and underestimated vital signs. According to the literature, RR is usually neglect due to shortcomings of current clinical monitoring techniques. These modalities require attachment of sensors to the infant's body leading to stress and discomfort. Moreover, removal of adhesive electrodes in preterm babies induce pain and epidermal stripping. In recent years, there has been an increasing interest for unobtrusive, contactless and reliable monitoring modalities to estimate RR. They aim to improve patients' quality of life as well as the use of medical resources. Thermal imaging is a remote and passive technique, which detects the radiation naturally emitted from an object, in this case the human skin, and does not use any harmful radiation. Moreover, thermal imaging does not need a light source. This particular characteristic is one of the biggest advantages of infrared tomography (IRT) over other imaging technologies.

There are different approaches to estimate RR in thermal videos. The most common is based on the fact that temperature around the nostril oscillates during the respiratory cycle. It consists of one inspiration, where cold air from the environment is inhaled, followed by one expiration, where warm air from the lungs is exhaled. Thermal imaging can be used to accurately detect these temperature fluctuations. Thus, the nose (region of interest - ROI) must be automatically located in the first frame. Forthwith, a rough tracking of the ROI must be performed to compensate motion artefacts. Lastly, the breathing waveform can be extracted and used for estimation of RR.

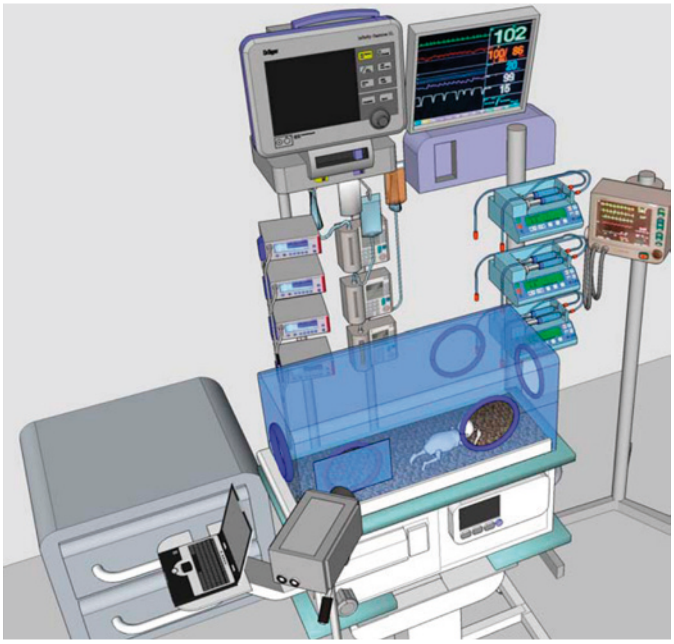

*Fig. 2: Monitoring system of respiratory rate based on thermal imaging in a newborn infant.*

**Funded by:** Fundação para a Ciência e a Tecnologia (FCT Portugal)

## Smart Dialysis – Optimization of Hemodialysis by means of Multimodal Monitoring

Over the last few decades, continuous advances in dialysis technologies have increased the safety and efficacy of hemodialysis (HD). Nevertheless, the improved patient care has not translated into a clear improvement of survival rates. At present, the most common acute complications during hemodialysis are hypotension (20 - 30 %), muscle cramps (5 - 20 %), nausea and vomiting (5 - 15 %), and headache (5 %). Intradialytic hypotension (IDH) is defined as a symptomatic drop in systolic blood pressure of more than 25 mmHg or as an absolute systolic blood pressure below 90 mmHg. The causes of IDH are multifactorial. Main underlying factors are volume depletion induced by rapid removal of plasma volume with an ultrafiltration rate (UFR) higher than the plasma-refilling rate as well as impaired compensatory mechanisms. Negative effects of intradialytic hypotension include patient discomfort, a decrease in hemodialysis efficacy, and an increase in the need for medical interventions. More importantly, IDH-prone patients exhibit a higher mortality than those without intradialytic hypotension.
Thus, the project aims at integrating continuous BIS measurements into the clinical dialysis procedure, in order to establish a diagnostic method for the early detection of blood pressure instability and the prediction of dialysis outcome. This method is planned to be combined with non-contact vital sign monitoring to produce a real-time multimodal monitoring system. Our hypothesis is, that this multimodal system can predict IDH episodes and, if needed, support the adjustment of ultrafiltration profile and dialysate fluid composition. A further aim of the project is to develop a model, which is able to explain the hypotensive reaction. Such a model will serve as a basis for the establishment of early warning predictors of hypotensive episodes. These predictors will be based on vital signs like electrocardiogram (ECG), photoplethysmography (PPG), breathing and facial temperature imaging.

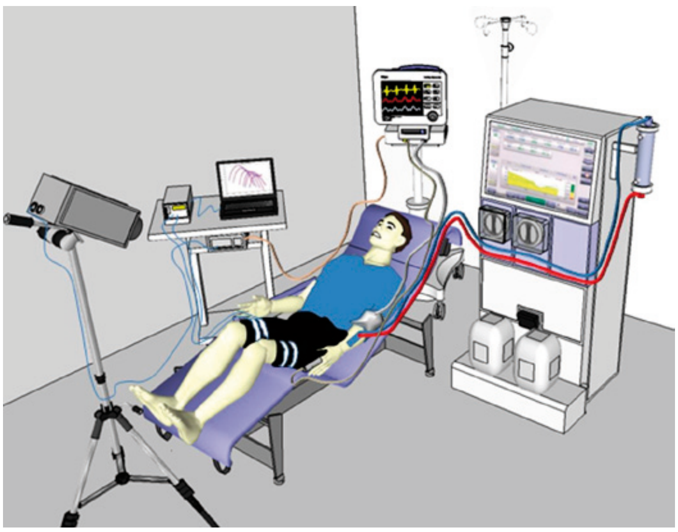

*Fig. 3: Smart dialysis system with multimodal monitoring.*

## Driver State Monitoring

Self-driving cars become reality in the automotive industry. The first test vehicles already find their own way on highways and in dense rural areas. It is expected that, in 2025, this will be a normal course of life. One crucial part of autonomous driving is the so-called handover, so that the automatic driving mode hands over all control to the human driver, for example in a difficult traffic situation that exceeds the capabilities of the automated system. But how can it be guaranteed that the driver is capable of taking over the steering wheel? In some situations such as sleeping or unconsciousness, a monitoring of the driver status is necessary, including driver's behaviour and driver's condition. Especially, the medical condition of the driver is of great interest.


*Fig. 4: Automated monitoring of driver state.*

Driver state monitoring has its own history at MedIT. In 2007, we first introduced non-contact ECG in a car, demonstrating its feasibility for heart rate monitoring and detection of driver stress. Since 2013, the project has been extended to assess driver states with respect to distraction and workload, being two risk factors for car accidents. Currently, the project incorporates a larger portfolio of different sensors, in particular cameras, recording physiological and behaviouristic driver data. All sensors have been integrated into a test vehicle offering an interesting and unique research platform. Using data recorded during test drives on a dedicated test facility with a well-defined distraction and workload profile, we intend to derive metrics to assess and predict driver states. This metrics can be used not only for securing handover procedures, but also for risk mitigation. For example, the exhaustion of human driver should be detected and autonomous driving systems can take over the control.

**Funded by:** Ford Motor Company, European Commission

## Oscillatory Electrical Impedance Tomography (oEIT)

Assessment of mechanical lung properties is of prime importance for respiratory monitoring and diagnosis of lung diseases. Oscillatory Electrical Impedance Tomography is a new technology combining two non-invasive methods, the lung function test forced oscillation technique (FOT), and the electrical impedance tomography (EIT) for respiratory online monitoring. FOT is based on measurements of the complex respiratory impedance over a frequency range between 4 and 30 Hz, where sinusoidal forced pressure signals created by the FOT device are superimposed on the patient's spontaneous breathing. By capturing the responding flow at the airway opening, the frequency response of the system and lung parameters can be estimated.
The basic principle of EIT is based on the injection of a harmless alternating current into the human thorax through a 16-electrode belt. By rotating the injecting current based on the adjacent electrode pair and measuring the resulting voltages, an impedance distribution can be scanned with a high dynamic frequency (50 Hz). EIT provides dynamical information about global and regional ventilation by reconstructing 2D cross-sectional images, which are strongly correlated with the regional ventilation lung volume. Performing EIT simultaneously during a FOT measurement provides additional 2D EIT images at different frequencies. Each pixel of the image includes three frequency components: the spontaneous breathing, the heartbeat and the oscillation. New features such as oscillatory tidal image and phase delay distribution should provide useful information on detection and localization of lung diseases. A measurement system was constructed and illustrated in Fig. 5. Oscillatory tidal image shows how oscillation signals are distributed in lung and heart regions.

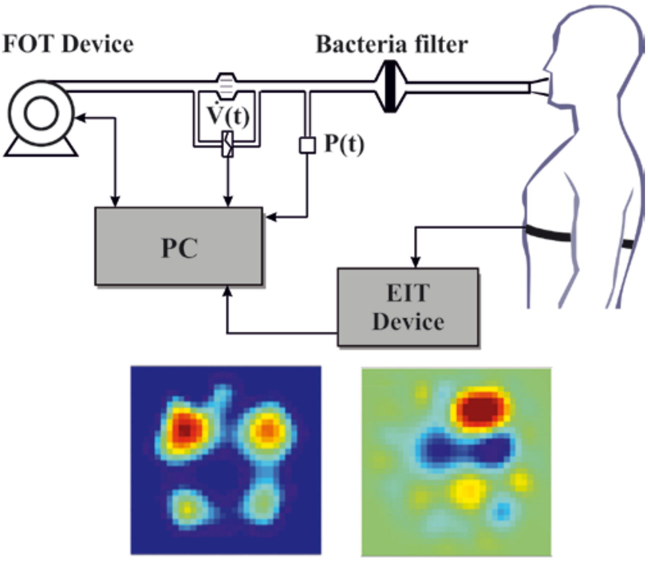


*Fig. 5: System configuration of oEIT.*

## Robust Physiological Control of Rotary Blood Pumps

Ventricular assist devices (VADs) are increasingly used to treat advanced stage heart failure. If the native heart is unable to maintain a sufficient blood flow to the organs, a VAD can be used to restore this function and relieve the heart. However, setting the appropriate VAD speed for a particular heart failure patient requires lots of experience. We thus use robust control methods to automatically adjust the pump flow such that the patient's blood flow demand is satisfied. Our system, called Assistance, offers the treating physician a single, intuitive setting option for continuous-flow left VADs (LVADs).

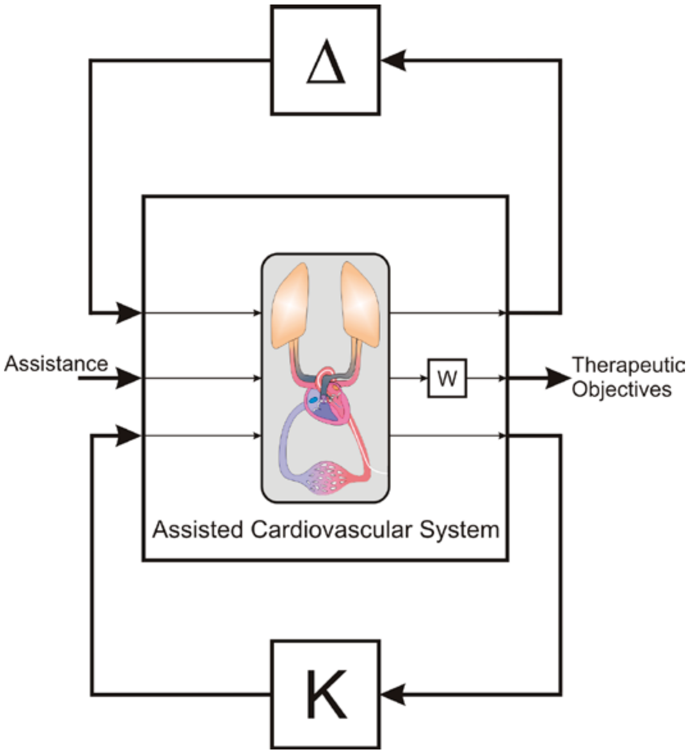


*Fig. 6: Robust control of rotary blood pump.*

The Assistance is defined by the time-averaged ratio of LVAD flow and total cardiac output. A proportional-integral controller sets the pump speed to keep the Assistance at the predefined level. The LVAD amplifies the remaining physiological control loops and supports the native heart function. The controller optimally complements the native blood flow and pressure regulation by including a frequency domain description in the controller synthesis. The system is implemented using a dSPACE real time system with Abiomed Impella CP in an ovine animal model for acute myocardial infarction. A continuous measurement or estimation of pump flow and total cardiac output is then required. However, for the case that the control loops affecting the cardiac output are unimpaired, the Assistance control strategy can sufficiently maintain the systemic circulation. Therapies with targets such as recovery or weaning can be acheivable.

**Funded by:** German Federal Ministry of Research (BMBF)

## Mechatronics in Rehabilitation

Robot-aided rehabilitation can be classified as an intelligent mechatronic system. In this work, three main aspects, namely mechanical design, electronics and patient-cooperative control strategies are of concern. The challenge of rehabilitation robot is to design a light-weight actuator for wearing comfort. The development of a variable stiffness actuator (VSA) is carried out and integrated into robot-aided rehabilitation. The benefit of this subsystem is to adjust the stiffness automatically in order to interact with an unknown dynamical environment.

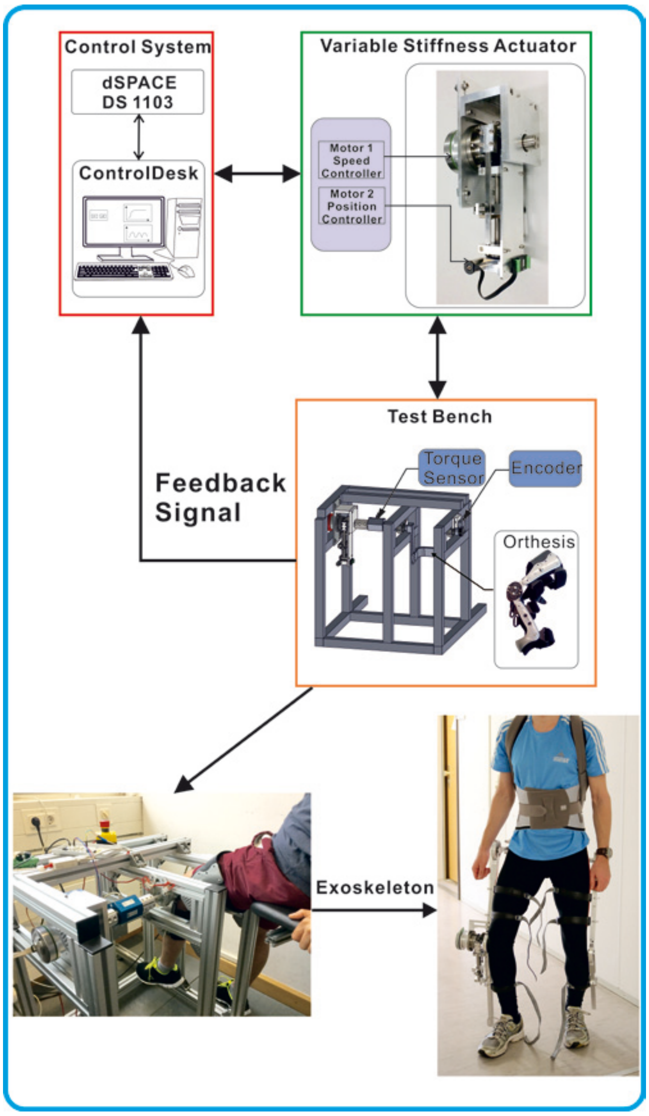


*Fig. 7: Mechatronics in rehabilitation.*

Moreover, a control strategy should be designed to avoid possible oscillations, which might occur, due to the time-varying stiffness coefficient. Hence, different control methods such as robust and gain-scheduling controller were investigated to ensure good stability margins and tracking performance. To enable a patient-cooperative control, bio-feedback information is required during the training process. In this scope, movement support is tested by human-in-the-loop configuration as an active part in the loop.

The testing environment is depicted in Fig. 7, where a one degree-of-freedom (DOF) knee orthosis is designed to realize similar test condition compared to a swing phase during a healthy gait-cycle. In addition, we can use the observable joint torque to tune the controller gains and change the actuator stiffness in real time. Thereby, a control of human movement effort during training can be achieved, whilst simultaneously saving the power of actuator in order to track the stiffness variation. Further research works will include bio-feedback based trajectory estimation and exoskeleton with treadmill training.

**Funded by:** Chinese Scholarship Council (CSC)

## Sectoral Bioimpedance Spectroscopy

The early detection of lung pathologies such as pneumonia or pulmonary edema is of great importance for the outcome of the patient, especially in ventilated patients. Currently, a combination of x-ray and blood gas analysis is used to detect such pathologies. However, these technologies have two major disadvantages as they do not provide continuous results and potentially harm the patient. Thus, the goal of this project is to use bioimpedance spectroscopy (BIS) in order to detect pathologies in local sectors of the lung. BIS measurements are principally performed by injecting a small current (with a compliance to the safety standard) into the body and measuring the resulting impedance in a frequency range from 1 kHz to 1 MHz. Typically, transthoracic or hand-to-hand electrode configurations are used that do not provide any local information. In order to find electrode positions that allow a regional lung monitoring, a complex simulation study was intensively performed. For this, a finite-element model as shown in Fig. 8 was used and the effect of electrode positions on the acquired impedance data was analyzed. The sensitivity of BIS measurements can be focused to desired lung regions using both external and internal electrodes, which can be for example integrated in breathing tubes (Fig. 8). Our preliminary results indicate that the electrical properties of healthy and pathological lung differ. Thus, we expect to be able to detect lung pathologies from BIS data.

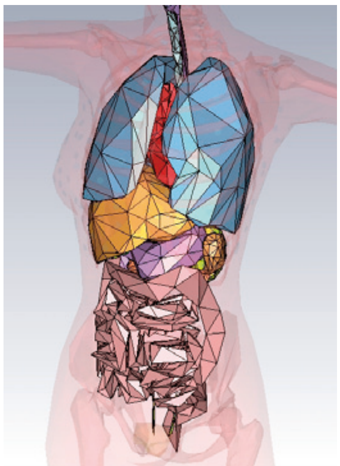

*Fig. 8: Finite element simulation of sectoral bioimpedance spectroscopy with an internal electrode.*

**Funded by:** German Research Foundation (DFG)



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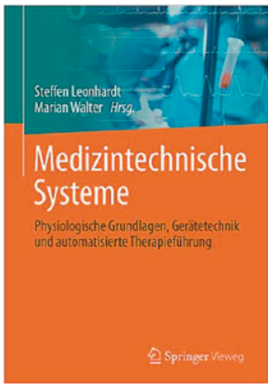


## Prizes and Awards

- S. Leonhardt: appointed “Distinguished Lecturer” of the IEEE “Enginieering in Medicine and Biology Society (EMBS)”, term 2015-2016.
- P. Vetter won 1st Poster-Award whilst X. Yu & C. Pereira and C. Castelar shared 2nd Poster-Award in session “Biomedical Engineering” at POSTER 2016, Prague.
- I. Elixmann: Aschoff-Prize 2016 from Christoph Miethke GmbH & Co. KG and Aesculap AG, Germany.
- V. Blazek: Erich Krieg Medal from the German Society of Phlebology, Dresden, Germany.
- A. Böhm, X. Yu and W. Neu (Multichannel ECG-T-Shirt) and S. Weyer and F. Weishaupt (RheoDetect) were the Top 21 participants at Texas Instruments Innovation Challenge (TIIC) – Europe Design Contest.
- C. Hoog Antink: 1st Prize for patient safety 2016 from DGBMT, Germany.
- B. Venema and D. Teichmann: Borchers Plakette 2016 from ProRWTH.
- S. Leonhardt: invited guest professor as part of the Global Initiative of Academic Networks (GIAN) program, Indian Institute of Technology (IIT) Madras, India.

## People at MedIT