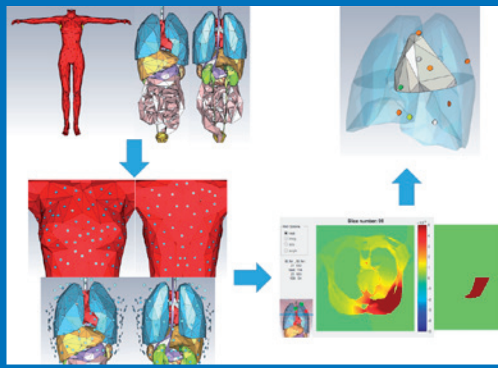
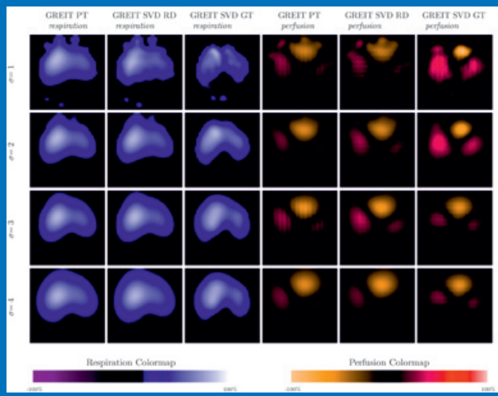
medIT

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

Staff (Full time equivalents)

Walter, Marian, Dr.-Ing., Senior Scientist
Blazek, Vladimir, Prof. Dr.-Ing., Senior Scientist
Misgeld, Berno, Dr.-Ing., Senior Scientist
Wartzek, Tobias, Dr.-Ing., Senior Scientist
Teichmann, Daniel, Dr.-Ing., Senior Scientist
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.
Blanik, Nikolai, Dipl.-Ing.
Böhm, Anna, Dipl.-Ing.
Brendle, Christian, Dipl.-Ing.
Castelar Wembers, Carloas Emilio, M.Sc.
Hentze, Benjamin, Dip.-Ing.
Hochhausen, Nadine, Dr. med.
Hoog Antink, Christoph, Dipl.-Ing.
Ismail, Abdul Hamid, M.Sc.
Kӧny, Marcus, Dr.-Ing.
Lehmann, Sylvia, Dr. med.
Leicht, Lennart, Dipl.-Ing.
Liu, Lin, M.Sc.
Lüken, Markus, M.Sc.
Ngo, Chuong, Dipl.-Ing.
Orschulik, Jakob, M.Sc.
Paul, Michael, M.Sc.
Penzlin, Bernhard, Dipl.-Ing.
Pohl, Antje, Dipl.-Ing.
Pomprapa, Anake, Dr.-Ing.
Rüschen, Daniel, M.Sc.
Schlebusch, Thomas, Dr.-Ing.
Venema, Boudewijn, Dr.-Ing.
Vetter, Pascal, M.Sc.
Weyer, Sören, Dipl.-Ing.

Guests

Havlík, Jan, Ph.D. (Visiting Professor)
Kumar, Varadarajan Jagadeesh, Ph.D. (Visiting Professor)

RWTH AACHEN UNIVERSITY

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.

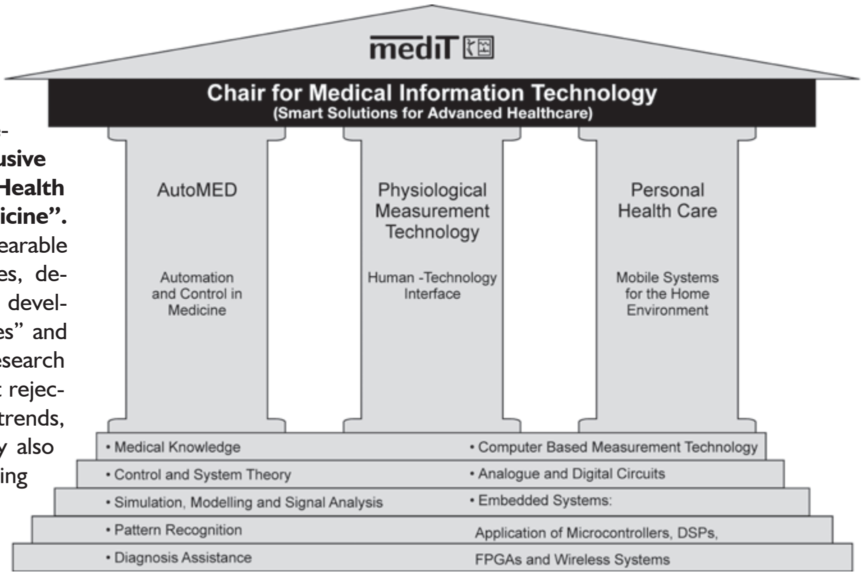


Fig. 1: Research profile of MedIT.

Ongoing Research - Selected Projects

Cooperative Control of ECMO and Mechanical Ventilator for Acute Lung Injury

Whenever artificial ventilation is barely possible to maintain physiological gas exchange, extracorporeal membrane oxygenation (ECMO) is usually applied to prevent hypoxia and the inherent danger of death. The role of ECMO is to provide supplemental gas exchange and to relieve patients from possible excessive stress introduced by a ventilator. The adjustment of ECMO settings must be conformed with general clinical guidelines, but typically in an irregular time interval. Thus, no continuous intra- and interindividual therapeutic optimization is supported.

To resolve this issue, the automation is introduced for cooperative control of ECMO and mechanical ventilation in this research work. A traditional closed-loop system relied only on a complex and slow blood gas analyzer for measuring control variables. A new control system is configured as shown in Fig. 2 by adding two standard anesthetic gas monitors in order to measure oxygen (O2) and carbon dioxide (CO2) fractions at the in- and outlet of the gas phase of the oxygenator. Moreover, an extended Kalman filter is applied to estimate O2 and CO2 gas transfer rates across the membrane with no reliance to the complex blood gas analyzer. In addition, we could achieve similar measurement accuracy compared to the standard arterial blood gas analysis with the samples taken before and after the oxygenator simultaneously. Using gas transfer as control variables, safe and reliable ECMO control is realizable.

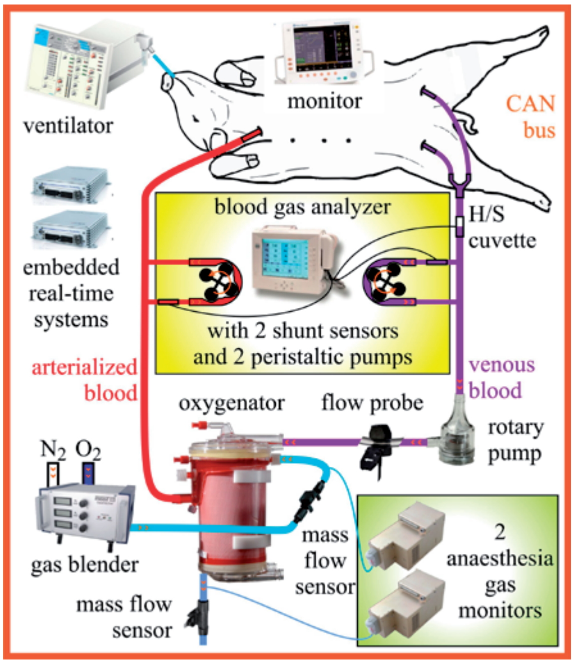


Fig. 2: System configuration of cooperative control of ECMO and mechanical ventilator.

For implementing the cooperative control, a robust and decentralized control system has been set up to adjust the extracorporeal gas transfer rates according to the demand of the patient. Thus, performance tracking is evaluated based on physiological target control by cooperative adjustments of the ventilator and ECMO control system. Finally, the overall algorithmic performances of this embedded real time system are assessed by porcine models of induced lung injury with surfactant wash-out using repetitive lung lavages.

Funded by: German Research Foundation (DFG)

Impedance Cystovolumetry

Some patient groups suffer from an impaired bladder volume sensation. This is the case with paraplegics who, depending on the degree of neural structure damage, can even experience a complete lack of urinary function. A common therapy for these patients consists of self-catheterization schemes under a fixed time schedule to empty the bladders. A too short time interval between catheterizations reduces the quality of life and increases the risk of urinary infection and urethral damage. Contrarily, a too long time interval increases the risk of complications such as overdistension of the bladder wall, autonomic dysreflexia or hydronephrosis. A demand-driven emptying scheme would therefore be preferred. In this regard, impedance cystovolumetry is a promising concept for the non-invasive and continuous monitoring of bladder volume in order to estimate the appropriate moment for catheterization. This concept is depicted in Fig. 3: An electrode configuration integrated into the underwear, connected to a portable device which provides volume estimates wirelessly to a patient interface.

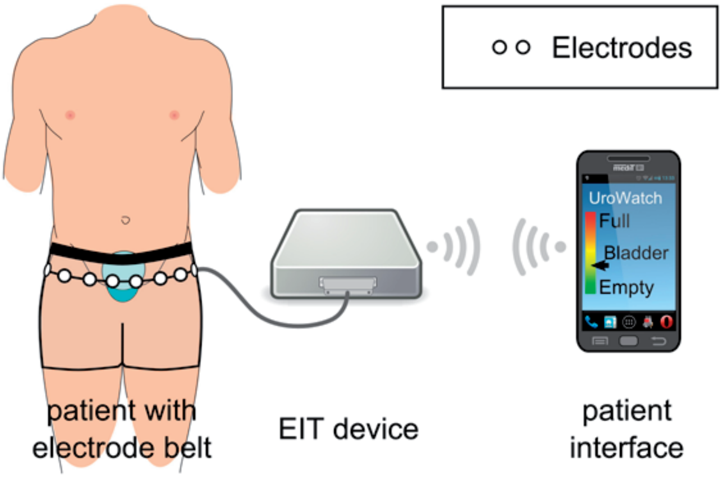


Fig. 3: Electrical impedance tomography measurement for cystovolumetry.

Our aim is to investigate Electrical Impedance Tomography (EIT) as a potential method to provide this continuous bladder volume measurement. The set-up consists of an EIT device and an electrode configuration placed in the lower abdomen region. A small, fixed current (for example 5 mA at 50 KHz in compliance with IEC 60601-1) is applied to the body between two electrodes and the resulting voltage potential of all remaining electrodes is recorded. Bladder volume can then be estimated by exploiting the difference in conductivity between urine (5 - 25 $mScm^{-1}$) and the surrounding tissue (0.2 – 4 $mScm^{-1}$). This method has already shown that lower abdomen global impedance decreases linearly with increasing bladder volume. Additional challenges such as the optimization of electrode arrangement, estimation algorithms, and movement artifact suppression are being addressed.

Funded by: German Federal Ministry of Research (BMBF)

Rehabilitation Robotics

Robot-aided motor training can help to improve the movement ability of patients with, for example, spinal cord injury, hemiplegia or hemiparesis. Mobile robotic support solutions are required for patients with a remaining motor impairment. The development of a device in the form of an active orthosis is the aim of this project. An active orthosis should guarantee patient-cooperative movement support. A key property for this is a gentle and soft interaction and supportive behavior. Hence, a new actuator is developed in order to mechanically adjust its output stiffness over a wide range. A mechanical diagram of this so-called "Mechanical Rotatory Impedance Actuator" (MRIA) is shown in Fig. 4. New feedback control algorithms that guarantee this stable interaction with the patient are currently developed.

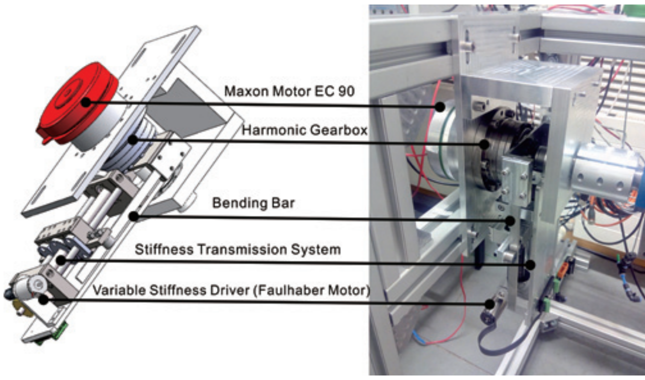


Fig. 4: Mechanical rotatory impedance actuator.

To ensure a patient-cooperative behavior of the rehabilitation robot, the supportive control system should recognize the current state of the patient's motor system. The "Integrated Posture and Activity Network by Medit Aachen" (IPANEMA) body sensor network (BSN) is employed with new electromyography (EMG) and 9-degrees-of-freedom orientation sensors. These applications are the real-time detection of spasticity and joint impedance. IPANEMA sensory information is also used in the rehabilitation robot for online trajectory generation as well as in the estimation of the patient motor system state.

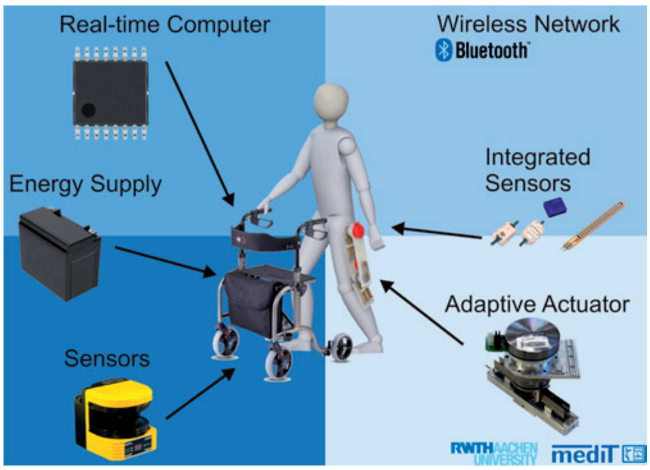


Fig. 5: System realization of rehabilitation robotics.

Funded by: Self-funded

Sensor fusion

Today, a multitude of sensors to measure vital signs exists. They range from classical, clinical modalities such as electrocardiography (ECG) or photoplethysmography (PPG) using a fixed contact with the patient over loosely coupled mechanical sensors to completely non-contact approaches such as video-based PPG imaging. While the first category usually offers supreme signal quality, sensors of the latter categories are far less obtrusive to the user, cheaper and can be integrated into objects such as beds, seats or even bathtub pillows. This generally comes at the cost of a decreased signal quality. Our goal is to develop advanced modelling and signal processing methods for multiple sensors that allow the extraction of vital signs in scenarios where the quality of every individual sensor may not be adequate. Different approaches were developed, one being based on self-similarity analysis of signals to extract cardiac rhythmicity. This allows heart rate monitoring during sleep at home or biofeedback.

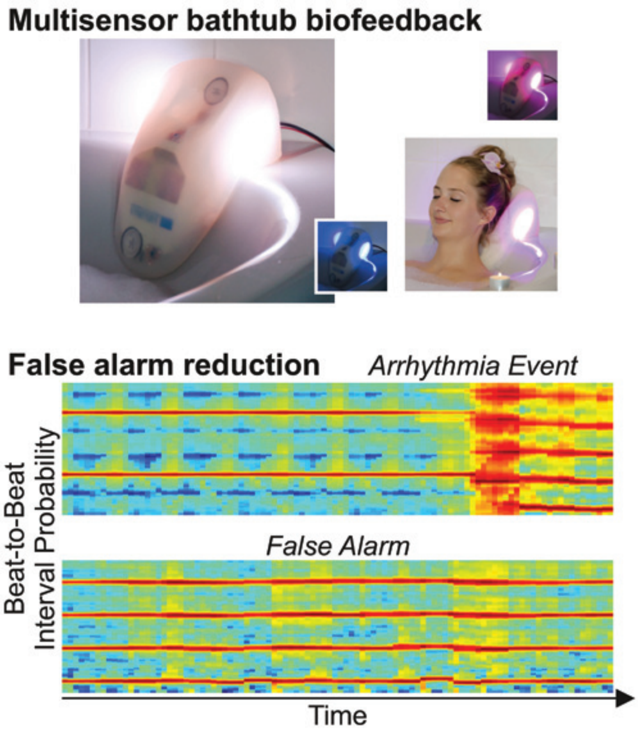


Fig. 6: Top: Multisensor bathtub pillow providing optical feedback to the user for breathing control. Bottom: Beat-to-beat heart rate estimation using multimodal patient monitor data. Differences between true and false arrhythmia alarms are visible in the two-dimensional correlogram.

In actual clinical practice, an abundance of false alarms is created leading to discomfort on the side of the patients and alarm fatigue on the side of medical staffs. Our proposed methods of advanced signal processing for multimodal sensor fusion in combination with machine learning strategies help to reduce false alarms, while true alarms that indicate potentially life-threatening conditions are kept.

Funded by: Self-funded

Mimic Monitoring of Patients with Postoperative Stress and Pain

Nowadays, postoperative stress and pain is still only evaluated subjectively based on the experience of the physician. Beside the knowledge about the kind, course and result of the surgery as well as monitored vital parameters, he uses his “clinical view” assessing movements of the patient, perspiration, lacrimation and changes in the facial expression.

In the course of the cooperative project “Mimic Monitoring – Development of an infrared thermographic infrared thermographic (IRT) -based system concept for patient monitoring during intensive care” within the network “SmartCareUnit – Intensive Care Units of Tomorrow,” we are developing a camera-based monitoring system for automated and more objective assessment of the patient’s pain and stress level in the intensive care unit. The contour curve of the face as well as striking facial features are tracked dynamically and the temperature profile is evaluated to detect changes in the facial expression, onset of tearing or change in breathing frequency. An example of a grimacing patient is shown in Fig. 7.

Fig. 7: Infrared thermographic still of a patient at rest (left), the same patient, but grimacing (middle), and marked features of automatic mimic analysis (right).

The combination of morphological and thermographic information is realized in the processing chain shown in Fig. 8 for the automated evaluation of the patient’s level of pain.

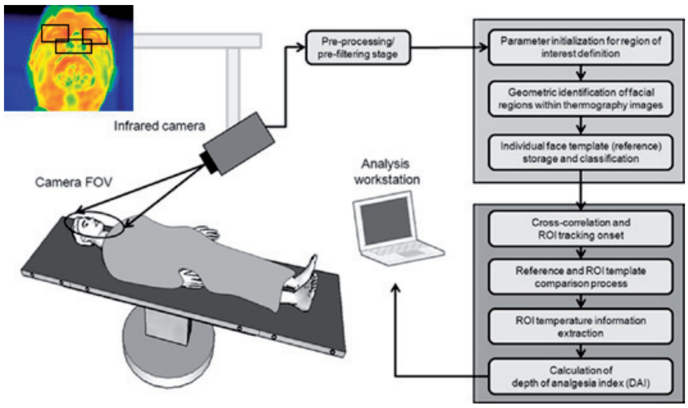


Fig. 8: Modular processing chain of the IRT mimic monitoring.

Funded by: German Federal Ministry of Economics and Technology (BMWi-ZIM)

Multi-Frequency Electrical Impedance Tomography for Detecting Lung Diseases

Lung diseases continue to be a huge clinical problem, as they are associated with high mortality rates. The continuous monitoring of respiratory and cardiac activities for these patients is mandatory in intensive care units (ICU). In order to monitor the development of these diseases, patients have to be relocated outside the ICU for the magnetic resonance tomography (MRT) or computerized tomography (CT) scans. Since these are associated with high resource consumption and not available at the bedside, treatments and ventilator settings rely merely on arterial blood gas analysis.

Electrical Impedance Tomography (EIT) is a non-invasive and radiation-free imaging technique, in which the impedance distribution of a thorax is determined. Additionally, it is available on bedside and permits real-time monitoring. Up-to-date commercial devices employ time-difference imaging, which has shown to be a promising medical imaging technology for monitoring lung ventilation, particularly regional ventilation during recruitment maneuvers, and for controlling the position of the endotracheal tube.

Based on bio-impedance property, it is known that measurement of tissue impedance at different frequencies can be used to distinguish intracellular and extracellular compartments. Therefore, frequency-difference imaging is a promising technique. The measurements are performed at two or more frequencies and the relative difference between both measurements is computed at different frequencies at the same instance. This technique is particularly of interest due to the combination of examining tissue dispersion and spatial resolution. Furthermore, it does not require reference in time. Lung diseases could probably be evaluated more precisely. Therefore, a multi-frequency EIT system, presented in Fig. 9, has been developed in order to evaluate and to detect injured lung tissue by computing differences between measurements at different frequencies.

Fig. 9: System setup for multi-frequency electrical impedance tomography.

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

Russian-German Conference on Biomedical Engineering 2015

It was honorable to host the 11th German Russian Conference on Biomedical Engineering (formerly called Russian-Bavarian Conference) in Aachen on 17th – 19th June 2015. The conference established itself as a fruitful platform for scientific and cultural exchange among researchers as well as a venue for initiating cooperative Russian-German research projects. The conference was organized in a pleasant and constructive atmosphere:

- Invited keynote speaker session from Russian and German experts with various on-going research topics such as artificial kidney technology, closing the loop in biomedical engineering, cell-material interactions, cryotechology and instumentation for molecular imaging as well as women in biomedical engineering
- One-minute poster teaser and open contributed poster session
- Guided tours to Helmholtz-Institute, Institute of Textile Technology and Institute of Laboratory Animal Science relavant to the partial advancement of biomedical engineering at RWTH Aachen University
- City tour in Aachen
- The Conference Gala Dinner at the tri-border area in the midst of Germany, the Netherlands and Belgium.

According to the interest and active involvement in this conference, we have a large number of experts with more than 80 researchers of 50 Russian professors and scientists and have thereafter achieved many cooperative outcomes. At the end of the conference program, three best scientific contributions were well selected and awarded by the program committees including the best paper award. We definitely appreciate all the contributors, co-organizers and participants, who contribute to and take part in our great success of the RGC 2015.

Selected References 2015

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Prizes and Awards

- S. Leonhardt: appointed "Distinguished Lecturer" of the IEEE "Engineering in Medicine and Biology Society (EMBS)", term 2015-2016.
- T. Wartzek: award for Patient Safety in Medical Engineering 2015 of the DGBMT.
- S. Weyer: IWIS best poster award from TU Chemnitz, Chemnitz, Germany.
- B. Misgeld: DAAD scholarship at Tsinghua University, Beijing, China.

Conference Orgainization

[1] Russian-German Conference on Biomedical Engineering, June 17^{th} -19^{th}, 2015 at RWTH Aachen University.

People at MedIT