mediT | RWTH AACHEN UNIVERSITY

Medical Information Technology

Faculty of Electrical Engineering
and Information Technology

Smart Solutions for Advanced Healthcare

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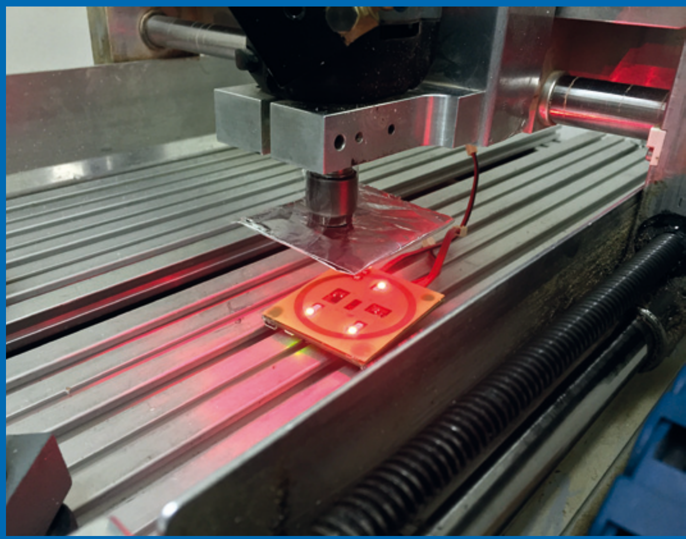

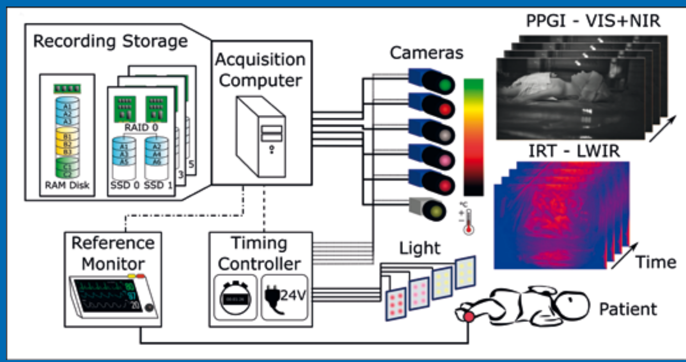

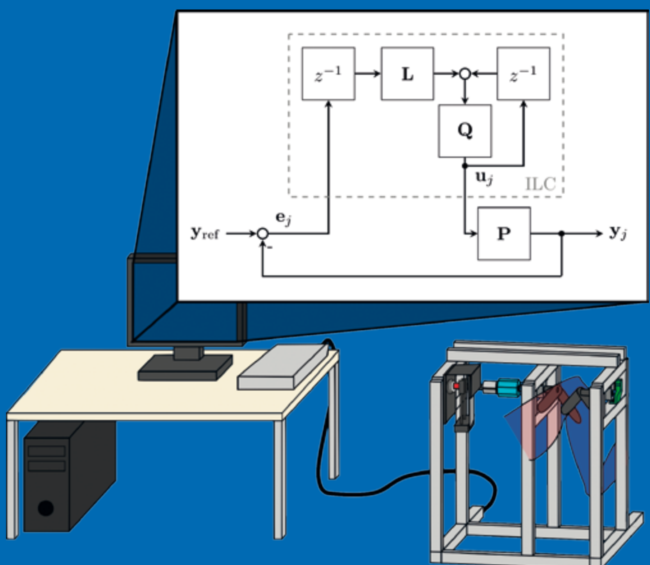

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Introduction

The 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.

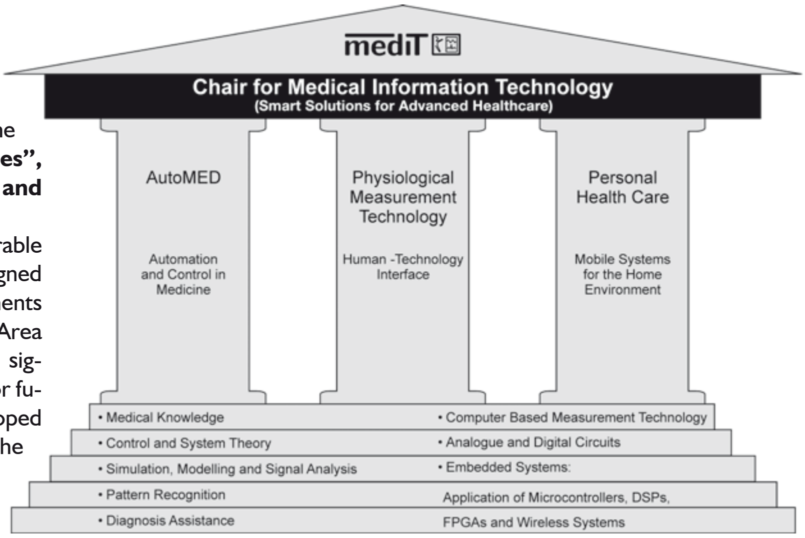

Fig. 1: Research profile of MedIT.

Ongoing Research – Selected Projects

Regional Lung Perfusion by Electrical Impedance Tomography

In intensive care unit, gas exchange in the lung of patients with acute respiratory distress syndrome (ARDS) is often severely impaired. For these patients, a careful guidance of ventilation therapy is essential for survival. Regional lung ventilation (V) and regional lung perfusion (Q) are the critical variables for ventilation care. Due to the fact that gas exchange only takes place in lung regions of both adequate ventilation and perfusion, it would be highly beneficial to also measure and quantify regional lung perfusion. Electrical impedance tomography (EIT) can be applied to monitor regional lung perfusion in real-time at bedside, which is a noninvasive and radiation-free imaging modality. The principle of EIT is based on the injection of small current into electrode pairs in a successive order of a belt (usually 16 or 32 electrodes) that is placed around the thorax of the patient. This yields different voltages across the thorax from which tomographic images of

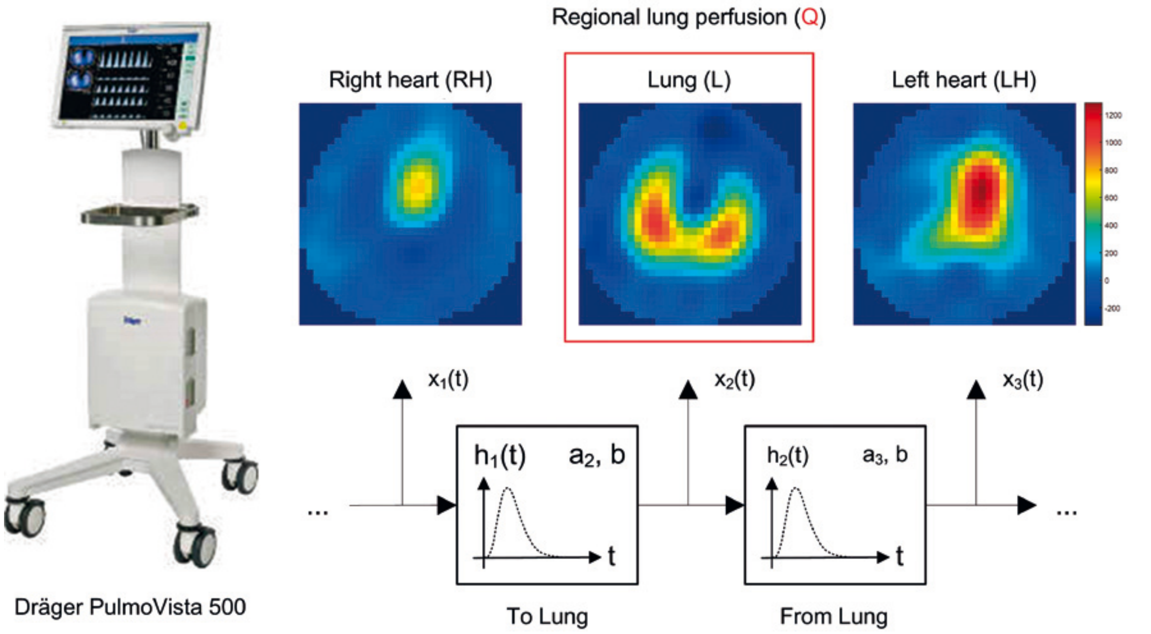

Fig. 2: Monitoring of regional lung perfusion based on electrical impedance tomography.

tissue impedance can be reconstructed. Tissue impedance strongly varies with lung air content and it yields the ventilation-related signal (VRS) from which regional lung ventilation is obtained. Regional lung perfusion can be determined either from the cardiac-related signal (CRS) or the indicator-based signal (IBS). While the CRS describes impedance changes in the lung region resulting from pulsatile activity of the heart, the IBS can be obtained by electrically conductive contrast agents, such as hypertonic saline. The focus of this project is to monitor regional lung perfusion based on the IBS. The work covers model-based algorithms and signal processing to separate right-heart (RH), lung (L) and left-heart (LH) phases of the IBS. Furthermore, it involves finite element simulation (FEM) and in-vivo validation of contrast agents in order to advance clinical applicability. The overall motivation is to derive regional ventilation to perfusion ratio (V/Q) by EIT to achieve patient individual, lung protective guidance in ventilation therapy.

Funded by: German Research Foundation (DFG)

Parkinson's Disease Monitoring

Parkinson's disease (PD) is the most common neurodegenerative disease and its predominance is growing in population ageing. It is associated with a series of neurological movement disorders. These include the main symptoms of the well-known Parkinsonian triad, which is defined in terms of rigidity (stiffness of the extremities and cogwheel effect), tremors, and akinesis / bradykinesis (movement deprivation / deceleration). Most of these syndromes are directly connected to the movement. For the diagnosis of Parkinson's disease, the occurrence of one of these symptoms can be used among other symptoms such as freezing of gait (FoG), postural instability, and orthostatic dysregulation, which appear individually.

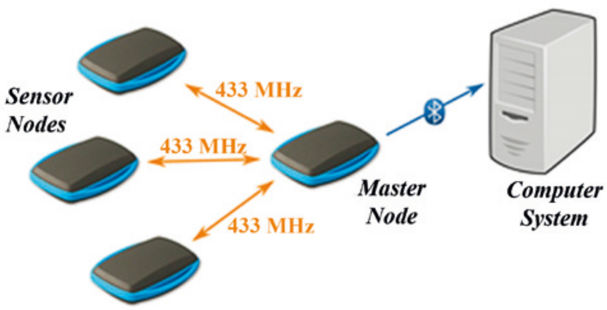

Fig. 3: System configuration of body sensor network (BSN) with the application to Parkinson's disease monitoring.

The focus of this project is to develop a body sensor network (BSN) distributed over the body (i.e. wrists, joints, ankles), which is able to accurately classify and quantify the various Parkinsonian symptoms by using different sensor modalities for real-time monitoring. To this end, biomechanical and physiological models are designed in order to identify appropriate parameters for assessing the patient's constitution by fusion of the collected sensor data and the classification of movement type is of particular interest, which can be used not only for Parkinsonian symptom but also for the fall prediction.

Video Camera-based Functional Imaging of Vital Signs

Contactless monitoring of vital signs is advantageous for patient comfort. Compared with conventional sensors such as photoplethysmography (PPG) or temperature probes, camera-based sensing does not require cabling or skin contact and it does not carry the risk of medical adhesive-related skin injuries (MARSI). These modalities can be therefore used for patients with sensitive skin like neonates. Videos carry spatially resolved information of vital signs.
In thermal imaging, temperature values can directly be extracted from the video sequence. In light-based video cameras, signal processing can be used to extract the PPG signal from skin pixels. Here, each pixel is used as a remote PPG probe. Consequently, a variety of vital signs can not only be extracted from a single point but also from the whole body regions. Thus, spatial differences can be made visible and allow for enhanced diagnostics. Similar to imaging modalities such as computer tomography (CT) and magnetic resonance imaging (MRI), a functional assessment becomes feasible. Currently, processing power is insufficient for real-time computing of imaging applications. However, this allows remote monitoring of heart rate and breathing rate as classical one dimensional (1D) vital signs.

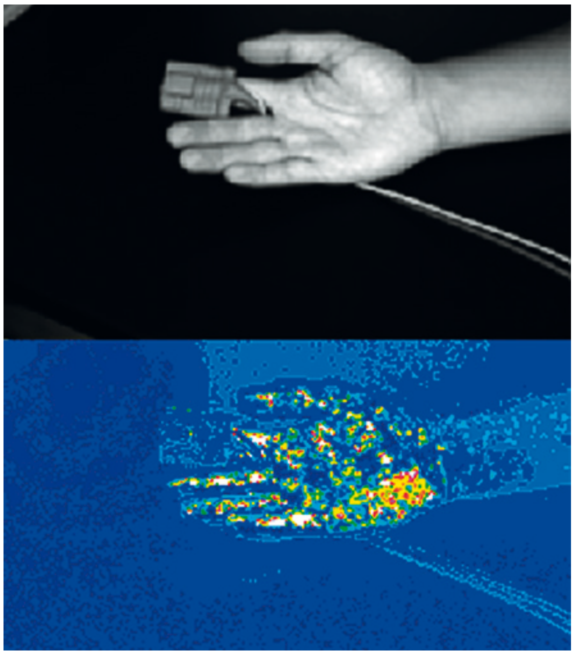

Fig. 4: Functional imaging of vital signs.

To demonstrate the imaging approach, the first illustration in Fig. 4 shows a single preprocessed image of a video sequence of a hand. Here, pixels are grouped together which results in a blurry and blocky representation. The second illustration shows the mapping of the signal strength of alternating AC components in relation to slow varying DC components extracted from the video sequence. Strong variation can be observed in the palm of the hand, where blood volume clouds move over time. In comparison, there is less variation visible at the forearm. Further research will focus on the robustness of the sensing modalities and their potential for medical applications.

Vital Signs Monitoring with Seat Integrated Sensors for Driver State Estimation

Due to the progression of autonomous and semi-autonomous driving, research in driver state estimation has become a topic of increasing interest. Nevertheless, the driver state can be used to improve road safety in all stages of the development towards autonomous cars. For example, in non-autonomous cars, if inattention is detected, warning signals can be played via speakers. For semi-autonomous cars, an emergency maneuver can be initiated, if the driver does not respond to first warning signals. The information can also be used to make a safer transition between autonomous and human controlled driving with improved human-machine interaction (HMI). If the driver is incapable of driving, i.e. falling asleep or fainting, vital signs allow detecting, whether the driver needs medical attention and an ambulance should be informed.

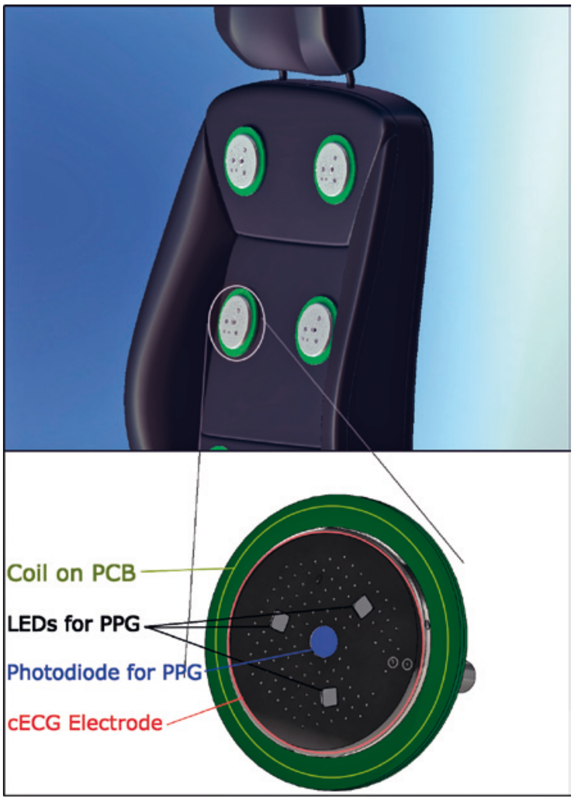

Fig. 5: *Car seat integrated with multi-sensors for driver state estimation.*

To preserve the convenience of today's driving, our research is focused on unobtrusive measurement techniques for driver state estimation. These sensors have inferior signal quality and are more prone to movement artifacts compared to attached counterparts. In this project, a seat integrated multimodal solution is evaluated. The history of driver state monitoring at MedIT started with the capacitive ECG (cECG) integrated into the driver seat. In subsequent studies, sensors have been evaluated in multiple studies. There have been, for example, studies with cameras, cECG and magnetic induction measurement (MIM). A new multimodal sensor, which combines the measurement of cECG, MIM and PPG through the fabric in a single unit, is developed and evaluated in the car. The goal of the sensor is to robustly extract heart rate (HR) and respiratory rate (RR) with high coverage rate in automotive environments. Therefore, data from multiple sensors, each combining the three mentioned measurement modalities, will be fused to estimate the parameters. Further signal features will be extracted and data-driven algorithms will be developed to detect driver states.

Funded by: European Union's Horizon 2020 research and innovation programme

A New Centre for Gerontotechnology

Non-contact and unobtrusive vital signs monitoring has nowadays become one of the most important research topics. To this extent, we bring our existing non-contact measurement technologies into a new area of Geriatrics that focuses on personal health care of elderly people for individual needs. A patient room laboratory and a motion laboratory have newly set up in Franziskushospital Aachen, which is part of the new Department of Geriatrics at RWTH Aachen University that we cooperated with. In the patient room laboratory, various non-contact sensors have been installed, for example, photoplethysmography-imaging (PPGi), infrared thermography, capacitive ECG sensor integrated in bed and further advanced signal processing algorithms are developed in order to unobtrusively extract vital signs such as heart rate and respiratory rate.

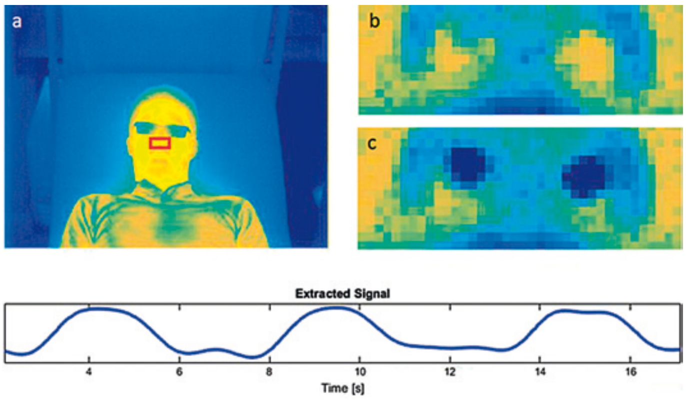

Fig. 6: *Measurement of respiratory rate using infrared thermography. a: thermal image. b: area around the nose during expiration (warm). c: area around the nose during expiration (cold). Bottom: extracted respiration signal.*

Due to the fact that non-contact monitoring techniques are more sensitive to patient's movement than conventional measurement modalities, we also use multiple sensors and sensor fusion technologies to enhance robustness and the strength of the signals.

In the motion laboratory, we develop and test personal healthcare devices and also perform gait analysis since accurate examination of the locomotor system is of importance in rehabilitation, gerontology and sports medicine. Different technologies can be used for the gait analysis, for example, body-supported inertial sensor nodes, multi-camera system and stationary pressure/force measuring devices. In our new facility, the development of gait training and gait therapy concepts can be realizable with the application to patient-oriented rehabilitation robotics. A wide range of researches has been conducted in terms of human biomechanical models of muscular activity towards electromyography (EMG), testing rehabilitation robotic prototypes under clinically approved conditions and its safety concern, and the specific mobility limitations of the patient target group.

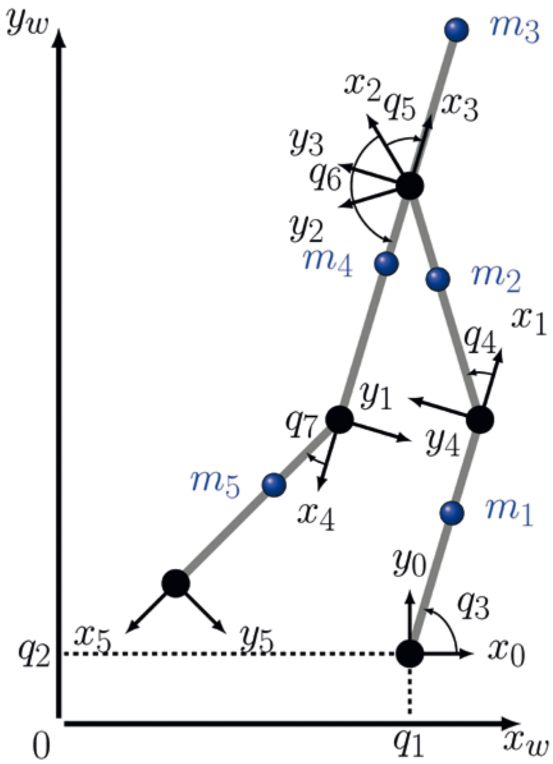

Fig. 7: Model of the human lower extremity.

For instance, a musculoskeletal model of the human lower extremity is shown in Fig. 7 in order to simulate musculotendon function and muscle coordination during movement. The model incorporates the salient features of muscle and tendon, specifies the musculoskeletal geometry and musculotendon actuators. This includes the active isometric moment of these actuators about the hip, knee, and ankle joints.

Fig. 8: Motion laboratory located at Franziskushospital Aachen.

The new established cooperation has been made with kinesiologists from the team of Prof. Dr.med. Bollheimer from the Department of Geriatrics at RWTH Aachen University Hospital. Future research questions can therefore be addressed.

Funded by: Robert Bosch Foundation

Blood Glucose Modelling and Control for Diabetes Patients

The number of people with diabetes mellitus was around 415 million worldwide in 2015 and is predicted to increase to 642 million by 2040. Approximately 10% of them have diabetes mellitus Type 1, which means they always need exogenous insulin injection to regulate their blood glucose. Improper control of their blood glucose concentration can lead, on the one hand, to hyperglycemia and induced secondary complications, on the other hand, to hypoglycemia, which may be caused by over-delivery of insulin and is life-threatening. Proper control of patients' blood glucose concentration is therefore essential to improve health and quality of life. To achieve this goal, the combination of theoretic and clinical research is carried out to facilitate the development of innovative control strategies and to enhance the understanding of the glucose metabolism. Specifically, animal trials on Göttingen MiniPigs were conducted for mathematical modelling of the glucose metabolism, which is crucial for model predictive control design and for in silico studies.

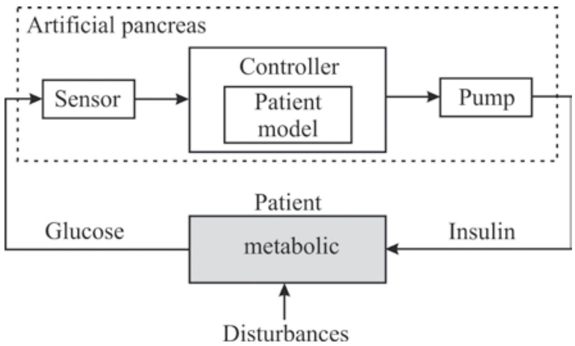

Fig. 9: Schematic of blood glucose management with an artificial pancreas.

Theoretical work focuses on state observers and controllers that are capable of controlling of glucose for a broad spectrum of patients. This is an essential field of research because inter-patient and intrapatient variations are relatively high. Recent work merged machine learning methods with model predictive control for personalized control in personal health care. With this new approach, the controller is able to intensively learn and intelligently change patient-specific parameters during closed-loop control and incorporate the predicted future parameter changes in the control decision. Our expertise in the field of glucose modelling and control is enlarged with a newly started cooperation. As part of the Karman Fellowship program, bilateral guest visits with Harvard University have initiated this new cooperation in 2017. From the RWTH Aachen, Dr. Berno Misgeld and Lukas Ortmann have visited Harvard University, Cambridge, MA, USA.

Selected References in 2017

[1] Boehm A, Yu X, Leonhardt S, Teichmann D: Correction of the unobtrusive ECG using system identification. Electronics. 2017. 6(4), 94, doi:103390/electronics6040094.

[2] Brendle C, Mülders T, Kühn J, Janisch T. Kopp R, Rossaint R, Stollenwerk A, Kowalewski S, Misgeld B, Leonhardt S, Walter M: Physiological closed-loop control of mechanical ventilation and extracorporeal membrane oxygenator. Biomed. Eng.-Biomed. Tech., 62(2):199-212, 2017.

[3] Hoog Antink C, Leonhardt S, Walter M: A synthesizer framework for multimodal cardiorespoiratory signals. Biomed. Phys. Eng. Express. 2017.

[4] Korn L, Rüschen D, Zander N, Leonhardt S, Walter M: Real-time ECG simulation for hybrid mock circulatory loops. Artificial Organs. Doi: 10.1111/aor.13000.

[5] Leicht L, Skobel E, Knackstedt C, Mathissen M, Sitter A, Wartzek T, Möhler W, Reith S, Leonhardt S, Teichmann T: Capacitive ECG monitoring in cardiac patients during simulated driving. IEEE Trans. Biomed. Eng. 2017.

[6] Misgeld BJE, Thiel M, Schubert P, Leonhardt S: H∞–Sliding-Mode Beobachterentwurf. Automatisierungstechnik. 2017.

[7] Ngo C, Spagnesi S, Munoz C, Lehmann S, Vollmer T, Misgeld B, Leonhardt S: Assessing regional lung mechanics by combining electrical impedance tomography and forced oscillation technique. Biomed. Eng.-Biomed.Tech, 2017.

[8] Penzlin B, Liu L, Leonhardt S, Misgeld B; Measurement and estimation capabilities for a class of variable impedance actuators. International Journal of Simulation Systems, Science & Technology. 2017.

[9] Pomprapa A, Leonhardt S, Misgeld B: Optimal learning control of oxygen saturation using a policy iteration algorithm and a proof-of. concept in an interconnecting three-tank system. Control Engineering Practice. 2017.

[10] Rüschen D, Prochazka F, Amacher R, Bergmann L, Leonhardt S, Walter M: Minimizing left ventricular stroke work with iterative learning flow profile control of rotary blood pumps, Biomedical Signal Processing and Control. 2017.

[11] Schwaiberger D, Pickerodt PA, Pomprapa A, Tjarks O, Kork F, Boemke W, Francis RCE, Leonhardt S, Lachmann B: Closed-loop mechanical ventilation for lung injury: a novel physiological-feedback mode following the principles of the open lung concept. Jounal of Clinical Monitoring and Computing. 2017.

Prizes and Awards

- B. Misgeld: RWTH ERS fund at Harvard John A. Paulson School of Engineering and Applied Sciences, Cambridge, MA, USA.
- C. Hoog Antink and B. Penzlin won 1st Prize awards in session "Biomedical Engineering", D. Rüschen won 3rd Prize award in session "Electronics and Instrumentation", and D. Umutcan Uguz received an undergraduate prize at the 21st International Student Conference on Electrical Engineering (Poster 2017), Prague, Czech Republic.
- V. Blazek: Medal award in the garden of the senate of the Czech Republic.
- D. Rüschen: 2nd Prize at the Young Investigators Competition at the European Medical and Biological Engineering Conference (EMBEC), Tampere, Finland
- C. Castelar: 2nd Prize at The 9th Meeting of the International Society for Hydrocephalus and Cerebrospinal Fluid Disorder, Kobe, Japan

People at MedIT