

Medical Information Technology

Faculty of Electrical Engineering
and Information Technology

Smart Solutions for Advanced Healthcare

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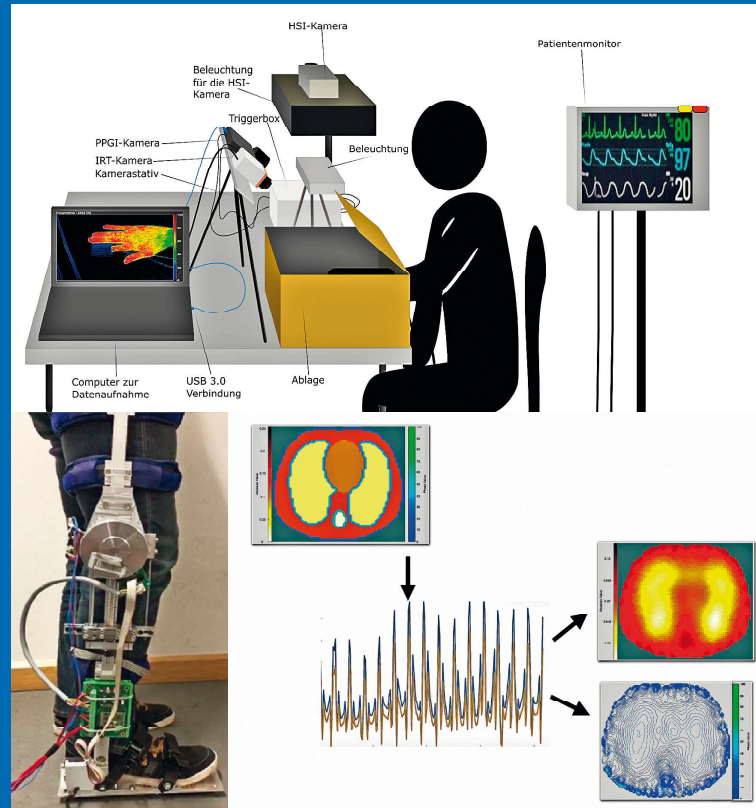
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Introduction

The 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-

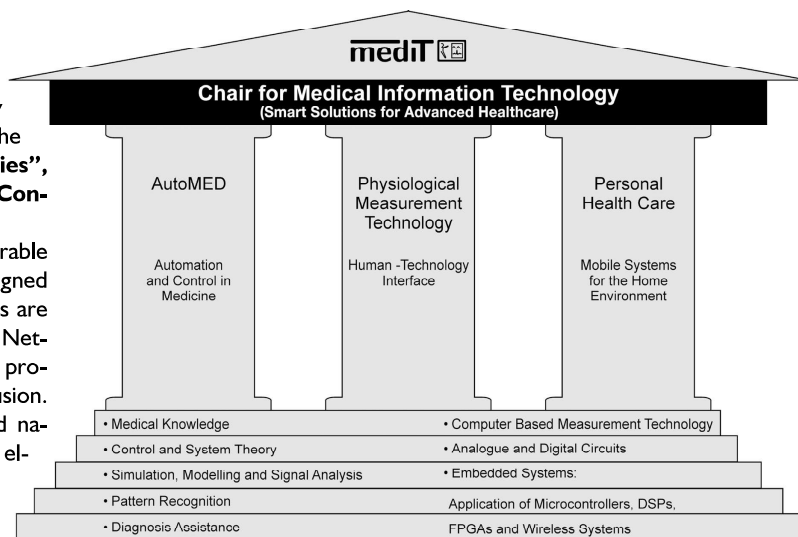


Fig. 1: Research profile of MedIT.

contact sensing techniques (e.g. magnetic bioimpedance), bioimpedance spectroscopy and inductive plethysmography. Active research is currently conducted in biomechanics.

Ongoing Research – Selected Projects

Bioimpedance Volumetry for the Monitoring of Hydrocephalus

Hydrocephalus is a disease characterized by the abnormal enlargement of the ventricles of the brain. It occurs due to the disruption of the production-circulation-absorption cycle of cerebrospinal fluid (CSF) as a result of an obstruction in the CSF pathways. It is often associated with elevated intracranial pressure (ICP), although in those groups of patients suffering from Normal Pressure Hydrocephalus (NPH), the mean ICP remains mostly within physiological range. A reduction of the dynamic intracranial compliance plays an important role even the exact pathophysiology is still unclear.

Our aim is to investigate the feasibility of the bioimpedance technique for continuous ventricular volumetry. By integrating electrodes to the tip of the drainage catheter and taking advantage of the fact that CSF has a much higher conductivity ($\sigma_{\text{CSF}} = 2.01 \text{ S/m}$) than its surrounding tissues ($\sigma_{\text{parenchym}} = 0.17 \text{ S/m}$), a combination of tetrapolar measurements might allow for a correlation to the amount of intraventricular CSF. We therefore focused on investigating, designing and testing the envisioned bioimpedance drainage catheter by conducting finite element (FE) simulation studies with anatomical and simplified anatomical models, shown in Figure 2.

Funded by: German Research Foundation (DFG)

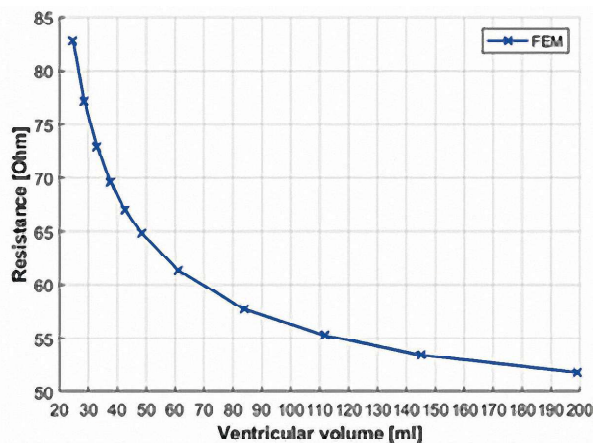
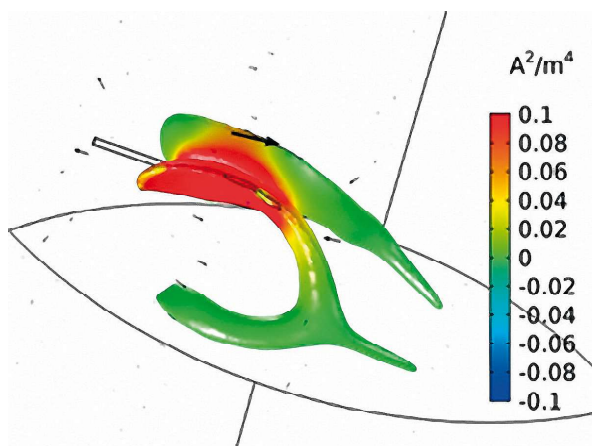


Fig. 2: Left: Sensitivity distribution [A^2/m^4] and Right: FE simulation results for the measured resistance [ohm] as a function of ventricular volume [ml].

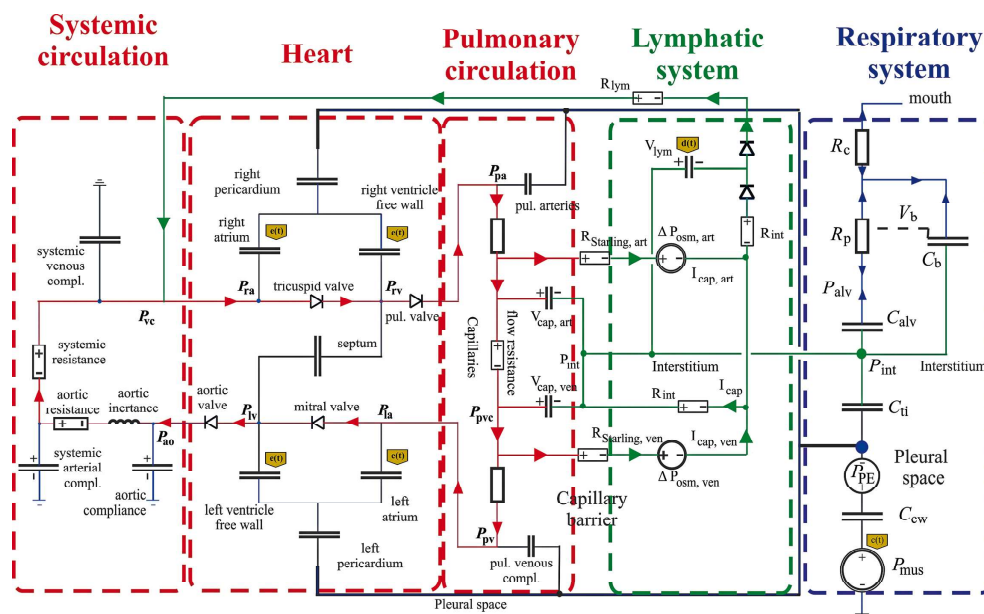
Object-oriented Modeling of Cardiopulmonary Dynamics and Respiratory Diseases

In precision medicine, mathematical and computer-based models propose the customization of healthcare in terms of medical treatments as well as medical decisions for individual patient. Physicians can predict more accurately which treatment and prevention strategies for a particular disease should work in the defined groups of patients. In this project, we focus on medical modeling at the system/organ level and aim to develop a computational model of cardiopulmonary dynamics for analysis of respiratory diseases, i.e. cardiogenic pulmonary edema.

The lumped-element model was implemented in the object-oriented language based on Matlab Simscape, in which the system equations are presented by physical blocks and connections. The cardiopulmonary model includes more than 30 elements, which correspond to the same number of physiological functional components of the cardiopulmonary system. The cardiovascular system was developed based on the model of Smith et al. with the extension of atria and non-linear characteristics of the veins and lung capillaries. Nonlinear PV relationships were included to give the model a higher robustness against parameter uncertainties, especially at boundary conditions for the collapse of the capillaries or veins. The proposed respiratory model is a novel nonlinear model, which considered the bronchial collapse, pleural dynamics, and lung-chest wall interconnected elasticity.

Figure 3 represents the overall model of cardiopulmonary system including the fluid balance and the lymphatics. The proposed model provides physiologically stable results for cardiopulmonary interactions, which could be directly compared with clinical and animal data from literature. Pulmonary diseases such as heart failure, cardiogenic congestion and edema can be simulated in order to observe the system behavior and response. The model can be used as a simulator in a user-interactive software tool for educational and training purposes or as a bed-side model-based monitoring tool applied for personal health care.

Fig. 3: Object-oriented modelling of the cardiopulmonary system.



MuSeSe – An Armchair for Unobtrusive Health Monitoring

The MuSeSe, a multi-sensor armchair developed at MedIT, is a research prototype that was built for the analysis of several technical aspects of unobtrusive sensing. It consists of different low-cost sensors to analyze cardiorespiratory activity which are integrated into back and seat, see Figure 4. Four different modalities are used, in particular, capacitively coupled electrocardiography (cECG), photoplethysmography (PPG), ballistocardiography (BCG), and high-frequency (HF) impedance. While cECG records the electrical activity of the heart, PPG measures pulse-synchronous optical changes. BCG records mechanical activity and HF impedance is very sensitive to changes in electrical conductivity inside the thorax, which are mainly induced by respiration.

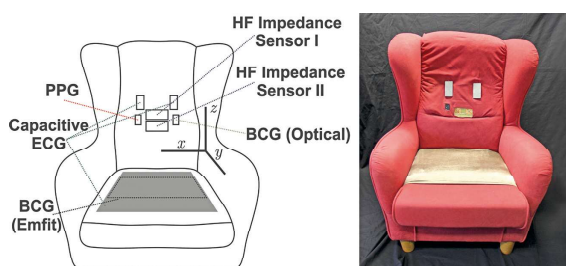


Fig. 4: An arm chair for unobtrusive health monitoring.

The selected modalities show different characteristics in terms of accuracy and robustness. For example, cECG gives the most precise cardiac signal but is easily disturbed by motion, while PPG is more robust in that aspect. BCG from the seat is obviously insensitive to the type of cloth worn on the torso. To exploit the respective strengths and compensate for weaknesses, concepts for sensor fusion were developed and evaluated on data acquired with MuSeSe. In particular, a powerful motion capture system of the Clinic for Internal Medicine and Geriatrics at the Franziskushospital Aachen was used as a reference to analyze motion tolerance. Larger studies including patients with a broad range of pathologies associated with old age need to be performed to proof the practical value.



Modelling of Heart Tissue using Customized Silicone

Cardiovascular disease remains the leading cause of death in developed countries. Due to diseases such as hypertension, atherosclerosis or other genetic risk factors as well as an unhealthy lifestyle in an aging society, more than 400 million people worldwide suffered from heart disease in 2015, resulting in the deaths of approximately 18 million people. Reduced perfusion of myocardial tissue caused by, for example, obstruction in the coronary arteries reduces the pumping performance of the heart. In severe cases, left ventricular assist device (LVAD) therapy can be used to sufficiently supply affected myocardial tissue with oxygenated blood to assist the heart muscle for recovering its functionality. In case of heart muscle recovery, it is desirable for the patient to wean from the device.

To date, there is no adequate method to detect heart muscle recovery in LVAD therapy. In order to establish a new method based on the measurement of electric conductivity, this project focuses on the development of customized silicone heart models to mimic the electrical properties of the heart in order to determine the recovery status of the heart muscle.

Previously, it has been shown that the electrical properties of myocardial tissue change during ischemia, so that these changes are a possible estimate for measuring the condition of myocardial tissue. To this purpose, initial attempts have been made to develop silicone models that mimic the electrical properties of heart tissue. This was done by mixing different carbon materials into the insulating silicone. Initial results showed that the higher the carbon concentration in the silicone, the higher the conductivity of the silicone samples.

In addition, cost-effective 3D casting moulds were developed to model the anatomy of the left ventricle. An internal paraffin wax core, which is removed during the casting process, ensures a hollow ventricle. Figure 5 (a) shows on the left side of a shell of the casting mould including the paraffin wax core, (b) represents the silicone ventricle mock-up and (c) presents silicone plus carbon ventricle mock-up with different electrical properties using customized silicone to model the heart muscle.

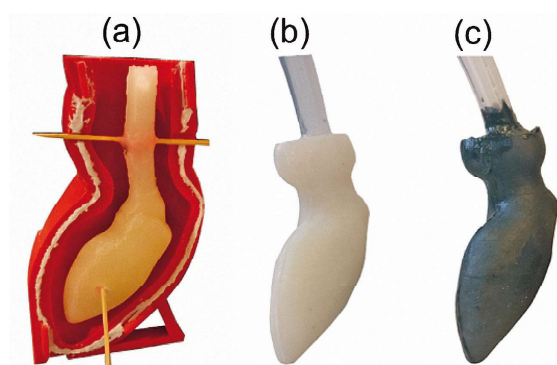


Fig. 5: a) Casting mould including the paraffin wax core fixed by wooden sticks in the center. b) Silicone ventricle mock-up. c) Silicone plus carbon ventricle mock-up.

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

The Smart Bandage – Multi Sensor Wound Monitoring

The continuous measurement and evaluation of chronic wounds could improve the treatment of patients with chronic venous insufficiency (CVI) significantly. Developing such a sensor device requires a deep understanding of the effects of local changes in hemodynamics as well as tissue properties, therefore our work follows a holistic approach covering five research topics: the identification of meaningful biological parameters that can be measured by sensors available on the market; the implementation of tissue and leg models for the simulation of wounds and their effect on those parameters; the measurement and evaluation of parameters using non-contact, camera based technologies; the design and manufacturing of a sensor device that can be integrated into a bandage; the fusion of the multi sensor data to allow for wound status diagnosis.

Wound diagnosis in clinical practice is still based on visual inspection and personalized patient survey. Potential biological indicators were identified in close cooperation with clinical partners within the project. Based on this, our research focuses on the measurement of temperature, perfusion, oxygen saturation and bio-impedance for wound diagnosis. Infrared thermograph (IRT) of wounds and surrounding tissues were recorded using thermal cameras in a clinical setting, where significant temperature drops have been identified inside chronic wounds – in contrast to the temperature of a healing wound of a healthy individual. Image processing algorithms are developed for the automatization of the parameter identification process, where non-physiological tissue regions are identified and temperature information is processed.

The effects of changes in tissue properties on the bio-impedance are simulated using a 3D-model of the human lower leg. Simulation results show that changes in tissue behavior can be identified, which are present during wound development as well as wound healing. Exemplary for the holistic approach, the multi sensor bandage design and the IRT data processing are displayed in Figure 6.

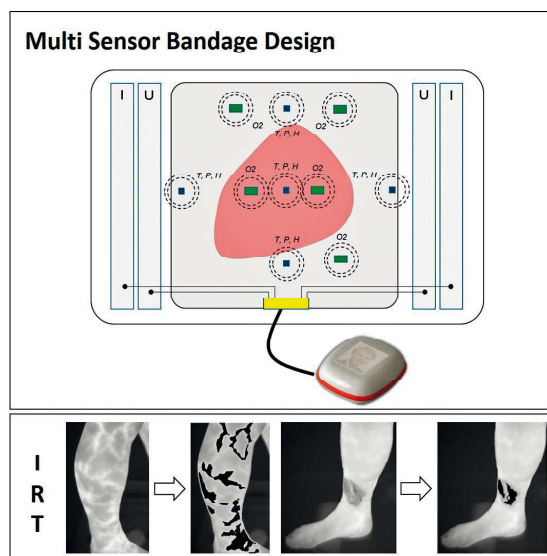


Fig. 6: Multi-sensor wound monitoring system.

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

Tissue Identification by Electrical Impedance Tomography

Electrical Impedance Tomography (EIT) is a radiation free imaging modality to represent impedance distributions inside the human body. Based on its principle, EIT injects a series of harmless sinusoidal current into the body around the thorax and measures the resulting surface potentials. 928 measurements can be acquired for a 32 electrode system. The reconstruction algorithm maps these voltage measurements to a 32×32 -pixel image with high temporal resolution in real time. The traditional time-differential EIT uses these measurements to reconstruct conductivity changes over time at a single frequency e.g. ventilation and perfusion monitoring. A novel approach acquires transfer impedances at various frequencies, called multi-frequency EIT (mfEIT). Utilizing the frequency specific behavior of tissue, EIT has the potential to generate conductivity maps of the body including tissue specific information and to identify regional tissue types. Therefore, this project has two main aspects. On the one hand, a new measurement device, called AixTOM, is under development to satisfy the sophisticated requirements of mfEIT, which mainly imply frequency stability from a few kHz up to one MHz. On the other hand, the reconstruction itself is challenging and requires novel approaches for better image quality and usefulness in clinical interpretation. The reconstruction can be described as a least-square problem and the Gauss Newton algorithm is one way to find a stable solution. Optimizing the reconstruction parameters to find a suitable map of the measured transfer impedances onto a conductivity image is a complex and challenging task. Figure 7 shows the whole EIT acquisition chain (from left to right): The electrode belt around the chest is physically connected to the mfEIT device (AixTOM) via the cables. Within the AixTOM device, it consists of signal generator, signal acquisition unit, and signal processing unit, where field programmable gate array (FPGA) can be programmed and customized. Further computation and reconstruction of the image stream is then carried out in a laptop for data representation. The pre-processed signals are reconstructed to a map of complex conductivity differences, which contain tissue specific information. Possible applications are the early detection of extracellular water from an edema or secretion of a pneumonia in an early state of the disease.

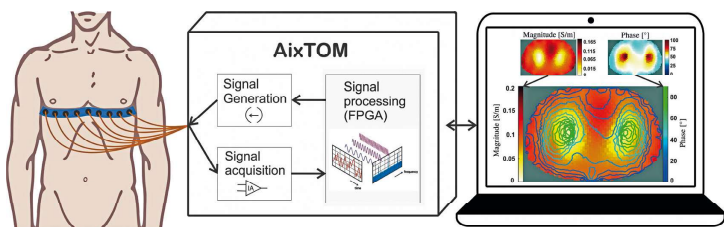


Fig. 7: The multi-frequency electrical impedance tomography (mfEIT) device, produced at MedIT, called AixTOM.

Automating Mechanical Ventilation for Better Patient Care

A patient is placed on mechanical ventilation when natural breathing is no longer able to ensure sufficient gas exchange (oxygenation and carbon dioxide elimination). The mechanical ventilator takes over the work of breathing, either completely or partially. Although often lifesaving, the mechanical ventilator can also further damage the lungs, if not correctly set by the clinician. The clinician therefore has to choose ventilator settings, such as peak inspiratory pressure (PIP), positive end-expiratory pressure (PEEP), breathing frequency (f), inspiratory to expiratory ratio (I:E), and fraction of inspired oxygen (FiO_2), which ensure proper gas exchange and prevent ventilator induced lung injury (VILI), also known as protective ventilation. However, every patient is different and changing with time (due to illness progression for example) and as such these ventilator settings need to be updated continuously. In the present clinical environment, this is however not possible.

An option is to automate mechanical ventilation by using physiological closed-loop control. In this case, the targets for the oxygenation and carbon dioxide are to be controlled. By measuring physiological signals, such as oxygen saturation (SxO_2) and end-tidal CO_2 (etCO_2), and designing a suitable controller, ventilator settings can be optimized even when the clinician is not present. In today's clinical environment, major focus is placed on protective ventilation, which also needs to be considered during the controller design. For this reason, medical expertise and optimisation strategies of tidal volume and applied pressures are incorporated into the controller design. An example for such a system is shown in Figure 8, where the individual controller aspects are grouped together in the controller and examples of physiological signals to be measured are given. By including the patient in the loop, using physiological feedback and medical expertise, the resulting ventilation therapy becomes more individualised for each patient and results in better patient care.

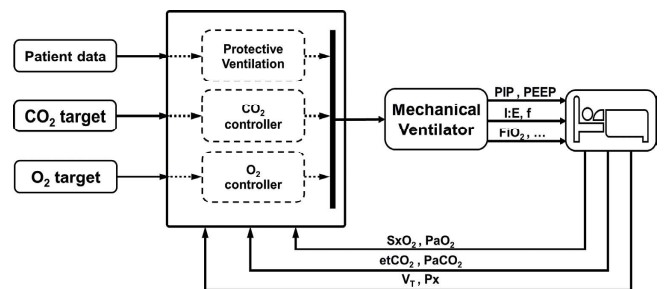


Fig. 8: Physiological closed-loop control of mechanical ventilation concept.

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



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Prizes and Awards

- L. Korn was selected for the yESAO exchange award 2018 in Madrid, Spain.
- S. Leonhardt was awarded the title "Doctor Honoris Causa" in recognition of his scientific achievements in biomedical engineering at CTU Prague.
- D. Rüschen won the prize for best talk award at the "Regelungstechnisches Kolloquium", Boppard, Germany.
- P. von Platen was awarded the second prize in the Young Investigators Competition at the World Congress on Medical Physics and Biomedical Engineering in Prague, Czech Republic.
- B. Misgeld has received the best paper award at IFAC BMS 2018 in Sao Paulo, Brazil.

Conference Organization

- [1] ICBEM and RGC, May 23rd -25th, 2018 at RWTH Aachen University, Aachen, Germany.
- [2] DGBMT+Annual Conference of the DGBMT (HIA-all chairs)

People at MedIT

