medIT

Medical Information Technology

Faculty of Electrical Engineering and Information Technology

Smart Solutions for Advanced Healthcare

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Introduction

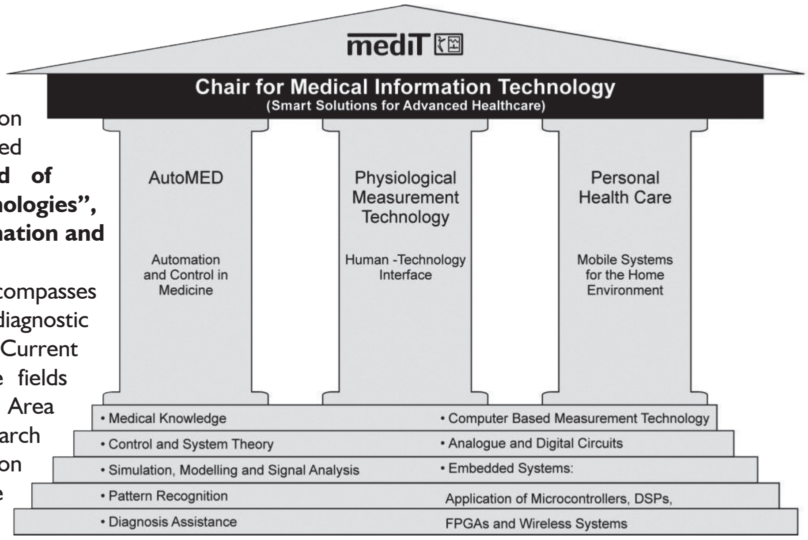


Fig. 1: Research profile of MedIT.

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.

Ongoing Research - Selected Projects

Contactless Control of the Incubator Temperature using Infrared Thermography

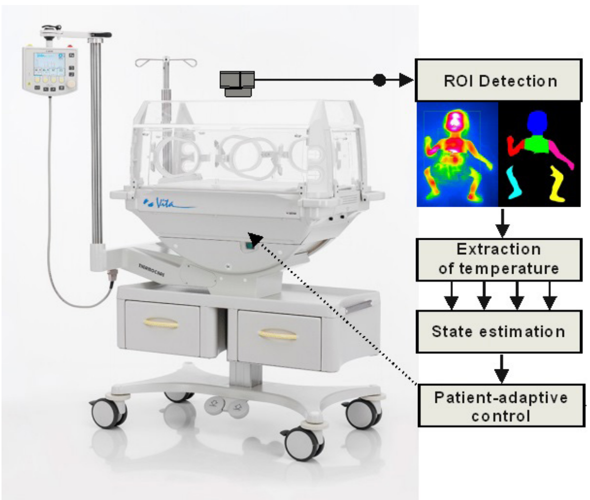


Fig. 2: Concept of contactless control of incubator temperature using infrared thermography [source: weyermed.com].

Since preterm infants are very delicate to heat loss after birth and the thermoregulation of their surrounding environment is crucial for the survival during neonatal intensive care. A neonatal incubator typically provides such regulation to newborn infants by monitoring body temperature and providing the needed warmth by heating the surrounded air. However, traditional monitoring systems usually require invasive or skin-contacted sensors, which can increase the risk of infection and damage the immature skin of neonates. In addition, the wiring of the sensors also complicates the work of the nursing staff and increases the psychological stress of the family. Parents often subjectively perceive the large number of sensors as an indicator of the severity of their child's care/illness.

The project aims to optimize the temperature control of the incubator using infrared thermography. Together with our project partners (Weyer GmbH, Dieter Richrath GmbH, and Uniklinikum Aachen), we want to develop a prototype that combines contactless temperature monitoring and individual thermoregulation inside the incubator. The use of infrared thermography makes it possible to measure the temperature not only at a few dedicated points, but also spatially resolved on the surface of the mattress. In particular, the measurement includes not only the temperature distribution on the mattress of the incubator, but also the temperature distribution of the patients themselves, becoming part of the control loop without contact. In this process, image processing algorithms are used to automatically detect regions of interest (ROIs) that serve as "virtual temperature sensors. This allows the monitoring of the temperature distribution of the neonate, which will be summarized in a novel „inhomogeneity index". Furthermore, the metabolic activity and the individual heat demand can also be estimated.

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

Data Fusion for Continuous Health Monitoring of Vehicle Drivers

Many traffic casualties can be traced back to driver fatigue, drowsiness or other critical physiological states such as heart attacks and strokes. Due to the aging demographics, the number of casualties can be expected to increase. Especially in partly autonomous vehicles, it is therefore crucial to monitor the fitness of a vehicle driver since the driver must be capable of taking control over the vehicle at any moment. With respect to the aging society, in-vehicle health monitoring also closes the gap of personal health care at home for early detection of various diseases. For personal health care applications, unobtrusive sensing technologies on different modalities are typically used, which can be invisibly embedded into fixed and secured objects, such as driver seats or driver cabins. These sensors include capacitive electrocardiography (cECG), ballistocardiography (BCG), magnetic induction (MI) sensors, radar and camera-based techniques.

Based on different sensor modalities, data fusion techniques can be employed on three different levels (see Fig. 3). First, signal-level fusion can be employed on the raw signals to increase the coverage and accuracy for the estimation of vital signs, such as cardiac and respiratory signals. Second, feature-level fusion can be applied on previously extracted features such as heart rate or breathing rate to classify the health status of a. Third, decision-level fusion can be used to decide whether the driver is fit for driving or not, and further measures can automatically be taken into action. These measures can include the coffee cup symbol, used often nowadays to point out drowsiness or fatigue with the recommendation to take a break. Yet telemedicinal approaches could also be a corrective measure in case of a heart attack or a stroke, wherein their detection might be combined with the automatic notification of an ambulance. In the latter case, the car could also automatically drive into a safe location to prevent possible car accidents.

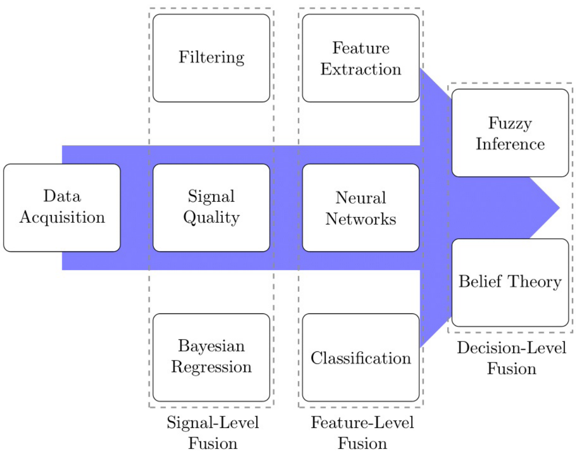


Fig. 3: Process of data fusion with examples for each level.

Automated Phrenic Nerve Stimulation with Mechanical Ventilation

The inactivity of diagphragm during traditional mechanical ventilation can lead to ventilator-induced diaphragmatic dysfunctions (VIDD), which are associated with 30 % of mechanically ventilated patients who are difficult to wean from the mechanical ventilator and to 10 % who face prolonged weaning. To ensure diaphragm activity, the phrenic nerve can be stimulated artificially. Together with Uniklinik RWTH Aachen, this project aims to develop a closed-loop system, which controls the phrenic nerve stimulation and the mechanical ventilation.

The closed-loop system must keep the patient in a safe condition and the diaphragm should be sufficiently stimulated to prevent VIDD. A configuration of the system is shown in Fig. 4. The stimulator generates electrical impulses, which are transmitted near to the phrenic nerve, causing a contraction of the diaphragm. The patient takes an artificially generated spontaneous breath. The real-time control system receives measurements from the stimulator, the mechanical ventilator and the patient monitor. The stimulator measures the voltage and current during the stimulation impulses whilst the mechanical ventilator measures the airway pressure and the flow in and out of the lung; the patient monitor measures the patient's condition such as the heart rate. Based on these measurements, the real-time control system adjusts the settings of the stimulator and the mechanical ventilator.

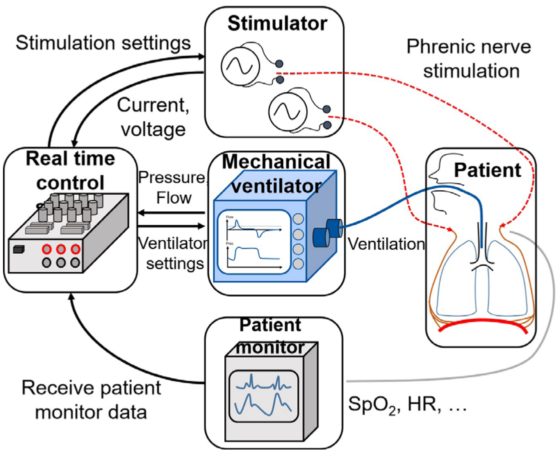


Fig. 4: Configuration of the closed-loop system with parallel phrenic nerve stimulation and mechanical ventilation.

This critical application imposes challenges on the overall system in terms of the least invasive method to place the electrodes near the phrenic nerve, an error of the stimulation and mechanical ventilation control algorithm, and an overstimulation that may lead to muscle fatigue.

Funded by: German Research Foundation (DFG)

Estimation of Force and Torque Development based on Dynamic Muscle Properties

Elders are suffering from a lack of mobility, typically resulting from ongoing age-related muscular atrophy. To relieve this process, early application of muscle development by training has proven as a valuable tool. Nevertheless, there is no feasible tool to assess the muscles force/torque development solely based on physiologic and dielectric tissue properties. One way to establish such a force/torque estimator is the algorithmic fusion of different measuring modalities, assessing indicators of physiological, morphological and metabolic aspects during muscle activity using the surface Electromyogram (sEMG) and Electrical Impedance Myography (EIM).

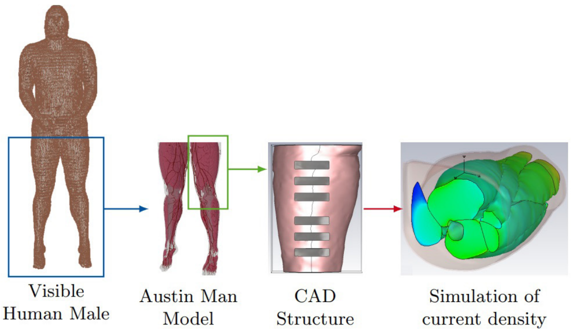


Fig. 5: Development of an FE-Model enabling simulation of current density within the upper leg.

A comprehensive analysis is investigated based on the physiological, morphological and metabolic processes of muscle activity and their impact onto the measured EIM and sEMG signals. Source separation strategies shall provide deeper insights into the superimposed processes shaping the signals, later approximating the dynamic process of muscle contraction and relaxation.

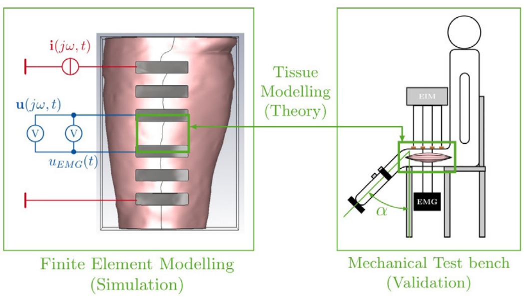


Fig. 6: Combination of theoretic knowledge, FEM and measurements to establish the basis of a force/torque estimation approach.

To realize this goal, an anatomical correct Finite Element Models (FEM) representing the human extremities are designed and consequently validated by measurements.

Funded by: German Research Foundation (DFG) and the Russian Foundation for Basic Research (RFBR)

Validation of Regional Lung Perfusion Monitoring using Electrical Impedance Tomography

For comprehensive cardiorespiratory monitoring of a patient, both the independent and synergetic knowledge of the pulmonary ventilation and perfusion status is imperative. As far as clinical practice is concerned, these two components are estimated resorting to techniques ranging from basic lung function tests to medical imaging. Despite the latter even being capable of estimating the invaluable ventilation-perfusion ratio, none grants us a chance of simultaneous, real-time, and non-invasive monitoring of ventilation and perfusion.

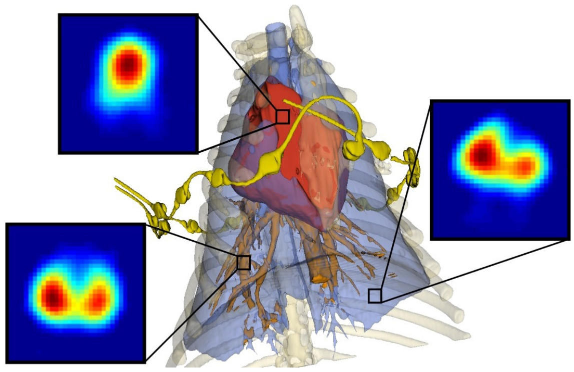


Fig. 7: Regional lung perfusion monitoring using electrical impedance tomography.

This project aims at validating electrical impedance tomography (EIT) as a perfusion monitoring technique, in the realm of ventilation-perfusion estimation. Therefore, the main mission is to compare the perfusion analysis promoted by EIT data with that of state-of-the-art Perfusion Computerized Tomography (CT-P), both simultaneously obtained from animal trials with an embolism-based damage model. Such endeavours will yield a thorough qualitative and quantitative characterization of the technique for perfusion using the challenging reference of CT-P, which, due to its invasiveness, cannot be used in clinical ventilation-perfusion practice, despite its superior accuracy.

Furthermore, the project seeks to investigate the underlying sources of this EIT perfusion signal. The signal is thought to result from the combined activity of single sources, like the movement of large calibre vessels, the pulsatile blood signal, down to the orientation of the blood cells. In this scope, we are constructing multi-physics models that can individually mimic these sub-components, allowing us to assess their influence. The perfusion signal is about an order of magnitude smaller than that from ventilation, with partially overlapping spectra, making it a non-trivial source-separation problem. We believe that the success of this work would provide the missing puzzle piece in the quest for the grail of cardiorespiratory monitoring.

Funded by: German Research Foundation (DFG)

Acquisition of Physiological Parameters for the Diagnosis of Affective Disorders

It is estimated that mental disorders account for 10% of the global burden of disease and are the leading cause of years lived with disability among all disease groups. Especially, affective disorders are the most important types of illness in terms of the duration of incapacity to work. Through acquisition of physiological data like photoplethysmography, skin response and temperature distributions, diagnostic markers will be defined that will allow a more precise diagnosis of the individual disorders. A more reliable differential diagnosis and improved monitoring of the course of therapy are the ultimate goal.

In this project not only contact based methods are used, but also the fusion of two inconspicuous measurement techniques, namely photoplethysmography imaging (PPGI) and infrared thermography are applied. PPGI enables the recording of heart rate and perfusion in the tissue as well as the quantification of the microcirculation, while infrared thermography shows the radiation of the patient's own heat. This enables local temperature distributions and central-peripheral gradients to be recorded and further analyzed. In addition, the system could enable the monitoring of a respiratory rate and other physical activities.

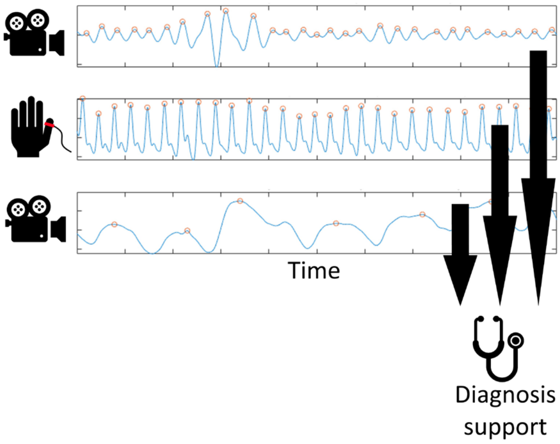


Fig. 8: Decision-based learning from sensor fusion for affective disorder classification.

Making use of predictive machine learning algorithms, both the individual and the combined predictive power for several relevant parameters can be determined. This requires the use of feature extraction, transformation and dimensionality reduction techniques combined with cross-validation of different learning paradigms including generative, discriminative, and deep learning approaches. This will help to increase diagnostic accuracy and improve treatment outcome for the depressive and schizophrenic patients, which seems highly relevant from clinical, scientific, and societal perspectives.

Funded by: European Regional Development Fund (ERDF)

Tremor Control using Deep Brain Stimulation

Related to the aging process of the population in western countries, researchers predict an increase of approximately 4.1 million Parkinson's patients worldwide in 2005 to 8.7 million Parkinson's patients in 2030. Since the treatment with medication often turns out to be insufficient or drug-resistant, Deep Brain Stimulation (DBS) is increasingly applied as an alternative treatment option.

DBS is also used to manage Tourette-syndrome, tremor, dystonia, and epilepsy. DBS is evolving as an effective treatment modality in certain neurological and psychiatric conditions. It has become an indispensable option for patients who have a poor response to medical therapy. During a neurosurgical intervention, small electrodes are implanted into specific regions of the basal ganglia, which are responsible for the control of motor functions. Through electrical impulses emanating from the electrodes, the regions of interest are excited such that symptomatic movement patterns are significantly reduced.

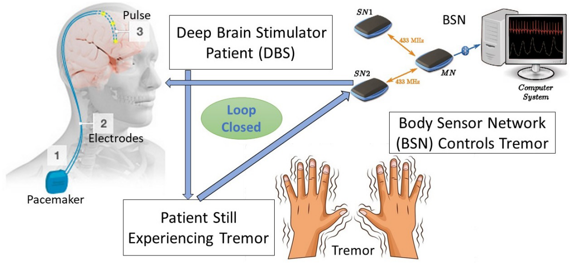
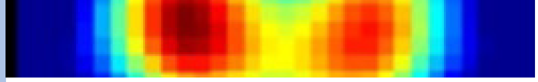


Fig. 9: Overview of tremor control using DBS.

The main risks of DBS are surgery itself, side effects after surgery, and side effects of stimulation. The side effects from stimulation could be managed with proper DBS control. Electrode polarity, stimulated frequency, pulse width, and current amplitude are stimulation parameters determining which neural elements in the surround of a stimulating electrode are being recruited. Although DBS is invasive with high risk and often associated with postoperative pain, it has been shown to have promising effects in some patients. With proper preoperative selection and follow-up, it can be the key for a better lifestyle for patients whose disability may not improve with medications. Controlling DBS automatically through an external programmable device that communicates with internal pulse generator (IPG) is the project's main idea. The IPANEMA body sensor network (BSN), containing motion sensors like accelerometer, gyroscope, and magnetometer, is also used as a tool for synchronized measurement for tremor monitoring in real time.

Funded by: German Academic Exchange Service (DAAD)



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Prizes and Awards

- C. Hoog Antink was admitted to the Young College of the North Rhine-Westphalian Academy of Sciences and Arts, January 2020.
- C. Ngo received the Borchers-Plakette 2020, ProRWTH.
- D. Rüschen won the 3rd prize for patient safety in medical technology, DGBMT, September 2020.

People at MedIT