medit

## Medical Information Technology

### Faculty of Electrical Engineering and Information Technology

# Smart Solutions for Advanced Healthcare


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Glöckner, Daniele, Secretary
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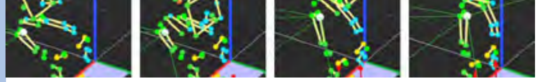



## Introduction

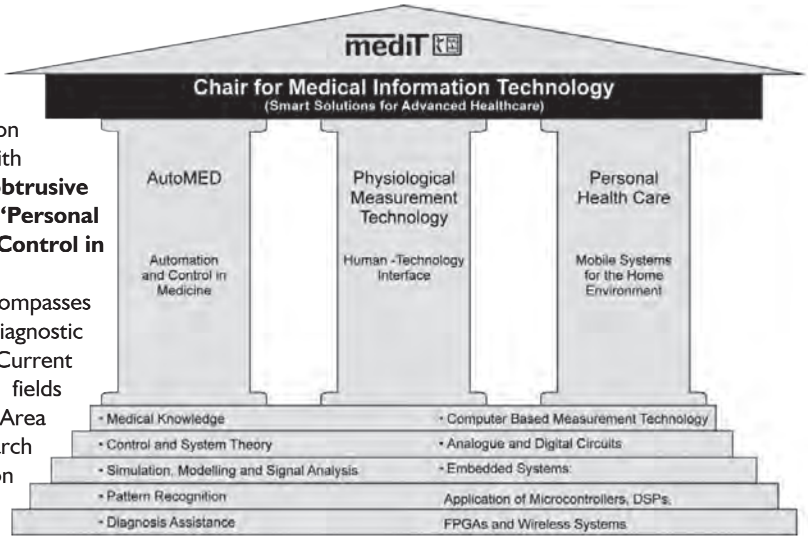


*Fig. 1: Research profile of MedIT.*

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

### Rehabilitation Robotics for Patients with limited Walking Ability

Wearable lower-limb exoskeletons can assist patients with limited walking abilities, e.g., due to post-stroke hemiplegia, by providing additional torques to the subject's joints. We investigate novel drive concepts and different control approaches to make such systems more secure and user-friendly. On the hardware side, we focus on lower limb exoskeletons with variable stiffness actuators (VSAs), see Fig. 2.

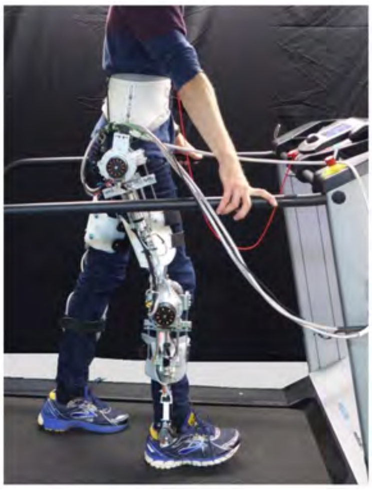

*Fig. 2: Gait experiment on a treadmill with lower-limb exoskeleton and serial elastic actuators in hip and knee joint.*

These actuators are characterized by an elastic, adjustable coupling between the exoskeleton and the patient, thus ensuring a higher safety. Additionally, the elastic element functions as a torque sensor for the human-machine interaction torque by measuring the spring deflection using high precision encoders.

One crucial part in cooperatively assisting the patient's rest motor function with these VSAs is to detect the pa-tient's intention to move. Our approach to addressing this challenge is based on the system theoretical know-ledge. Using detailed mathematical models of the exoskeleton's and patient's dynamical behavior and the interaction torque measurement via the elastic actuator, we can estimate the patient's movement in real-time. This approach is advantageous because the patient does not need to be equipped with additional sensors such as electrodes to measure muscle activity. Having detailed knowledge about the patient's movement intention is essential for implementing further control strategies. For example, it can be used to realize a behavior of the exoskeleton similar to an e-bike, where a certain assisting factor amplifies the subject's torque. On the other hand, the information about the patient's joint torque can also be used to quantify the strength and fatigue of the patient during rehabilitation training. Our goal is to combine the concepts of variable stiffness actuators, patient-cooperative control, fatigue estimation and gait stabilization to obtain an overall concept that safely and user-friendly assists patients and physiotherapists in rehabilitation training.

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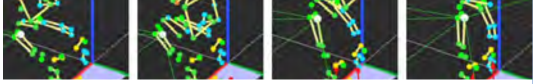






## Hybrid FES-Exoskeleton on Human Body Rehabilitation

Clinical rehabilitation and postoperative rehabilitation are critical for patients' health, especially for the elders. The most common impairment is a lower limb and upper limb paresis. Functional electrical stimulation (FES) and exoskeleton are regarded as necessary methods to rehabilitate body motion. However, implementing these two methods alone cannot achieve the desired goal of gait motion control. One promising way to assist body rehabilitation is a hybrid electromechanical system. Therefore, the objective of the project is to develop and evaluate a hybrid robotic system, which combines FES technology, body motion track system, and sensors, see Fig. 3.

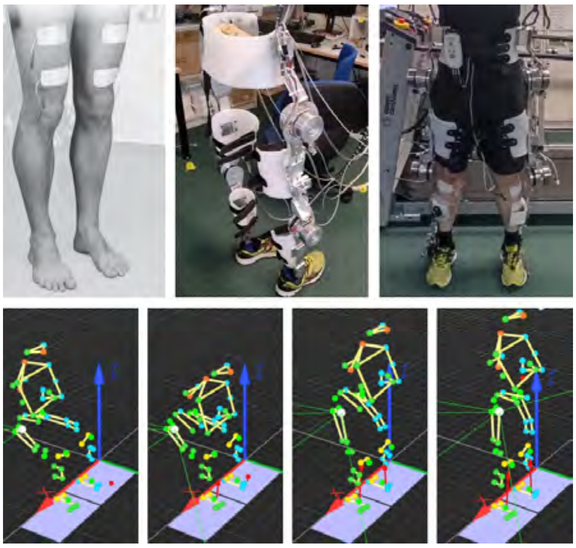


*Fig. 3: Concept of hybrid exoskeleton in body motion rehabilitation during sit to stand test.*

To archive this goal, the motion capture system is first used to get the precise trajectory of basic body motions as walking, sit-to-stand and so on. Exoskeletons with four motors are designed and attached to hips and knees. They mainly keep the body stable and provide torque assistance when moving. The FES system, which has four channels, is applied on the tibialis muscle, soleus muscle, gracilis muscle, and rectus femoris muscle. Instead of stimulating the muscle itself, stimulating the muscle's nerve will fully contract the muscles. Furthermore, muscle fatigue and EMG signal are also considered in the rehabilitation process. Combining the exoskeleton with neurological methods and sensors could enhance the performance of the closed-loop system. This hybrid system can be applied in rehabilitation centres. Further studies and applications are underway to evaluate the efficacy and control strategy in a clinical trial.

## Multi-modal Camera-based Wound Diagnosis by Means of Neuromorphic Computing

The term chronic wound refers to a breach of our protective barrier, the three layers of skin. Here the orderly wound healing process somehow stagnates, often at the inflammatory stage. In order to timely treat or even to prevent such wounds, an early detection and a close supervision of conclusive wound parameters is desired, for instance dimensions and temperature distribution. This could not only improve the treatment, but also reduce the costs and the stress for the patients. This project envisions to relief healthcare professionals in hospitals or outpatient care from paper forms, disposable rulers and subjective, educated guesses during (chronic) wound evaluation by developing a small, mobile, AI-based and contact-less 1-Click-Solution. The resulting diagnostic tool will only require one push of a button to perform visual and thermal inspection, infer the wound parameters, store them on clinical servers, conduct an analysis of the long-term development and report all of this back to the attending physician, see Fig. 4.

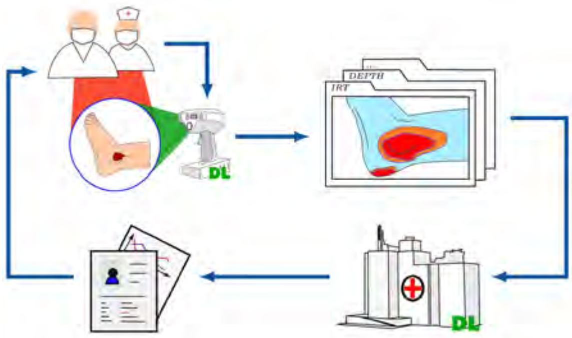
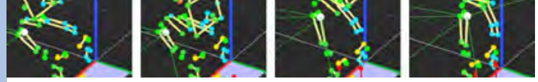



*Fig. 4: Illustration of smart wound scanner.*

Designing such a mobile wound scanner involves a multi-modal, camera-based approach for visual and thermal image acquisition. It is also equipped with a brain-like processing unit for image processing and computationally intensive deep learning (DL) algorithms. Currently, available GPUs for AI-applications are not yet optimized for energy efficiency though, hence limiting the abilities of mobile devices. Therefore, this project is embedded into the future cluster NeuroSys, consisting of 30 academic and industrial project partners. The cluster aims to establish a leading local industry for development of so-called neuromorphic hardware for such autonomous systems, dedicated to artificial intelligence. This kind of hardware will be solely designed for a fast and energy efficient implementation of neural networks, allowing complex yet mobile applications such as the wound scanner.

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





## Modelling and Validation of a decentralized Breathing Gas Source Estimation

The global Covid-19 pandemic came with a severe shortage of mechanical ventilators due to a mismatch of high demand and insufficient availability. Aiming for an affordable and fast producible but yet life-saving ventilator the MedIT institute designed and built its very own one: the people's ventilator "PV1000". However, this ventilator still relies on a high pressure supply with respect to both air and oxygen and the distribution of the latter can be challenging depending on the infrastructure of the country. For further steps it is therefore desired to add a decentralized source of breathing gas. The first approach includes the use of a medical blower to compress the surrounding air and a common oxygen concentrator for an increased fraction of Oxygen (FiO2). Designing the functional architecture in general with its hardware components alone while searching for an optimum can be time-consuming and the testing procedure of mechanical ventilators under realistic circumstances comes with high cost and effort. Therefore, a precise simulation instrument not only with respect to pressure and flow but also with respect to oxygen concentration is of high interest. For this purpose Mathworks provided an enhanced Simscape model such that H2O (humidity), O2, CO2 and N2 can be tracked. Fig. 5 shows the structure of the Simscape model.

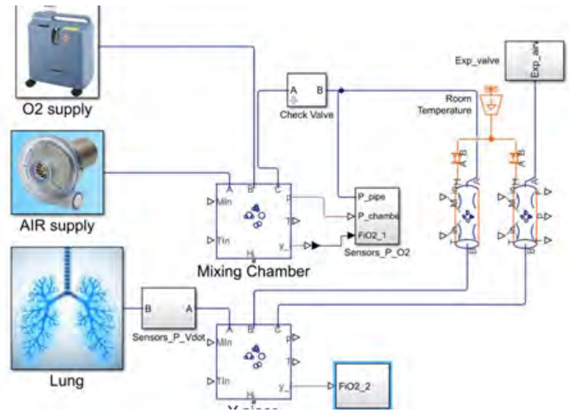



*Fig. 5: Model of the decentralized breathing gas source.*

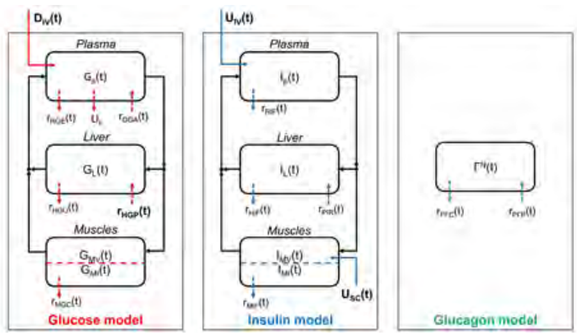
Low compressed air and oxygen is delivered by constant flow sources and both outputs are fed into a mixing chamber. A check valve ensures uni-directional flow towards the lung. Pressure, flow and oxygen concentration can be obtained at multiple locations and the model is aimed to be validated using a hardware test bench of equal architecture with several modes of ventilation.

The overall purpose is to create a simplified digital twin for simulating mechanical ventilation but also with respect to the effect on a potential patient. Further stages of oxygen diffusion, transport and consumption are going to be included in the future.

## Blood Glucose Control in the Intensive Care Unit

Patients in the intensive care unit often face stress hyperglycemia and high glycemic variability. Stress hyperglycemia can occur after an acute illness, surgery, or disease and is described by high blood glucose levels exceeding 140 mg/dl. Glycemic variability describes the strength of oscillations in BG throughout the day. As recent studies show, both stress hyperglycemia and high glycemic variability are associated with higher morbidity and mortality. Stress hyperglycemia is induced by a series of stress hormones, which increase insulin resistance. The detailed mechanisms are still unknown. Intensive insulin therapy of critically ill patients can reduce the risk of hyperglycemia. Nonetheless, a successful treatment needs to prevent hypoglycemia where blood glucose drops below 70mg/dL. There is no global consensus for a protocol and a glycemic target for insulin therapy in the critically ill. Furthermore, current treatments are limited due to the non-continuous monitoring of the blood glucose level.

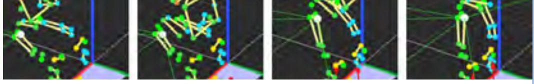
Mathematical models describing the blood glucose metabolism enhance understanding of the pathophysiology of stress hyperglycemia. Typically, these models describe the interaction of glucose, insulin, and glucagon in different body compartments, see Fig. 6. The impact of nutrition or exogenously administered insulin on blood glucose can be studied. Especially changes in insulin sensitivity and resistance and their influence on the blood glucose dynamic




are of interest.

*Fig. 6: Compartment model to describe the blood glucose metabolism. The model consists of subsystems for glucose, insulin and glucagon.*

Models of the glucose metabolism can assist in improving insulin therapy and developing closed-loop systems for automatized insulin therapy. Especially robust control methods are of interest as they guarantee a stable and robust performance for a large patient group.





## Blood Glucose Control during Physical Activity in type I Diabetes Mellitus

Patients with Diabetes mellitus type I cannot produce the blood glucose lowering hormone insulin. Instead, the blood glucose level is controlled by an exogenous injection of insulin. An adequate insulin dose is essential to prevent low blood glucose levels (hypoglycemia), which pose an acute danger. Additionally, it can prevent high blood glucose levels (hyperglycemia), which cause secondary diseases in the long-term. Due to the delayed effect of subcutaneously injected insulin, the insulin dose must be determined foresightedly. Multiple disturbances like meals or physical activity impede a precise prediction of the insulin demand. This project focuses on the particularly challenging impact of physical activity, which depends on multiple factors like exercise type, intensity, duration, nutritional status, and inter-individual differences.

Mathematical models of the glucose-insulin metabolism are a valuable tool in the development of strategies for blood glucose control. They enable simulations and forecasts of the blood glucose level and can thus be used to develop and validate control strategies. The literature describes several models of the glucose-insulin metabolism considering the impact of physical activity. However, none of these models was thoroughly evaluated. Even though the model accuracy is essential for the significance of simulation results and derived control strategies, there is only little information about it.

In the course of this project, pre-existing models describing the impact of physical activity on the glucose-insulin metabolism are analyzed, and a new model is developed. Both models from literature and the newly developed model are implemented and evaluated with clinical data to identify the best model. There are two long-term objectives. The first goal is the implementation of a simulator, which can be used to develop and validate blood glucose control strategies during exercise. Different exercises and patients shall be covered. The second goal is a model-based assistance system, which provides individually optimized suggestions for therapy adaptations for announced physical activity, see Fig. 7.

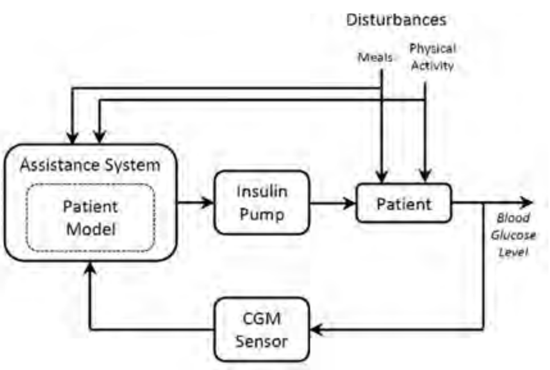



*Fig. 7: Scheme of the assistance system: The assistance system receives manually inserted information on meal intake and physical activity and is furthermore informed by a sensor for continuous glucose monitoring (CGM). The insulin delivery is then adapted based on the received information and on an individualized model of the glucose insulin metabolism.*

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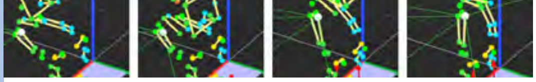
## Electrical Impedance Tomography for Mammography

Breast cancer is the most common life-threatening cancer affecting women around the world. Its survival rate can be significantly improved with early diagnosis and early treatment. There are different imaging modalities for breast cancer detection such as magnetic resonance imaging (MRI) screening, mammography with two x-ray beams at different angles, and sonography based on ultrasound-screening. The quality and performance of these techniques are still limited, for example, when dealing with dense breast tissue, facing the variability of personal experience and struggling with the issue of time consumption. To overcome these disadvantages, a novel approach for the detection of breast cancer is developed in this project.

The main goals are to develop an imaging modality that allows for early detection of breast cancer and its therapy. Together with our project partners (Goethe University Frankfurt, Lisa Laser Products OHG, Dr. Sennewald Medizintechnik GmbH and Infineon Technologies AG), we develop a system that combines imaging of breast cancer and minimally invasive therapy. For the therapy a laser system will be developed by Lisa Laser Products OHG for the early treatment of breast cancer. The imaging will be realized with the help of electrical impedance tomography (EIT) and millimeter-wave-radar (mmW). In the past, both EIT and mmW were implemented individually with mediocre success. Since EIT and mmW cover different parts of the electromagnetic spectrum, a combination of both techniques should be able to compensate for the drawbacks of each individual technology.

Although EIT has been well established in the two-dimensional domain, technology transfer to the three-dimensional domain is limited and will be a challenging task. Hence, further research on optimal patterns of current injection and voltage measurement is required in order to reconstruct breast images effectively. Due to the lack of short-term impedance dynamics inside the breast, new reconstruction algorithms will be developed, because time-difference EIT cannot be applied in a meaningful way. Thus, we will focus our research on image reconstruction using AI methods. Artificial neural networks are a promising way to enable reference free reconstructions of EIT images. However, the main challenge is to find appropriate ways to generate sufficient training data. These challenges can be overcome by strong cooperation with all project partners.

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





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## Prizes and Awards

• C. Hoog Antink has been appointed as professor in the Department of Medical Engineering at the Department of Electrical Engineering and Information Technology at TU Darmstadt.
• S. Leonhardt has been awarded with VDE Badge of Honour in Silver.
• S. Leonhardt has been accepted into IEEE's Technical Committee of Cardiopulmonary Systems and Physiology-Based Engineering (CSPE).
• K. Schröder has been awarded the title of Germany's best apprentice in the state-recognized training occupation of mathematical-technical software developer.
• M. Walter has finished his habilitation and was awared the venia legendi, the permission for independent university teaching.

## People at MedIT