Medical Information Technology

Faculty of Electrical Engineering
and Information Technology

Smart Solutions for Advanced Healthcare

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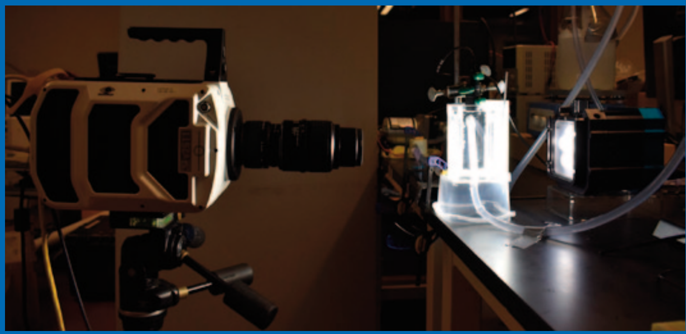

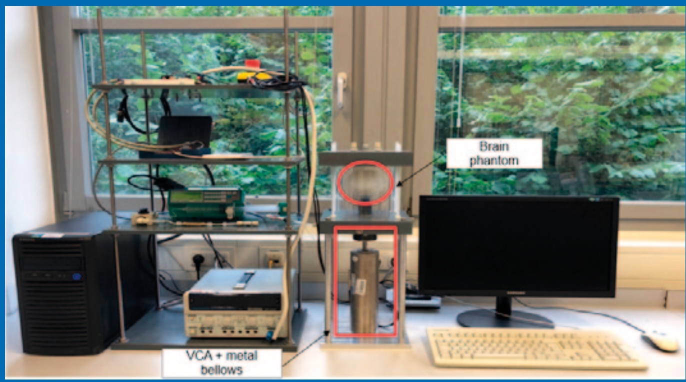

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Introduction

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

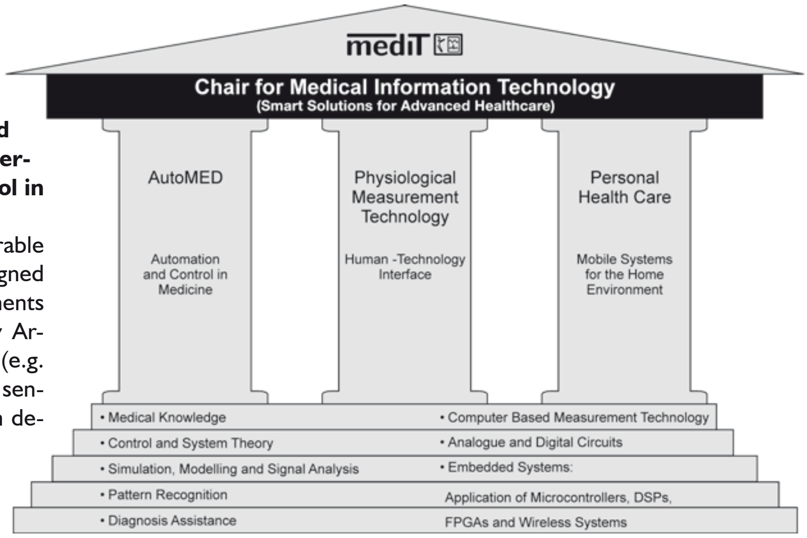

Fig. 1: Research profile of MedIT.

Ongoing Research – Selected Projects

Non-invasive Monitoring of the Peripheral Arteriovenous Oxygen Difference

Deficient oxygenation in tissues henceforth causes hypoxic cell damage, which is critical in vital organs such as heart and brain. Under normal physiological conditions, oxygen delivery and consumption relate to each other and are crucial for sustaining the fluctuating demands of cellular metabolism. To monitor regional oxygen distribution, the pulse oximeter can non-invasively be used and its working principle is to illuminate the skin with two specific wavelengths in order to distinguish absorbing property between oxygenated and deoxygenated hemoglobin, yielding peripheral oxygen saturation. Some microcirculatory dysfunctions such as diabetes mellitus and sepsis can alter the cohesion between oxygen supply and consumption. Thus, the determination of these factors is crucial for early diagnosis of tissue abnormality.

In blood circulation, blood flows to the organs via arteries and returns to the heart and lungs through veins. Therefore, oxygen consumption in the organs can be determined by the difference between its saturation in arteries and veins. In this project, we are developing a non-invasive monitoring system for the venous oxygen saturation in parallel with the arterial one. Our project partner (ELCAT GmbH, Munich), which specializes in cardiovascular diagnosis, is developing a hardware platform, while we design and implement the signal processing and algorithmic tasks. The novelty relies on the use of the venous muscle pump, which considers dorsal ankle extensions at a fixed frequency for generating easily identifiable venous blood volume variations, as shown in Figure 2. A reflective sensor placed on the foot detects these variations and obtains motion artifacts through accelerometers.

For signal processing, we implement different algorithms, which account for a variety of light-tissue interaction models in an anisotropic medium with multiple refraction layers. Simultaneously, the test of a wide range of filtering techniques is carried out for removing motion artifacts based on the data from the accelerometer. Besides, the analysis of the influential parameters such as the use of different wavelengths and sensor geometries entails another important aspect of the investigation. Monte Carlo simulations of the light interaction with a foot model will further validate our previous results.

Funded by: German Federal Ministry of Economic Affairs and Energy (BMWi)

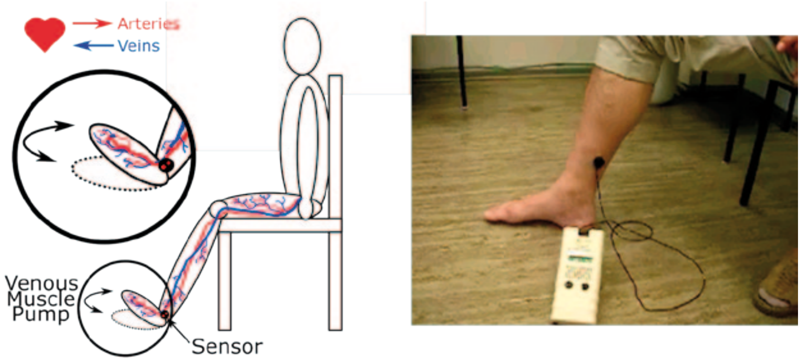

Fig. 2: Monitoring concept of peripheral arteriovenous oxygen difference.

Camera-based Early Detection of Sepsis in Newborns

In the neonatal intensive care unit (NICU), the occurrence of sepsis in newborns is one of the most common complications and poses a major threat to mortality and long-term morbidity due to the often-unspecific symptoms. Because of the rapid progression, the rate of mortality increases by 7.6 % every hour if antibiotic therapy is delayed. Therefore, sophisticated surveillance systems are crucial for an accurate early prediction when the condition is onset.
For monitoring purposes, various vital parameters are typically recorded using contact-based measurement techniques such as electrocardiography (ECG) and photoplethysmography (PPG). Some limitations such as the immature skin with the missing subcutis and the associated inefficient barrier to the environment of the neonate can

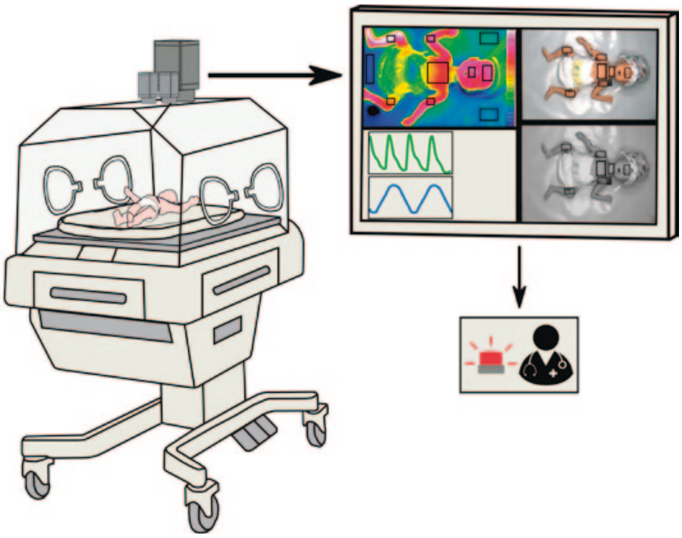

Fig. 3: A camera-based surveillance system for blood poisoning detection in neonates.

be the major issues in practice that the patient can be unintentionally injured or infected during the replacement of the adhesive electrodes. Therefore, the use of contactless measurement technologies should relieve the strain on the medical staff and the parents and enable infectious conditions to be continuously detected as early as possible.
The first signs of septic shock could be detected automatically using our proposed camera-based system based on the fusion of two unobtrusive measurement techniques, namely photoplethysmography imaging (PPGI) and infrared thermography. The PPGI enables the recording of heart rate and perfusion in the tissue and the quantification of microcirculation whilst infrared thermography presents the radiation of the patient's own heat. This allows local temperature distributions and central-peripheral gradients to be recorded and further analyzed. Furthermore, the system could enable the monitoring of respiration rates and physical activity. The early warning parameter should be derived and indicated directly at the incubator for triggering other therapeutic decisions in order to improve the survival rates of neonates in the future.

Funded by: German Research Foundation (DFG)

Breast Cancer Detection with the Aid of Electrical Impedance Tomography

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 time-consuming issue. To overcome these disadvantages, a novel approach for the detection of breast cancer is developed in the project.

Fig. 4: Schematic of a female breast. [Source: Kjpargeter – Freepik.com]

The project aims 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 Infeneon 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). Both EIT and mmW were individually considered in the past 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 technology.
Although EIT has been well established in the two-dimensional domains, technology transfer to the three-dimensional domains is limited and becomes 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. These challenges can be overcome by strong cooperation with all project partners.

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

Lower-Limb Exoskeleton for Gait Assistance with Compliant Actuators

A wearable lower-limb exoskeleton can be designed to assist the human gait by providing additional torques at the subject's joints using electric or other energy-based actuators, which can be applied for supporting age-related diseases and partial gait disorders, e.g., post-stroke hemiplegic patients. Therefore, it is crucial to achieving a safe interaction between a human and the machine. To address this challenge, we propose a tailored-made compliant actuator, composing of a mechanical-rotary variable impedance (MeRIA). The main idea behind this actuator is to transfer the generated motor torque via an adaptable elasticity to the human joint. The series elasticity is realized by two leaf springs and allows smooth interaction between the stiff motor and the compliant knee or hip joint of the patient. A unilateral exoskeleton is built using two compliant actuators (one at the hip joint and another at the knee joint, presented in Figure 5) to assist hemiplegic patients with additional torques and thus regain mobility and stability during walking. A power supply unit and a real-time controller are stationed on a walker. This walker is used not only for technical purposes such as measuring vital parameters i.e. electrocardiogram (ECG), but also for safety and stability reasons during rehabilitation training.

Fig. 5: *Realisation of the unilateral exoskeleton.*

Our goal is to achieve a patient-cooperative control that provides sufficient assistance torques for the patient as needed. Hence, a variety of sensors is used to detect the patient's states and movement intention, e.g., ground reaction force (GRF), angular positions, and surface electromyography (sEMG). These measurements are used to implement and validate different control strategies such as cascade, robust, and iterative learning approaches for position, impedance, and sensitivity control.

Funded by: German Research Foundation (DFG) and Stiftung Universitätsmedizin Aachen

Improving Hemolysis in Ventricular Assist Device Therapy using Physiological Control Strategies

Heart failure is one of the root causes of mortality in developed countries. Due to the imbalance between a restricted number of donor hearts and a huge number of patients, ventricular assist devices (VADs) are widely used as a bridge to transplantation or for destination therapy. In this project, we develop control strategies for such device, called Sputnik rotary blood pump (RBP), which was recently developed by our project partner from the "National Research University of Electronic Technology" in Moscow. It assists the heart in pumping blood from the left ventricle into the aorta.

Typically, RBPs operate either at a constant speed or at a constant flow, which may lead to risky situations i.e. overpumping or underpumping. To deal with changing demand in the cardiovascular system (CVS), advanced operating strategies using closed-loop physiological control are required to adapt blood flow. Its closed-loop configuration is provided in Figure 6.

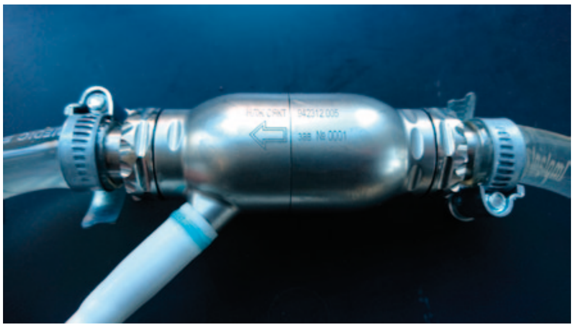

Fig. 6: *Rotary blood pump (Sputnik RBP) used for a closed-loop physiological control.*

One of the main technical issues in building a VAD system is the minimization of hemolysis. Much work has been dedicated in the past to optimize the pump geometry in this respect. Within this research project, we want to investigate whether hemocompatibility can be improved by optimizing the dynamic control of the RBP. In order to achieve this, a model of hemolysis dependent on operating conditions has to be identified. Our hemolysis model will be based on the information from literature and the data from hemolysis experiments. Using this model, we will subsequently develop optimized physiological control strategies, which provide the required hemodynamics and minimize blood damage.

The optimized physiological control strategies will be evaluated using the operating principle of a preexisting hybrid mock circulatory loop to validate their performances in a wide range of dynamic load conditions. Different dynamic load conditions include physiological as well as pathological conditions. For hemolysis assessment of our control strategies, the mock circulatory loop needs to be hemolysis optimized and porcine blood will be used.

Funded by: German Research Foundation (DFG)

Blood Glucose Control in the Intensive Care Unit

General patients in the intensive care unit (ICU) often face two main issues: stress hyperglycemia and high glycemic variability. Stress hyperglycemia can occur after an acute illness, surgery or disease. It is typically induced by a series of stress hormones, increasing insulin resistance. The detailed mechanisms are still unclear, and it is determined by extreme blood glucose (BG) level (> 140 mg/dl) whilst high glycemic variability is defined by the great swings of BG level throughout the day. Both stress hyperglycemia and high glycemic variability are associated with higher morbidity and mortality. To handle these issues, intensive insulin therapy is required to reduce the risk of hyperglycemia and simultaneously prevent excessive glycemic variability. Furthermore, it is crucial to prevent the life-threatening condition of hypoglycemia (BG level < 70 mg/dL). It is, therefore, a challenge to achieve these goals for life-saving.
A closed-loop system based on continuous BG measurement is proposed for insulin therapy by automatically injecting a proper amount of insulin at the right time. The system configuration is shown in Figure 7. The BG level is measured continuously in the venous blood. An expert system receives BG target range and patient data from a clinician. Within the expert system, a patient model incorporates the knowledge of glucose metabolism, the interaction between glucose and insulin, the pancreatic release of insulin, and preceding patient databases. Based on the dynamic input variables and the underlying patient model, a robust control technique is of interest for the development and evaluation of the overall system because its stable and robust performance is guaranteed for a large patient group.

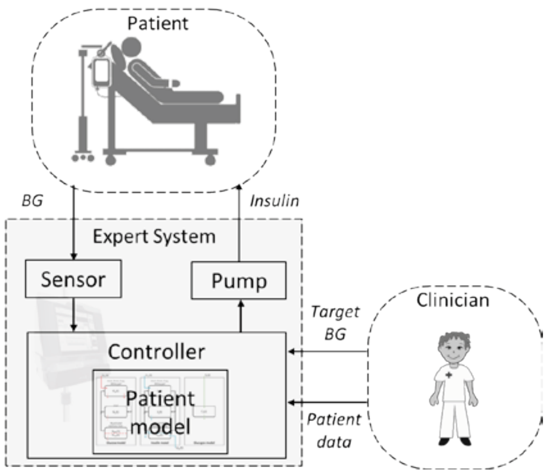

Fig. 7: Closed-loop control of blood glucose based on insulin therapy in the ICU.

Funded by: German Federal Ministry of Economic Affairs and Energy (BMWi)

Challenges of Unobtrusive ECG Monitoring

Capacitive electrocardiogram (cECG) electrodes can sense ECG signals through the clothing of a subject, by providing a capacitive coupling between the subject and analog instrumentation. cECG electrodes have been proposed and tested for a wide variety of applications by implementing the same principles of medical instrumentation in different scenarios. However, the suggested applications of cECG revolve around the out-of-hospital monitoring of vital parameters, where unobtrusiveness is aimed for at the expense of reduced signal quality, instead of becoming a tool for clinical diagnosis or an alternative for the gold standard ECG. The course of cECG is shaped by its inferiority to normal ECG in terms of signal quality, which can be attributed to several factors such as very high coupling impedance, triboelectric surface charges and high susceptibility to motion artifacts.
In cECG, the high impedance of the coupling between the human body and the analog instrumentation converts the existence of triboelectric surface charges into a dire problem by slowing down their discharge, thus, prolonging their influence. Moreover, even the smallest mismatches between the electrode impedances are reflected tremendously in the common-mode rejection of the analog instrumentation, as the impedance range of the electrodes becomes closer to the input impedance of the instrumentation. Aside from the electrode impedance mismatch, the variations in the coupling impedance were shown to cause motion artifacts.

Fig. 9: Multi-channel cECGs integrated in a car seat.

These drawbacks of cECG lead to a low time-coverage in the signal availability, which is tried to overcome by monitoring with multi-channel cECGs to utilize signal fusion, as presented in Figure 8. Another way to make cECG a reliable tool is to understand all obstacles and solve the problems. Therefore, a significant amount of effort should be put into a better understanding of phenomena in cECG such as motion artifacts and triboelectricity.

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Prizes and Awards

- C. H. Antink received the Borchers-Plakette 2019, ProRWTH.
- L. Korn won 1st prize whilst S. Lyra and M. Paul won 2nd prize in the session of "Biomedical Engineering" at POSTER 2019, Prague.
- S. Leonhardt was giving guest lectures at the Massachusetts Institute of Technology (MIT).

People at MedIT