mediT

Medical Information Technology

Faculty of Electrical Engineering and Information Technology

Smart Solutions for Advanced Healthcare

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

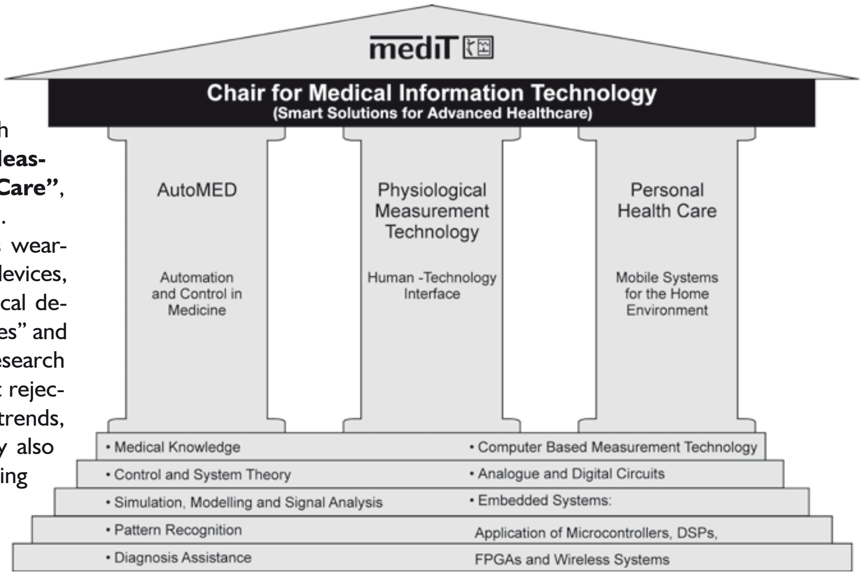

Fig. 1: Research profile of MedIT.

Selected Ongoing Research Projects

Cardiac Neuromodulation – Electrical Stimulation Modulates Heart Rate

Tachycardia or an elevated heart rate (HR) is an independent risk factor for a higher overall mortality. Patients with the underlying disease require quick diagnosis and treatment. Pharmacological approaches are limited due to their disadvantages regarding side effects, compliance, exclusivity, maximum effectiveness and lack of dynamic adjustment of heart rate.

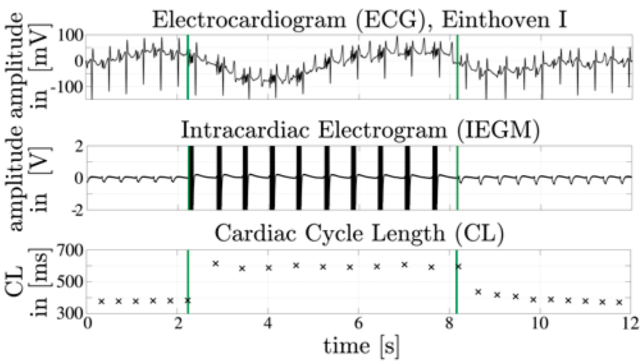

Fig. 2: *The experimental results of cardiac neuromodulation between 2.1 s and 8.1 s based on an anesthetized sheep.*

Cardiac neuromodulation is hence applied in investigating its effects to heart rate. Since the sinoatrial (SA) node is the main pacemaker of the heart, modulated by the autonomous nervous system (ANS), intracardiac stimulation of the vegetative hotspot would allow exclusively a change of heart rate. As pacing the heart can cause fibrillation according to the time of stimulation, the major challenge of this technique is to stimulate at the right time. Thus, neurostimulation triggers onto the intracardiac electrogram measured with the same electrode catheter used for the stimulation pulses. Measured at the sinoatrial node, stimulation pulses are applied with a short delay after the local action potentials to ensure all heart muscle cells are refractory**.** With a certain stimulation period, high-frequency pulses activate the parasympathetic hotspot close to the sinoatrial node. In animal experiments, we further investigated the developed neurostimulation device with respect to the most efficient stimulation parameters varying stimulation pattern (e.g. monophasic and biphasic rectangular pulses) voltage amplitude, stimulation burst frequency, stimulation period and delay between trigger signal and stimulation start.

An example of a neuromodulation is shown in Fig. 2 with ECG and intracardiac electrogram and the interbeat cycle length (reciprocal value of heart rate). Heart rate before the neuromodulation period is relatively high (~ 158 bpm). During neuromodulation, Heart rate shows an immediate decrease to a level of approximately 100 bpm or by 37 %.

Funded by: German Research Foundation (DFG)

OR.NET – Secure and Dynamic Networking in Operating Room and Clinic

Based on medical information technology, device interoperability has been a central issue for years. The usage of computer-based medical system increased dramatically in daily routine with a considerable improvement of clinical treatment. Innovative and smart algorithms can also be established such as improved intelligent alarm concepts, decision support and automation procedures with dependencies and synergies among medical devices. The proposed system does not only analyze vital parameters from different sources, but also uses and combines different methods of signal analysis and model-based approaches in order to provide a decision support system in anesthesia with the manufactured independent device interconnection and plug and play functionality.

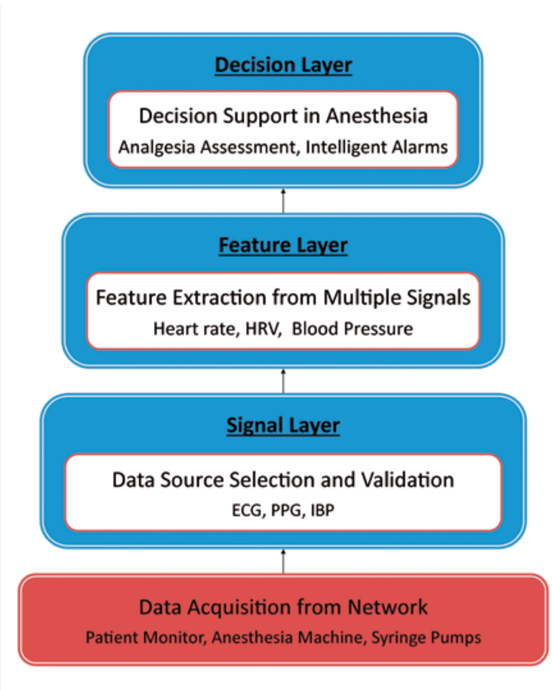

Fig. 3: *Layer model for decision support in anesthesia.*

State-of-the-art internet standards and protocols such as Ethernet, TCP/IP and web services are used. Additional standards as HL7, DICOM and ISO11073 are integrated in order to ensure interoperability. Beside the architecture and protocols, new concepts for human machine interaction and risk analysis will be implemented with the approvability and standardization. New concepts for device operation and information visualization will be integrated with an anesthesia workstation. Furthermore, a decision support system, including intelligent alarms and analgesia assessment, is carried out. In addition, further aspects as the interaction with postoperative care and hospital will be considered in order to fulfill the patient-oriented care.

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

Adaptive Functional Electrical Stimulation

Deformations of leg veins are a common phenomenon: while just about 10% of the German population are free from symptoms, 59% suffer at least from telangiectasia and similar syndromes. The remaining 30% show severe symptoms due to chronic vein problems such as varicose veins, fluid accumulations, or venous leg ulcers. The development of a device for diagnostics and therapy is our aim.

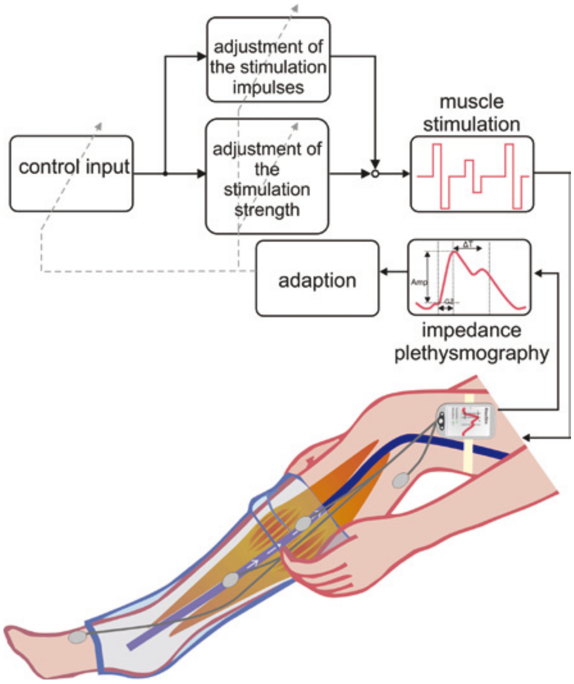

Fig. 4: *System Realization of adaptive functional electrical stimulation.*

By automatic and adaptive induction of electrical impulses, the pumping mechanism to support the venous blood flow from the legs back to the heart is stimulated. Hence, venous insufficiency is compensated. The trend of blood flow is determined by the measurement of the pulsatile change of conductivity in the observed segment (impedance plethysmography IPG). Superficial and low veins as well as lymphatic vessels are compressed due to muscle contractions, triggered by electrical stimulation. Lymphatic and blood flow is then increased. "Adaptive stimulation" allows the automatic adjustment of the stimulation intensity according to the electrode transfer impedance, the gait, the physical activity level, and the tissue perfusion. Furthermore, the stimulation frequency and the pulse width adjust automatically in order to improve the transport of venous blood. Therefore, this system can treat and prevent vein problems. Blood congestion is decreased and chronic tissue injuries are prohibited. In addition, the patient receives a feedback about the condition of his veins. The signal of the impedance plethysmography can be used to extract this information. The amplitude of the pulse wave is dependent on the amplitude of the blood pressure and the vessel elasticity. Hence, it is influenced by the local blood pressure, the position-dependent hydrostatic pressure difference, the regulatory stress of the vascular wall, and the anatomy of the vascular wall which is relevant for diagnostics.

Funded by: German Federal Ministry of Economics and Technology (BMWi-ZIM)

Biofeedback with Wearable In-ear Photoplethysmography

Vegetative dysfunctions are disorders that occur in a dysregulation of the autonomic nervous system. This affects body functions, which are controlled by the autonomic nervous system, such as circulation, respiration and metabolism. These dysfunctions can be due to stress as a result of illness or pain. Stress in turn can also cause disease itself and prevent or delay the healing process. Stomach, heart or breathing problems, headache or back pain can be indications of autonomic dysfunction.
A successful therapy requires the development of new options for individualized, non-invasive diagnostics. New approaches aim to substantiate the therapeutic success through the active involvement of the patient. For this, a biofeedback system is implemented based on photoplethysmography (PPG). Physiological functions can be controlled using biofeedback if they are connected to cortical structures of the central nervous system (CNS). Further, these functions have to be related to the two branches of the autonomic nervous system, the sympathetic nervous system (SNS), and the parasympathetic nervous system.
PPG is a non-invasive, optical method to obtain blood volume shifts at the point of measurement. Blood volume shifts are generally caused by blood pressure variations coming from various physiological processes. Therefore, PPG is capable of identifying many different vital signs like heart and respiratory activity or blood pressure variations while the in-ear PPG system is capable of detecting rhythmic, vital phenomenon that are directly linked to the CNS. With a user feedback based on a mobile phone (smartphone), a technological/ biological regulation loop is realized, whereby the patient is trained to influence (regulate) vegetative functions to reduce stress. Additional to the in-ear biofeedback system, algorithmic approaches are developed that are important for CNS related biofeedback, as shown in Fig. 5.

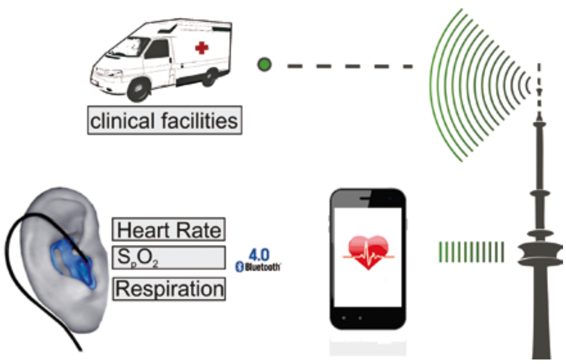

Fig. 5: *Biofeedback.*

Funded by: German Federal Ministry of Economics and Technology (BMWi-ZIM)

Automatic Protective Ventilation Based on ARDSNet Protocol

A dysfunction of the pulmonary system i.e. acute respiratory distress syndrome (ARDS) triggers an impaired gas exchange with severe progressive hypoxemia and hypercapnia. In intensive care medicine, the therapeutic approach is mainly based on the application of mechanical ventilation. Since gas exchange of oxygen and CO_2 is the prime essence of the respiratory function, automatic control of an artificial ventilation system was set up for the treatment of patients with ARDS based on a medical expert system in a star topology as shown in Fig. 6.

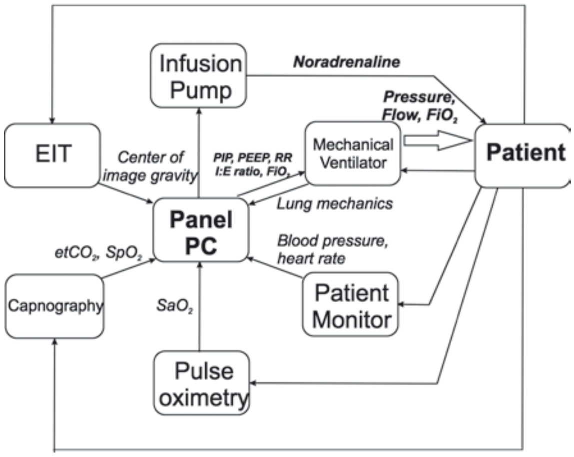

Fig. 6: *System configuration of the automatic protective ventilation based on the ARDSNet protocol.*

The overall multitasking program with a goal-oriented structure was coded with LabVIEW graphical programming in a platform, called “Ventilab”. This particular closed-loop expert system can actively and intelligently perform a long-term treatment by the standardized and well-known ventilation strategy, namely Acute Respiratory Distress Syndrome Network (ARDSNet) protocol.
Based on this protocol, the three main goals of the ventilation therapy are the stabilization and regulation of oxygenation, restricted plateau pressure as a protective measure and control of blood pH. In addition, low tidal volume per weight between 4 ml/kg and 8 ml/kg is proposed with a significant outcome of reduced mortality by 8.8 % compared to the conventional ventilation therapy. Using porcine models with surfactant wash-out by repetitive lung lavages, the algorithmic performances were assessed by biochemical properties of standard arterial blood gas analysis, mechanical properties of the ventilatory parameters, and the pathophysiological change non-invasively measured by real-time electrical impedance tomography with the distinctive results of lung morphology. This automatic ventilation therapy system offers not only standard continuous care for patients with ARDS, but also a minimization of the workload of daily clinical practice, which should eventually optimize the overall cost of treatment for the whole community.

Funded by: German Federal Ministry of Economics and Technology (BMWi-ZIM)

Noncontact Breathing and Pulse Measurement

Continuous monitoring of respiratory and cardiac activity is of importance in health monitoring systems. Due to the side-effects of conventional methods (e.g. skin irritation, contact problems or large energy requirements), noncontact methods offer a favorable alternative. Recently, the fusion of magnetic induction and reflective photoplethysmography was realized in our research group. Combining both sensor techniques, it is possible to monitor different physiological parameters at the same measurement location. This reduces the application effort and the size of the device, and enables investigation of dependencies between different physiological measurements without time-shifts or damping-effects due to mechanical propagation.
The principle of magnetic induction is based on the fact that respiratory and heart activities result in displacement of organ boundaries and blood across the thorax. This will cause a measurable change in the body's electrical impedance distribution. By magnetic induction measurements, which use inductive eddy currents, a noncontact determination of those changes is possible. The main technological challenge is to handle very small signals in a noisy environment. Therefore, special importance has to be paid to the use of a highly precise and fast circuit design inside the radio frequency measurement parts.
The reflective photoplethysmography light of a specific wavelength is emitted into a tissue region under investigation and the fraction of light, which is reflected (after superficial penetration) by the thorax, is recorded. Since the light intensity at the measurement site depends on blood flow, this sensor technique is well suited for cardiac pulse detection. We combined both sensor principles in a mobile device, which is able to monitor respiration and pulse in a noncontact way enabling unobtrusive monitoring.

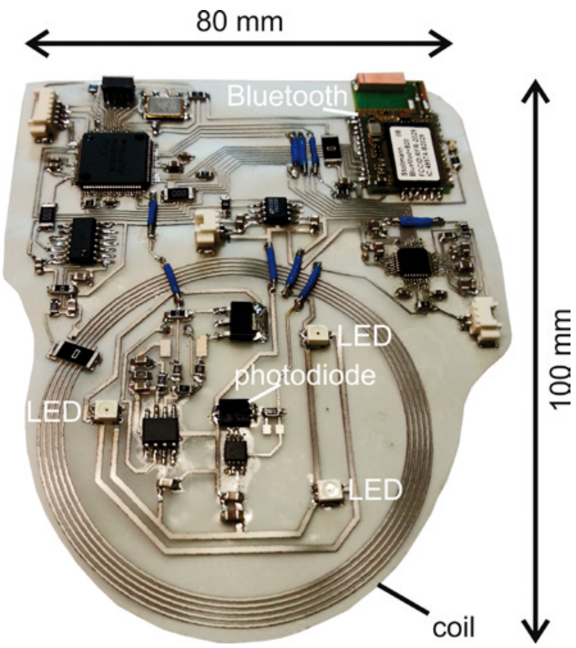

Fig. 7: *Photograph of a novel device for unobtrusive and mobile vital sign monitoring.*

The prototype is fabricated on a small printed circuit board, which can easily be put into a shirt pocket or the inner-pocket of a jacket. Due to the flexible carrier material on the printed circuit board, the invented device is able to change its form and cope with the uneven thoracic surface.

Funded by: German Federal Ministry of Economics and Technology (BMWi-ZIM)

Development of a Novel EEG-based Neuro-feedback System for Home Use

Attention deficit and hyperactivity disorder (ADHD) is one of the most common neurological diseases in children with a prevalence of 7-17% in boys and 3.3-6% in girls at the age of 6-12 years. ADHD is often treated with medication, which can cause unwanted side effects with a considerable number of non-responders. Other therapies like neurofeedback are possible alternatives in treating ADHD. Recent studies have shown that neurofeedback can have lasting effects on attention even after the termination of the therapy.
Using neurofeedback therapy, patients are taught how to control parts of their own brain activity. This is achieved by recording, for example electroencephalography (EEG) data and displaying instantaneous visual feedback. The patient has to control an avatar in the direction indicated on the screen. At least 30 sessions of one hour each are required to learn this technique.

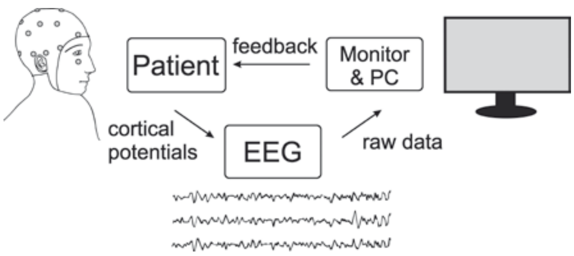

Fig. 8: *A novel EEG-based neurofeedback system for home use.*

Thus, the aim is to develop a portable device in order to perform neurofeedback therapy at home. This way, parents would help their children carry out the training while medical staff can check and supervise the course of the treatment remotely. Therefore the system has to be easy to use and still deliver all the benefits of the therapy in the clinic. New user-friendly electrodes with noise immunity are developed. A testing platform was also constructed to evaluate electrical characteristics of the electrodes. Different materials were characterized in this process. Moreover, electrodes were assembled to fit into a novel and visually appealing electrode cap. Furthermore, signal processing methods for the recorded EEG are developed to deal with a small signal with an amplitude of a few μV, which is interference-prone.

Funded by: German Federal Ministry of Economics and Technology (BMWi-ZIM)

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Prizes and Awards

- V. Blazek: Felber-Medal in Gold from CTU, Prague, Czech Republic.
- M. Walter: DAAD scholarship at IIT Madras, Chennai, India.
- M. Ulbrich, N. Blanik, B. Venema, D. Rüschen and M. Paul: 1st, 2nd Poster-Award in session “Biomedical Engineering”, 1st Poster-Award in session “Natural Science”, 1st Poster-Award in session “Electronics and Instrumentation” and 1st prize of Master’s student, respectively, at POSTER 2014, Prague.
- S. Leonhardt: Fellow of the North Rhine-Westphalian Academy of Sciences and Humanities and Arts, Germany.
- D. Teichmann: Best Paper Award from BSN 2014, Zurich, Switzerland.
- D. Rüschen: Springorum medal 2014 from ProRWTH.
- A. Pohl: Semi-finalist in the Rosanna Degani Young Investigator Award, IEEE Computing in Cardiology conference 2014, Cambridge, MA, USA.
- T. Wartzek: Borchers-Plakette 2014, ProRWTH, and Friedrich-Wilhelm prize 2014, RWTH Aachen University.

People at MedIT