medit

Medical Information Technology

Faculty of Electrical Engineering and Information Technology

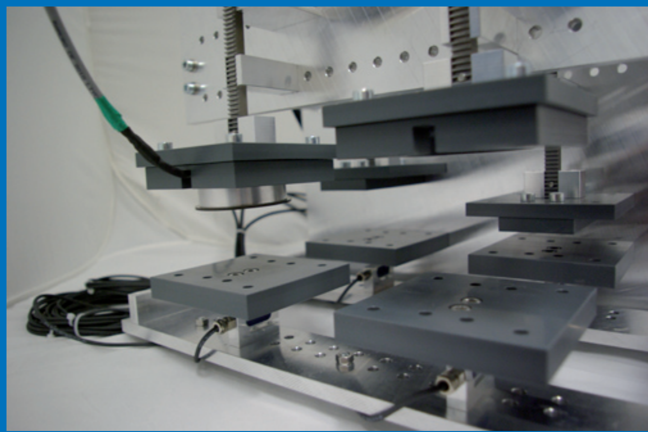
Smart Solutions for Advanced Healthcare

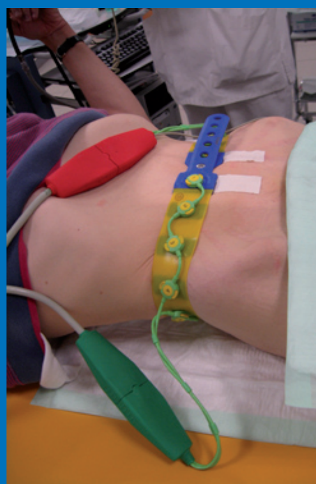
Director

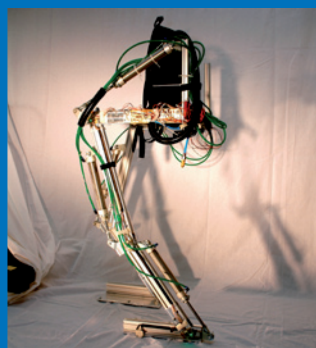
Univ.-Prof. Dr.–Ing. Dr. med.
Steffen Leonhardt, M.S.

Philips Chair for Medical Information Technology
Helmholtz-Institute for Biomedical Engineering
Pauwelsstrasse 20
52074 Aachen

Phone: +49 (0)241 80-23211 (office)
Fax: +49 (0)241 80-82442
Email: medit@hia.rwth-aachen.de
Web: http://www.medit.hia.rwth-aachen.de

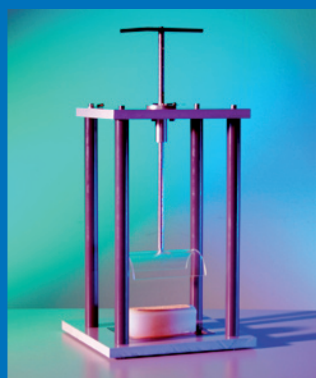






Staff (Full time equivalents)

Walter, Marian, Dr.-Ing., Senior Scientist
Blazek, Vladimir, Prof. Dr.-Ing., Senior Scientist
Misgeld, Berno, Dr.-Ing., Senior Scientist
Balzer-Sy, Heidi, Admin. Assistant
Clever-Offermanns, Bettina, Admin. Assistant
Wrobel, Walter, Dipl.-Ing., Laboratory Engineer
Kerschgens, Melanie, IT Administrator
Voigtländer, Paul
Abbas, Abbas, M.Sc.
Aguiar Santos, Susana, M.Sc.
Blanik, Nikolai, Dipl.-Ing.
Brendle, Christian, Dipl.-Ing.
Brüser, Christoph, Dipl.-Ing.
Cordes, Axel, Dipl.-Ing.
Czaplik, Michael, Dr. med.
Eilebrecht, Benjamin, Dipl.-Ing.
Elixmann, Inga, M.Sc.
Foussier, Jérôme, Dipl.- Ing.
Gerlach-Hahn, Kurt, Dipl.-Ing.
Heinke, Stefanie, Dipl.-Wirtsch.-Ing.
Hoog Antink, Christoph, Dipl.-Ing.
Ismail, Abdul Hamid, M.Sc.
Kerekes, Anna, Dipl.-Ing.
Kim, Saim, Dipl.-Ing.
Köny, Marcus, Dipl.-Ing.
Lunze, Katrin, Dipl.-Ing.
Pikkemaat, Robert, Dipl.-Ing.
Pohl, Antje, Dipl.-Ing.
Pomprapa, Anake, M.Sc.
Schlebusch, Thomas, Dipl.-Ing.
Teichmann, Daniel, Dipl.-Ing.
Ulbrich, Mark, Dipl.-Ing.
Venema, Boudewijn, Dipl.-Ing.
Wartzek, Tobias, Dipl.-Ing.
Weyer, Sören, Dipl.-Ing.



RWTH AACHEN UNIVERSITY

Introduction

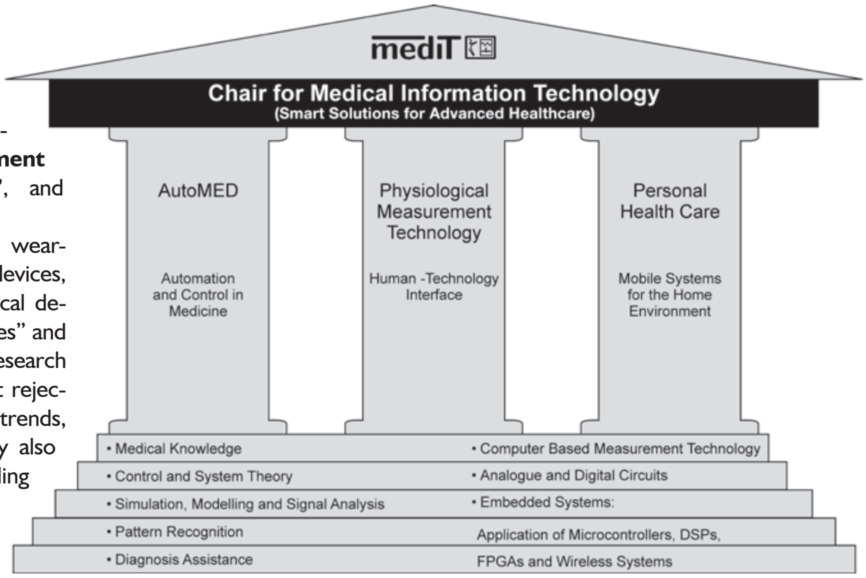


Fig. 1: Research profile of MedIT.

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.

Selected Ongoing Research Projects

Cardiovascular Sleep Monitoring with in-ear Pulse Oximetric Sensors

Cardiovascular diseases are among the most common causes of death in western industrial nations. Therefore, early determination of the cardiovascular risk factor is required for preventive measure. The project aims to assess the cardiovascular functionality using photoplethysmographic (PPG) signals acquired from an in-ear sensor. By long-term monitoring of vital signs such as heart rate or arterial oxygen saturation, it provides a comprehensive personal health care system which can also meet the daily patient's requirements of mobility, usability and robustness.
Pulse oximetry is a reliable, non-invasive method for monitoring of vital signs. In comparison to conventional systems, which are applied to peripheral parts of the body, our approach is based on an alternative solution, namely a "reflective PPG sensor", which can be placed in the auditory canal. This allows a 24/7 measurement with particularly high wearing comfort. Since in-ear measurement would bring some essential advantages, new areas of application will be developed (i.e. personal health care and sports). As a major advantage, stable conditions concerning perfusion and temperature are expected, since the nearby brain perfusion is sustained in all situations. Therefore, compared to conventional finger-clip sensors, even in case of shock-induced centralization, a valid measurement can be ensured.
The central component is a micro-optic reflective sensor, which is sealed within a biocompatible ear mold. An electrical measurement equipment, as a sensor interface, performs direct high resolution data conversion for long-term data recording by a personal computer.

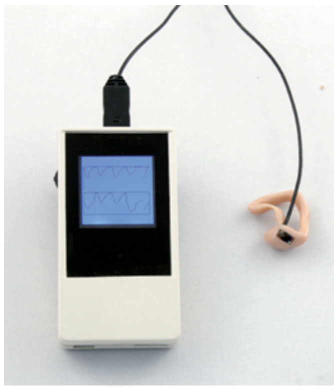


Fig. 2: The in-ear sensor and the measurement equipment.

We studied the feasibility of a clinical appliance of the sensor system for cardiovascular monitoring during sleep which may allow diagnosis of sleep apnea in future. Accordingly, human trials were performed in a sleep laboratory on patients with a clinical suspicion of sleep apnea. With evaluation focuses on heart rate and oxygen saturation and in comparison to standard PPG measurements, our results demonstrated that nocturnal long-term measurement of oxygen saturation and heart rate is possible with sufficient accuracy.
Funded by: Ziel 2. NRW

Oxivent - Oxygen on-demand Clinical Ventilation

The aim of this project is to control O_2 and CO_2 non-invasively in mechanically ventilated patients based on a homogeneous lung model. It should lead to a regulation of oxygen saturation (SpO_2) and arterial CO_2 tension ($PaCO_2$) in blood circulation. Therefore, O_2 supply and CO_2 level can be maintained within the proper levels during clinical ventilation. The hardware configuration is composed of a mechanical ventilator with a remote control access, a

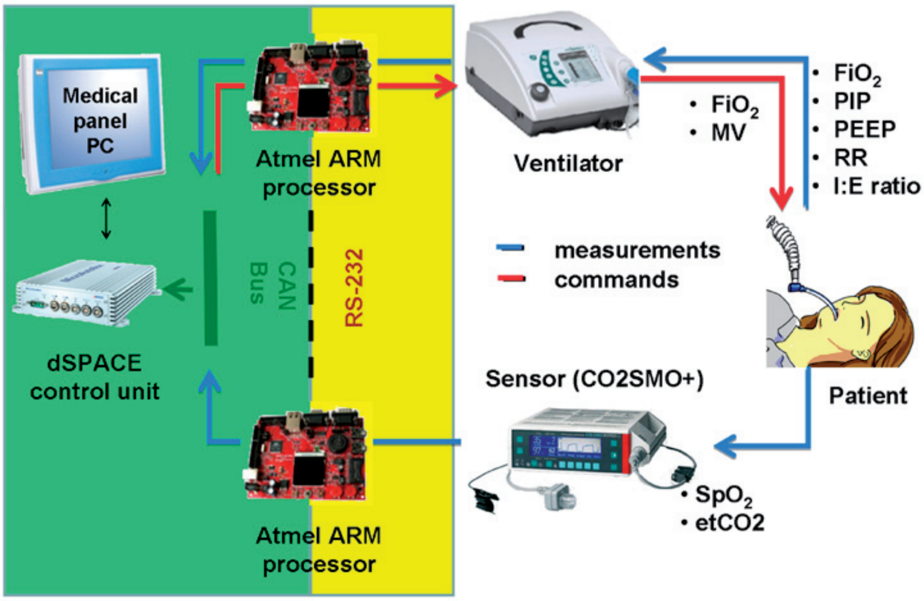


Fig. 3: Setup of Oxivent system.

capnography with a pulse oximeter, a dSpace control unit MicroAutoBOX II, and a medical panel PC. A closed-loop system is designed with the aid of Atmel ARM processor-based as a backbone for data conversion between RS232 and Controller Area Network (CAN) protocols. All ventilation parameters, as end-tidal CO_2 ($etCO_2$) and SpO_2 are transmitted over CAN bus. The CAN protocol helps to facilitate all data transmission among the nodes using message-based infrastructure. The advantage of this protocol is to avoid data collision with the highest speed at 1 Mbits/s. Modeling and system identification are carried out to describe the complex nonlinear respiratory system. With this model-based approach, various robust control system designs for instance control, synthesis, adaptive control, etc, are implemented and their performance to control gas exchange on account of $etCO_2$ and SpO_2 using patient-in-the-loop can be evaluated. The proper ventilation parameters are automatically adjusted using MATLAB with Simulink on every breathing cycle. The graphical user interface is also provided on the medical panel. The application will be suitable for intensive medicine, anesthesia and ventilation support during sleep.

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

Capacitive ECG for Mobile Applications

After successful developing / integration of capacitive ECG (cECG) in a driver's seat in 2011, the close cooperation between the Ford Research Center Aachen and MedIT was continued, however this time, with aim of exploring deeper issues of medical engineering in vehicles. The major question, as a take-along from the previous project, addressed in 2012 was the reason why capacitive ECG only works in about 80 % of all subjects and what needs to be done to improve this percentage to near 100 %. In order to answer this question, several investigations have been performed including a laboratory study with more than 70 subjects varying in body sizes, clothing, and position of the heart. The study was setup and carried out to statistically analyze different influencing factors on the signal quality collected by the capacitive ECG device.

The results showed a significant influence of the contact pressure between the subjects and the electrodes as well as a dependency of the position of the heart on the system's output. In order to exclude the clothing material as an impact factor on signal quality, component tests were done. In accordance with the results of the laboratory study, combinations of textile materials holding the potential of static charges showed a substantial impact on the transfer characteristic of the system. As a prospective approach to reduce static charges, the implementation of an active moisturization system was initiated.

Furthermore, several other approaches such as pressure sensitive or wide area textile electrodes were investigated arguing for rather smaller electrodes in order to ensure an appropriate contact pressure. In this way, work in 2012 was affected by many insights into the reasons for non-applicability of capacitive ECG measurements in some subjects, which will lead to further dedicated developments in 2013. Also in 2013, the cooperation between the Ford Research Center Aachen and MedIT will continue addressing even more measuring modalities for an unobtrusive monitoring of the driver's health status and wellbeing.

Cooperation with: FORD Research Europe, Aachen

Fig. 4: Multichannel capacitive ECG system integrated into a driver seat.

iShunt – Intelligent Mechatronic Implants for Hydrocephalus Therapy

The human brain is immersed in the so-called cerebrospinal fluid (CSF), which protects the brain from mechanical stress (e.g. concussion), helps support its weight through buoyancy, and also serves for the nutrient supply

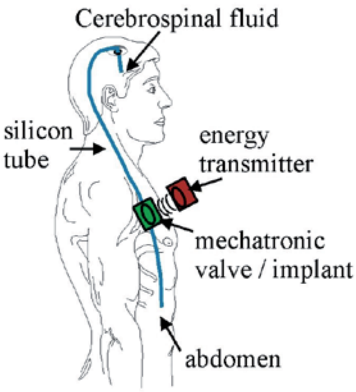


Fig. 5: Concept of iShunt system for control of liquid flow within the external drainage as developed at MediT.

of the brain. In normal situations, production and re-absorption of this fluid are balanced. However, disruption of this balance can lead to a build-up of fluid in the skull (Hydrocephalus). In this case, the most common solution today is the implantation of a passive pressure-control valve and a catheter system (known as a "shunt"), which drains excess fluid into another body compartment (usually the abdominal cavity). Every year 18,000 Hydrocephalus patients are implanted with shunts. The existing shunts often show severe problems with the adaption of the CSF drainage to the physiological circumstances, leading to an unhealthy over- or under-drainage.

Therefore, the project "iShunt" aims at the development of new intelligent implants for an adaptive drainage of CSF. Furthermore, on the basis of physiological measurement data (as intracranial pressure, body position, flow of fluid, pulse amplitude, elasticity of the brain, and amount of pathological intracranial pressure waves) and their interpretation, an adjusted drainage shall be realised. As the single pulse waveform and amplitude in intracranial pressure due to heartbeat seems to be a promising control parameter for a future shunt, a signal pulse waveform determination and classification algorithm have been developed and implemented in the iShunt. For patient monitoring, the measured data is transmitted via telemetry.

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

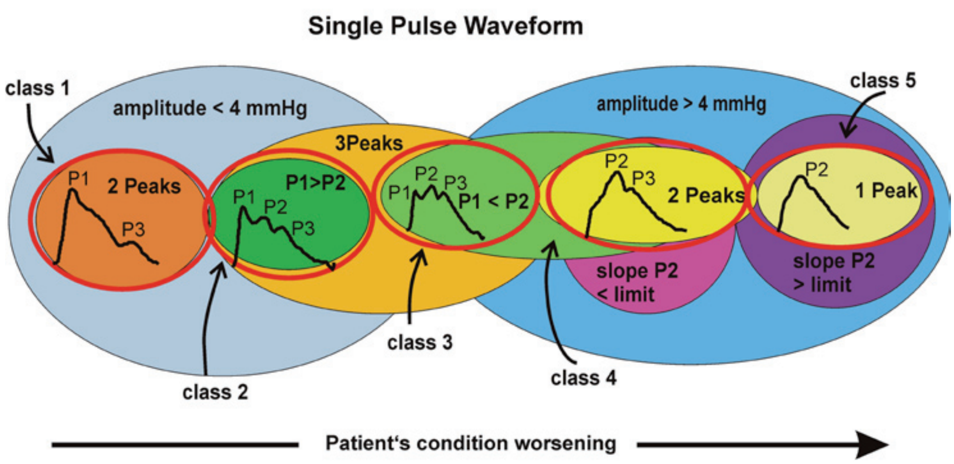


Fig. 6: Signal pulse waveform determination and classification algorithm.

Magnetic Induction Monitoring

Continuous monitoring of respiratory and cardiac activities is especially important in health monitoring systems. As the application of conventional methods is associated with side-effects (e.g. skin irritation, contact problems or large energy requirements), the magnetic induction method offers a promising alternative.

The method is based on the fact that both respiratory and heart activity 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 contactless determination of those changes is possible.

Fig. 7: Realization of a magnetic induction textile method integrated into T-shirt.

The main technological challenge is to handle very small signals in a noisy environment. Therefore, special importance was given to the use of a highly precise and fast circuit design inside the radio frequency measurement parts, and to maintain low power consumption as the application is intended for mobile monitoring scenarios.

Initially, we developed a multi-channel magnetic induction system, which was applied to a chair. The magnetic field is sent out and measured by a coil placed on the chair's back-rest. This gives the possibility to monitor the vital parameters during daily routines, e.g. office work, car driving, or during watching TV. The back-rest is made of acrylic glass in order to have a direct view of the coil position with respect to the body.

Recently at MedIT, magnetic induction sensors were also integrated into textiles, and by developing a system, which maintains low power consumption, it was possible to build a magnetic induction T-Shirt for mobile use. The shirt comprises four sensors (three at the front and additional one at the back) whose data is simultaneously acquired. The data is preprocessed by a microcontroller and transmitted wirelessly to a PC, where it is stored and visualized. The sensing coils are sewn into the textile and all electronics are placed on flexible printed circuit boards. The device is powered by a lithium battery.

In a proof of concept, good functionality of the system was verified by measurements on human volunteers.

Funded by: European Union, Project Heart Cycle

Automatic Blood Glucose Control in Patients with Diabetes Mellitus

According to the World Health Organization, in 2011 approximately 346 million people worldwide were suffering from diabetes mellitus. For 2030, the International Diabetes Federation predicts an increase up to 540 million people. Diabetes mellitus is characterized by a reduced or even lacking pancreatic insulin production which leads to an increased blood glucose concentration (BGC). Patients with type 2 diabetes mellitus have an increased insulin demand due to reduced insulin sensitivity of the glucose consuming cells which initially can be treated by diets and sports before an intensive insulin therapy is required. In contrast, patients with type I diabetes mellitus are instantly dependent on extracorporeal insulin administration.

Nowadays insulin therapy in patients with diabetes is performed by the patient himself consisting of BGC self-monitoring, calculations of the required insulin dose and self-injection of insulin. As it is difficult to determine the proper application rate of insulin by a few daily blood glucose measurements, hypo- or hyperglycemic events cannot be avoided. This may lead to acute life-threatening situations such as coma including persistent neurological damage or secondary disorders like nephropathy and retinopathy.

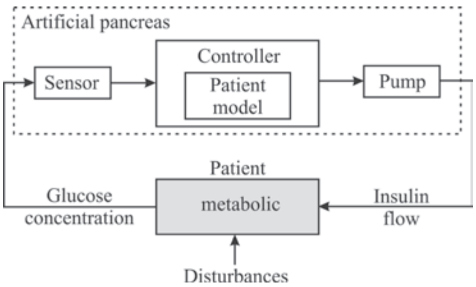


Fig. 8: Realization of artificial pancreas concept.

An optimal solution for blood glucose control would be an artificial pancreas, which has been a research topic since the early 1970's. In Figure 8, a flow diagram of the artificial pancreas is shown. Depending on the continuously sensed BGC as a control variable, the control algorithm calculates the required insulin dose which is injected automatically by a pump. The control algorithm usually includes a model of the patient's glucose-insulin system.

For the time being, no fully automated closed-loop system is available which can guarantee that the BGC stays within physiological boundaries. Several limitations caused by control and plant properties as well as missing reliable glucose sensor still have to be handled. The focus of research in the field of blood glucose control is on designing an appropriate control algorithm and constructing a continuously measuring blood glucose sensor to improve insulin therapy in diabetic patients.

Innovative Medicine with Electrical Impedance Tomography (EIT)

At MedIT, EIT has always been one of the focus research areas. It has been applied with several scenarios as stand-alone or in combination with other methods to improve health care of patients. Basically, EIT is a recently developed imaging technique through which changes of the conductivity distribution along a horizontal body cross section can be monitored using a ring of external surface electrodes.

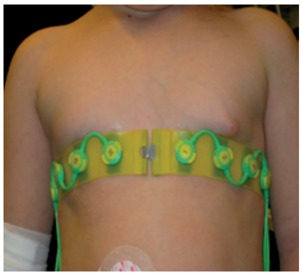


Fig. 9: Application of EIT system on children during lung function test.

One of the ongoing projects at MedIT involves application of EIT for treatments of patients with cystic fibrosis, asthma, acute lung injury (ALI), or acute respiratory distress syndrome (ARDS). For these purposes, the EIT method will be used to monitor the regional ventilation changes of the lung to help in developing an automated ventilation system that can perform complex ventilation strategies through closed-loop control based on medical expertise.

Recently, within the UroWatch project neurological diseases as paraplegia or age-related diseases like diabetic neuropathy, which result in inadequate perception of bladder filling level, have been also addressed at MedIT using EIT method. These diseases usually reduce patient's quality of life and drastically increase care requirements with the patient misses to go to toilet when the bladder is full.

For patients with paraplegia, who cannot control their bladder emptying, a frequent solution is the regular use of self-catheterisation, as described by Guttmann. Since to date, no portable monitoring device to continuously measure bladder filling level is available, patients have to follow a strict rhythm for bladder emptying, like every four hours. Drawbacks of this fixed scheme are that the bladder may be emptied when not necessary or that the emptying might come too late, resulting in damages to the urogenital tract due to an overfull bladder.

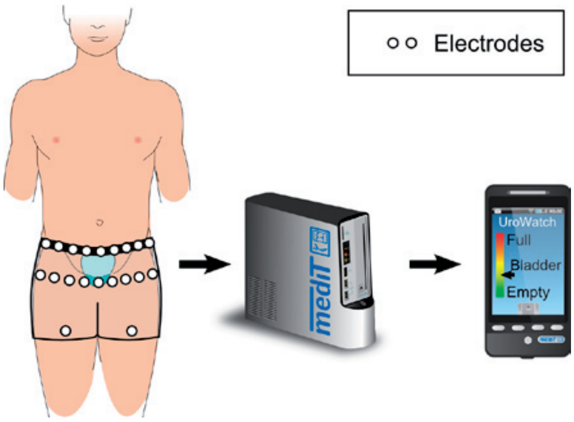


Fig. 10: UroWatch system setup.

In the UroWatch project, a device continuously measuring and showing bladder volume on a display is developed, which will help the patients to install a more flexible, demand-driven emptying scheme. The system measures the change in abdominal impedance resulting from a change of urine volume by EIT. The work involves finite element simulations of the abdominal area, measurement hardware design, reconstruction of volume estimation algorithms, and patient studies.

The UroWatch project is funded by: German Ministry of Education and Research (BMBF)

Selected References 2012

[1] Elixmann I, Walter M, Kiefer M, Leonhardt S: Simulation of Existing and Future Electromechanical Shunt Valves in Combination with a Model for Brain Fluid Dynamics. Acta Neurochir Suppl 2012; 113: 77-81.

[2] Czaplik M, Eilebrecht B, Walocha R, Walter M, Schauerte P, Leonhardt S, Rossaint R: The Reliability and Accuracy of a Noncontact Electrocardiograph System for Screening Purposes. Anesth Analg 2012; 114(2): 322-327.

[3] Cordes A, Foussier J, Pollig D, Leonhardt S: A Portable Magnetic Induction Measurement System (PIMS). Biomed Tech (Berl) 2012; 57(2): 131-138.

[4] Venema B, Blanik N, Blazek V, Gehring H, Opp A, Leonhardt S: Advances in Reflective Oxygen Saturation Monitoring with a Novel In-Ear Sensor System: Results of a Human Hypoxia Study. IEEE Trans Biomed Eng 2012; 59(7): 2003-2010.

[5] Pikkemaat R, Tenbrock K, Lehmann S, Leonhardt S: Electrical Impedance Tomography: New Diagnostic Possibilities Using Regional Time Constant Maps. Applied Cardiopulmonary Pathophysiology 2012; 16(2): 212-225.

[6] Eilebrecht B, Henriques J, Rocha T, Walter M, Paredes S, de Carvalho P, Czaplik M, Leonhardt S: Automatic Parameter Extraction from Capacitive ECG Measurements. Cardiovascular Engineering and Technology 2012; 3(3): 319-332.

[7] Abbas AK, Heimann K, Blazek V, Orlikowsky T, Leonhardt S: Neonatal Infrared Thermography Imaging: Analysis of Heat Flux during Different Clinical Scenarios. Infrared Phys Technol 2012; 55(6): 538-548.

[8] Brendle C, Niesche A, Korff A, Radermacher K, Leonhardt S: Femoral Test Bed for Impedance Controlled Surgical Instrumentation. Acta Polytechnica 2012; 52(5): 17-21.

[9] Weyer S, Röthlingshöfer L, Walter M, Leonhardt S: Evaluation of Bioelectrical Impedance Spectroscopy for the Assessment of Extracellular Body Water. Acta Polytechnica 2012; 52(5): 120-124.

[10] Leonhardt S, Lachmann B: Electrical Impedance Tomography – The Holy Grail for Ventilation and Perfusion Monitoring?. Intensive Care Med 2012; 38(12): 1917-1929.

[11] Aguiar Santos S, Venema B, Leonhardt S: Accelerometer-Assisted PPG Measurement during Physical Exercise using the LAVIMO Sensor System. Acta Polytechnica 2012; 52(5): 80-85.

Prizes and Awards

- A. Abbas: 1st prize “Patient Safety in Medical Technology 2012” at BMT 2012, Jena, Germany.
- D. Teichmann: IFMBE Young Investigator Award at the WC2012 in Beijing, China.
- I. Elixmann: Best Paper Award at 46. German Control Engineering Meeting, Boppard, Germany.
- A. Pomprapa: 1st prize in student competition at the IEEE EMBS BHI 2012, Shenzhen, China.
- S. Weyer, S. Santos, C. Brendle: 1st, 2nd, and 3rd prizes respectively at POSTER 2012, Prague, Czech Republic.
- H. Lüpschen and J. Wilkomm: Friedrich-Wilhelm Prize at the RWTH Aachen 2012.
- H. Lüpschen: Finalist of the “Deutschen Studienpreis“ Ph.D. thesis competition by Körber-Stiftung. 11 finalists out of 431 in total.

People at MedIT