mediT

Medical Information Technology

Faculty of Electrical Engineering and Information Technology

Smart Solutions for Advanced Healthcare

Director

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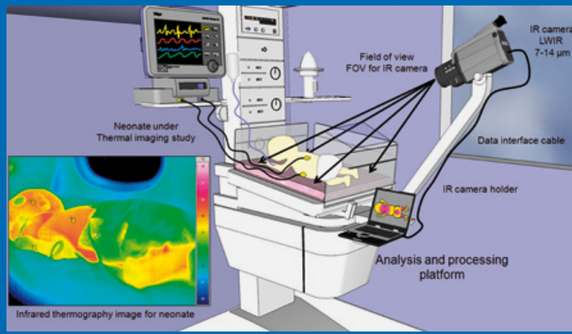

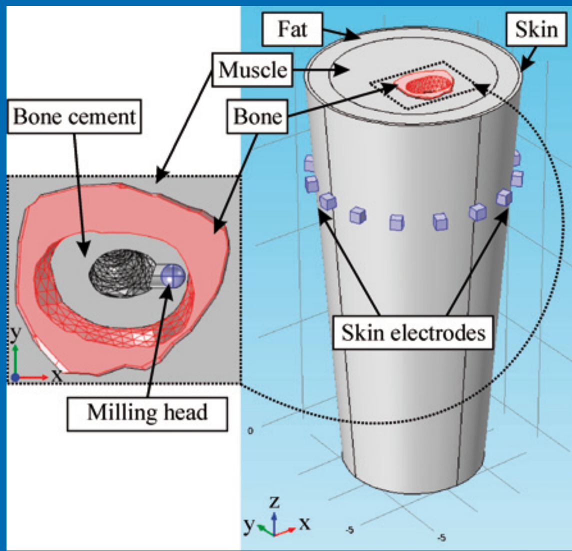

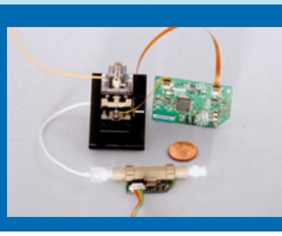

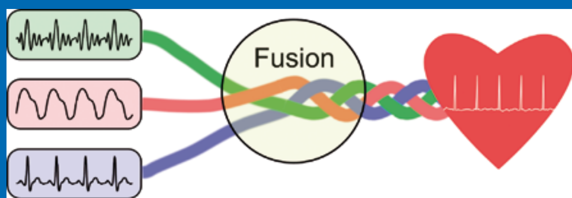

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RWTH AACHEN UNIVERSITY

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).

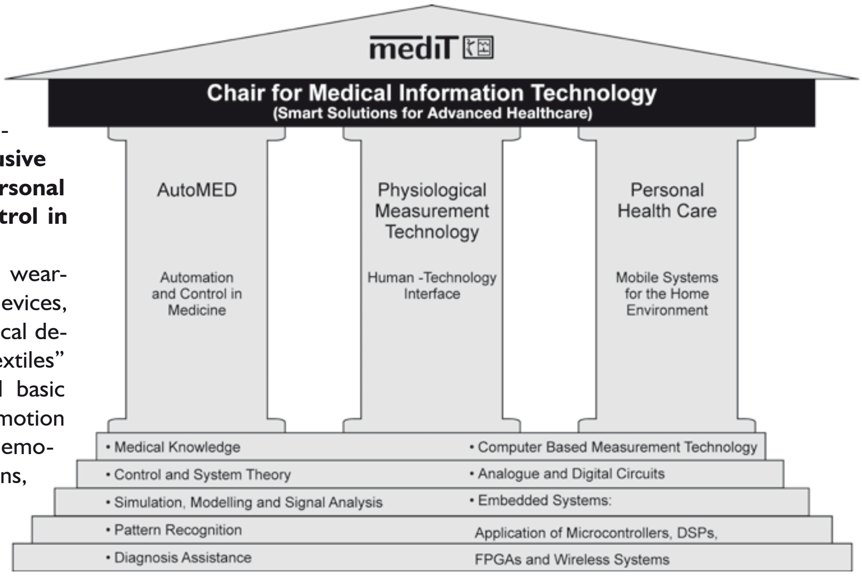

Fig. 1: Research profile of MedIT.

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.

10 Years MedIT

After 10 years, we are looking back on an exciting decade of scientific achievements, successful publications, patents and dissertations, newly created lectures and educational specializations for our students and, last but not least, a rich social life. The start was on August 1st, 2003, when the Philips Chair for Medical Information Technology (MedIT) came into operation with research orientation on sensing and information processing in medical applications. Over the years and within this strategic orientation focusing on technical concepts and technologies, we have established several visionary areas of medical applications, including 'Smart Life Support', the 'Wireless Incubator', 'Motion Assistance', and 'Medical Technology goes Automotive'. We are actively involved in many joint academic-industrial research projects (both national and international) and have established many research links to our University Clinic, to both the experimental facilities and many clinical units. We have also established an international network of collaborators and friends, such as Institute of Biomedical Engineering (IBME) of Imperial College London (ICL, UK) and Bauman Moscow State Technical University. Furthermore, we had the honor in 2007 to cohost both the 4th Body Sensor Networks Conference in Aachen and the 42nd Annual Conference of the German Society for Biomedical Engineering, while in 2012, we organized the 10th AUTOMED Conference, which attracted around 100 participants.

As the years go by, maintaining this pace of growth and consistent strategies for efficient work remains key challenge for us. The prospects look highly encouraging in this regards, and we look forward to many more years of success, scientific achievements, and innovations.

Selected Ongoing Research Projects

IPANEMA – Body sensor network

Body sensor networks (BSN) emerged as an interdisciplinary area consisting of inexpensive, body-worn sensors that allow continuous health monitoring solutions. The BSN thereby consists of several sensor units (slave nodes) connected wirelessly to a central processing unit (master node). The Integrated Posture and Activity Network by MedIT Aachen (IPANEMA) was developed as a modular and flexible BSN using a star-shaped communication architecture between master and slave nodes via the 433 MHz ISM band. The slave nodes of the IPANEMA BSN are designed to allow for a modular integration of different sensor modules. Collected data can be sent to a host computer from the master node using a Bluetooth connection.

Besides already existing IPANEMA BSN sensor modules, as accelerometer, electrocardiogram, and hygro-/thermometer, newly developed sensor modules comprise a full nine degrees-of-freedom (9DOF) magnetic/inertial sensor and a two-channel electromyography (EMG) sensor using surface electrodes. The 9DOF sensor can be used to measure for example segmental limb orientation, thereby allowing the extension of the IPANEMA BSN to new application areas such as fall prediction and detection, gait analysis and motion intention detection and supervision. The IPANEMA BSN EMG sensor was used to develop an algorithm for spasticity detection for hemiplegic patients. First results were obtained using clinical data, recorded with a commercially available EMG system. Different imitated movements and subsequent recordings with the IPANEMA BSN EMG sensor showed promising results. Thus research is directed

towards online estimation of spasticity and joint stiffness, as well as the estimation of gait parameters using hybrid modelling techniques in connection with the IPANEMA BSN.

Funded by: UMIC, RWTH Aachen

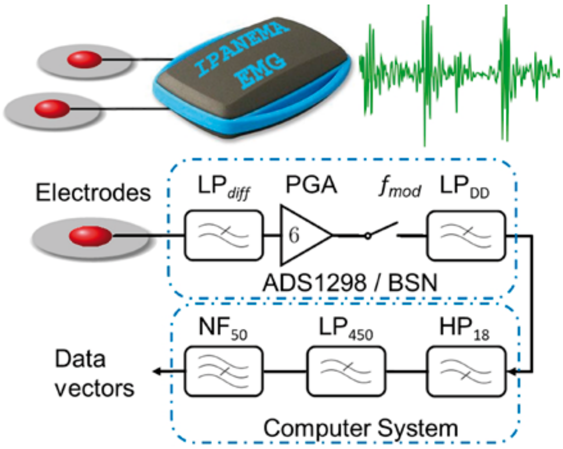

Fig. 2: The IPANEMA EMG setup.

FEM Simulation of Impedance Based Measurement Methods

Cardiovascular diseases are the most common cause of death in Western Europe. One of these diseases is chronic heart failure (CHF), from which 2 million people are suffering and this number increases every year by half a million. The basic definition of CHF is a state at which the heart is unable to provide sufficient pump action to maintain adequate blood flow into the periphery. Reasons for that can be dysfunctions concerning filling, contractility, or emptying of the ventricle.

Bioimpedance is a simple, cheap, and non-invasive method to acquire parameters reflecting the cardiac health status of the patient by measuring the electrical impedance of body tissues. On one hand, these parameters can be used to estimate the body composition, especially the accumulation of edema. On the other hand, hemodynamic parameters such as cardiac output can be assessed.

To optimize measurement processes and enhance the understanding of the electrical behavior of body tissues under excitation by external electrical currents, finite element method (FEM) simulation is utilized. FEM simulations can be used to describe complex structures by subdividing them into simple finite elements. FEM is suitable for different electromagnetic applications, e.g. static problems for calculations in frequency and time domain. Physical values are assigned to the edges, faces and volumes of these substructures. Using FEM simulations, it is possible to deduce the frequency and time dependency of the impedance of body tissues or body segments comprising a mixture of body tissues. In addition, physiological and pathophysiological processes can be modelled and their influence on impedance measurements can be simulated.

The influence of lung edema on thoracic bioimpedance measurements was analyzed. In particular, bioimpedance spectroscopy (BIS) and impedance cardiography (ICG) measurements were simulated. For BIS measurements it could be shown that it is possible to detect fluid accumulations in the lungs at an early stage. In addition, optimal electrode positions could be identified for this purpose. Concerning ICG measurements, a possible explanation for large deviations of cardiac output estimation by this technology when monitoring heart failure patients could be established.

Funded by: Ziel 2-NRW, EU-Project, Industry

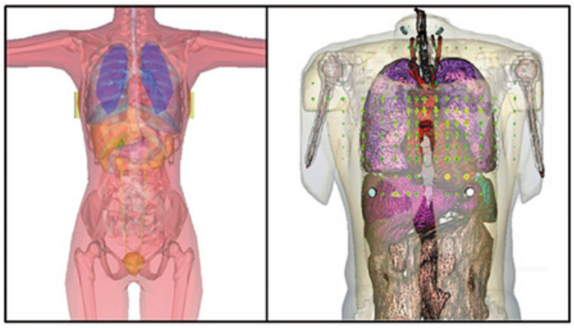

Fig. 3: FEM models of the human body.

Photoplethysmography Imaging: A Camera-based Technique for Unobtrusive Monitoring of Skin Perfusion

Photoplethysmography Imaging (PPGI) is a consistent advancement of classical Photo-plethysmography. It is based on the same basic principle: the optical damping of skin is modulated by blood volume changes and can be monitored by evaluating the recorded intensity of light passing through it. This allows extensive analysis of blood perfusion dynamics and related vital parameters.

Instead of a classical skin-attached PPG-sensor (usually containing a light emitting diode and a photodetector in close distance), the PPGI system consists of an external illumination unit

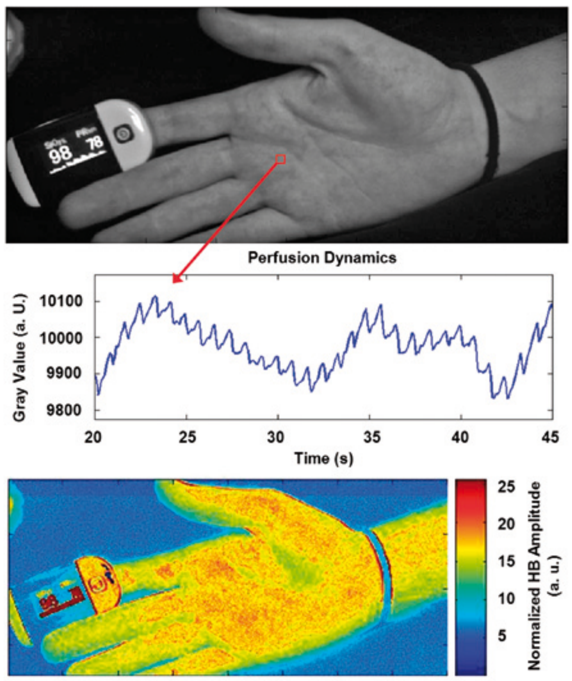

Fig. 4: Photoplethysmography image of the hand.

and a high-sensitive optical camera capable of detecting even small-sized alterations of light intensity originating from blood volume changes inside the observed skin region. This method is generally capable of detecting the same vital parameters as classical PPG. Furthermore, the use of a camera as a detector adds benefits of contactless measuring and with spatial resolution. These advantages open up new fields for application as monitoring skin perfusion reaction to an allergic test. A continuous improvement of the general monitoring ability of the overall system can be considered as basic objective goal for us in MedIT. This concerns the selection and application of a camera system, the illumination strategies, as well as adaptation of analyzing algorithms according to individual requirements. The latter is closely associated with signal processing tasks like recognition and separation of different vital signs (e.g. heartbeat, breathing, or vasomotion) inside the recorded perfusion signal. On this basis, inferable parameters like arterial oxygenation can be calculated.
Funded by: BMWi-ZIM

Impedance Controlled Surgical Instrumentation (ICOS)

In industrialized countries, total hip replacement procedures are frequently performed to improve quality of life and maintain mobility of the aging society. Due to the demographic change and the increasing survival expectation for the upcoming years, an increase in the number of procedure is expected in the future. Accordingly, since the average life time of hip joints endoprosthesis is between 12 and 15 years, the number of revisions for the artificial hip joints is also most likely to increase. During the revision of cemented artificial hip joints, the old bone cement (BC) has to be removed completely to ensure proper fixation of the new hip joint implant. This is conventionally done by hammer and chisel, which causes a high mechanical force injection and with no real-time control. For this reason, the risk of damaging the bone or the surrounding tissue is unavoidable. To avoid these disadvantages and achieve high patient safety, a real-time control of the milling process during bone cement removal was developed at MedIT. Our proposed surgical scenario includes a sliding contact system which conducts the alternating measurement current to the fast rotating milling shaft. Over the milling head the current is coupled into the patient tissue and the voltage between the milling head in the femur and the patient's leg skin are measured. The measured values are used to calculate the spectral two-point bioimpedance from which the thickness of the residual bone cement in the femur will be deduced.
During the preparation of experimental trails and for identifying the measuring system, an experimental setup has been developed, which includes a xyz-milling table, LCR meter, motor, and a dSpace MicroAutoBox as an interface with computer. In addition, a femoral test bed was designed with an inner diameter of 15 cm, corresponding to the diameter of an adult human leg, and 16 replaceable electrodes placed on its wall to enable different measuring setups. In the bottom of the femoral test bed, 2 options for fixing a bone cement-dummy (hollow cylinder) are integrated, one in the middle and another excentric according to human physiology.
Funded by: German Ministry of Education and Research (BMBF)

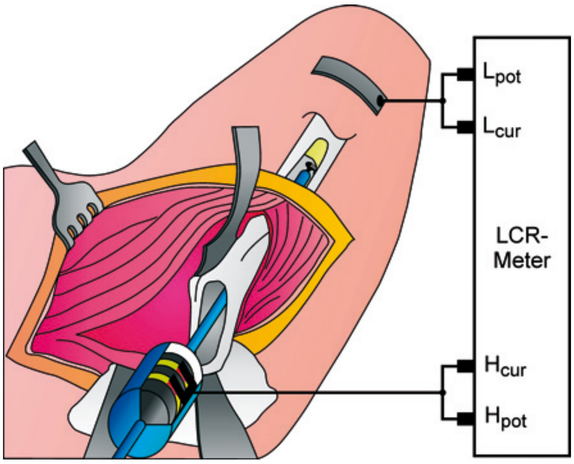

Fig. 5: ICOS Operation Theatre.

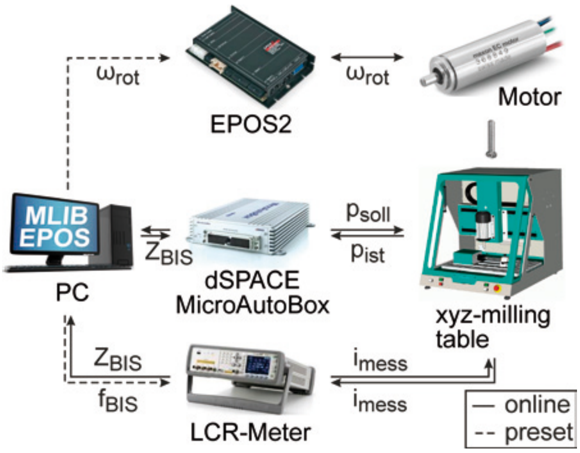

Fig. 6: Experimental setup for the ICOS project.

Neonatal Infrared Thermal Imaging (NIRT)

Premature babies suffer from an incompletely developed thermoregulatory system, necessitating temperature maintenance in a small target range. However, up to date pathophysiological details are still unknown. Therefore, mathematical models can contribute to improve the understanding of pathophysiology and to simulate diverse interactions. To maintain body temperature in a small target range, precise monitoring is required. Central and peripheral temperatures of infants are usually measured by cable-bound sensors that are placed into the rectum or attached to the infant's skin. Infrared imaging emerges as a contactless, absolutely non-invasive monitoring modality with a great potential in neonatology, namely to reduce morbidity of preterm infants and to improve their medical care. It has the potential to replace conventional temperature sensors, since it is able to detect radiated thermal energy emitted from the baby's surface.
The project aims to develop a mathematical model of the thermoregulatory system of preterm infants in order to gain more detailed knowledge about pathophysiology regarding heat transfer and influences of external factors. To validate it, measurements in neonates will be performed at the RWTH Aachen University Hospital by using an Infrared

camera. In addition to that, proper imaging processing algorithms to detect patterns of physiological signals, such as heart rate, breathing, and vasomotor rhythms, will be developed. Furthermore, the construction of new alternative measurement probes that should be able to replace IR cameras in the future for a better cost-effectiveness is planned.

Funded by: DAAD, FCT (Portugal)

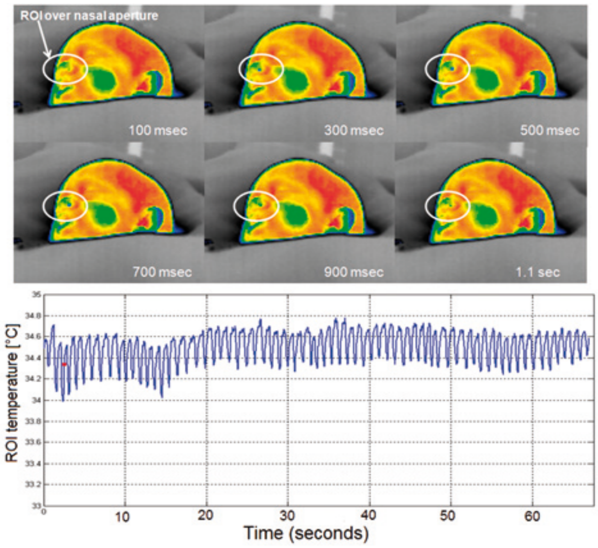

Fig. 7: NIRT signal of defined ROI temperature trend over neonate's nasal aperture.

Impedance Zystovolumetry

Neurologic diseases like paraplegia or age-related diseases like diabetic neuropathy often result in inadequate perception of bladder filling level due to destroyed nervous structures. As a result, this leads to incontinence, since the patient misses to go to toilet when the bladder is full. Quality of life for the patient is decreased and the care requirements are drastically increased. For patients with paraplegia who cannot control their bladder emptying, a frequent solution is the regular use of self-catheterization, as described by Guttmann. Since up to date, no portable monitoring device to measure bladder filling level continuously is available, patients have to follow a strict rhythm for bladder emptying, every four hours. Drawbacks of this fixed scheme are for example 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.

In this project, a device for continuous measurement and showing of the 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 in urine volume by Electrical Impedance Tomography. The work also involves finite element simulations of the abdominal area, measurement hardware design, reconstruction of volume estimation algorithms, and patient studies.

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

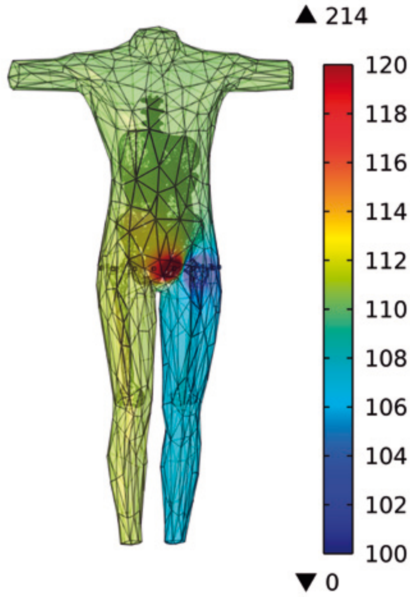

Fig. 8: Electrical Potential distribution throughout the human body.

Heart-Control - Methods for Closed-loop Control of Ventricular-Assist Devices

Ventricular-assist devices (VAD) are a common therapy option for patients with terminal heart failure. While they are often used to bridge the temporary gap of time until a donor organ becomes available ("bridging to transplant"), these devices are increasingly employed for longer periods ("destination therapy"), due to the shortage of available organs and the increasing maturity of the devices. Therefore, demand-oriented control of pump output becomes more and more important. With this project, a novel hybrid hardware-in-the-loop (HIL) test stand for VADs was developed in which parts of the diseased physiological system are simulated in software. Being the first of its kind, this test stand has no valves and very fast dynamics, allowing to imitate physiological mechanics much more accurately than traditional mock loops.

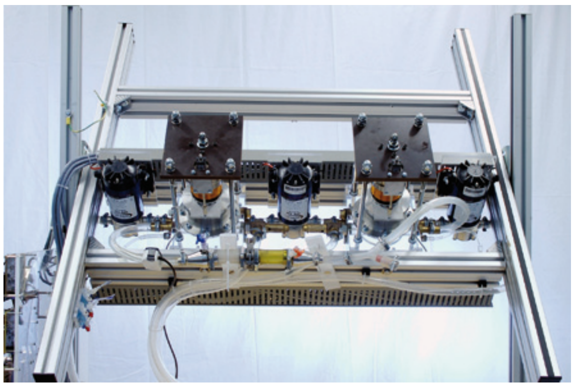

Fig. 9: *A novel hybrid hardware-in-the-loop test stand for ventricular-assist devices.*

Funded by: Ziel 2-NRW

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Prizes and Awards

- J. Foussier: Top 5 finalist of the IFMBE Young Investigators Competition at ICHI 2013, Vilmaoura, Portugal.
- M. Ulbrich: CST University Publication Award 2013 in the category "Best Short Paper".
- A. Pohl: Best Paper Award at ICLSE 2013, Hong Kong, China.
- C. Hoog Antink: Graduate Award from the SEW-EURODRIVE-Stiftung and Springorum-Denkmünze 2013 from ProRWTH.
- C. Hoog Antink (1st place), A. Kerekes and M. Köny (3rd place), and A. Pomprapa (1st place): Poster-Award at POSTER 2013, Prague; sessions "Biomedical Engineering" and "History of Science".
- A. Pomprapa: Best Paper Award at SKIMA 2013, Chiangmai, Thailand.
- L. Rötlingshöfer and H. Lüpschen: Borchers-Plakette 2013 from ProRWTH.
- B. Venema: 3rd place of the EMBS Student Paper Competition at the IEEE EMBS Special Topic conference on Point of Care Healthcare Technologies 2013, Bangalore, India.
- T. Schlebusch: Best Poster Award 2013 from the NRW Society for Urology.
- M. Walter: Senior Member of the IEEE (Feb 2013).
- S. Leonhardt: Member of Board of Trustees at the Eduard Rhein Stiftung.

People at MedIT